# Numerical and Experimental Investigation of Bolted Connections with Blind Rivet Nuts

Cezary Borowiecki[1,2(✉)], Artur Iluk[2], Paweł Krysiński[1],
Eugeniusz Rusiński[2], and Marek Sawicki[2]

[1] Rawicka Fabryka Wyposażenia Wagonów RFWW RAWAG Sp. z o.o. ul.,
Tysiaclecia 5, 63-900 Rawicz, Poland
cezary.borowiecki@pwr.edu.pl
[2] Faculty of Mechanical Engineering, Wroclaw University of Science
and Technology, Łukasiewicza 5, 50-370 Wroclaw, Poland

**Abstract.** In the article authors presented numerical and experimental investigation of bolted connections with blind rivet nuts. Classification of screw connections and the associated validation process are described. The influence of the strength of connected elements on the strength of connection is discussed. Authors present also tests results and mode of failure of rivet nut connection. Results are significantly lower than values declared by manufacturer of a blind rivet nuts.

**Keywords:** Blind rivet nut · Bolted connection · Testing method

## 1 Introduction

Bolted connection is commonly used in most of structures. Wide range of advantages convinced designers to entrust major role in carrying structures. For calculation bolt/screw connection multiple analytic approaches is established. From the other hand authors present a few approaches to model and simulate bolt connections in Finite Element Method software environment. Furthermore authors shows threats which might occur in construction when some modifications are present. In this case standard nuts with washers were replaced by rivet nuts. The aim of this paper is to underline the major issue which reveals in bolted connections in train equipment structure.

In this article authors focused on bolted connection of a driver cabin door leaf frame with a hinge. This connection is consists of a screw with countersunk head and a blind rivet nut installed in a frame. In this case standard analytical calculations of bolt connections based on VDI2230 may be insufficient and detailed FEA or real tests are recommended.

## 2 Overview of Structure

All railway vehicles designed for European market are classified in categories based on structural requirements of the vehicle bodies. The doors mentioned in this article are dedicated to light duty metro vehicles, category P-IV in reference to PN-EN 12663-1

E. Rusiński and D. Pietrusiak (Eds.): CAE 2018, LNME, pp. 88–95, 2019.
https://doi.org/10.1007/978-3-030-04975-1_11

standard [1]. This standard determines also load cases for vehicle body and equipment attachments like cab doors, for example. In this case static and fatigue load cases were required. The door leaf shall be loaded by longitudinal, transverse and vertical accelerations. Forces occurring in the structure can determine by FEM calculations.

Since the DIN 25201 [2] standard is obligatorily required by end-users bolted connections in vehicle structures must be classified. Based on DIN 25201 part 1 three categories divide bolted connections into risk classes, depending on the importance of the screw connection. Starting with the least important, design engineer describes connection as G class, M class or H class. Classes are defined as follows: G class, form German *Gering*, means low class of risk and it is assigned to the screw connection, which if it fails leads only to loss of comfort for the passengers and/or operator staff, M class, form German *Mittel*, means medium class of risk and it is assigned to the screw connection, which if it fails leads to a malfunction of the vehicle, and H class, form German *Hoch*, means high class of risk and it is assigned to the screw connection, which if it fails there is direct or indirect danger for life and health. For M and H classes screw calculations are mandatory.

The door leaf frame is made out of aluminum alloy EN AW 6060T6 extruded profiles with welded corners made out of aluminum EN AW 5457 H111. The hinge mechanism is made of the S355 steel. A few additional parts, such as spacer between frame and hinge mechanism are made of the 1.4301 stainless steel. The hinge to frame connection is consists of four M8 screws with countersunk head and blind rivet nuts installed in a frame. The connection has been classified as the M class of risk.

Focus of this paper is region marked by circle at Fig. 1. Elements such as window, lock mechanism or plastic cover shells are not considered in this paper and its influence is neglected. It should be noted that in the simulations mass of entire structure was taken into account [4].

