DOI 10.2478/ama-2023-0005

DESIGN OF A HEIGHT-ADJUSTABLE BOARDING SYSTEM FOR A NEW DOUBLE-DECK RAILWAY VEHICLE

Pavol ŠŤASTNIAK*, Michal RAKÁR, Jakub TÍŽEK****

*Faculty of Mechanical Engineering, University of Žilina, Univerzitná 8215/1, 010 26 Žilina, Slovakia
**Škoda Transportation, 1. máje 3176/102, 709 31 Ostrava, Czech Republic

pavol.stastniak@fstroj.uniza.sk, michal.rakar@skoda.cz, jakub.tizek@skoda.cz

received 27 June 2022, revised 18 October 2022, accepted 6 November 2022

Abstract: This paper deals with a solution for faster and safer boarding and leaving of passengers at railway station platforms from 150 mm to 550 mm higher than the head of the rail. This conception is based on the requirements of railway infrastructure administrators, transporters and also manufacturers of passenger rolling stock. This device is designed for the new double-deck railway vehicle for suburban and regional transport, which fulfils legislative and normative requirements that are specified for the selected area of vehicle construction and operational features. Selected parts of the construction were verified through a series of simulation analyses. This article also includes a study that deals with optimization of the boarding area considering designed changes in the construction of the floor and a draft for modification of the vertical clearance of the boarding entrance area in a rough construction of the vehicle.

Key words: double-deck railway vehicle, boarding system, railway station platform, simulation, FEA

1. INTRODUCTION

Recently, the number of passengers and goods transported by rail has been growing significantly. This can also be seen as a result of the European Union’s commitment to carbon neutrality by 2050 [1, 2]. In this case, railway transport becomes friendly, safe and sustainable. This calls for significant renewal, modernization and expansion, in the means of transport and infrastructure [3–9].

One manner of reaching transport efficiency is related to the reduction of transport time. This can be achieved by increasing the maximum speed of vehicles. Another way is connected to lowering the time for boarding and leaving, because it reduces a train’s stop time [10]. This is also related to limiting the use of additional stairs and platforms as they are very often not suited to a train and rail platform leading to unsafe situations with respect to health [11, 12].

The European Commission has set in its regulations two platform heights on newly built or reconstructed railway tracks [13, 14]. Subsequently, the development of the vehicles is adapted to these platform heights so that the boarding edge (vehicle floor) is approximately at their level. However, reconstruction of the existing infrastructure is not progressing fast enough to eliminate the problem of platform diversity soon.

Therefore, manufacturers offer various types of vehicles and equipment (e.g. ramps and fixed or moving steps). The paper presents the results of research work on the development of auxiliary equipment for a double-decker railway vehicle for suburban and regional transport. The aim of the paper follows the project of a device for boarding and leaving if the distance between the head of the rail and the height of the platform ranges from 150 mm to 550 mm. This was reached at the requirements of the COMMISSION REGULATION (EU) No 1299/2014 and No 1300/2014 [13, 14] for approval. The article studied verifies whether the boarding area meets the legislative requirements in case the vehicle would be operated on lines with a platform height of between 550 mm and 760 mm above the top of the rail.

2. PLATFORMS FOR VEHICLES USED IN SUBURBAN AND REGIONAL TRANSPORT

The station platform is one of the basic elements of the railway infrastructure because it allows boarding and leaving based on safety rules. It represents a connection between the static and dynamic parts of the transport system, which makes it an important factor for evaluating the safety of the entire transport process.

According to the literature [14], on newly built and upgraded tracks, the nominal platform height should be 550 mm or 760 mm above the top of the rail. Both types of platforms (height of platforms 550 mm and 760 mm) are being used in Germany. In the Czech and Slovak Republics, platforms with a height of 550 mm only are used. In the case of suburban and regional rolling stock, manufacturers ensure to adapt the boarding edge height to the platform height in order to achieve safe and comfortable boarding for passengers [15, 16] (Fig. 1).

In the Czech Republic, there are still a large number of platforms that are <400 mm, which were built many years ago and do not comply with current legislations [13, 14, 17]. For this reason, boarding vehicles with a boarding area adapted for platform heights of 550 mm above the top of rail operated on tracks with platforms <400 mm (e.g. 210 mm) are often uncomfortable.

For this problem, manufacturers are taking action to install fixed (Fig. 2) or movable steps (Fig. 3) [18, 19]. These devices fulfil a safety requirement because they fill the gap between the platform and the boarding area.


Fig. 1. Railway vehicles with adapted boarding–leaving zone

Fig. 2. Fixed step in the railway vehicle Talent of Bombardier Transportation: 1 – boarding area of the vehicle; 2 – fixed step; 3 – platform

If the vehicle is to be operated on tracks with a platform height of 550 mm above the top of rail and the vehicle has a boarding area height adapted to this platform, the movable step (1) (Fig. 3) should be installed just below the boarding area of the vehicle (3) (Fig. 3).

Fig. 3. Extendable steps on the vehicle 14Ev from Škoda Transportation: 1 – movable step; 2 – additional step; 3 – boarding area of the vehicle

When operating a railway vehicle with different platform heights, manufacturers install additional steps (2) (Fig. 3) under the first retractable step. This solution assists passengers in boarding the vehicle from platforms <400 mm above the top of rail.

