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Performance Analysis of Rear Under Run Protection Device (RUPD) on Truck Based on Vehicle Safety Standards in Indonesia

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ABSTRACT

The rear under-run protection device is an apparatus installed on goods vehicles with a rear section that is more than 700 millimeters above the road surface. The height disparity between two vehicles may lead to the passenger compartment of a smaller vehicle colliding with and sliding under the chassis of a larger vehicle. This device is mounted to reduce the risk of fatalities resulting from rear-end collisions. This study aims to evaluate the design of rear under-run protection devices on goods vehicles to determine whether they meet the prerequisites set forth in the applicable Indonesian regulations. This is achieved by conducting modeling and testing simulations using software based on the finite element method. The evaluation results indicate that the underrun protection design satisfies several required technical criteria; however, non-conformities remain in structural dimensions and joint integrity, including a cross-member height of 80 mm (< 100 mm), a member length of 2200 mm (< 2300 mm), a cross-bar deflection reaching 419.5 mm (exceeding the ≤ 400 mm limit), and the use of welded joints instead of the required bolt–nut connections. Consequently, structural and mounting system modifications are necessary to achieve full compliance with the applicable standards.

1. Introduction

Economic activities and infrastructure development that continue to grow will be in line with the increase in the movement of people and goods on the roads. Increased vehicle mobility, both in number and frequency, will raise the likelihood of probable traffic accidents and road transport incidents. Traffic accidents are unplanned, unexpected incidents on the road involving automobiles and/or other road users that cause human casualties and/or property damage.

An unavoidable accident is expected not to cause death or serious injury. However, there is a type of accident that carries a high risk of death: collisions between small passenger vehicles and the rear, sides, or fronts of heavy vehicles, such as trucks. The height difference between the two vehicles can cause the cabin or passenger compartment of the small vehicle to crash into the undercarriage of the heavy vehicle [1]. As a result of the incident, the passenger cabin of the small vehicle is inevitably severely damaged, rendering it unable to protect the passengers and driver inside, and at risk of serious injury or even death. The rear under-run protection device on freight vehicles is considered effective at reducing fatalities among passengers wearing seat belts in rear-end collisions, even at relatively high speeds.

The intrusion of the passenger vehicle cabin in this accident was caused by the height of the truck's rear construction from the road surface, the absence of an under- run protection device, and also the poor design of the under- run protection device [2]. To prevent such incidents, it is necessary to install an under-run protection device at the rear of the truck. With the installation of this device, it is hoped to reduce the risk of passenger injury in small vehicles.

Risk reduction can occur if the under-run protection device can absorb the energy generated by the impact. The ability of a vehicle to absorb collision energy and protect passengers is called the vehicle's crashworthiness. Crashworthiness is related to energy absorption through controlled mechanisms and damage models, allowing for gradual changes in load profiles during absorption. The structure that can be crashed into must be designed to absorb impact energy in a controlled manner, with the passenger compartment moving without the passengers experiencing high deceleration, which can cause serious internal organ injuries, especially brain damage. The size and mass of the vehicle provide a certain level of protection, but can have negative inertia effects [3].

The accident involved a small car and a trailer truck on the Kapuk Toll Road in North Jakarta on the morning of October 18, 2023. This accident resulted in the death of the Sigra car passenger, and the driver sustained serious injuries [4]. The condition of the passenger vehicle showed severe damage to the front, while the rear of the trailer truck sustained minor damage. Another incident, two people died and one was critically injured in a rear-end truck accident on the Medan-Kualanamu-Tebing Tinggi Toll Road in Lubuk Pakam District, Deli Serdang Regency, North Sumatra, on Thursday, February 2, 2023. The minibus crashed into the rear, going under the truck. The passenger car's body went under the truck. The top of the private car was open and completely damaged. The truck was not installed with equipment or rear bumper [5].

A head-on collision between a heavy vehicle hit from behind by a small vehicle poses a risk of death for passengers in the small vehicle. One of the efforts made by the government is to issue Government Regulation No. 5 of 2012 concerning Vehicles which stipulates that goods vehicles, trailers or trailers with a height of the runway and/or the rear and/or sides of the body more than 700 (seven hundred) millimeters measured from the road surface, and/or the rear axle more than 1,000 (one thousand) millimeters measured from the outermost side of the rear must be equipped with an under run protection device. Further provisions state that the rear under-run protection device referred to must be installed on Motor Vehicles of the type Goods Vehicle with a JBB of 5,000 (five thousand) kilograms, trailers, or trailers. The requirements for under-run protection devices have been determined, but no further regulations have been issued on how to evaluate or test the performance of under-run protection devices installed on vehicles.

