Experimental verification of numerical calculations of railway passenger seats

B Ligaj1,*, M Wirwicki, K Karolewska and A Jasińska

UTP University of Science and Technology in Bydgoszcz, Faculty of Mechanical Engineering, Department of Biomedical Engineering, Al. Prof. S. Kaliskiego 7, 85-796 Bydgoszcz, Poland

Email: bogdan.ligaj@utp.edu.pl

Abstract. The construction of railway seats is based on industry regulations and the requirements of end users, i.e. passengers. The two main documents in this context are [1], [2] and [3]. The structure of seats, as in sitting spaces in the vehicle, concerns two particular components: the seat itself and the seat frame for fixing it to the rail vehicle structure. Due to the requirements of the regulations, the system should be considered holistically. The main design criterion is rigidity, with further criteria being specified as mass, durability, strength, etc.

Due to the functional and normative criteria for the seats and their attachments to the rail vehicle structure, three types of solutions have been developed: fixing the seats to the floor on two legs (Figure 1a), attaching the seats to the side wall and the floor on one leg (Figure 1b) and fixing the seats to the side wall only (Figure 1c), with the lattermost being the most challenging solution.

Experimental studies of rail passenger seats are based on the guidelines of the UIC 566 [2]. This document standard formulates the following conditions for carrying out tests under static load conditions (Figure 2):

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Experimental studies of rail passenger seats are based on the guidelines of the UIC 566 [2]. This document standard formulates the following conditions for carrying out tests under static load conditions (Figure 2):

1. a) Armrest load:
2. - force $F_4 = F_5 = 0.75$ kN applied to the free end of the armrest, load acting upwards (force direction: vertical)
3. - force $F_6 = F_7 = 0.75$ kN applied to the free end of the armrest, load acting on the side (force direction: horizontal),

1. b) Seat load:
2. - force $F_1 = 1.0$ kN applied to the seat centrally along the width, 50 mm from the edge (force direction: vertical)
- force $F_2 = 1.2$ kN applied to the seat centrally along the width of the seat, 50 mm from the edge (force direction: vertical)
c) backrest load:
- force $F_3 = 1.5$ kN applied centrally to the upper part of the backrest (force direction: horizontal)
d) hinged table load:
- force $F_8 = 0.75$ kN applied centrally to the table (force direction: vertical).

Figure 1. Methods of fixing the seats to the frame of a rail vehicle: a - to the floor on two legs [2], b - to the side wall and to the floor on one leg [3], c - outboard system, to the side wall only [3]

Figure 2. Loading the seats during static load tests [1]

The study was to carry out static load tests of passenger seat frames. The paper presents the construction of the test bench and the results of experimental and numerical studies of passenger seat rail frames.

2. Methods

2.1 Bench for experimental studies involving seats
The test bench is shown in Figure 3. It consists of: a frame, a transverse beam, two electric cylinders with a force value of 6 kN, a strain gauge amplifier. It has a modular structure that allows for its expansion depending on the structure of the seats. The bench is designed so as to make it possible to
examine the seats of any mounting system to the frame of the rail vehicle, meeting the requirements as set out in the UIC 566 standard [2]

2.2 Test results
Experimental studies of the passenger seat frame were carried out in accordance with the UIC 566 [2] standard. The test program included separate tests for loads applied to the seat, backrest and armrest. A detailed study program is provided in Table 1.