If the rough construction of the vehicle does not allow placing both steps in the space under the interior floor, then a lower step is installed under the vehicle bottom. This is not very popular, because if the vehicle is operated at low values of temperatures, then snow and ice could limit the movement of the auxiliary step [20].

For these reasons, it is necessary to propose new solutions.

3. TILT PLATFORM CONCEPT

When proposing boarding the vehicle by means of movable steps or adjusting the boarding area, it was necessary to proceed in accordance with the literature [14] and [17].

A level entrance according to the PRM TSI regulations can be considered as the entrance from the platform to the door of the railway vehicle, when the interior of the vehicle boarding area does not contain any steps. The gap between the end plate of the entrance door or also of the extended bridge platform/step and the station platform does not exceed 75 mm measured horizontally and 50 mm measured vertically.

A movable step is in this case defined as a retractable device built into the vehicle below the level of the vehicle door area and is fully automatic and activated in conjunction with the door opening and closing procedures [21].

The auxiliary step must extend before the vehicle door is opened and passengers are allowed to get on/off and conversely, the step can only be retracted if the door is already closed, and it is not possible to enter/exit the vehicle.

In the design of the entrance, stairs are very important parameters, l_2 and l_3 (Fig. 4). Parameter l_2 is the maximum height between the upper surface of the external step and the step inside the vehicle (or the floor) if there are no more steps in the vehicle boarding area. Parameter l_3 represents the minimum depth of the step.

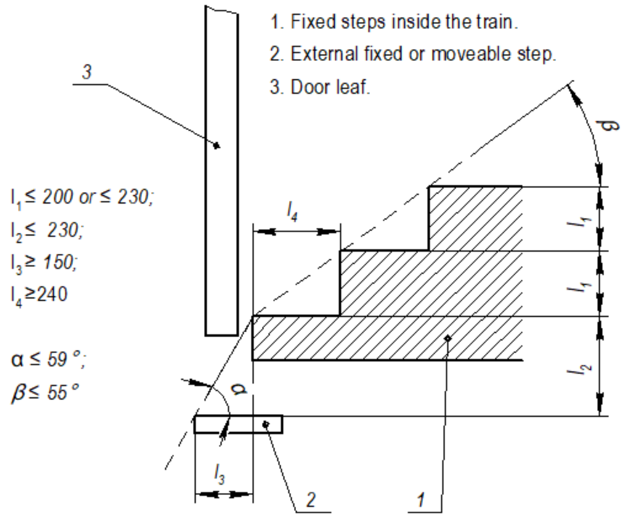

Fig. 4. Dimensional requirements for interior and exterior stairs (STN EN 14752)

It follows from the entry conditions provided that a suitable solution is to use a retractable and folding mechanism that can quickly and safely unfold/fold to the required height above the rail.

The designed height-adjustable boarding platform (1) (Fig. 5), which is installed as a separate device in the vehicle, has dimensions of 1,450 mm x 915 mm x 130 mm. It is a 4-mm thick bent sheet metal, in which holes are cut to lighten the construction. At the top of the height-adjustable boarding platform the original self-supporting EN AW-6060 (AlMgSi) aluminium alloy plate with a 75-mm wide warning strip (2) and part of the vehicle floor (3) is used.

In order to install the boarding platform under the interior floor, it is placed in the rough construction of the vehicle at an angle of 5° in the direction of the floor slope. The maximum permissible height of the module is limited by the height of the milled hole in the rough construction of the railway vehicle (130 mm). The width is also limited to 1,450 mm.

To create sufficient space for the construction of the mechanism, a structural material should have mechanical and physical

 DOI 10.2478/ama-2023-0005

properties for resistance on loading and mass, respectively. Therefore, sandwich panels made of EN AW-6060 (AlMgSi) aluminium alloy were selected. The module is mounted to the C profiles of the vehicle by means of profiles and strength screws (Fig. 6).

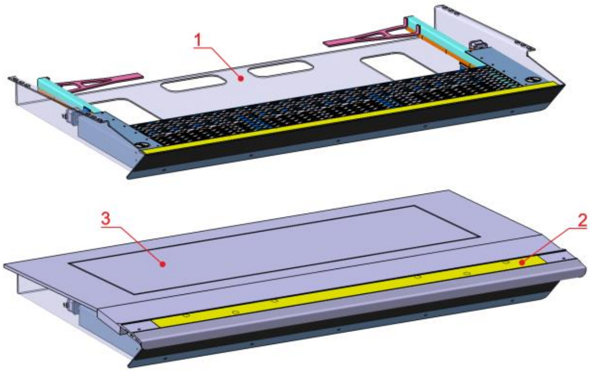

Fig. 5. Main components of the height-adjustable boarding platform for boarding and leaving for a railway vehicle: 1 – the height-adjustable boarding platform; 2 – wide warning strip; 3 – part of the vehicle floor

