

# DESIGN OF A TRAIN ARTICULATION SYSTEM

## NAČRTOVANJE IN IZRAČUN PRIKLOPNIKOV VAGONOV

Gordan Grgurić<sup>1</sup>, Tihomir Mihalić<sup>3†</sup>, Andrej Predin<sup>2</sup>

**Keywords:** train articulation system, rail vehicle, Jacobs bogie, conical bolt, strain, FEM, railcar, articulation coupler, joint

### **Abstract**

A train articulation system is a joint or collection of joints at which something is articulated, or hinged, for bending. This paper deals with the construction of a passenger train's articulation system in which the wagons are connected via Jacobs bogies. The work includes the construction, design, finite element method (FEM) analysis and comparison of the results of strains gathered by FEM and analytical methods. Furthermore, the comparison of the welded type and casted tape of joint is contemplated using permitted strains and the feasibility of a particular construction as criteria.

### **Povzetek**

Vlakovni povezovalni sistem je spoj oziroma skupek spojev, ki omogoča vožnjo vlaka oziroma vagonov v ovinek. Prispevek obravnava konstrukcijo spojnega sistema potniškega vlaka, kjer so vagoni povezani z jacobson bogijami (dvoosno podvozje vlaka). Delo vključuje zasnovanje, konstrukcijo in analizo z uporabo metode končnih elementov (MKE) ter primerjavo rezultatov deformacij in obremenitev pridobljenih z MKE in analitičnimi metodami. Prav tako je bila narejena primerjava med zvarjenim in ulitim spojem glede na dovoljene obremenitve in izvedljivost določenega spoja.

<sup>†</sup> Corresponding author: Tihomir Mihalić, PhD., University of Applied Sciences, I. Meštrovića 10, 47000 Karlovac, Croatia, Tel.: +385 98 686 072, E-mail address: [tihomir.mihalic@vuka.hr](mailto:tihomir.mihalic@vuka.hr)

<sup>1</sup> University of Applied Sciences, I. Meštrovića 10, 47000 Karlovac, Croatia

<sup>2</sup> University of Maribor, Faculty of Energy Technology, Hočevarjev trg 1, 8270 Krško, Slovenia

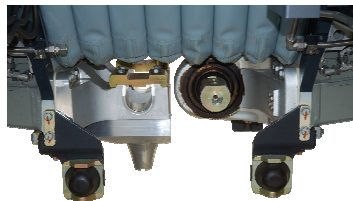
## 1 INTRODUCTION

Jacobs bogies are a type of rail vehicle bogie commonly found on articulated railcars and tramway vehicles. Instead of being underneath a piece of rolling stock, Jacobs bogies are placed between two train sections (Figure 1). The weight of each car is spread on one half of the Jacobs bogie. It is a semi-permanent joint used for the composition of passenger trains, because the joints of freight wagons are expected to enable the possibility of quick assembly and disassembly of the wagon. The advantages of these joints for passenger trains are increased security at derailment as well less weight and lower cost of the composition since bogies are heavy, complex, and expensive structures. The ride is smoother and quieter due to their being fewer bogies in the composition. The disadvantages are a constant connection and the possibility of dismantling the composition only in the workshop. A lower number of bogies means higher axle loads, [1].



*Figure 1: Jacobs bogie*

A train articulation system is a joint or collection of joints at which something is articulated or hinged for bending. The articulation coupler used in a Jacobs bogie (Figure 2) is an element that forms the connection between the bogie and wagon. The joint is functionally composed of a conical stud (Figure 3), which enters its slot on the bogie (Figure 4) and the flange with four screws and the seat attached to the chassis of the first wagon. On the other side of the joint, that is the second wagon, bolts are connected to its chassis (Figure 5). Given that the task structure, strains in the cast, and welded variants of the conical stud and flange are calculated and analysed in this paper. Two methods for calculating strains have been used. Strains in the conical stud are calculated with the conventional analytical method for long, thin rods, which is then modified to better describe the short, thick rod that the conical stud actually is. Then, the entire flange with the conical rod was calculated in FEM.



