A Review on Finite Element Method for Static Analysis of a Passenger Bogie Frame

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ABSTRACT

The development of the railway bogie includes analysis and testing of the bogie frame as an important and integral member of the bogie. The main purpose of the bogie frame is to withstand or transfer vertical loads of the superstructure with payload, lateral forces caused by negotiating the curves, the interaction between rail and wheel and longitudinal force. Static analysis of the bogie frame ensures safe, reliable and efficient operation. However, many researchers have applied different methods of determining the stability and safety of the railway bogie and different methods and analyses have been used under different loading conditions. However, studies which tend to have a combination of different methods and conditions during analysis are rare and considered in very few cases. The main aim of this review paper is to identify the weakness associated with the existing different methods used in static analysis of a passenger bogie frame and make suitable recommendations. Therefore, from this review paper, the research question of "what best finite element methods have been used for static analysis of the passenger bogie frame is being answered”. A literature review was systematically collected, identified and sorted to come up with literature that applies to our study. Different review articles have been looked into and proper consideration has been put on (28) articles that address the research gap identified where the different methods applied in the respective articles have been studied and compared with the international standards.

Keywords: *Static Analysis, Bogie Frame, Loading conditions, International Standard, Finite Element Method.*

INTRODUCTION

The bogie is one of the most important components which is responsible for withstanding all the vertical loads of the superstructure with payload, and lateral forces caused by negotiating the curves, supporting, loads due to track irregularities and guiding [1][2]. A bogie is an important structure that comprises about 37% of the total weight of a railway vehicle [3] and supports various components such as power, traction, suspension components etc. Static loads which are random are subjected to the bogie frame and thus resulting in fatigue failure, affecting stability and jeopardizing the safety of the entire railway vehicle [4][5].

The development of railway bogie frames comprises different stages involving stress calculations, design, static analysis, testing and validation for safety purposes and efficient operation. The material characteristics, geometry dimension and loads of the bogie frame may have uncertainties after manufacture or during operation which result in errors in analysis and cause differences between analysis results and actual events as required by the international standards [6]**.** As a key component of the bogie, the reliable operation of the bogie frame with its structure seen in figure 1, is the top priority for the operation safety of the railway system [7]. Most previous reviews have been focused on fatigue life assessment of a railway bogie frame [5] load analysis of a railway vehicle [8], and damage failure of a passenger bogie [9]. Those reviews have been performed from various studies conducted about structural analysis of a railway bogie frame [10][11][12] and others performed by focusing on fatigue analysis [13][14][15][16][17][18]. Due to the role played by the component, several studies were conducted by Huang et al. [4] and Kassner et al. [19] through structural strength bogie simulation and determining the fatigue life and carrying out comparisons with experimental results. Oyan *et al.*, 1998 conducted studies about the static structural strength of rapid transit systems bogie frame at different static loads using finite element analysis and modified Goodman for failure criteria [20]. During static analysis of the bogie frame, it is of great importance to carry out the proper calculation of loading requirements.

According to the reviewed papers, there are variations in determining the loading conditions, which may lead to different results during analysis. To the best of the authors' knowledge, no detailed review explains the variation in methods used for static analysis of a railway bogie frame. The main aim of this review paper is to identify the weakness associated with the existing different methods used in static analysis of a passenger bogie frame and make suitable recommendations. This is because there is a need to have a general formula which can accommodate different types of existing bogie frames in a railway system. Therefore, this paper review focuses on the important requirements for validation of static strength of any kind of bogie frames under the different exception loads and compares the different methods used with the international standards. This review of the static analysis of the bogie frame provides important guarantee guidance for the safe and reliable operation of the bogie. At the same time, it provides important references for the strength analysis schemes of bogie frames in other similar projects. The next sections of this review will focus on studies conducted by various researchers, the methods used, factors considered, results obtained and possible gaps.

The review is organized through five sections. A process used in collecting the articles used for this review has been detailed in section two about the review methodology. The third section details different literature from previous works done by various researchers. Next, a discussion part on various results found by researchers and their variations has been elaborated in section four. Lastly, the conclusion from the review has been presented in section five.