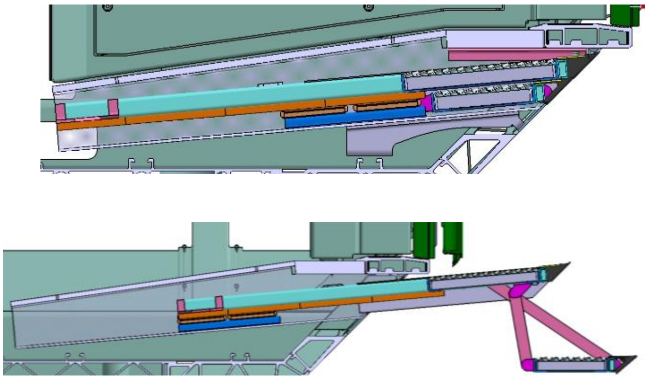

Fig. 6. Tilted lower step-cross section

The construction of the upper and lower step frames (Fig. 7) consists of a welded construction of closed square welded profiles measuring 30 mm x 30 mm with a wall thickness of 3 mm (2), bent L-profiles made of sheet metal 3 mm (3), rectangular welded profile measuring 30 mm x 15 mm with a wall thickness of 2 mm (4), sheets forming a reinforcement 3-mm thick (5) and a plastic plate (1) with a warning yellow strip 45 mm wide.

An important parameter in the design of steps is the mass of the structure, on which the forces acting on the structure will depend:

$$F_s = G_s + F_l, \quad (1)$$

where $G_s = M \cdot g$ – self-weight of the step, N; M – mass of the step, kg; F_l – load from the considered carrying capacity, N.

The studies conducted show that the design of the steps can be made from different materials [22, 23]. These are, for example, various variations of metal or plastic floor gratings, or special aluminium and composite sandwich panels with anti-slip surface treatment that can be used as the filling [22, 23]. The main factors determining the choice of materials of the boarding surface are determined. These factors are divided into several groups:

1. Safety (reliability) factor (f_r), which includes the strength of the material (e.g. plastic, steel, aluminum, etc.) and the coefficient of friction (slip) of the step surface (e.g. smooth anti-slip surfaces).
2. Aesthetic factor (f_a), which includes appearance and practicality (the ability to use steps with different types of shoes, including stilettos).

In accordance with these factors, an objective function has been developed to determine the optimal material of the boarding surface:

$$M(f_r, f_a) \rightarrow min, \quad (2)$$

The physical meaning of the objective function is that when selecting the material for the boarding surface, it is necessary that the mass tends to be a minimum while achieving the maximum safety and comfort.

In accordance with the developed objective function (2), a hot dip galvanized expanded metal grating was suggested. It guarantees low maintenance costs, low weight and at the same time sufficient safety.

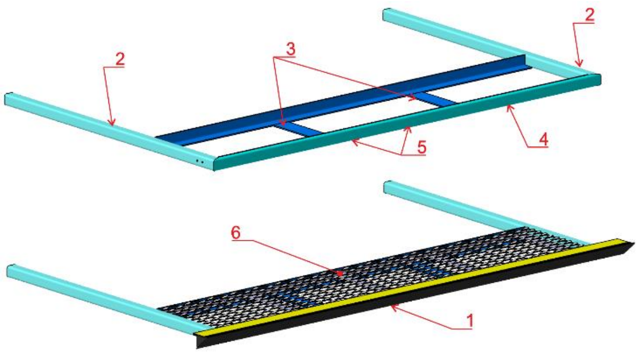

Fig. 7. Sub-components of the upper step: 1 – plastic plate, 2 – welded construction of closed square welded profiles, 3 – bent L-profiles, 4 – rectangular welded profile, 5 – sheets forming a reinforcement, 6 – hot dip galvanized expanded metal

The upper step is ensured by a linear guide (Fig. 8) and consists of the special shape rail (1) and a runner with rolling elements (2). The rails are fixed on the underside of the square profile on both sides of the frame of the upper step. The runners are fastened with screws to a bracket (3) made of 3 mm thick sheet metal. The actuator, which ensures the extension of the upper step, is realized by a DC motor with a toothed belt or a chain.

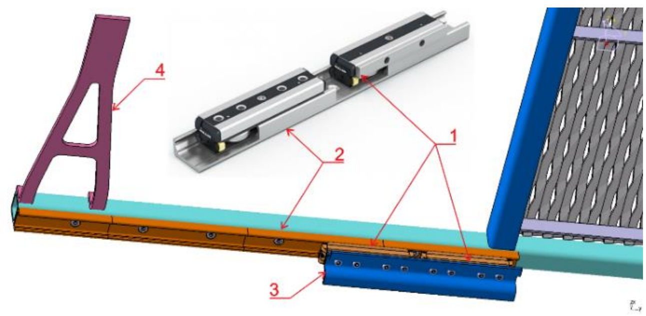

Fig. 8. Details of upper step: 1 – special shape rail, 2 – runner with rolling elements, 3, 4 – bracket

DOI 10.2478/ama-2023-0005

In terms of functionality, simplicity and weight saving of the mechanism, the construction of the lower step is designed as part of the upper step. To help passengers board from the platforms at a height of 550 mm above the top of rail, the upper and lower steps slide out together as one unit. In the case of boarding passengers from platforms 150 mm above the top of rail, after the train stops at the station, the upper step is first extended so that parameter l_3 (150 mm) is observed. Subsequently, the lower step will start to tilt down from the upper step. The mechanism for tilting the step consists of a pair of arms (7) and (8), which are rotatable and mounted on brackets with pins (5), (6), (9) and (10) (Fig. 9).