*Figure 2: Articulation coupler of Jacobs bogie*



**Figure 3:** Flange with conical stud



**Figure 4:** Slot on the Jacobs bogie where conical stud enters



**Figure 5:** Bolts connected to the chassis of the second wagon of the Jacobs bogie joint

## 2 ANALYTICAL METHODS FOR CALCULATING STRAINS IN THE CONICAL STUD OF A JACOBS BOGIE

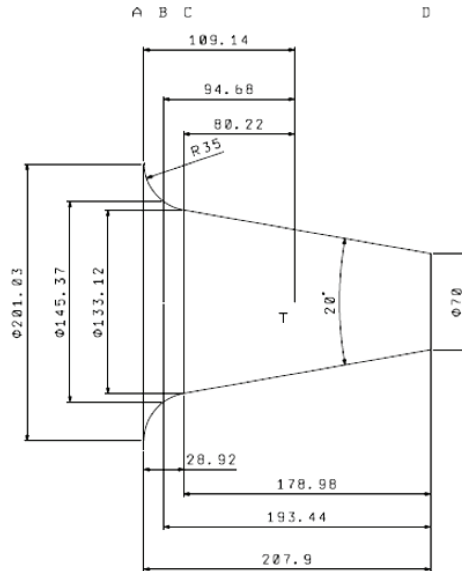
Analytical, basic methods from the strength of materials field were used. The complex load was considered, composed of bending moment, normal (axial) forces and transverse forces. Furthermore, stress concentration due to changes in the cross-section as an important factor for dynamically loaded structures was also included in the analysis. The terms for stresses, deformations, and displacements are valid with certain assumptions and limitations, which are, according to Alfrević, [2]:

1. Height of the rod is small compared to its length; it should be  $h/l \leq 0,2$  to  $0,25$  with error expectancy of about 2%
2. A maximum slope of the tangent to the elastic line of  $\alpha_{max} \leq 0,05$  to  $0,1$  rad;
3. Stresses should be analysed in the cross sections which are far from the ends of the rod, supports and places where the concentrated load is. Sufficient distance can be considered the height of the rod  $h$ .

For the conical stud, crucial criteria are the first and third conditions. It is evident from Figure 6 that the proportion of the rod does not meet the criteria. If we look at the cross section C, the

value of  $h/l = 0.744$ , which is significantly higher than prescribed by the first condition. Regardless of that, calculations were carried out for the purpose of the comparison of the results and the assessment of the usability of the method for the type of tasks.

This work was carried out with the presumption that the joint must have a durable, dynamic strength to withhold force of 100 kN. Furthermore, the force that appears on the joint when the train is moving at the speed of 36 km/h collides with the still, braked wagon was calculated to be 385 kN. Such a high load may not appear even once or can appear several times over the duration of the part's use.



**Figure 6:** Conical stud and referred cross-sections A, B, C, and D

In each cross-section equivalent, stress according to the Huber-Mises-Hencky (HMH) theory and maximal stress were calculated. The following results were obtained:

- Cross-section A:  $\sigma_{equ} = 7,296$  MPa,  $\sigma_{max} = 14,22$  MPa
- Cross-section B:  $\sigma_{equ} = 13,958$  MPa,  $\sigma_{max} = 34,423$  MPa
- Cross-section C:  $\sigma_{equ} = 16,639$  MPa,  $\sigma_{max} = 35,867$  MPa

The highest stress is calculated at Cross-section C, so with it, the increase of stress due to the variable cross-section area was taken into account, according to *Machinery Handbook*, [3]. This

$$\text{stress is } \sigma_k = \frac{\sigma_{max} \cdot K_f}{k_1 \cdot k_2 \cdot k_3} = 60,21 \text{ MPa}$$

