Finite element analysis of village car pickup ladder frame chassis- a case study

Ahmad Roziqin, Kriswanto, W Aryadi
Mechanical Engineering Department, Universitas Negeri Semarang
ar_unnes@mail.unnes.ac.id

Abstract. This study aims to analyse the structural design of a village car chassis that uses a ladder frame type to simulate extreme road conditions in countryside areas. The research method used is finite element analysis. The material used for the simulation is Carbon steel tube JIS G 3472 STAM, STAM 440 G and for the bracket used Carbon Steel AISI 1020 (UNS G10200). The load simulation was varied from the chassis conditions of 0°, 15° uphill, and 15° downhill. The pedestal conditions on the chassis are varied from 4 wheels to 3 wheels. The variation of loads applied to the chassis structure consists of 1) normal loads and 2) extreme loads. Based on the data from the analysis of static loading on the village car chassis, the maximum stress generated was 297 N/mm² in the 15° uphill chassis conditions without the support of one right rear wheel. The maximum displacement was 12.2 mm in 15° uphill conditions without the support of one left rear wheel. The average value of von mises stress on the chassis was 156.41 N/mm² with an average safety factor value of 2.19 and an average displacement value of 4.36 mm. It can be concluded that the chassis design is safe to withstand dynamic loads according to industry specifications.

1. Introduction
Indonesia is a very large market for the automotive industry, it is a country with a tropical climate and its people need adequate means of transportation. In an effort to increase mastery of automotive technology, it is necessary to develop automotive products. The village car is one of the automotive products developed by UNNES in an effort to create automotive product that has ability and durability in countryside road. One of the main components of the vehicle is the chassis as a support for the other components of the vehicle. The chassis design adopted to village cars is the ladder frame type. This type is generally used in heavy vehicles and has significant issues to overcome the increasing demands for higher performance, which is lower weight to satisfy fuel economy requirements [1]. In product development process, design must be tested through the design and simulation stages, especially for chassis design because it has to support vehicle loads. While many approaches have been used to study the different characteristics of the chassis, experimental and finite element methods stand out as the most accurate and widely used methods. In the finite element analysis of static load elements, load input and constrain settings are required in the chassis structure. In the village car chassis test, a simulation approach to normal conditions and extreme conditions is used to test the toughness of the chassis structure to travel steep terrain in the countryside road.
2. Briefs of Calculation and Analysis Of Chassis Strength

The finite element method can analyse the chassis design to ensure there is no failure in chassis structure, especially in knowing the stress and displacement of the structure. By knowing the stress value of the structure, we will get many benefits for product development in the manufacturing process. The determination of the stresses in a truck chassis before manufacturing is important due to the design improvement and it is investigated [2]. By doing a finite element method analysis, you will get many benefits for the manufacturing process and reduce production costs. The analysis using finite element method, weight of chassis frame can be optimized and it is feasible to analyse the modified chassis frame before manufacturing [3]. In the finite element analysis, the load that applied on the chassis is conditioned to approach the actual conditions. It can give you concrete measurement, and your design can be optimized.

The automotive chassis was optimized with constraints of maximum shear stress, equivalent stress and deflection of chassis under maximum load, also a sensitivity analysis is carried out for weight reduction [4]. The load simulation that applied on the chassis structure according to the needs of the analysis. The mathematical stress analysis of a platform integrated structure mounted on vehicle chassis designed for unconventional type of loading pattern is needed to perform certain simulation. In the FEM analysis, the village car chassis uses an approach that simulates extreme conditions on countryside roads. The fatigue study and life prediction on the chassis in order to verify the safety of this chassis during its operation using Finite Element Method (FEM) was discussed in detail [6]. The modifications of the existing bracket have in reduction of stress values leading to safe design was investigated [7]. With FEM analysis, it can be done to be a consideration and to improve the design before it is produced.

