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Fatigue Failure Analysis Of Bogie Frame Due To Static Load

Ilham Satrio Utomo[1], Baihaqi Fadhilah Muhammad[1], Ajeng Tyas Damayanti [1]

[1]Indonesia Railway Polytechnic,
Jl. Tirta Raya, Madiun City, 63161, Indonesia

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ABSTRACT

This bogie design is used on trains. The purpose of simulation testing is necessary to ensure the strength and safety of the bogie frame design. Tests carried out to determine the durability of a construction are fatigue testing simulations. Fatigue failure is caused by fluctuating loads and it is necessary to simulate fatigue testing on the bogie. The method used in this research is the finite element method. The static test simulation results show that the maximum von Mises stress of 135.47 occurs at element 1675 with a safety factor of 2.4. The test simulation results on 9 loading combinations have a maximum average value of 110.16 MPa.

Corresponding Author:

Ilham Satrio Utomo
Department of Mechanical Engineering, Indonesian Railway Polytechnic
Jl. Tirta Raya, Pojok, Nambangan Lor, Manguharjo, Madiun, Jawa Timur 63161, Indonesia
Email: kontak@ppi.ac.id

1. INTRODUCTION

A bogie is a complex construction of the train's wheelset, bogie frame, suspension, and braking system. Bogies provide flexibility to the train against the rails. Bogies change the direction of the wheelset following the rails when the train crosses a curve. The part of the bogie that receives a large load when the train is operating is the bogie frame.

The bogie frame supports the entire load of the carbody, connects the bogie to the wheelset, and acts as a support for other bogie components. The majority of bogie frames are made of steel. The bogie frame parts are connected by welding to form a complex bogie frame. The production of bogie frames goes through a testing phase to obtain an operating licence.

In producing trains, safety and comfort factors are paramount. This is regulated by a standard listed in the Minister of Transportation Regulation No. 16 of 2022 concerning Design and Engineering of Railway Facilities, stating that a bogie must be able to accommodate the loading received without permanent deformation. So that in the design process until mass production, construction testing of railway facilities using special software simulations is carried out to determine the ability of construction to the maximum load without experiencing plastic or permanent deformation and to determine the ability of construction to operational loads applied within a certain period of time (Minister of Transportation RI, 2022).

The strength of the bogie frame is ensured to fulfil the acceptance criteria because it supports the large load of the train. One test that is written and needs to be done to determine the durability of a construction is fatigue testing simulation. Fatigue failure is caused by fluctuating loads and it is necessary to simulate fatigue testing on train components, especially on bogies that receive the entire load of the train with fluctuating load conditions (Indonesian Minister of Transportation, 2022).

From observations in the field, simulation uses finite element method (FEM) software to simulate the design of the bogie frame structure because the simulation results obtained are accurate [1][2], [3]. Structural simulation loading follows the applicable standards for each type of test structure[4]. This is done to ensure that the design is safe and meets the criteria according to applicable standards before manufacturing the product[5]. Analysis and testing follow the UIC 515-4 standard on "Passenger Rolling Stock Trailer Bogies - Running Gear, Bogie Frame Structure Strength Test", this standard describes the bogie frame loading test method (UIC, 1993). The bogie frame material SM490 A has tensile and yield strengths of 325 MPa and 490 MPa, respectively. In this study, it was found that the bogie frame has a minimum safety factor of 1.4 and an estimated life of 2.5×10^7[6]

This study was conducted to determine the strength of the bogie frame structure on bogie whether it meets the required standards or not. Referring to UIC 515 - 4 of 1993, normal service loading is applied in the analysis of bogie frame design strength[7]. Normal service loading values of train bogie frames are operational conditions with load combinations (load cases) that occur repeatedly. The strength of the bogie frame against normal service loading is called fatigue limit strength or endurance limit. The endurance limit approach is carried out by static simulation testing with normal operational loading calculations..

2. RESEARCH METHOD (10 PT)

By default the material that has been defined in the engineering data menu is structural steel, because the type of material used is not structural steel, it is necessary to add a new type of material to the engineering data menu. The data added is the mechanical properties of the SM490 A material, as shown in the figure below.