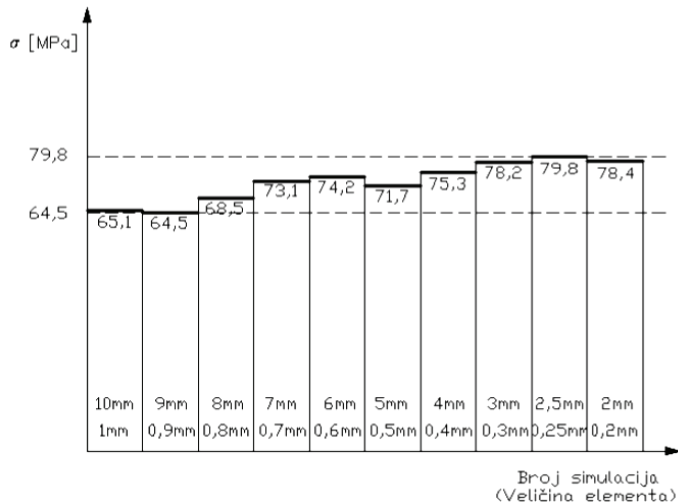
where the coefficients are  $K_f = 1,175$ ,  $k_1 = 1$ ,  $k_2 = 0,7$ ,  $k_3 = 1$ .

As stated before, the discussed conical stud is a short, thick rod. This means that the most influential parameter is the ratio of length to height. As much as this ratio is lesser than 3, the type and distribution of stresses start to change and differs significantly from those calculated for long rods. Previously, it was believed that as the rod becomes shorter, the method for long rods when applied to them shows greater strain than is realistic, Young, [4]. However, the

emergence of numerical methods determined the exact opposite. Stresses increase significantly the lower the ratio of length to height is; this has been proven with experiments, [4], as well as with our results. For this conical stud, the ratio is  $l/h = 1,344$ . Young, [4], states that it is possible to calculate the stress using a method for long rods and then increase strains by the coefficient obtained considering the previously mentioned ratio. Thus, a coefficient of 2.1 was used to multiply  $\sigma_{max}$  which yielded  $\sigma_k = 75.32$  MPa.

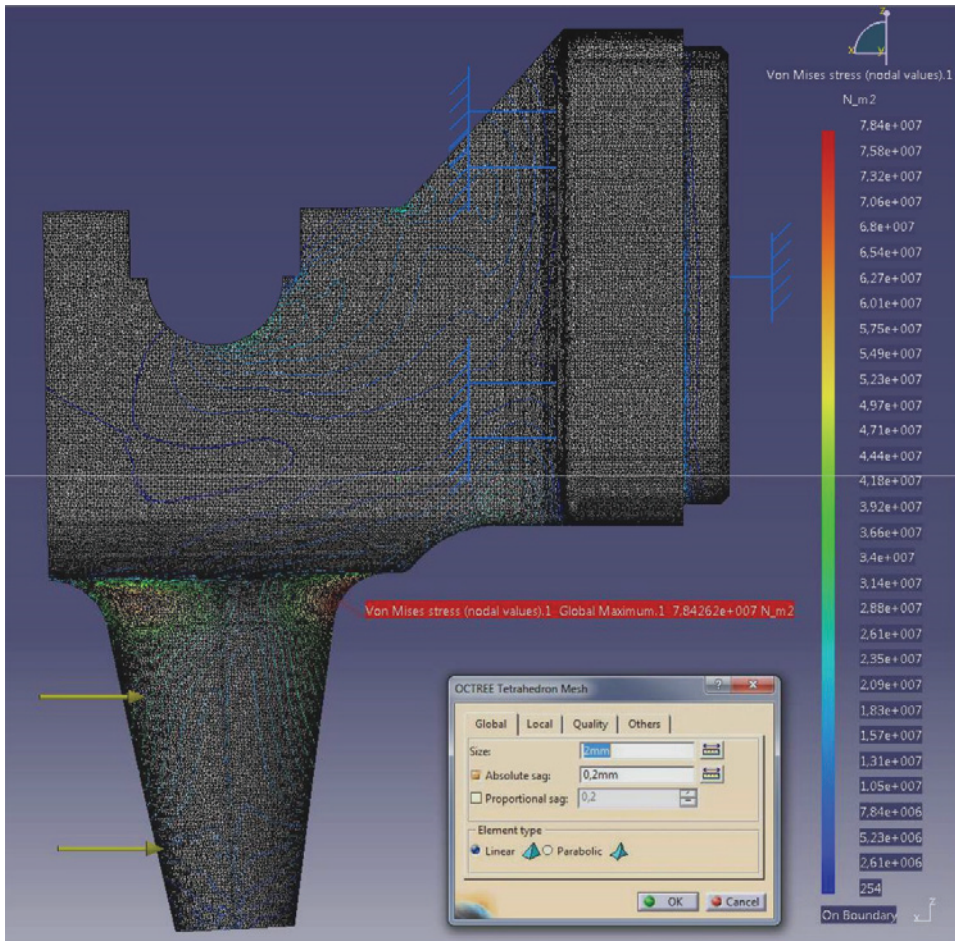
### 3 FEM ANALYSIS OF A CAST CONICAL STUD WITH AN ENTIRE FLANGE