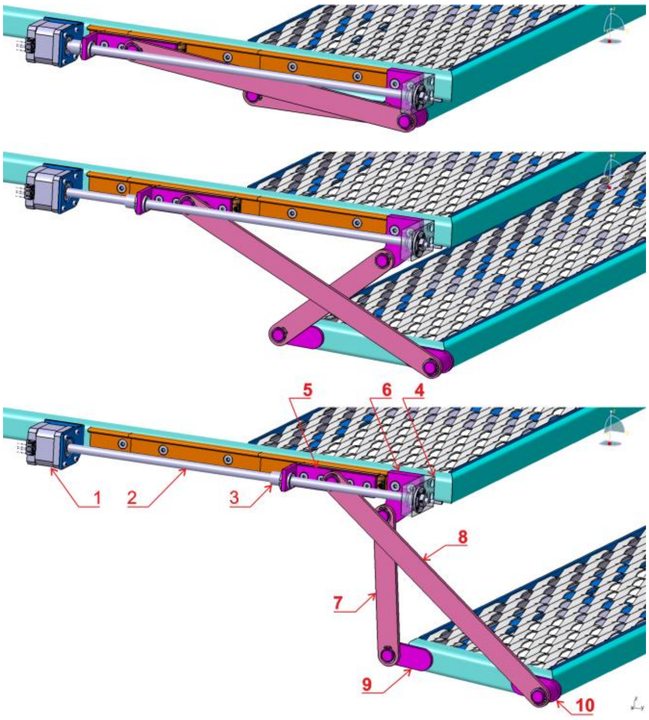

Fig. 9. Tilt mechanism of lower step

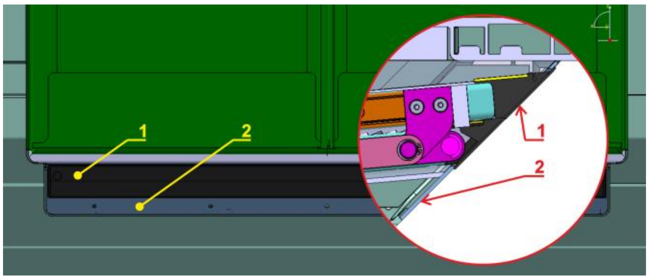

Fig. 10. Details of construction of the vehicle: 1 – non-rigid plate, 2 – sheet metal cover

The profile (5) is installed along a linear guide runner. Also, a nut (2) is attached to the profile (5), into which the screw (3) of the linear drive (1) is screwed. The principle of the lower step tilting function is that after the linear actuator has been actuated, the linear movement of the nut mounted in the profile is transmitted to the linear guide runner due to the rotation of the screw. By moving the arm (8), the force is transmitted to the lower step, and under the influence of the arm guide (7), the lower step is tilted towards the station platform. By suitable adjustment of the lengths of the arms, the lower step must be set not turned by 5° as the upper step, but in a horizontal position for better comfort when boarding the passenger (Fig. 6).

The contact surface with the exterior consists of a pair of non-rigid (e.g. plastic) plates (1) together with a sheet metal cover (2), which forms the filling of the remaining part of the milled hole in the rough construction of the vehicle (Fig. 10).

On the front surface of the plates, an overlap seal is designed, which should slide against the sheet metal cover when the step is inserted into the vehicle and thus seal the gaps between the step plates and the sheet metal cover. Otherwise, rainwater or snow could enter the vehicle and the designed structure, leading to failure of the mechanism. Placing the whole construction (module) inside the vehicle is also advantageous because heat from the interior passes into this space. If the non-rigid plates still freeze, there is a possibility to install the heating on the exposed parts.

4. THE PLATFORM IN FEM APPROACH

For functional and strength analysis, it is important to correctly determine the loads that affect the design of the boarding device [14–26].

Standard [17] defines the value reflecting stress of 4 kN/m^2 in the vertical direction (in the *z*-axis). It follows that the load value for the lower step is 780 N and for the upper step it is 1,638 N. The selected load value was also determined on the assumption that no more than two passengers could board or leave at the same time through the door of a vehicle with a clear usable width of 1,300 mm. The weight of one passenger according to the literature [17] is equal to 80 kg. After adding up the weight of the passengers and adding the weight within the coefficient of safety, choose a load capacity for both steps at 300 kg.

The strength analysis of the designed construction was conducted in the 22.2 ANSYS software. The 3D model was modified (simplified) in SpaceClaim.

For the strength analysis, parts of the tilting mechanism together with the construction of the lower step frame were selected as key supporting elements. The original tread surface from expanded metal was replaced by a simple plane. Due to the symmetry of the construction a half model for the simulation was used.

The shorter arm bracket is attached to the upper step frame and the longer arm bracket is connected to the linear guide runner. When the step is in the end position, the linear guide runner cannot move because it is held in this position by the linear actuator nut. Therefore, these two elements are considered to be fixed.