Table 1. Study program and test result

| Lp | Area of load application | Load value | Stress value [MPa] |
|----|--------------------------|------------|-------------------|
|    |                          |            | Point A           | Point B           |
| 1  | Seat load                | F1 = 1.0 kN | 75 MPa            | 70 MPa            |
| 2  | Seat load                | F2 = 1.2 kN | 86 MPa            | 65 MPa            |
| 3  | Backrest load            | F3= 1.5 kN | 125 MPa           | 138 MPa           |
| 4  | Backrest load            | F4 = F5 = 0.75 kN | 109 MPa       | 118 MPa           |
| 5  | Armrest load             | F6 = F7 = 0.75 kN | 39 MPa            | 48 MPa            |

Figure 3. Test bench

2.3 Results of numerical calculations
Numerical analysis of strains and stresses in the test objects was performed using the finite element method using the ABAQUS 6.6-4 software. Three-dimensional finite elements C3D4H (Fig. 4) were used for discretization of the above 3D models. A material model was used to describe material
properties. For this purpose, the material model was described as a Young’s modulus of $E = 2.1 \times 10^5$ MPa and a Poisson’s ratio of $v = 0.3$. The results of numerical calculations are presented in Table 2.

Figure 4. Four-mode 3D C3D4H element used in numerical calculations

| Lp | Area of load application | Load value | Stress value [MPa] |
|----|--------------------------|------------|--------------------|
|    |                          |            | Point A | Point B |
| 1  | Seat load                | $F_1 = 1.0$ kN | 94.5 MPa | 93.5 MPa |
| 2  | Seat load                | $F_2 = 1.2$ kN | 100.7 MPa | 84.5 MPa |
| 3  | Backrest load            | $F_3 = 1.5$ kN | 158.2 MPa | 173.9 MPa |
| 4  | Backrest load            | $F_4 = F_5 = 0.75$ kN | 142.5 MPa | 135.4 MPa |
| 5  | Armrest load             | $F_6 = F_7 = 0.75$ kN | 45.7 MPa | 48.2 MPa |

3. Results and Discussion

Comparing experimental results with numerical results (Table 3) for points A and B allowed to determine the existing differences. It follows from it that higher stress values are obtained by numerical calculations in the range of 0.2 MPa to 35.9 MPa.

Table 3. Comparison of experimental results and numerical results

| Lp | Area of load application | Test (Table 1) | Calculation (Table 2) | Difference | Test (Table 1) | Calculation (Table 2) | Difference |
|----|--------------------------|----------------|-----------------------|------------|----------------|-----------------------|------------|
|    |                          | Point A | Point B | Point A | Point B | Point A | Point B | Point A | Point B |
| 1  | Seat load                | 75 MPa  | 94.5 MPa | 19.5 MPa | 70 MPa  | 93.5 MPa | 23.5 MPa |
| 2  | Seat load                | 86 MPa  | 100.7 MPa | 14.7 MPa | 65 MPa  | 84.5 MPa | 19.5 MPa |
| 3  | Backrest load            | 125 MPa | 158.2 MPa | 33.2 MPa | 138 MPa | 173.9 MPa | 35.9 MPa |
| 4  | Backrest load            | 109 MPa | 142.5 MPa | 30.4 MPa | 118 MPa | 135.4 MPa | 17.4 MPa |
| 5  | Armrest load             | 39 MPa  | 45.7 MPa | 6.7 MPa  | 48 MPa  | 48.2 MPa | 0.2 MPa  |

The reason for the differences should be seen in the manner of loading the seats during experimental research. As a result of the load applied to the seat structure, the deflection is deformed, which can affect the direction of operation and the value of the load. In case of numerical calculations it is difficult to accurately model the way of loading the seats and their susceptibility resulting from the applied materials for the seat and the back.
4. Conclusions
This study performed static load tests of passenger seat frames according to UIC 566 (3rd Edition, dated 7 January 1994) and the EN 12663-1: 2010+A1:2014. Construction of the test bench and the results of experimental and numerical studies of passenger seat rail frames are presented. The test bench which consists of a frame, a transverse beam, two electric cylinders with a force value of 6 kN, and a strain gauge amplifier has a modular structure that allows expansion depending on the structure of the seats. Experimental results were compared with numerical results for points A and B. The numerical analysis was able to calculate the stresses at points A and B, with a difference in the range of 0.2 MPa to 35.9 MPa compared to the experimental results.

References

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