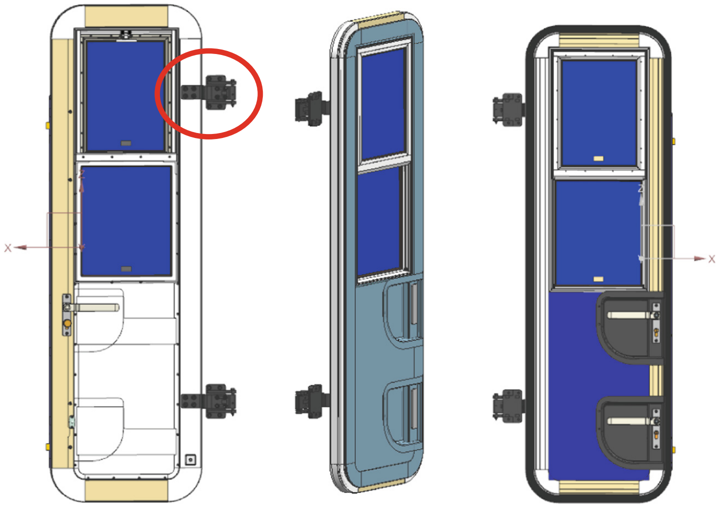

**Fig. 1.** The general geometry of the door: inner door surface, isometric view and outer surface

In the Fig. 2 detail view of considered geometry is shown. Parts has been numbered: 1. Hinge mechanism, 2. Door leaf frame, 3. Bolt, 4. Blind rivet nut, 5. Additional parts for positioning the door into a car body.

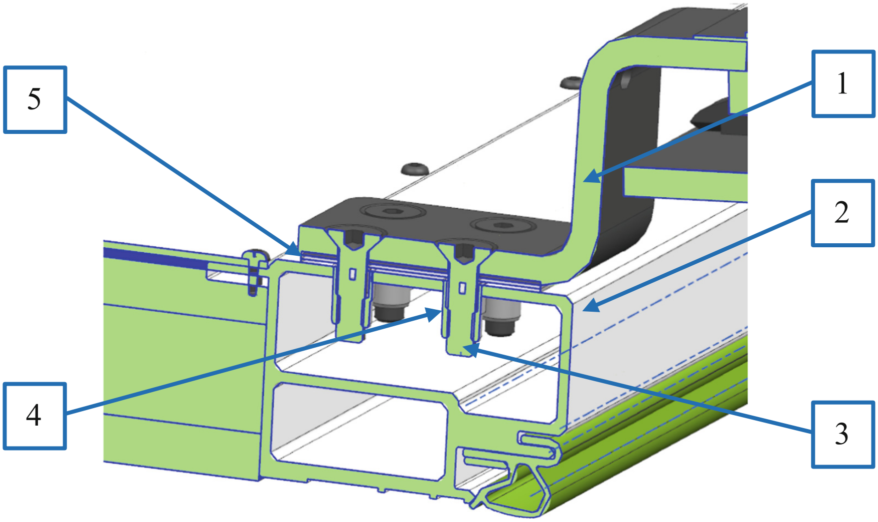

**Fig. 2.** Detail view of considered geometry

## 3 Finite Element Method Calculations

All FEM simulations were performed in Abaqus 6.13 [5]. Static general procedure was used without stabilization of contact definition and without taking into account the geometrical non-linearity. The linear elastic material model was used for all materials. Authors do not considered plastic deformations of structure.

The main goal of the FEA is to determine if the structure is safe in general. However, for bolted joint validation internal screw forces needs to be calculated for used as an input data for validation process.

There are several types of screw connection modeling methods. Depending on chosen method different values of internal forces can be shown as a result of calculations. In the Table 1 three approaches for simulation of bolted connections are given with respective names of models. All calculations was performed for full structure. For calculation most of part, including all in range of interest this paper, are represented by solid finite elements. The boundary conditions are applied in lock mechanism points and in non-movable hinge parts [6].