A mesh of volume finite elements for analysis of new design of tilt platform by finite element method has been created. The number of elements in the mesh was 48,189 and nodes 141,784. The percentage of elements with an aspect ratio of <3 mm was 74%. The dimensions of the finite element mesh model are at a scale of 1:1 to the dimensions of the structure being analysed. They are used as isoparametric, 20-node and 10-node elements with average size of elements at 2 mm (elements of the tilting mechanism) and 6 mm (other parts). The analysis is performed in a linear region. The distortion of the results of the analysis resulting from the introduction of the simplification mentioned is considered negligible. Consideration is given to the fact that the material is linear, elastic and isotropic.

The main parts of the construction were designed from structural steel of S355J2 (Properties: Min yield strength Re = 355 MPa, min, tensile strength Rm = 470 MPa, Young modulus of

DOI 10.2478/ama-2023-0005

elasticity E = 2.1e^5 MPa, Poisson´s ratio μ = 0.3 and density ρ = 7,850 kg · m^{-3}.
The proposed design for three loading conditions is analysed as follows:

– The first loading condition is according to the standard [17] on the area defined by parameter l_3 and useful step width of 1,300 mm (force value of 780 N in the direction of the *z*-axis). The maximum calculated value of stress is 110 MPa. The most stressed parts of the structure are the bracket with the pin and the upper part of the arm in the area of the hole for locking in the end position (Fig. 11). The largest value of displacement is located in the middle part of the lower step frame.
– The second loading condition is also according to literature [17] for an area of 200 mm x 100 mm at any place on the step surface (force value of 2,000 N in the direction of the z-axis). The maximum value of stress was levelled at 344 MPa (Fig. 12).
– The third loading condition is based on the increased safety factor (force value of 3041.1 N in the direction of the z-axis). The maximum calculated value of stress is close to 350 MPa (Fig. 13).

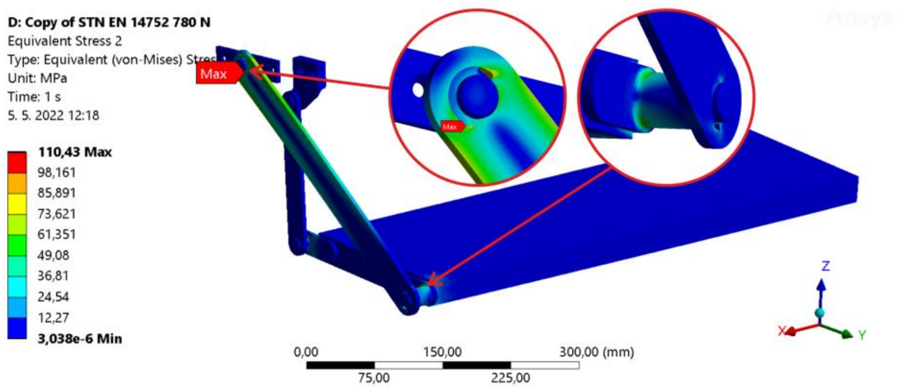

Fig. 11. Mises stress distribution from analysis under loading condition 780 N

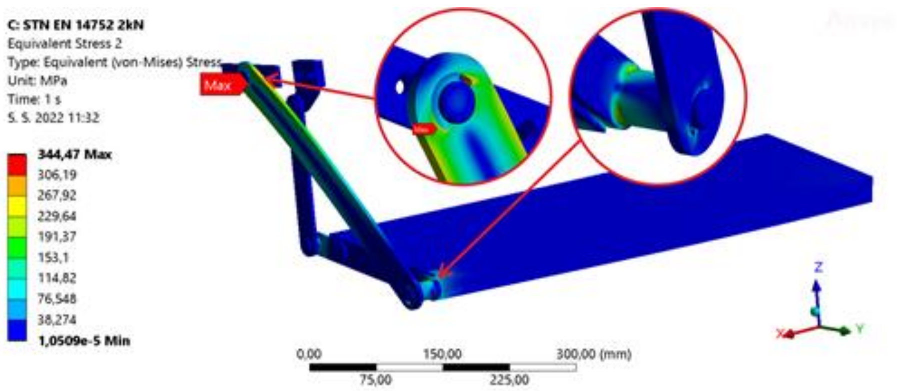

Fig. 12. Mises stress distribution from analysis under loading condition 2,000 N

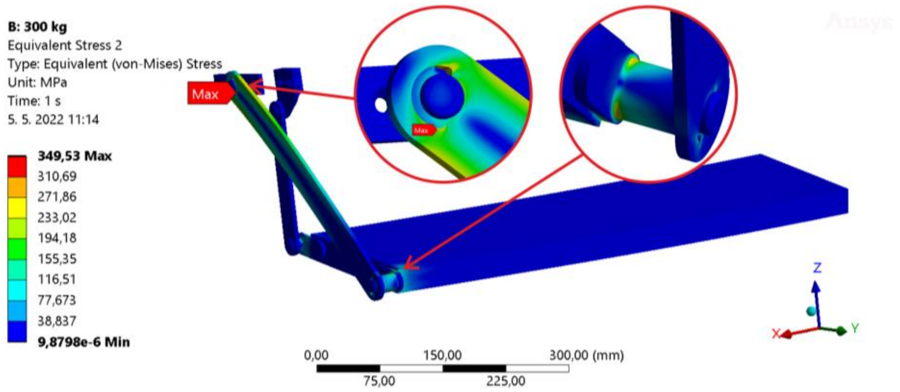

Fig. 13. Mises stress distribution from analysis under loading condition 3,041.1 N