Details of the underrun protection device follow the provisions of the Regulation of the Minister of Transportation of the Republic of Indonesia Number PM 74 of 2021 concerning Motor Vehicle Safety Equipment, which states that the rear underrun protection device installed on vehicles must meet the following requirements: a. made of iron or similar material; b. shaped as a pipe or rectangular bar covering the entire rear side of the vehicle or at least 80% (eighty percent) of the total vehicle width, installed at least aligned with or not more than 100 (one hundred) millimeters from the outermost rear end of the cargo body; c. installed with the lower edge height from the road surface not exceeding 550 (five hundred fifty) millimeters; d. installed with a departure angle of at least 8 (eight) degrees; and e. securely mounted to the chassis or subframe of the motor vehicle using bolted connections (bolt-nut) [6].

Other regulations related to under run protection device, but voluntary, are contained in the Indonesian National Standard (SNI), SNI 7522:2009 concerning rear under run protection device equipment for motor vehicles in categories N2, N3, O3 and O4, which is a standard that refers to ECE No. 58, Uniform provisions concerning the approval of: I. Rear Underrun Protective Devices (RUPDs), II. Vehicles with regard to the Installation of an RUPD of an approved type, III. Vehicles with regard to their Rear Underrun Protection (RUP). These provisions specify quality requirements for rear underrun protection devices as follows: 1. The height of the cross-member section shall not be less than 100 mm. The lateral extremities of the cross-member shall not be bent backward or have sharp outer edges. The outer edges of the cross-member must be rounded with a radius of not less than 2.5 mm; 2. The underrun protection device may be designed to have multiple positions at the rear of the vehicle; however, instructions must be provided to prevent incorrect installation. The force required by an operator to change the device's position shall not exceed 40 daN. The underrun protection device must have sufficient strength to withstand forces applied parallel to the vehicle's longitudinal axis. This must be demonstrated through testing based on the test procedures and conditions specified in this standard. The maximum horizontal deflection of the device observed during and after testing must comply with the limits set in this standard; 4. The distance from the ground to the lower edge of the underrun protection device, even when the vehicle is unladen, shall not exceed 550 mm across its entire width; 5. The width of the underrun protection device shall not exceed the width of the rear axle measured at the outermost points of the wheels (including tire bulges near the ground) and shall not be shorter by more than 100 mm on either side. If there is more than one rear axle, the widest axle shall be used as the reference; 6. After installation, the horizontal distance between the underrun protection device and the rearmost part of the vehicle shall not exceed 400 mm [7].

Kaustubh Joshi also stated that the truck uses a Rear Under-run Protection Device and follows IS 14812:2005 regulations to meet the stated safety requirements for protecting passenger cars while in operation. In his RUPD design, the maximum displacement of the RUPD rod is limited to 50 mm and the plastic strain is limited [8].

Several studies have been conducted on rear under-run protection devices to reduce the risk of rear-end collisions and improve vehicle safety. The purpose of this research is to conduct a preliminary assessment of the structural performance of existing underrun protection device designs on commercial vehicles, based on a linear approach commonly used in the early design stage, and to examine whether these designs meet the criteria required by the applicable regulations in Indonesia through modeling and testing simulations using the finite element method approach.

2. Methodology

2.1 Material and setup

The rear underrun protection device model to be studied was taken from one of the existing trucks, and its dimensions were measured as shown in **Figure 1**. Furthermore, the underrun protection device was modeled using Computer-Aided Design. The model was developed based on dimensional data from field measurements of the underrun protection device.

Figure 1. The truck which the RUPD was taken as a model

The Rear Underrun Protection Device (RUPD) is a passive safety device installed at the rear of heavy vehicles such as trucks or trailers. This device generally consists of a guard bar and a support member, both directly connected to the vehicle frame or main structure, as shown in **Figure 2**.