From the analysis the stress distribution (Von-mises stress) and deformations were carried out [8]. From the von Mises stress and deformation analysis, the safety factor number of the analysed structure can be seen. Safety factor or factor of safety in engineering define as a ratio of structure's absolute strength to the actual applied load. It is a measure of the reliability of design manufacture [9]. To determine the safety factor of a structure to be designed, the following rules can be used; 1) $n = 1.25$ to $2.0$ for the design of structures that withstand static loads with a high level of confidence for all design data; 2) $n = 2.0$ to $2.5$ for the design of machine elements that withstand dynamic loads with average confidence level for all design data; 3) $n = 2.5$ to $4.0$ for designing static structures or machine elements receiving dynamic loads with uncertainty regarding load, material properties, stress analysis, or environment; 4) $n = 4.0$ or more for designing static structures or machine elements that are subjected to dynamic loads with uncertainty regarding some load combination, material properties, stress analysis, or environment [10].

3. Test Method

The test method used is a finite element method simulation of static load on the chassis structure of the village car. In general, static load is used to determine the distribution of stress that occurs in the chassis. In this study, the load that given to the chassis structure uses the field testing conditions approach, where the conditions in countryside areas do not always have good road facilities, some are still in dirt and rock road conditions, so in this test a specific approach is carried out in testing the chassis structure. Investigation of the structural analysis and optimization of vehicle chassis with constraints of maximum shear stress and deflection of chassis under maximum load [11]. For the loads simulation, it uses two variations; 1) normal load, 2) extreme load (normal load x 3).

Table1. Static load testing variations

| Chassis condition | Loads | Support Simulation | Applied support | Released support |
|-------------------|-------|--------------------|-----------------|------------------|
| Normal 0°         | Normal| 4 wheels           | All 4 wheels    | -                |
The load simulation is carried out in normal and extreme conditions. Normal condition simulated with all of the wheels support the vehicle loads. Extreme condition simulated with only three wheels support the vehicle loads. Extreme conditions are used to simulate a vehicle running and experiencing obstacles or potholes. The loads values applied in the simulation on the chassis structure are described in the following table 2.

Table 2. Loads applied to the chassis

| Loads               | Support                | Normal (N) | Extreme (normal x 3) N |
|---------------------|------------------------|------------|------------------------|
| Engine & Transmission | Bracket engine & transmission | 1260       | 3780                   |
| Body & Passenger    | Bracket body           | 4100       | 12300                  |
| Pickup & Cargo      | Bracket pickup         | 7000       | 21000                  |

Figure 1. Applied load to the chassis

Material of chassis used carbon steel square tube product from ISTW type JIS G 3472 STAM, grade G, STAM 440 G, carbon steel tube. Material properties of this product described in the Table 3. The material of the supporting bracket in the village car chassis design uses AISI 1020 Carbon steel with its material properties described in the Table 4.

Table 3. Material properties of JIS G 3472 STAM (mechanical)[12]
| Grade | Designation | Tensile Strength N/mm² | Yield Point N/mm² | Elongation % Longitudinal direction | Flaring test |
|-------|-------------|-------------------------|-------------------|-----------------------------------|-------------|
| Grade G | STAM 440 G  | 440 min                 | 305 min           | 25 min                            | 1.15 D      |

**Table 4.** Material properties of AISI 1020 Carbon Steel (UNS G10200)

| Tensile Strength | Yield Point | Elongation% | Young Modulus |
|------------------|-------------|-------------|---------------|
| MPa              | MPa         | Longitudinal direction | GPa           |
| 420 min          | 305         | 15          | 205           |

4. RESULT AND DISCUSSION

There are two main test variations in the village car chassis analysis, namely testing with normal condition parameters and testing with extreme parameters. Each testing variation have different constrain to perform, normal condition simulated with 4 support, and extreme condition simulated with 3 support.

4.1. Normal Condition Test

There are 3 variations of the test in normal conditions, namely normal conditions 0°, uphill 15° and downhill 15°. All of normal condition test used 4 wheel support. As an example of the analysis, the simulation data of 0° normal load with 4 wheels support is displayed at Figure 1 below.

![Figure 1. Normal 0° simulation](image)

**Figure 2.** Von mises stress of normal 0° simulation
Maximum value of von mises stress (red area) = 68.6 MPa or 6.86477e+006 N m², minimal value of von mises stress (blue area) = 0 MPa or 310,962 N m²

![Figure 3. Displacement of normal 0° simulation](image)

Maximum displacement (red vector) = 0.0413056 mm, minimum displacement (blue vector) = 0 mm. Based on the simulated test data in Figure 2, Von mises stress < Yield stress (68.6 MPa < 305Mpa). Based on the simulated test data in Figure 3, Displacement is small 0.0413 mm.