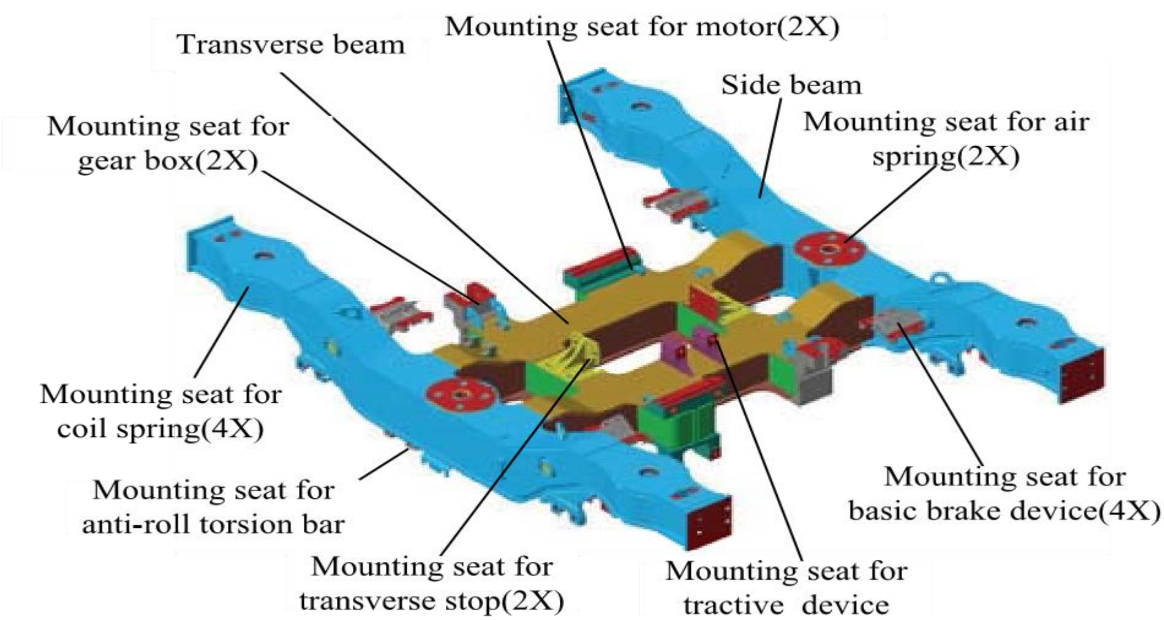

***Figure 1**. Bogie frame structure [21].*

REVIEW METHODOLOGY

This work is a review of the related research based on passenger bogie frame static analysis that has been done previously by different researchers. The previous research has been used as a reference to give complete information for this paper review, which aims to answer the research gap question "what best analysis methods have been used for static analysis of the passenger bogie frame ". All the papers considered under this review were downloaded from google scholar, science direct and advanced google search and some of the keywords and phrases that were used to avoid missing out on the relevant information and articles plus publications during the study review included "passenger bogie frame", "static analysis" and different publications and articles were identified and the most relevant publications that fulfil the research gap interests were chosen out and the rest rejected. During the review, only static analysis of passenger bogie frames using finite element analysis with ANSYS and ABAQUS were considered and the dynamic and fatigue analysis were rejected and the accepted articles were exported to mendeley for consideration.

LITERATURE REVIEW

At present, different methods are used to analyse for the safety, reliability and efficiency of passenger railway bogies which are compared to the specified standards such as EN 13749, EN 13798, UIC 615-4, UIC 515-4, TB/T 3548, JIS E 4207, [22][23][24] which include static analysis. Different researchers have applied different methods in static analysis of passenger bogie frames which aim in verifying that there is no permanent deformation when the bogie frame is under the combined effects of maximum loads that may occur during operation [25]. Different loading cases have been used by researchers such as the vertical static load which includes the gravity of the car body, axle, bogie, and passengers. The lateral load includes the wind force and centrifugal force of the car body and the longitudinal load has the traction force, friction force, and inertia force when braking [26]. The load and constraints are shown in Figure 2.