Table 1 Properties Material SM490 A

No.	**Parameter**	Unit	**Type of material**
			SM490 A
1.	Modulus elastisitas	GPa	200
2.	*Poisson's ratio*	-	0,3
3.	Massa jenis	kg/m^3	7850
4.	*Yield tensile strength*	MPa	325
5.	*Ultimate tensile strength*	MPa	490

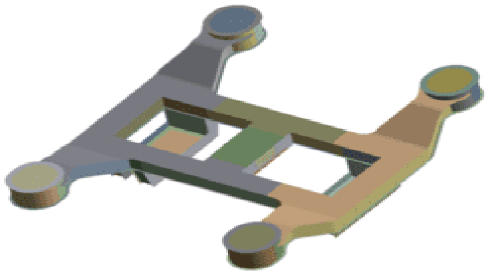

Figure 1 *Geometry Bogie Frame*

Post processing is the last stage based on loading simulations using Ansys Workbench 21 software. In this stage, the results of the simulations that have been carried out are explained in the form of the stress value of the bogie frame structure that has been simulated with normal operational loading[8].

The meshing process uses a quadratic element order. When the bogie model in Ansys software is a multiple body or consists of parts, the relationship of nodes between parts must be arranged so that they are connected. The process of setting the relationship of nodes between parts is shown in the figure below.

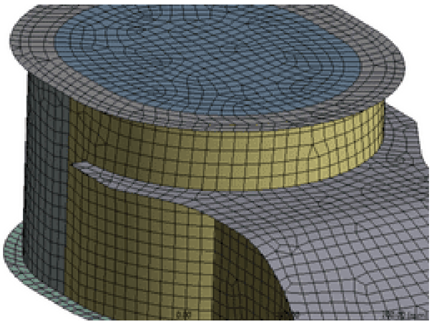

Figure 2 Meshing

Post processing is the last stage based on loading simulations using Ansys Workbench 21 software. In this stage, the results of the simulations that have been carried out are explained in the form of the stress value of the bogie frame structure that has been simulated with normal operational loading.

In carrying out the fatigue analysis, a total of 9 (nine) loading combinations were simulated. From the simulation results of each loading combination, several points were taken for maximum stress sampling which will be compared with the results of other loadcases. Taking the stress at this point is based on the location that often experiences maximum (critical) stress. In total, 12 points were observed, the majority of which were located on the top, bottom and sidebar wall plates.

3. RESULTS AND DISCUSSION

Calculations were carried out using Ansys Workbench 21 software. The parameters sought were the maximum von Mises stress, critical location, deformation size, and safety factor value when given a loading combination.

3.1. Static Testing Simulation

One of the tests in loading combination 9 reflects the state of the train when travelling with the maximum payload load over a curved road. Vertical loads due to the payload are applied to both fulcrums at the centre of the sidebeam. In addition, transverse loads will be applied due to the motion of the train through the curve. In applying the transverse load, the transverse load has caused the centre pivot to touch the rubber on the lateral stopper so it can be assumed that the transverse load has been distributed on the sidebeam.