Research of the best suitable boundary conditions was carried out. The finite elements used were of a linear tetrahedral shape. The size of finite elements at the change of the cross-section area and the radius was 10 times smaller than at the rest of the domain. FEM simulations were carried out using Autodesk Simulation Mechanical 2014 software. Furthermore, verification of the FEM model was carried out, and the results are shown in Figure 7.



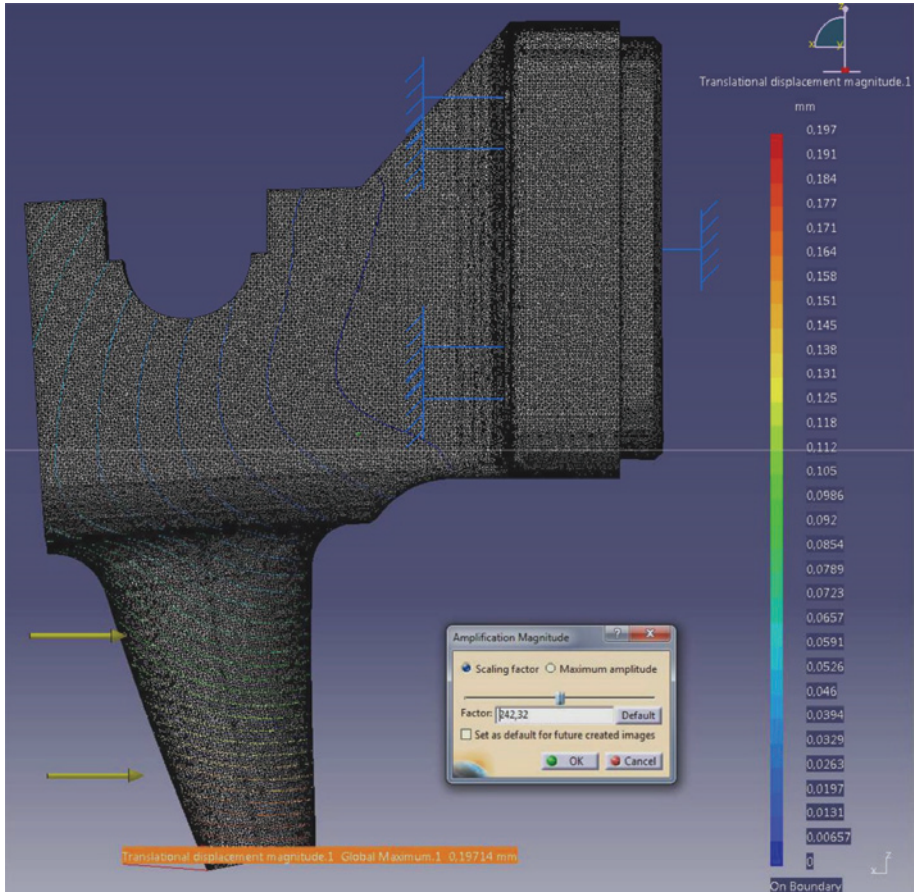
**Figure 7:** Verification of the FEM model

FEM analysis has given strain at the critical cross-section C,  $\sigma_{max} = 78.4$  MPa, Figure 8, and the maximal displacement was calculated to be 0.197 mm (Figure 10); the joint was loaded with 100 kN.