Based on the simulation results, it can be concluded that the construction fulfils the requirements of the current standards because stress values of the second and third conditions are below the yield stress of the material used (Re = 355 MPa). This

DOI 10.2478/ama-2023-0005

kind of data follows a static loading, but in the case of cyclic ones the boarding–leaving platform should be recalculated. This means that the problem considered is represented by a multistage numerical procedure and it is added to the next work schedule of the authors.

5. VEHICLE BOARDING AREA STUDY FOR PLATFORMS WITH A HEIGHT OF 760 MM ABOVE TOP OF RAIL

The boarding area of a railway vehicle is designed for platforms at a height of 550 mm above the top of the rail. The maximum value of an operational high of a boarding–leaving plate is expressed as 570 mm above the top of the rail. In a situation, where the vehicle stops at a platform with a maximum value of an operational high of 760 mm above the top of the rail, the height difference between the boarding levels is 190 mm.

This defines parameter δ_{v-} in the TSI PRM regulation [14]. The maximum permissible value of the δ_{v-} is 160 mm. This means that a railway vehicle does not meet the conditions according to the above-mentioned regulation and structural modifications to the vehicle's boarding area are required.

The current floor in the boarding area is sloped at an angle of 8.1° from the boarding edge to the centre and this is levelled in the middle of the vehicle. With reference to the input conditions, it is proposed to move the boarding plate 30 mm higher, that is, to a height of 600 mm above the top of the rail. With this change, the parameter δv– reached the minimum required value. The angle of slope of the ramp (8.5°) was also changed and the horizontal part of the boarding area followed 126 mm compared with the initial one reflecting the value equal to 455 mm (Fig. 14).

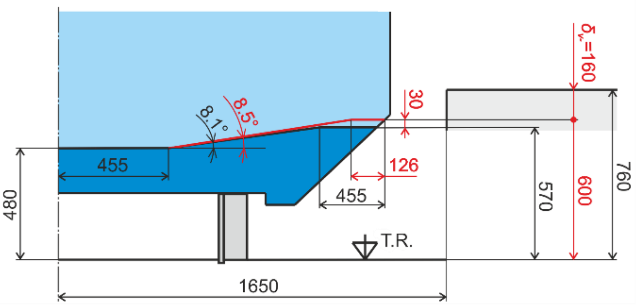

Fig. 14. Changes in the height and slope of the floor of the boarding area on the vehicle: black numbers follow initial dimensions; red numbers represent modified construction dimensions

It was also important to check the vertical clearance of the door. The standard [13] only defines boarding of a vehicle with a higher boarding edge with fixed interior steps from a lower platform (Fig. 15a). However, our case is the opposite: boarding from a higher platform to a vehicle with a lower boarding area that has no interior steps. For this reason, we considered the following:

- The lower line is directed from the edge of the platform to a point located at the end edge of the horizontal part where the floor begins to bend downwards towards the centre of the vehicle.
- The upper line is parallel to the lower line and is positioned to pass through the upper edge of the boarding area of the vehicle (Fig. 15b).

In this case, the useful vertical clearance l_1 has a value of 1,922 mm, which satisfies the condition of at least 1,900 mm, and we assume that a passenger with a height up to the value of parameter l_1 should not be restricted when boarding the vehicle.

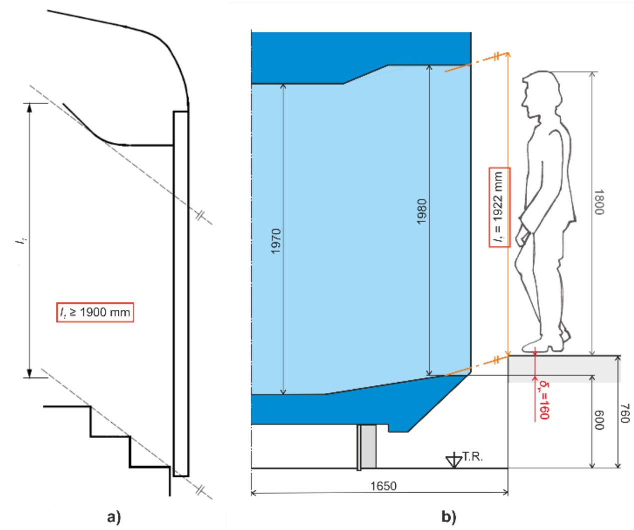

Fig. 15. Checking the vertical clearance of the vehicle's boarding area (a) according to STN EN 14752 and (b) own approach