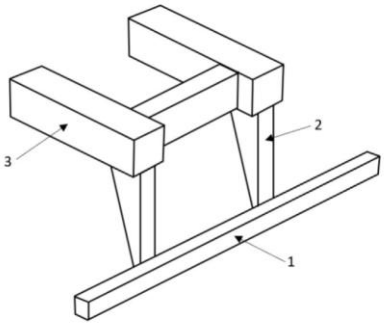


Figure 2. Rear underrun protective device. 1. RUPD guard/ cross bar; 2. Support member; 3. Vehicle frame [9]

Mechanical properties of the rear underrun protection device materials, including Young's modulus, density, Poisson's ratio, yield stress, and tensile strength, were obtained from protective device manufacturers. These properties are subsequently used as input parameters in a static analysis conducted using the finite element method.

2.2 Experimental Procedure

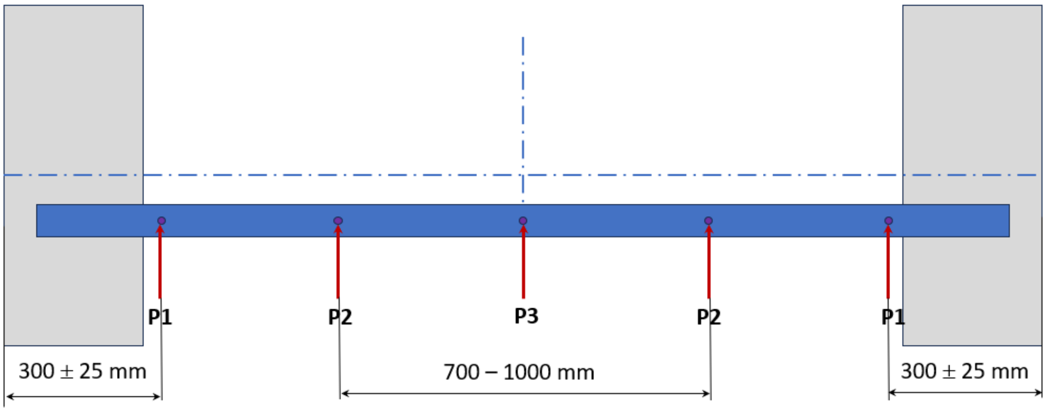
After determining all technical parameters and verifying the design geometry, the model can be simulated in accordance with SNI 7522:2009. The next stage defines the boundary conditions, namely the magnitude and location of the loading, as shown in the test in **Figure 3**. In this study, the technical aspects of simulating load magnitudes and configurations are described as follows: P1 = 25 kN, P2 = 100 kN, and P3 = 25 kN, with all three loads acting horizontally and perpendicular to the crossbar. What cannot be ignored is determining the contact between all parts of the device as the next step. By default, the application can automatically detect all contacts caused by the components. All contacts are initially defined as bonded, meaning that the surfaces cannot slide against each other or separate completely. For the rear underbody protection test, the crossbars and support members on both sides are welded together to ensure a permanent connection.

The next process uses the features of the mesh to discretize the continuous system being analyzed and reduce the main structure into smaller elements with a finite number of elements. A smaller local approach or part representation is used to simulate more complex objects from larger ones. The detailed parameters in this study use tetrahedral solid elements with a 20 mm element size, comprising 24,741 nodes and 11,736 elements. The convergence study considers displacement at the critical point as the evaluated parameter. The results show that the maximum displacement variation between meshes is 1.6%, as shown in **Table 1**. Since this difference is still acceptable, the solution is considered converged. Therefore, the 20 mm mesh is selected for further analysis because it provides a balance between accuracy and computational efficiency.

Table 1. Mesh Convergence Based on Displacement Change

Element Size (mm)	Total Element	Displacement (mm)	Error (%)
20	11736	419.5	-
16	15130	412.7	-1.6
10	30920	417.2	-0.5
4	92123	419.9	0.1

Running simulation/solving, which is the calculation process carried out through computerization according to the specified simulation process. From the input data, several results will be generated, namely von Mises stress and displacement.