SoF: \[
\frac{\sigma_v - 305}{68.6} = 4.433
\]
Safety factor is greater than 1, so the design is safe

4.2. Extreme Condition Test

There are 12 variations of the test in the extreme condition, namely normal conditions 0°, uphill 15° and downhill 15° with 4 variations of 3 wheels support and extreme load each. As an example of analysis, a simulation data of Uphill 15° load with 3 wheels support is displayed bellow.
Figure 4. Von mises stress of 15° uphill chassis condition with 3 support

Maximum value of von mises stress (red area) = 2,96941e+008 N/mm², minimum value of von mises stress (blue area) = 0 MPa or 0 N/mm².

Figure 5. Displacement of 15° uphill chassis condition with 3 support

Maximum displacement (red vector) = 10,7 mm, minimum displacement (blue vector) = 0 mm. Based on the simulated test data in Figure 4, Von mises stress < Yield stress (296 MPa < 305Mpa). Based on the simulated test data in Figure 5, Displacement is small 10,7 mm.

SoF: $\frac{\sigma_y}{\sigma_x} = \frac{305}{296} = 1,03$  Safety factor is greater than 1, so the design is safe.

Based on the variation of the static load analysis simulation described in Table 1, the results of the chassis structure analysis are summarized in table 5 below. Based on the data in table 5, the maximum value of von mises stress on the chassis occurs in the simulated 15° uphill condition without the right rear support of 297 N/mm². In this condition, the calculation of the safety factor is 1.03, so this result can still be said to be safe because the safety factor value is greater than 1. The maximum displacement occurs at a
15° uphill condition without support on the rear left with a value of 12.2 mm with a safety factor value of 1.23. The average von mises stress in the test simulation was 156.41 N/mm², still much smaller than the yield strength of the material of 305 N/mm². The average safety factor value of the test is 2.19 and the average displacement is 4.36 mm. Based on this data it can be concluded that the chassis design is safe and meets industry specifications to withstand dynamic loading with an average confidence level for all design data [10]. Maximum stress and displacement occur in the rear construction because the overhang of the pickup and cargo pedestal is too large. To further refine the design, wheelbase changes can be made to reduce chassis overhangs.

| Position (°) | Constraint                | Max. Value of von mises stress (N/mm²) | SF | Max. displacement (mm) |
|--------------|---------------------------|----------------------------------------|----|------------------------|
| 0            | All support               | 68.6                                   | 4.43 | 0.04                   |
| 0            | Rear Left Not support     | 124.6                                  | 2.45 | 4.33                   |
| 0            | Rear Right not support    | 124.2                                  | 2.46 | 5.24                   |
| 0            | Front Left Not support    | 148.4                                  | 2.06 | 3.57                   |
| 0            | Front Right not support   | 148.4                                  | 2.06 | 3.57                   |
| 15           | Downhill, All support     | 123                                    | 2.48 | 1.66                   |
| 15           | Downhill, Rear Left not support | 133                          | 2.29 | 4.13                   |
| 15           | Downhill, Rear Right not Support | 123                          | 2.48 | 5.14                   |
| 15           | Downhill, Front Left Not support | 155                          | 1.97 | 3.51                   |
| 15           | Downhill, Front Right Not support | 133                          | 2.29 | 3.52                   |
| 15           | Uphill, All support       | 123                                    | 2.48 | 0.166                  |
| 15           | Uphill, Rear Left Not support | 247                          | 1.23 | **12.2**               |
| 15           | Uphill, Rear Right Not Support | **297**                          | 1.03 | 10.7                   |
| 15           | Uphill, Front Left Not Support | 217                          | 1.41 | 4.33                   |
| 15           | Uphill, Front Right Not Support | 181                          | 1.69 | 3.22                   |
| min          |                           | 68.6                                   | 1.03 | 0.04                   |
| Max          |                           | **297**                                | 4.43 | 12.2                   |
| Average      |                           | 156.41                                 | 2.19 | 4.36                   |

5. CONCLUSION

Based on the data from the analysis of static loads using the FEM method on the village car chassis, the average value of von mises stress on the chassis is 156.41 N/mm² with an average safety factor value of 2.19 and an average displacement value of 4.36 mm. It can be concluded that the chassis design is safe to withstand dynamic loads according to industry specifications.

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