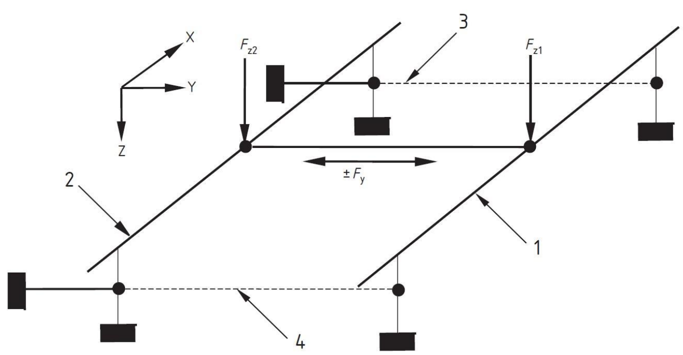

Figure 2*.Schematic diagram showing load conditions [26].*

Key

1 – Side frame 1

2 – Side frame 2

3 – Axle 1

4 – Axle 2

The loads that are subjected to the bogie frame cause high stresses on the various bogie components as studied by Yongyang Zhang,2016 [1]. The maximum stresses due to vertical and transverse load cases were found to be 146.9 Mpa for yield strength of the material of 355 Mpa using the analysis design software ABAQUS, and the forces acting on the frame were calculated from equations (1) and (2) respectively.

$$F_y = 2\left(10^4 + \frac{(m_v + c_1)g}{12}\right) \tag{1}$$

$$F_z = \frac{1.4g(m_v + c_1 - 2m^+)}{2} \tag{2}$$

Where F_y is lateral force and F_z is a vertical force, m_v is the weight of the vehicle, m^+ is the weight of the bogie, c_1 is the weight of passengers, and g is the acceleration due to gravity.

On contrary, the static analysis of the passenger bogie was studied by Bangsheng Xing, 2019 [1] and Shuo Zhang, 2020 [2] using FE analysis software. During the study, different numbers of axles and bogies were considered which gave room to deal with any type of bogie frame and the corresponding maximum stresses were found to be 307.6Mpa and 305.6Mpa respectively for the yield strength of the material of 355 Mpa when the transverse and vertical load cases were applied according to equations (3) and (4) respectively.

$$F_y = 2\left(10^4 + \frac{(m_v + c_1)g}{3n_a n_b}\right) \tag{3}$$

$$F_z = \frac{1.4g(m_v + c_1 - n_b m^+)}{n_b} \tag{4}$$

Where n_b is the number of bogies under a single carriage, n_a is a number of axles per bogie, other notations are the same as explained above.
Syed Yaseen, 2014 [27] studied static analysis of the passenger bogie by including a constant factor k which depends on exceptional load cases. This factor is normally equal to 1.4 due to

track induced force. The maximum and yield stresses were found to be 281.127 Mpa when the vertical and transverse load cases were applied using the equations (5) and (6) respectively.

$$F_z = \frac{kg(m_v + c_1 - 2m^+)}{2} \tag{5}$$

$$F_y = 2\left(10^4 + \frac{(m_v + c_1)g}{3n_a n_b}\right) \tag{6}$$

K is the factor that depends on exceptional load case this factor is normally equal to 1.4 due to track induced force.

The study done by Ruixian Xiue et al., 2020[5] showed that during the static analysis of bogie frame the effect of rolling and bouncing coefficients on loads can be considered because vertical force can be affected by the rolling coefficient (α) and bouncing coefficient (β). αF_z is the change of vertical load caused by the vehicle rolling, and βF_z is the change of vertical load caused by the vehicle's vertical movement. In normal operation condition, α= 0.1, β= 0.2.

According to the UIC615-4 standard, 15 different cases including 2 kinds of abnormal load conditions and 13 kinds of simulated operating load conditions. Among those cases, five of them were chosen and studied under the analysis done by Bangsheng Xing, 2019[26]. Among which operating conditions 1 to 4 are simulated operating conditions, and operating condition 5 is an abnormal load condition. In the calculation of the loads, the influence of the curve factors on the bogie were also taken into account. To simulate the change of vertical load caused by rolling and vertical movement of the vehicle body, the roll coefficient α = 0.1 and the rising and settling coefficient β = 0.2 were taken. According to the UIC615-4 standard, the load calculation for each working condition were obtained, as shown in the table below.