P1 - Horizontal force 25 kN or 12.5% of the force generated by the maximum mass of the vehicle
P2 - Horizontal force 100 kN or 50% of the force generated by the maximum mass of the vehicle
P3 - Horizontal force 25 kN or 12.5% of the force generated by the maximum mass of the vehicle

Figure 3. Location of the load on the RUPD during testing

The finite element method was chosen for the study because it offers several advantages. Using the finite element method can reduce the costs of prototype creation and testing [10]. The geometry of the underrun protection device model, tested using the finite element method, can be adjusted to match the dimensions of the actual underbody shield. Meanwhile, the forces acting can also be adjusted to the testing standards referring to ECE-R58. The selected software is suitable for loading conditions modeled as impact. The simulation is based on the geometric data of the under-run protection device from bodywork X. Through this simulation, the vehicle's safety level will be analyzed in accordance with the UN ECE-R58 standard previously discussed. The same method is used to measure and validate the side underrun protection device to determine whether it meets the requirements or not [11]. Modelling and finite element analysis for the rear under-ride guard of semi-trailer type do not yet meet the requirements of GB 11567-2017 "Requirements for Lateral and Rear Underrun Protection for Motor Vehicles and Trailers" [12].

3. Result and Discussion

Underrun protection device data for freight vehicles is obtained from the Universal Profile (UNP) type, which is a steel profile widely used in construction and industry, especially as part of the frame structure. Material properties of the UNP profile (structural steel) are obtained as follows. The values used in this study are summarized in **Table 2**.

Table 2. Properties of UNP material for rear underrun protection device

Properties	A36 (ASTM)
Tensile Strength (MPa)	400-550
Yield Strength (MPa)	250
Elastic Modulus (GPa)	210
Density (g/cm³)	7,85
Poisson's Ratio	0,30

ASTM A36 Carbon Steel was chosen as the best material because it offers an excellent balance of strength, cost-effectiveness, and availability. It provides adequate mechanical properties for structural applications, including good tensile strength and weldability, while remaining economical compared to higher-alloy steels [13].

The shape and size of the rear under-run protection device under study are shown in **Figure 4** for a U-profile transverse bar with a thickness of 5 mm.

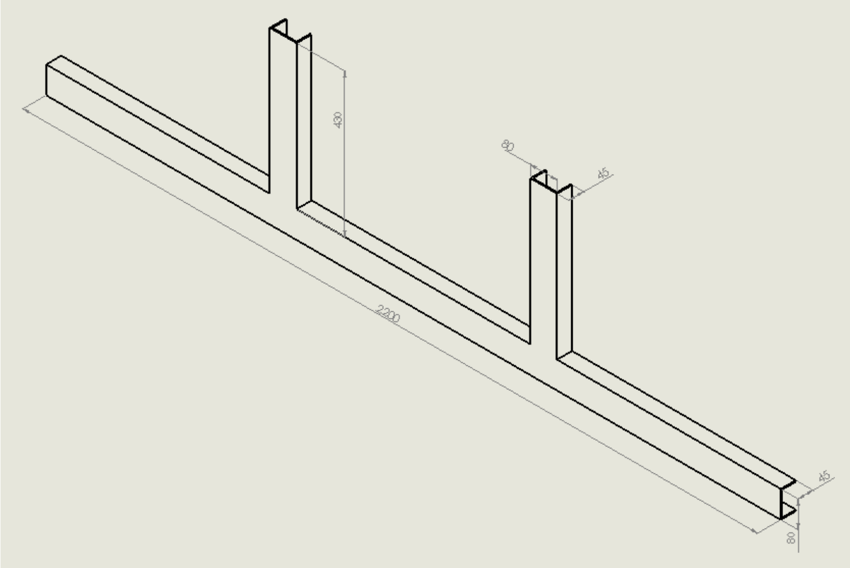


Figure 4. Rear under-run protection device model

Based on the results of observations on the fulfilment of the requirements for rear under-run protection device according to PM 74 of 2021 article 16, the following were obtained; the material must be made of iron and the results of observations of the RUPD model using ASTM A 36 structural steel which is a ferrous metal, the next provision is the shape of the rear under-run protection device in the form of a pipe or square, the shape of the model found is square with a U profile. The rear under-run protection device covers the rear side or at least 80% of the vehicle's width. Observations found that the vehicle's width is 2500 mm and the model's length is 2200 mm, so the model criteria are fulfilled. Furthermore, the rear under-run protection device is placed parallel to the rear of the vehicle in this case the cargo bed. However, the requirement that the rear under-run protection device be attached to the vehicle's chassis or subframe with a nut-bolt connection is not met, as the model is not attached to the chassis but to the cargo bed, with welding as the binding.