The approaches which are showed in Sect. 3 vary significantly, but in regions at some distance from the connection, the results are similar. It means, that the simplest approach (M1) might be used for examine the structure with assumption that bolt set is properly designed. It reduces the computation time and complexity of model.

**Table 1.** Differences between used FEM models

| Model name | Surface interaction | Normal behavior | Tangential behavior | Bolt element | Bolt pretension |
|---|---|---|---|---|---|
| M1 | *TIE | RIGID | RIGID | None | None |
| M2 | *CONTACT | Hard contact | Frictionless | RIGID BEAM | None |
| M3 | *CONTACT | Hard contact | $\mu = 0.2$ | Elastic BEAM | Nominal |

Based on FEM [7] results, it is possible to obtain the worst case scenario for bolted connection, when it is assumed no bolt pretension and frictionless contact. Under such assumptions, the highest possible bolt forces are calculated (M2 model) and used as a input data for screw connection validation process.

The M3model is the most advanced and contains a bolt pretension and contact with friction. It allows to check slipping and opening of the connection. However, the stress in the connection area may locally exceed permissible values for nominal parameters of bolt connection, such as support diameter, radius of influence, hole diameter and pretension force [8, 9]. This type of modeling can be further used for detailed submodeling. However, the retail representation of the screw connection with the use of riveted blind rivet nut is very complicated, authors decided to make an real tests and based on it considered about safety of the screw connection design.

## 4 The Real Strength Test

The strength of the blind rivet nut is provided by manufacturer in technical specification of the product. For stainless steel, M8 diameter, blind, open, rivet nuts, with special small countersunk head and hexagon shank, used in this example, standard values of the axial load, shear force and tightening torque are shown in Table 2, with manufacturer's remark *"These values may vary considerably depending on the quality, surface and dimensional accuracy of screws, sheet and the mounting hole - Tests are recommended"*.

**Table 2.** Parameters of then rivet nut declared by manufacturer

| Thread | Axial load (kN) | Shear force (kN) | Tightening torque (Nm) |
|---|---|---|---|
| M8 | 30.0 | 7.3 | 24.2 |

In order to prove safety of the bolted connection, experimental test should be conducted. In this case authors conducted three tests to check maximum force required to pull the blind rivet nut out of material, to check degradation of the preload force by plastic deformation of aluminum frame, and to check maximum shear force which can be carried out by the connection. The tightening torque defined in technical documentation of the door assembly has been used in all tests.

### 4.1 The Maximum Pull-Out Force Test

In the test blind rivet nuts were mounted in the door frame profile according to the door manufacturer technology. Profile was placed in special support with 22 mm hole. The support was fixed in lower grip of a test machine. During the test, threaded bolt mounted into rivet nut through the hole in support was fixed in upper grip of machine and pulled out with continuous recording of translation and pulling force [10].

The test has been conducted on 5 samples. Results are shown in Table 3. All test were carried out on Zwick&Roell machine with maximum axial tension force 33 kN.

**Table 3.** The results of the pull-out test

| Sample no. | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Axial force (kN) | 10.7 | 10.5 | 11.1 | 11.8 | 11.5 |

Maximum pull-out force was on the level 11.8 kN, which is three times smaller than the declared value of the blind rivet nut strength. The maximum pull-out force was limited by strength of the aluminum frame (Fig. 3).