Table 1. *Table for load calculation for 5 cases working conditions [26].*

Number	Vertical Right and Left loads		Lateral
	F_{Z1}	F_{Z2}	
Case 1	F_Z	F_Z	0
Case 2	$(1+\alpha-\beta)F_Z$	$(1-\alpha-\beta)F_Z$	0
Case 3	$(1+\alpha-\beta)F_Z$	$(1-\alpha-\beta)F_Z$	$+F_y$
Case 4	$(1-\alpha-\beta)F_Z$	$(1+\alpha-\beta)F_Z$	$-F_y$
Case 5	F_{Z1max}	F_{Z2max}	F_{ymax}

Examples of analysis using these standard equations and relevant data is summarized by reviewing the article done by Bangsheng Xing, 2019 [26]. The reviewed bogie frame is called SKMB-200 bogie frame made of SMA490BW type weather resistant steel; its allowable stress is 355MPa. The maximum stresses found during this analysis are 225.7 Mpa, 209.0 Mpa, 250.3 Mpa, 196.2 Mpa and 307.6Mpa for case 1, case 2, case 3, case 4 and case 5 respectively. The chart showing equivalent stress distribution of SKMB-200 bogie frame from Abaqus software under different 5 load conditions is shown in Figure 3.

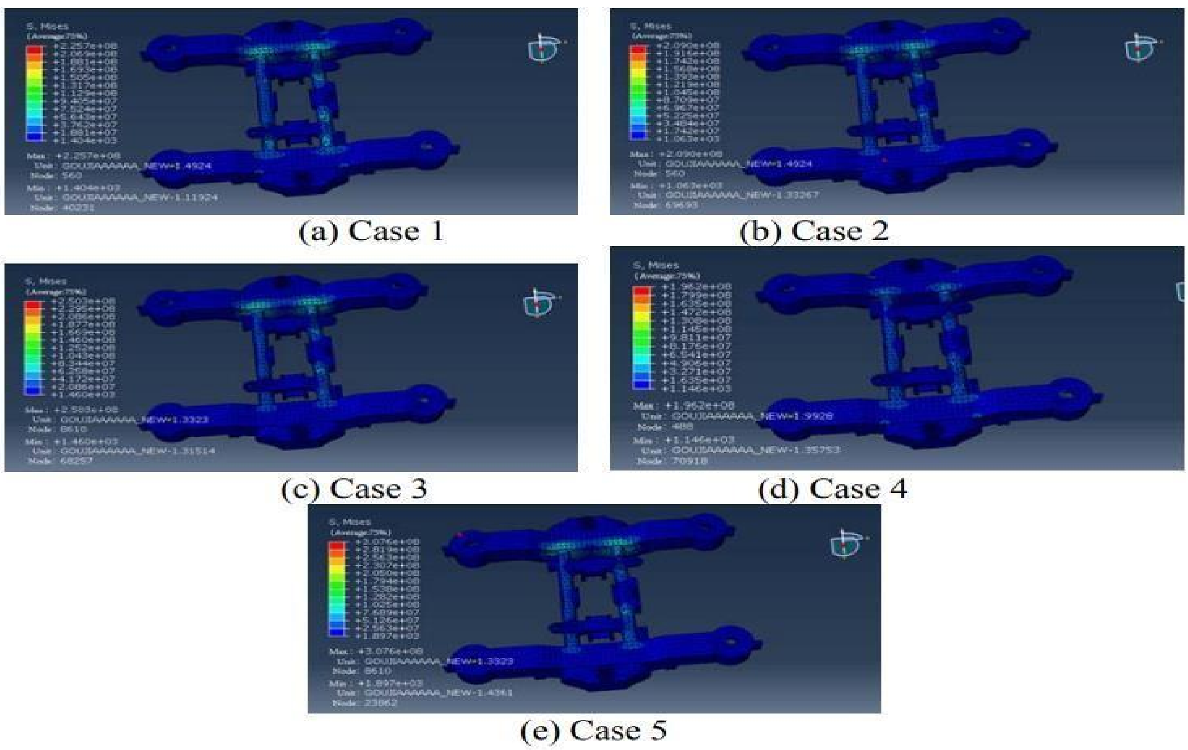

Figure 3. *Chart showing stresses distribution under 5 cases for SKMB-200 bogie frame [26].*