The provisions for rear under-run protection in Indonesia are also regulated in SNI 7522:2009, although they are voluntary, unlike those in PM 74 of 2021, which are mandatory. The fundamental difference is that SNI requires proof of the rear under-run protection's performance by following the established test conditions and procedures.

The test simulation of the rear under-run protection model, following the procedure in **Fig. 3**, yielded the results shown in **Figure 5**. The simulation was carried out with the following boundary conditions: a fixed support is used on the support member connected to the vehicle body, and the loading is applied as shown in **Figure 3**. Fixed support is chosen because it illustrates that the selected location is a welded joint with no free movement, either in translation or in rotation. The fixed support condition is adopted as a simplification representing an idealized case with maximum stiffness. This approach is used to obtain a conservative estimate of the structural response. However, the model has limitations, as it does not fully capture the vehicle frame's actual flexibility, which may affect stress distribution and deformation under real conditions.

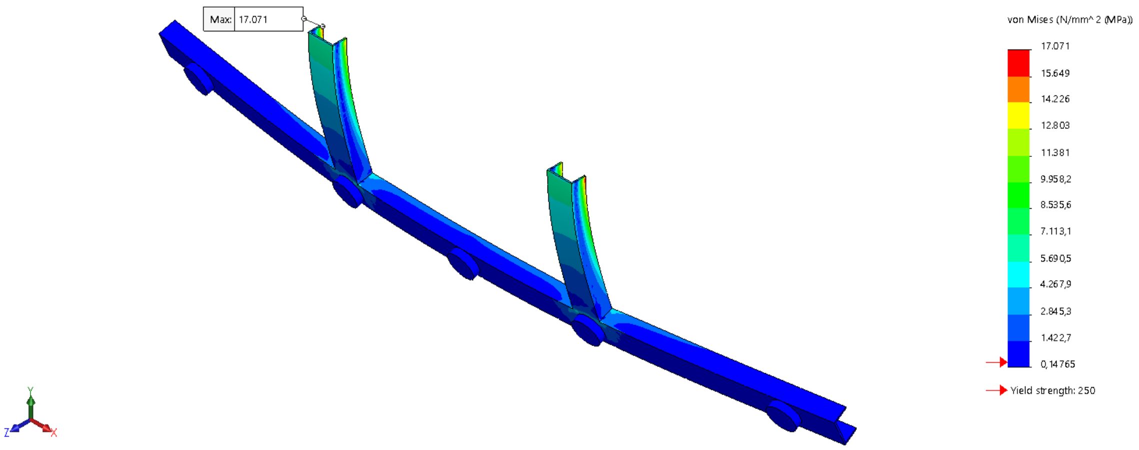


Figure 5. Results of stress distribution (von Mises) of the rear under-run protection

The stress distribution results shown in **Figure 5** indicate that the entire support member experiences loads exceeding the material's yield stress, which for ASTM A36 structural steel is 250 MPa. This also applies to the middle section of the transverse bar. This condition indicates that the structure or chassis component is highly vulnerable and at risk of failure when subjected to loading. The maximum stress occurs at the connection area between the support member and the vehicle frame, or at the support point, reaching 17071 MPa. Considering that the RUPD is shaped like a cantilever, the critical stress is expected to occur at the support.

Meanwhile, only the end section of the transverse bar experiences stress below the material's yield stress. A clearer illustration of the stress distribution exceeding the yield stress is shown in **Figure 6**.

In this study, linear static analysis was used as an initial approach to evaluate the structural response and identify potential failure based on the yield stress criterion. The results in **Figure 5** show that most structural elements, including the middle part of the transverse bar, experience stresses exceeding the yield strength of ASTM A36 steel of 250 MPa, while only the ends of the cross bar remain below this value; a clearer distribution of stresses exceeding the yield limit is shown in **Figure 6**. Although linear analysis is commonly used in the early design stage to, this method has limitations, as it cannot capture nonlinear material behavior, such as plasticity and stress redistribution after yielding [14]. Nevertheless, the results are sufficient to indicate that the structure does not satisfy the strength criteria, as the maximum stress exceeds the material yield strength.