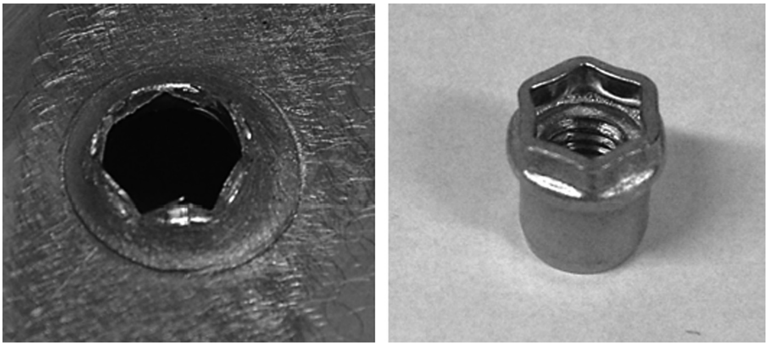

**Fig. 3.** View of sample after pull-out test: aluminum profile (left) and blind rivet nut (right)

### 4.2 The Pre-tension Loosening Test

The goal of the second, pre-tension loosening test was answer, when an assembled connection, loaded by increasing axial force, will loose of the preload necessary to keep the friction required for transfer shearing forces. Connections were assembled with special elements simulating a real connection. The test stand is shown in the Fig. 4. The test specimen was fixed in a steel frame and loaded.

The increasing pull-out axial force was applied to the connection and between subsequent loads the bolt every time was tightened with 17 Nm of torque. If the bolt was rotating during application of torque, it was evidence of losing pre-tension of the bolt. Loose of pre-tension was checked by measurement of angle of rotation during tightening.

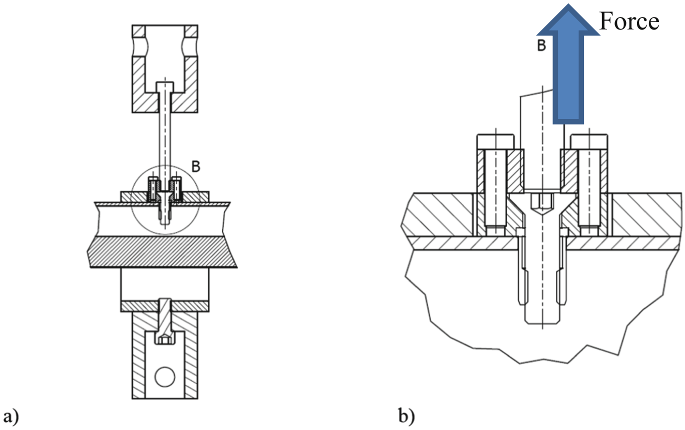

**Fig. 4.** Test stand for pull-out test: a) general view, b) detail of application of the tension force to the bolt head

Tests prove no loosening of the pretension force up to at least 3 kN. Properly installed blind rivet nuts will keep the pretension force at constant level after static load with maximum expected force.

### 4.3 The Maximum Shear Force Test

The last, maximum shear force test was conducted in order to resemble the real conditions. The tests of the shear force were conducted on full set of bolted connections with four bolts with blind rivet nuts, and positioning plates. Both sides of connection were equipped with flat plate fixed in grips of the testing machine. Connection was assembled with lubricated bolts and tightened with torque 17 Nm.

The first sample was tested up to 30 kN of shear force. The first slip was observed between additional parts for positioning the door (Figs. 5 and 6).