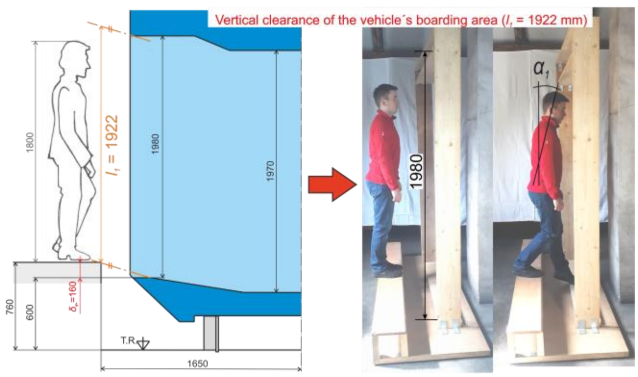

Fig. 16. Vehicle boarding test with vertical clearance l1 = 1,922 mm

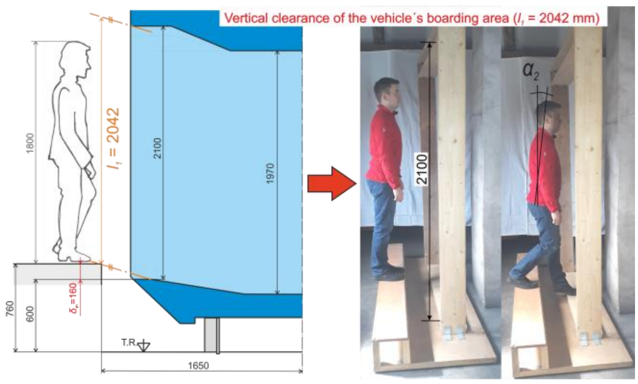

Fig. 17. Vehicle boarding test with vertical clearance l1 = 2,042 mm

However, the edge of the boarding area is above the height of a person standing on the railway platform. This case reflects that the passenger would be affected by his subjective feeling, which would cause him to bow his head when getting into the vehicle.

This idea was verified on a simple model: a vehicle's boarding area and a station platform. The test confirmed that the passenger tends to bow his head when boarding (Fig. 16, α_1).

Therefore, the height of the upper edge of the boarding was represented by 2,042 mm (Fig. 17), wherein $\alpha_2 < \alpha_1$. With this design, the passenger does not need to bow his head when entering the vehicle.

6. SUMMARY

This paper presented a new design of the boarding–leaving device for a railway vehicle at different height levels of platforms. The proposed construction, which was created on the basis of the authors' proposed objective function, combines a system of retractable and tilting steps, thanks to which passengers are boarded from plat-forms with a height ranging from 150 mm to 550 mm above the top of rail in accordance with the required European legislation [13, 17].

Selected parts of the device (a mechanism) which ensured tilting of the lower step was verified by a series of simulation calculations. Based on the FEM results the maximum calculated value of stress for first load conditions is 110 MPa, second is 344 MPa and third is 350 MPa. The most stressed parts of the structure are the bracket with the pin and the upper part of the arm in the area of the hole for locking in the end position. The largest value of displacement is located in the middle part of the lower step frame. Stress value proposed construction for the first, second and third load conditions below the yield stress of the material used (Re = 355 MPa). The designed device meets the current requirements of European legislation and after the optimization of selected structural elements, the prototype can be built and tested.

In the study of different clearance heights of the boarding opening on the model, a clearance height of the boarding opening of 2,100 mm proved to be the best compromise. The useful ground clearance l_1 is 2,042 mm, which meets the requirements of STN EN 14752. The ceiling edge of the boarding opening is located sufficiently above the head of the passenger standing on the platform. The passenger is not limited by the effect caused by the subjective feeling of bowing the head when entering the vehicle.