RESULTS AND DISCUSSION

By comparing the results from different researchers about the static analysis of passenger bogie frames the maximum stresses were in the range from 146.9MPa to 307.6 Mpa. Most of cases the results are different due to the consideration of the different weight of the vehicles, weight of bogie, the mass of passengers, number of axles and number of bogies. According to the standards, the bogie frame must experience the maximum stress which is smaller than the allowable yield stress of the material from which the frame is made normally for structural steel is 355 MPa. Many researchers didn't provide the general expression which can be used for analysis of different types of bogies. During structural analysis of bogie frame some researchers considered number of axles while others not and some put into consideration of the factor K due to track induced force. The different values of stresses were obtained which were in the range of standard i.e. Induced stress below than yield stress of the material.

Table 2. *Comparison of the results found by considering different factors in loading expressions from various study.*

Methods	Consider number of axles	Consider number of bogies	Consider the factor K	Maximum stresses (MPa)	Yield strength of the material used (MPa)	References
FE Abaqus	no	no	No	146.9	355	Yongyang Zhang,2016[1]
FE	yes	yes	no	305.6	355	Bangsheng Xing, 2019[26]
FE	yes	yes	no	307.6	355	Shuo Zhang, 2020 [21]
FE	yes	yes	yes	281.127	355	Syed Yaseen, 2014[27]

From table 2, it is clear that various stresses can be found when considering different factors in the expression of loading. Even though all studies provide results that is in line with the standards where the maximum induced stresses must be less than yield strength of the material, but the best expression is that can be adopted for any type of vehicle having various number of bogies, axles, considering loading factor K, rolling and bouncing coefficient. So the best recommended method expression which can provide the better analysis among the one reviewed is that conducted by Syed Yaseen, 2014 where analysis of stress due to forced vibrations was conducted through application of ANSYS software and the results compared for safety and reliability[28].

4.1 Challenges and future directions

The following areas needed further consideration in regards to static analysis of passenger bogie frames in order to improve the reliability, efficiency and safety of passenger bogie frames.

- Proper consideration of the right bogie mass (m^+), number of bogies (n_b), and the number of axles (n_a) should be correctly evaluated to have safe bogie frames.
- Proper application of the different boundary conditions with their respective load cases should be considered.
- Proper material selection that can withstand the various exceptional loads applied and the proper selection of the various engineering simulation software for example Abaqus and Ansys to detect the factor of safety and life for the different material components on the frame should be considered

CONCLUSION

In this review, it is noticed that there is various static analysis that have been carried out by different researchers. Static analysis of passenger bogie frames putting into consideration the number of axles and bogies were common amongst different researchers. However, this review has highlighted difference in methods used by various researchers which may give unrealistic results when it comes to the aim of achieving the reliable and safe bogie frame since in some researchers it has been observed that the number of axles and bogies were not put into consideration.

Number of papers reviewed is limited because it is difficult to analyse some of the online articles that were inaccessible due to the copyrights and most of the research has been published in local languages like Chinese which may not give a clear understanding of the whole passenger car bogies. Nonetheless, this review gives a clear view of the various methods used in evaluating the static analysis of passenger bogie frames in regards to reliability safety and efficiency. From the reviewed papers, it is observed that most researchers on static analysis of bogie frame considered they are BO-BO with only two axles so further analysis on other types including COCO with 3 axles is needed to analyse the possible changes. Also is a need to have a common way to find the weight of the vehicle and bogie and payload used in general analysis of passenger bogie frame in future work.

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CONFLICT OF INTEREST

The Authors announce that there is no conflict of interest for this review work

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