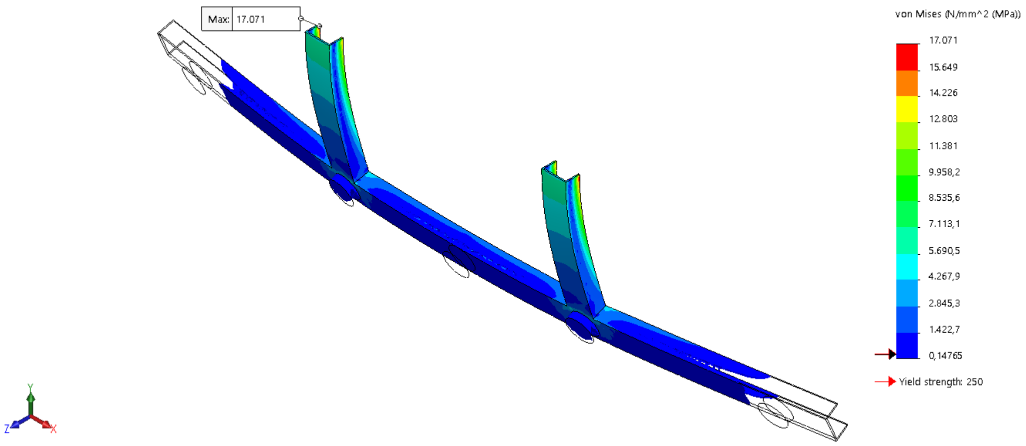


Figure 6. The results of the stress distribution above the yield stress of the model

Next, the results of the model simulation for displacement are shown in **Fig. 7**. The graph shows the displacement in the horizontal direction parallel to the direction of the force or the longitudinal vehicle, not the resultant displacement. In the finite element method, displacement indicates the magnitude of structural movement under applied loads. This parameter is used to assess stiffness, ensure deformation remains within safe limits, and verify that the design functions properly without structural failure [15]. According to the criteria, the longitudinal displacement of the vehicle is limited to 400 mm. By examining the graph of the displacement results, the displacement was found to exceed the limit. The part that experienced displacement exceeding the limit was at the end of the transverse rod of the vehicle's rear underrun protection device. The largest displacement value was 419.5 mm.

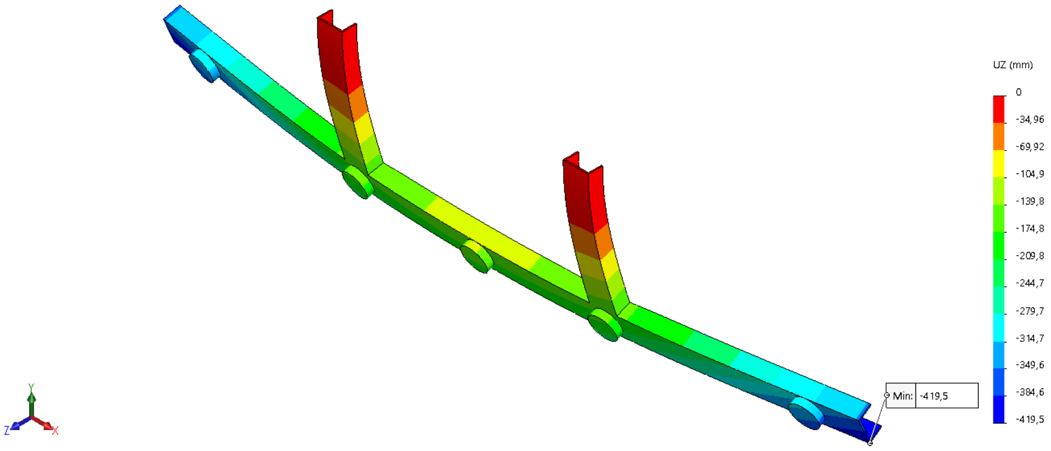


Figure 7. The results of the displacement of the model

The regulatory compliance evaluation conducted in this study indicates that several key requirements have been met, although certain limitations remain. In relation to the Regulation of the Minister of Transportation No. 74 of 2023, as shown in **Table 3**, compliance is demonstrated in the selection of material, as the underrun protection device is constructed from steel, as well as in its geometric configuration, which conforms to the prescribed rectangular shape.