REFERENCES

1. 2050 long-term strategy. (Internet]. Available from: https://climate.ec.europa.eu/eu-action/climate-strategies-targets/2050-long-term-strategy_en#stakeholder-input (accessed on 1 July 2022).
2. City of Paris: Carbon Neutral by 2050 for a Fair, Inclusive and Resilient Transition | France. (Internet]. https://unfccc.int/climate-action/un-global-climate-action-awards/climate-leaders/city-of-paris (accessed on 1 July 2022).
3. Holloway C, Thoreau R, Roan T-R, Boampong D, Clarke Th, Watts D, Tyler N. Effect of vertical step height on boarding and alighting time of train passengers. Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit 2016;230(4): 1234-1241. https://doi.org/10.1177/0954409715590480.
4. Thoreau R, Holloway C, Bansal G, Gharatya K, Roan T-R, Tyler N. Train design features affecting boarding and alighting of passengers. Journal of Advanced Transportation. 2016;50(8):2077-2088. Available from: https://doi.org/10.1002/atr.1446.
5. Gerlici J, Gorbunov M, Kravchenko K, Prosvirova O, Lack T. The innovative design of rolling stock brake elements. Communications - Scientific Letters of the University of Žilina. 2017;19(2):23-28.
6. Antony S, Long C, Becky PYL. Mengqiu C, Frank, W. Step-free railway station access in the UK: the value of inclusive design. European Transport Research Review. 2021; 13:1-12. https://doi.org/10.1186/s12544-021-00504-3.
7. Gerlici J, Gorbunov M, Nozhenko O, Pistek V, Kara S, Lack T, Kravchenko K. About creatiion of bogiie of the freiight car. Communications - Scientific Letters of the University of Žilina. 2017;19(2):29-35.
8. Gorbunov M, Gerlici J, Kara S, Nozhenko O, Chernyak G, Kravchenko K, Lack T. New principle schemes of freight cars bogies. Manufacturing Technology. 2018;18(2):233-238. https://doi.org/10.21062/ujep/83.2018/a/1213-2489/MT/18/2/233.
9. National strategy to boost accessibility for disabled passengers. (Internet]. Available from: https://www.gov.uk/government/news/national-strategy-to-boost-accessibility-for-disabled-passengers (accessed on 30 July 2022).
10. Sertler P. How parameters of infrastructure affect design of rolling stock for passenger transport. 21st International Conference on Current Problems in Rail Vehicles. 2013: 77-84.
11. Dižo J, Blatnicky M, Gerlici J, Leitner B, Melnik R, Semenov S, Mikhailov E, Kostrzewski M: Evaluation of ride comfort in a railway passenger car depending on a change of suspension parameters. Sensors. 2021;21(23):8138. https://doi.org/10.3390/s21238138.
12. Chudzikiewicz A, Krzyszkowski A, Stelmach A. Asymmetric threats in terms of safety of railway systems. Transport Problems, 2021;16(3): 131–140. https://doi.org/10.21307/TP-2021-047.
13. Commission regulation (EU) No 1299/2014 on the technical specifications for interoperability relating to the 'infrastructure' subsystem of the rail system in the European Union.
14. Commission regulation (EU) No 1300/2014 on the technical specifications for interoperability relating to accessibility of the Union's rail system for persons with disabilities and persons with reduced mobility.
15. The Disability Discrimination Act (DDA). (Internet]. Available from: https://www.sbb.ch/en/timetable/travel-advice/passengers-with-reduced-mobility/dda.html (accessed on 12 July 2022).
16. Accessible travel. (Internet]. Available from: https://www.sbb.ch/en/timetable/travel-advice/passengers-with-reduced-mobility/accessible-travel.html (accessed on 12 July 2022).
17. STN EN 14752+A1 (2022) Railway applications - Bodyside entrance systems for rolling stock.
18. Kundrata M, Tizek J. Double-deck push-pull trainsets Skoda. 24th International Conference on Current Problems in Rail Vehicles. 2019:389-398.
19. Blatnický M, Dižo J, Sága, M, Gerlici J, Kuba E. Design of a mechanical part of an automated platform for oblique manipulation. Applied Sciences. 2020;10(23):1-24. https://doi.org/10.3390/app10238467.
20. Kurčík P, Blatnický M, Dižo J, Pavlík A, Harušinec J. Design of a technical solution for a metro door system. Transportation Research Procedia.2019;40:67–773. https://doi.org/0.1016/j.trpro.2019.07.108.
Poppeová V, Bulej V, Zahoranský R, Uríček J. Parallel mechanism mechanism and its application in design of machine tool with numerical control. Applied Mechanics and Materials. 2013;282:74-79, 2013. https://doi.org/10.4028/www.scientific.net/AMM.282.74.
22. Fomin O, Gerlici J, Vatulia G, Lovska A, Kravchenko K. Determination of Vertical Accelerations in a Symmetrically Loaded Flat Car with Longitudinal Elastic-Frictional Beams. Symmetry. 2022;14(3):583. https://doi.org/10.3390/sym14030583.
23. Fomin O, Gorbunov M, Gerlici J, Vatulia G, Lovska A, Kravchenko K. Research into the strength of an open wagon with double sidewalls filled with aluminium foam. Materials. 2021;14(12):3420. https://doi.org/10.3390/ma14123420.
24. Koziak S, Chudzikiewicz A, Opala M, Melnik R. Virtual software testing and certification of railway vehicle from the point of view of their dynamics. Transportation Research Procedia. 2019;40:729–736. https://doi.org/10.1016/j.trpro.2019.07.103.

DOI 10.2478/ama-2023-0005
acta mechanica et automatica, vol.17 no.1 (2023)
Special Issue "Machine Modeling and Simulations 2022"

25. Kravchenko K, Gerlici J, Harusinec J, Kravchenko O. Research of the Characteristics of Wheel and Rail Contact under the Influence of Design and Operational Factors. Transport Means - Proceedings of the International Conference, 2021-October. 2021:865–870.
26. Kukulski J; Jacyna, M, Golebiowski P: Finite Element Method in Assessing Strength Properties of a Railway Surface and Its Elements. Symmetry. 2019;11(8):1014. https://doi.org/10.3390/sym11081014

This work was supported by the Cultural and Educational Grant Agency of the Ministry of Education of the Slovak Republic in the project No. KEGA 023ŽU-4/2020: Development of advanced virtual models for studying and investigation of transport means operation characteristics. This research was supported by the Cultural and Educational Grant Agency of the Ministry of Education of the Slovak Republic in the project No. KEGA 036ŽU-4/2021: Implementation of modern methods of computer and experimental analysis of the properties of vehicle components in the education of future vehicle designers.

Pavol Šťastniak: https://orcid.org/0000-0003-1128-7644

Michal Rakár: https://orcid.org/0000-0003-1164-3506

Jakub Tížek: https://orcid.org/0000-0003-2048-7226