**Figure 8:** Load of 100 kN,  $\sigma_{max} = 78,4$  MPa



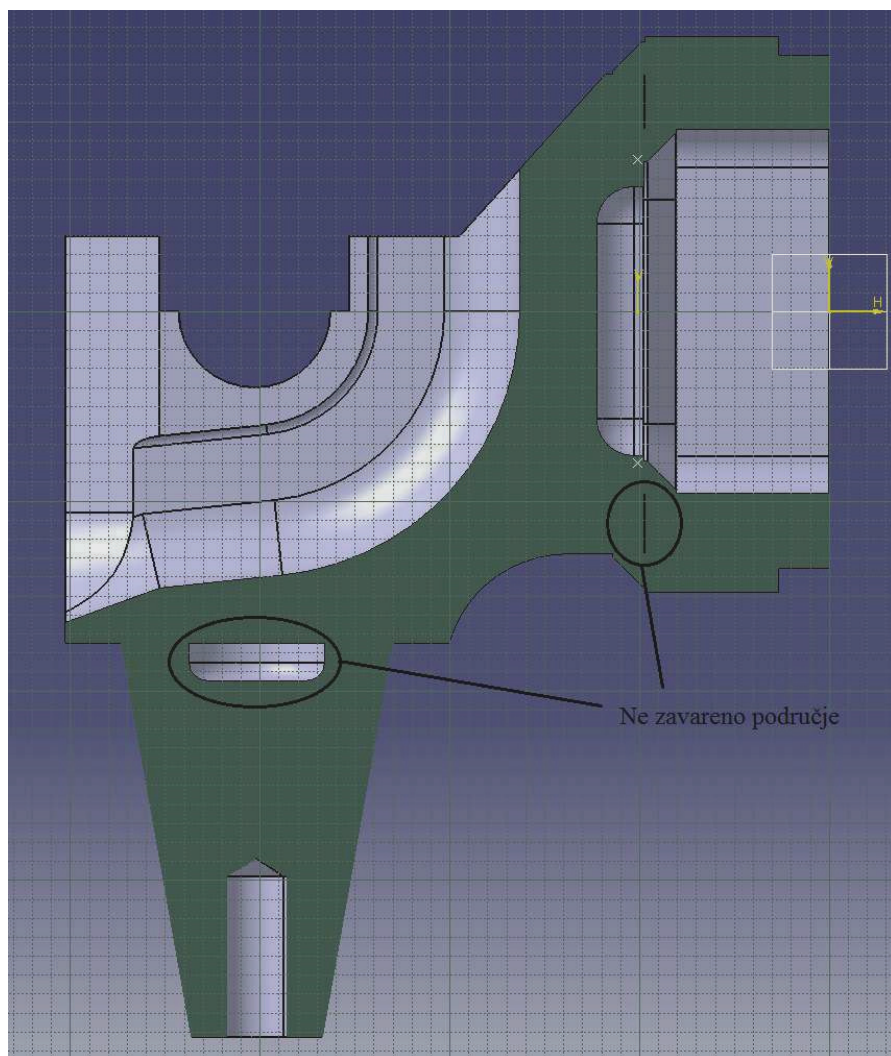


**Figure 9:** Load of 100 kN, maximal displacement 0,197 mm

For the given material  $R_m = 600\text{--}750$  MPa while  $R_{p0,2} = 400$  MPa at least, which means that the maximum strain is less than one quarter of the yield point. It is obvious that the criterion of strength with regard to the allowable stress  $\sigma_{allowed} = R_{p0,2} / 4 = 100$  MPa.