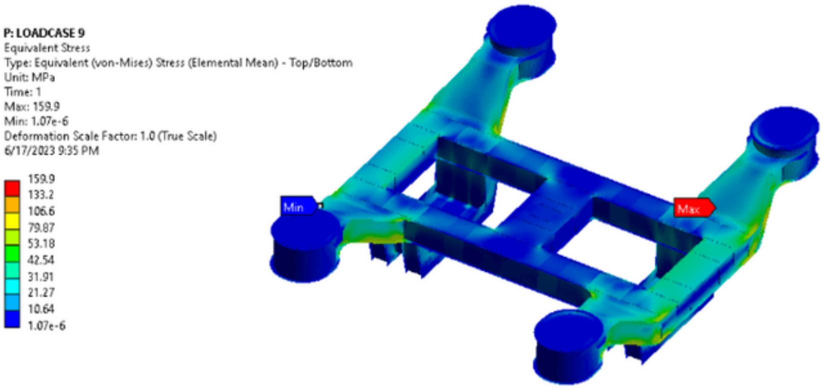

Figure 3 Loading Combinations

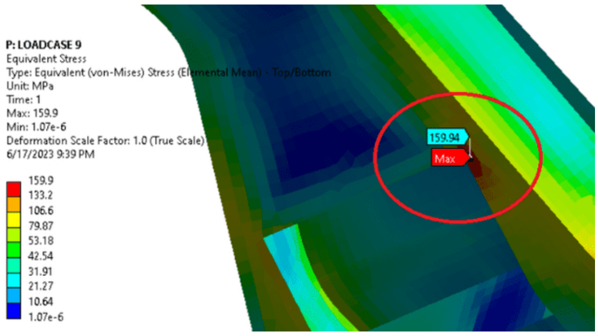

Figure 4 Loading Critical Point

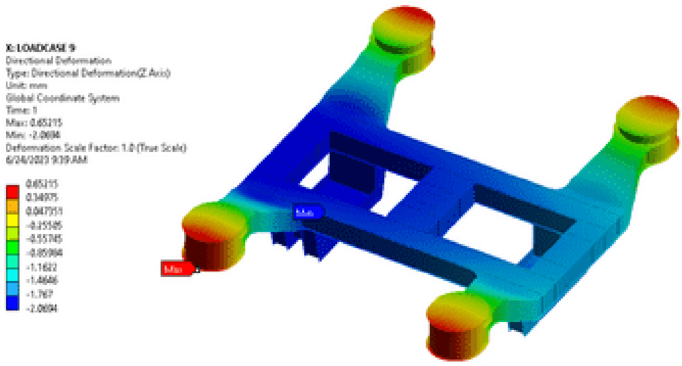

Figure 5 *Deformasi Z Axis*

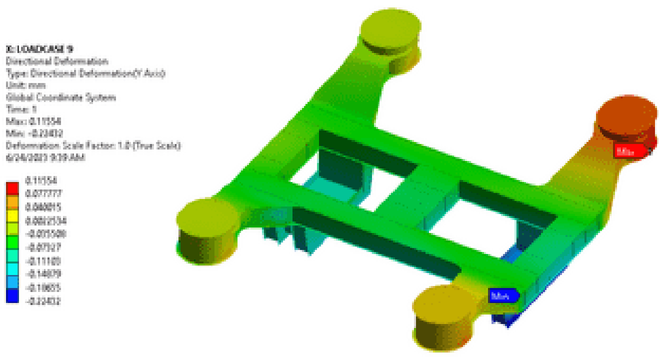

Figure 6 *Deformasi Y Axis*

Vertical and transverse loads applied to the brake support. As with loading combination 7, the stresses that occurred in the bogie frame were also considerable, as indicated by the majority of the green and blue coloured bogie frames (Figure 4). The transom region experienced an increase in stress in the range of 10 - 133 MPa (below yield). Similar to loading combination 1, the connection area between the traction rod support and sidebeam experienced a high stress concentration of 159.9 MPa (Figure 5). The maximum deformation occurred around 0.65 mm Z- and 0.115 mm Y- (Figure 6). This simulation fulfils the material safety criteria as the yield stress value of SMA490 A is 325 MPa.

3.2. Fatigue Testing Simulation

In the fatigue calculation, the dynamic loads from normal operation are modelled as static loads and compared with the fatigue limit of the goodman-smith criteria. In addition to the goodman-smith criteria, cumulative damage approach criteria can also be used as mentioned in the UIC 515-4 standard. The finite element model for the bogie frame used for the fatigue analysis is the same model as that used in the static analysis.

Based on the static simulation results, the critical elements for each loading combination are known. The critical location that occurs in each loading combination occurs in the arch area between the sidebeam bogie and the transom bogie, namely the connection area between the traction rod support and the sidebeam bottomplate. Then the element that has the largest von Mises stress region is selected. As shown in the picture below Figure 7 and Figure 8.

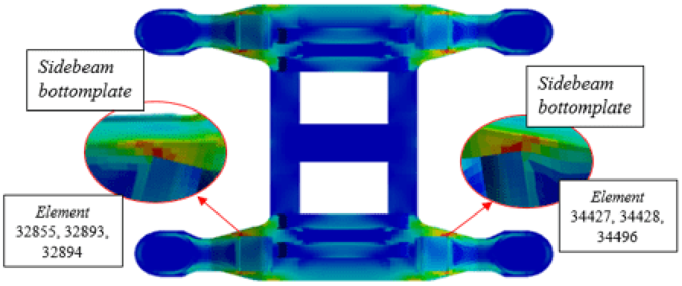

Figure 7 Critical location due to von Mises stress (F_{z2}) on the right side beam.