Table 3. Compliance Assessment with Ministerial Regulation No. 74 of 2021

Requirement	Result
Material: iron or equivalent	Compliant; constructed from steel
Shape: tubular or rectangular section	Compliant; rectangular profile
Length: minimum 80% and maximum 100% of the vehicle's total width	Compliant; vehicle width is 2500 mm and bar length is 2200 mm, corresponding to a ratio of 88%
Distance from the rear cargo wall: aligned or maximum 100 mm rearward	Compliant; aligned with the rear body structure
Ground clearance: maximum 550 mm measured from the lower edge of the under-run protection device	Not measured
Departure angle: minimum 8°	Not measured
Connection type to the vehicle: securely mounted to the chassis or subframe using bolt-nut connections	Non-compliant; welded connection applied instead of bolted joints

Furthermore, the crossbar length meets the requirement of exceeding 80% of the vehicle width, with a measured length of 2200 mm relative to a vehicle width of 2500 mm, corresponding to a ratio of 88%. The only identified deviation concerns the connection method, with welded joints used instead of the specified bolted connections; however, this choice may be attributable to practical or manufacturing considerations warranting further examination.

Regarding compliance with SNI standards, as shown in **Table 4**, the dimensional requirement for length has not been fully met. The specified range, between 2300 mm and 2500 mm for a vehicle width of 2500 mm, is not met by the actual dimension of 2200 mm. Nevertheless, it is important to note that this deviation is relatively limited and should be interpreted within the broader context of the overall structural configuration. Similarly, the performance-based evaluation indicates that the measured displacement slightly exceeds the allowable limit, reaching 419.5 mm, exceeding the prescribed maximum of 400 mm. While this result formally indicates non-compliance, the margin of exceedance remains moderate and provides useful insight for subsequent design refinement.

Table 4. Compliance Assessment with SNI 7522:2009

Requirement	Result
Cross-member section height ≥ 100 mm	Not compliant; actual height 80 mm
Length: max equal to rear axle width, min equal to rear axle width minus 100 mm on both sides	Not compliant; vehicle width 2500 mm so required length 2300–2500 mm, actual length 2200 mm
Distance from rear body wall: max 400 mm forward	Compliant; aligned with rear body
Distance from road surface: max 550 mm from lower edge of underrun protection	Not measured
Performance: max horizontal deflection ≤ 400 mm during and after testing	Not compliant; the deflection at the end of the cross bar reached 419.5 mm

The findings of this study suggest that compliance with geometric requirements alone does not necessarily guarantee optimal structural performance. However, the observed discrepancies should not be interpreted as a fundamental inadequacy of the design, but rather as an indication of the need for further optimization, particularly in aligning geometric compliance with performance criteria.

Accordingly, this study highlights the importance of incorporating a performance-based approach to structural assessment, while recognizing that practical design processes often involve trade-offs among regulatory requirements, manufacturability, and structural behavior. In this context, geometric compliance remains a relevant baseline, albeit one that should be supplemented by performance evaluation.

Finally, although SNI standards are not strictly mandatory, the results should be understood as part of a constructive assessment aimed at improving safety margins. Any identified non-compliance with performance criteria is therefore better viewed as an opportunity for incremental improvement rather than as a critical deficiency, with potential regulatory implications depending on the applicable enforcement and oversight framework.

4. Conclusion

This study shows that although the underrun protection device complies with several regulatory requirements, such as the use of steel material, conformity of geometric shape, and fulfillment of the length-to-width ratio of the vehicle in accordance with the Minister of Transportation Regulation No. 74 of 2021 there are still several aspects that do not meet the standards, particularly in the joint methods and the crossbar length dimensions based on SNI 7522-2009. In addition, performance-based evaluation results indicate that the displacement exceeds the allowable limit, suggesting that compliance with geometric requirements alone is insufficient to ensure optimal structural performance and safety. Therefore, this study emphasizes the importance of a performance-based approach to structural evaluation, in which geometric compliance must be complemented by verification of structural capacity and response to loading. This ensures that the resulting design not only meets regulatory requirements but also achieves a higher level of safety.

Conflict of interest

The authors declare no conflict of interest. The funders had no role in the design of the study, the collection, analysis, or interpretation of data, the writing of the manuscript, or the decision to publish the results.

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