#### 4 FEM ANALYSIS OF A WELDED CONICAL STUD WITH THE ENTIRE FLANGE

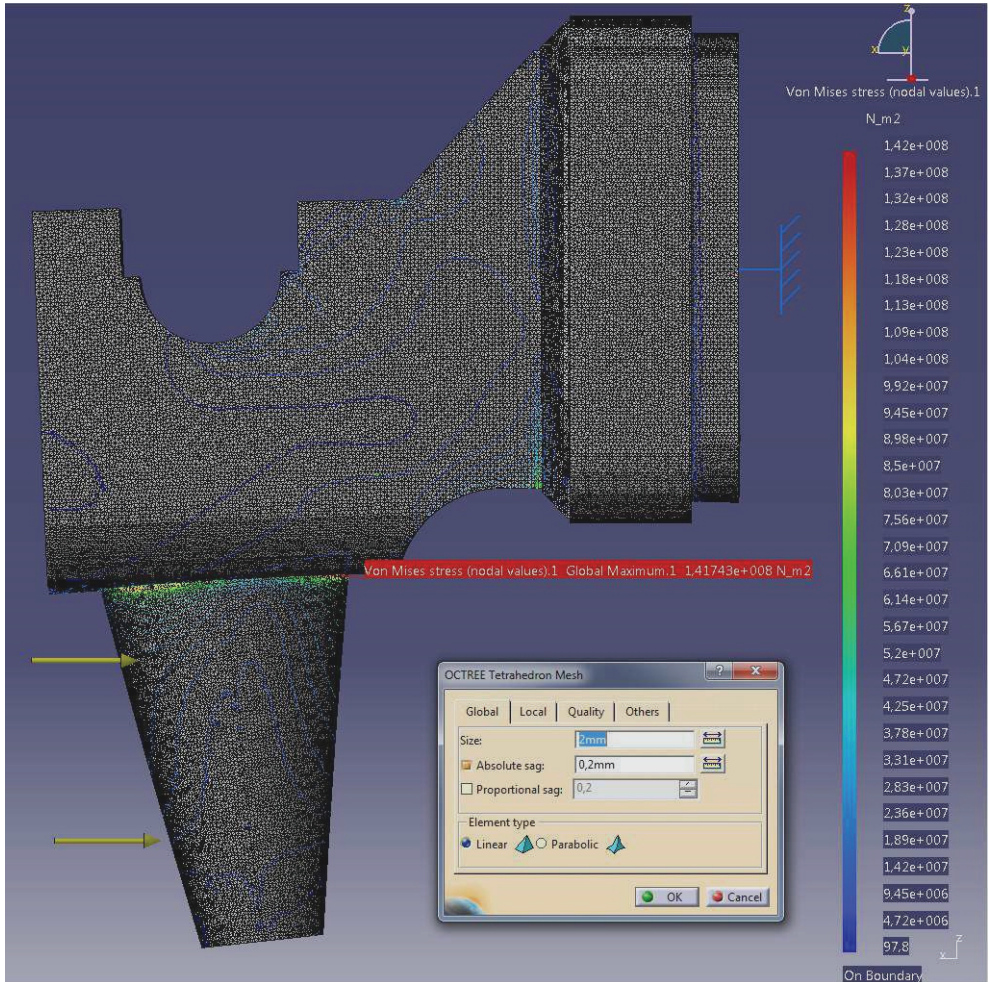
An articulation coupler has complex geometry and is a large part. Therefore, the production of a welded joint is a complex and demanding process. It was necessary to verify whether it is possible to make welded joint with the same functional dimensions. Figure 10 shows a welded version of the joint. The model of the joint was made as one body with the welds; in places that are not welded but are in contact, a tiny gap was left. The joint is composed of three parts: a conical stud, a body block, and a flange.



**Figure 10:** Welded version of articulation coupler

The FEM analysis has determined strain at the critical cross section C,  $\sigma_{max} = 142$  MPa (Figure 11), while the welded joint was loaded with 100 kN. This analysis has shown that the strain grows and exceeds one third of  $R_{p0.2}$ . Furthermore, corrosion during exploitation must be taken into consideration, since this is welded construction. It can be concluded that the welded design would not meet the strength criterion without significant changes in the dimensions, which is not possible.





**Figure 11:** Load of 100 kN,  $\sigma_{max} = 142 \text{ MPa}$

## 5 CONCLUSION

This work has proven that the cast construction of an articulation coupler satisfies the strength criterion while welded construction does not. The limiting factor concerning welded constructions is the dimensions of the joint, which are set and cannot be changed.

The usefulness of conventional analytical methods for preliminary calculations has been proven. However, analytical methods show that they cannot precisely calculate and determine the position of the stress on the critical part of the structure because the conical stud does not fit the conditions of the mechanics of materials field for long, thin rods.

In further research, other analytical methods for calculating strains in short, thick rods could be investigated for the purpose of calculating stress in railcar joints.

## References

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## Nomenclature

$\sigma_{equ}$	Composed stress calculated with HMM theory
$\sigma_{max}$	Maximal stress
$R_m$	Ultimate tensile strength
$R_{p0,2}$	Yield strength
$\sigma_{allowed}$	Allowed stress