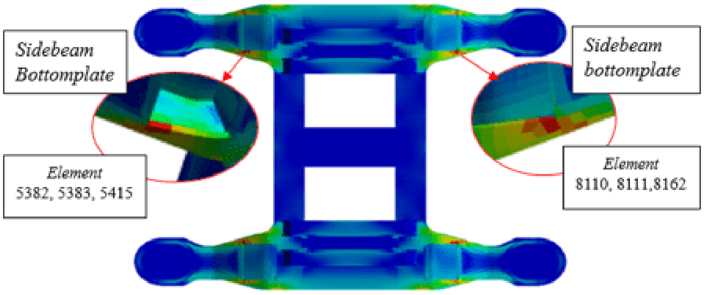

Figure 8 Critical location due to von Mises stress (F_{z1}) on the right side beam.

For each element, the smallest and largest stresses from all loading combinations were selected to determine the average stress and stress amplitude.

The fatigue simulation results in the form of the location of the critical element of the research object structure, the critical element stress value for each loading combination, and the plot of the critical element stress value with the goodman-smith diagram approach are described as follows

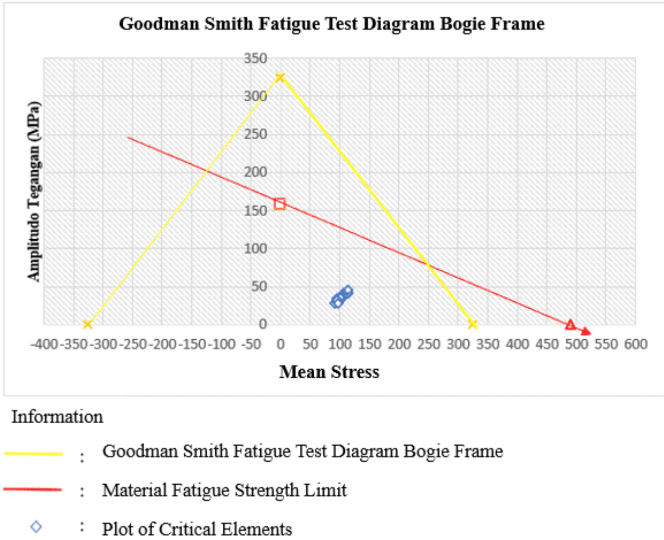

Figure 9 Goodman-Smith Diagram

Based on the analysis with the Goodman-Smith diagram above, it is known that all critical elements are in the infinite life of the material or meet the criteria for acceptance of the fatigue limit of the fatigue material.

Based on the research, convergence test, meshing quality was carried out to determine the mesh size. The stress of the research object fulfils the UIC 515 - 4 acceptability criteria based on the goodman - smith diagram approach. The highest stress amplitude on element 5415 is 113.62 MPa, while the accepted stress amplitude is 158.23 MPa which is taken from the fatigue allowable stress parameter of the material. All the average stresses of the research object fulfil the acceptance criteria, which is less than 325 MPa based on the material yield strength parameter. The bogie design research can be declared to meet the strength and durability of the bogie frame structure based on the Minister of Transportation Regulation No. 16 of 2022 concerning Design and Engineering of Railway Facilities.

4. CONCLUSION

The static test simulation results show that the maximum von Mises stress that occurs is still below the yield stress of the SM490 A material, so it can be concluded that the bogie structure design is believed not to experience plastic deformation. The maximum von Mises stress of 135.47 occurs at element 1675 with a safety factor of 2.4, this stress occurs when the bogie structure design experiences maximum loading on one side of the bogie frame, experiencing a transverse force in the Y + direction in loading combination 9.

The test simulation results on the bogie structure design using Ansys Workbench 21 R1 software show that the design is believed to be safe from fatigue failure. The test simulation results on 9 loading combinations have a maximum average value of 110.16 MPa. The entire stress of the test simulation results shows that it is still within the endurance limit stress limit of SM490 A material of 158.23 MPa. So it can be concluded that the bogie frame structure design is suitable for use, because it is believed that it does not experience fatigue failure when operated at its normal operating load limit.

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