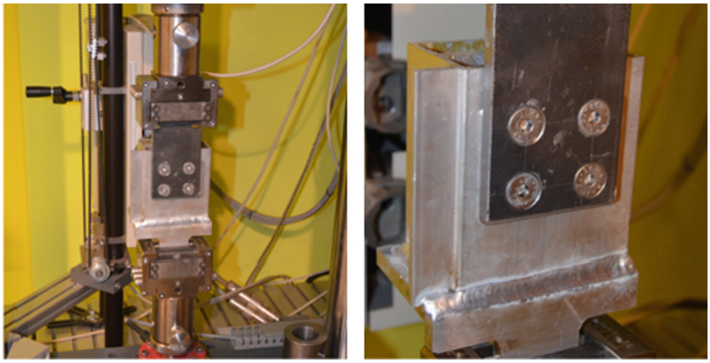

**Fig. 5.** Assembled connection for a shear force test on testing machine.

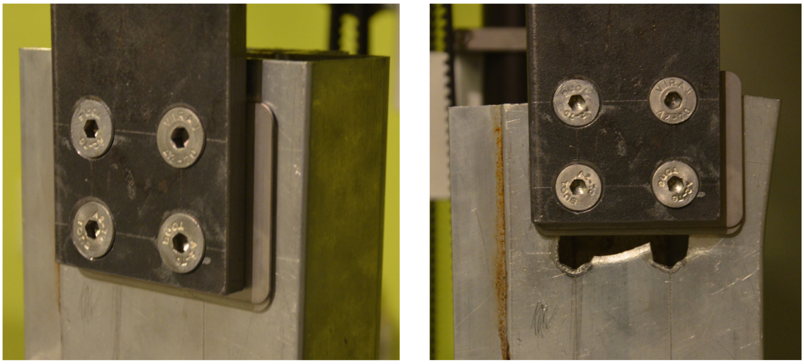

**Fig. 6.** Sample 2 – after slip of stainless steel washers(left), destroyed connection (right)

Subsequent increase of shear force result in complete tear-out of the aluminum profile. Maximum shear force carried out by connection was 32.5 kN.

On both samples the first slip is visible at force 6.4 kN. The slip starts on the contact surface between stainless steel washers. The slip was observed during the test as a smooth process, without slip-stick behavior. Subsequently, the aluminum profile is progressively teared out by moving nuts up to complete destroying of the connection.

## 5 Summary and Conclusions

Classification of screw connections and the associated validation process has been described. To prove the safety of the structure FEM calculations and real tests were conducted and presented. Verification of more sophisticated bolted joint for example connection which included using of blind rivet nut is a complex process. Blind rivet nut manufacturers are showing strength of the connection without detailed information about boundary conditions. Real tests or detailed FEM calculation are required to prove strength of the connection.

It was also developed screw connection modeling method to determinate internal force in screws as an input data for other tests.

Experimental tests have been carried out in order to check the strength of blind rivet nut connection in the driver cabin door. Three kinds of test of the blind rivet nut connection have been carried out – pull-out test, loose of pretension test and shear test. Components used in test were a real components or geometrically equivalent ones. The experimental test allows the acquisition of realistic limit forces, which also can be used for evaluation of numerical simulation.

All forces connected with the discussed screw connection determined by FEA were on lower level than maximum admissible values designated in real tests.

## References

1. PN-EN 12663-1 + A1:2015-01, Kolejnictwo – Wymagania konstrukcyjno-wytrzymałościowe dotyczące pudeł kolejowych pojazdów szynowych – Część 1: Lokomotywy i tabor pasażerski (i metoda alternatywna dla wagonów towarowych)
2. VDI 2230: Systematic calculation of highly stressed bolted joints; Joints with one cylindrical bolt
3. DIN 25201-1: Design guide for railway vehicles and their components - Bolted joints - part 1: Classification of bolted joints
4. Krysiński P, Łagoda T Badanie drzwi i okien szybkich pociągów, Rynek Kolejowy, No 4/2008, ss 74–75
5. Abaqus 6.13 User Guide. http://dsk.ippt.pan.pl/docs/abaqus/v6.13/index.html. stan na dzień 20 Apr 2018
6. Altair University, Practical Aspects of Finite Element Simulation, e-book. https://altairuniversity.com/free-ebooks-2/free-ebook-practical-aspects-of-finite-element-simulation-a-study-guide/ stan na dzień 20 Apr 2018
7. Zienkiewicz OC et al (1977) The finite element method. McGraw-Hill, London
8. Rusiński E, Czmochowski J, Smolnicki T (2000) Zaawansowana metoda elementów skończonych w konstrukcjach nośnych. Oficyna Wydawnicza Politechniki Wrocławskiej
9. Rusinski E (1990) Mikrokomputerowa analiza ram i nadwozi pojazdów i maszyn roboczych. Warszawa: Wyd. komunikacji i łączności
10. Totten GE, Xie L, Funatani K (2004) Modeling and simulation for material selection and mechanical design, Marcel Dekkler, Inc