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Development of an improved design of a high-capacity passenger railcar for the railways of Uzbekistan

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ABSTRACT In the context of the rapid growth of passenger traffic by rail, one of the priorities is to increase the efficiency of rolling stock use. The key direction in solving this problem is to increase the passenger capacity of railway coaches while ensuring a high level of their structural strength, reliability and safety. This study presents an improved design of the body of a passenger coach with increased capacity, developed taking into account modern requirements for comfort, environmental friendliness and operational efficiency. To assess the design characteristics, a comprehensive analysis was carried out, including theoretical calculations of the stress-strain state of the body elements using the finite element method. Numerical modeling made it possible to identify critical areas of the structure and optimize its parameters to increase strength and reduce material consumption. The simulation results were supplemented and confirmed by experimental tests of the prototype, conducted in conditions as close as possible to real operation. The data obtained indicate that the design meets the requirements of current regulatory documents, including safety and durability standards. The proposed design demonstrates improved operational characteristics, which makes it promising for use in the design and modernization of new-generation passenger coaches. The research results can serve as a basis for further developments in the field of innovative railway transport, providing an increased level of comfort and efficiency.

KEYWORDS: passenger railcar; passenger capacity; design; frame; stress; strength; testing

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Научная статья

Разработка усовершенствованной конструкции пассажирского вагона увеличенной вместимости для железных дорог Узбекистана

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АННОТАЦИЯ В условиях стремительного роста объемов пассажирских перевозок по железной дороге одной из приоритетных задач становится повышение эффективности использования подвижного состава. Ключевое направление в ее решении — увеличение пассажировместимости вагонов при обеспечении высокого уровня прочности, надежности и безопасности конструкции.

Представлена усовершенствованная конструкция кузова пассажирского вагона повышенной вместимости, разработанная с учетом современных требований к комфорту, экологичности и эксплуатационной эффективности. Для оценки характеристик конструкции был проведен комплексный анализ, включающий теоретические расчеты напряженно-деформированного состояния элементов кузова с использованием метода конечных элементов. Численное моделирование позволило выявить критические зоны конструкции и оптимизировать ее параметры для повышения прочности и снижения материалоемкости. Результаты моделирования были дополнены и подтверждены экспериментальными испытаниями опытного образца, проведенными в условиях, максимально приближенных к реальной эксплуатации.

Полученные данные свидетельствуют о соответствии конструкции требованиям действующих нормативных документов, включая стандарты безопасности и долговечности. Предложенная конструкция демонстрирует улучшенные эксплуатационные характеристики, что делает ее перспективной для применения в проектировании и модернизации пассажирских вагонов нового поколения. Результаты исследования могут служить основой для дальнейших разработок в области создания инновационного железнодорожного транспорта, обеспечивающего повышенный уровень комфорта и эффективности.

КЛЮЧЕВЫЕ СЛОВА: пассажирский вагон; пассажировместимость; конструкция; рама; напряжения; прочность; испытания

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INTRODUCTION

As the network of railway routes expands and modern railway lines are put into operation, there is a growing need for streamlining passenger services. The major task is to make the most of resources of the passenger services system, while necessarily providing proper and safe conditions for meeting people's needs[1].

A viable solution is to purchase rolling stock abroad or localize its production in the Republic of Uzbekistan, with the latter being a better option in the long run. Since 2009, the Tashkent Plant for Construction and Repair of Passenger Carriages Joint-Stock Company (TVSRZ JSC) has been manufacturing 61-907 wagons[2] which have been used as a basis for modifications, such as sleepers, special-purpose carriages, and Class I (Business), II (VIP) and III (Economy) coaches [1, 2].

To improve the performance of passenger services, it is important to expand the capacity of coaches, increase train speeds, and reduce costs per passenger. As international experience shows, this can be achieved by using long-wheelbase or double-deck coaches [3–5]. However, double-deckers have a number of design constraints, such as high weight, complex design, high costs, and incompatibility with the current railway infrastructure in the Republic of Uzbekistan.

A number of comprehensive studies are currently underway to assess the structural strength and fatigue durability of the body frame of passenger coaches. A special focus is put on analysing the stress-strain state of structural elements under various operational loads [6–8]. They examine the causes of possible malfunctions and defects that can affect the structural reliability and safety in the long run [9]. Research and development projects create numerical and computer models of coach bodies that allow for high-precision computations using the finite element method. These models help identify critical stress concentration areas, optimize geometry of load-bearing elements, and predict the service life of the structure under various modes of operation [10–15]. This approach is necessary to develop modern higher-capacity passenger coaches that meet current requirements for strength, reliability and safety.

Thus, at the first stage it was decided to develop a long-wheelbase coach in line with traffic safety and good performance requirements.

The purpose of the study is to develop engineering solutions for the design of a high-capacity passenger coach geared to the conditions in the Republic of Uzbekistan.

SUBJECT OF THE STUDY

The subject of this study is the design of the body of a 61-907 open-space coach built by TVSRZ JSC which can carry 48 passengers [16].

[1] Resolution of the President of the Republic of Uzbekistan No. PP-28 dated January 27, 2025 "On measures for further development of the transport and logistics system in the Republic of Uzbekistan".
[2] TU 17923832-013. 61-907 passenger compartment coaches with air conditioning. Tashkent. JSC "TVSRZ". 2022:41.

THEORETICAL RESEARCH

For the purposes of theoretical research, a 3D simulation model of the coach body was designed in SolidWorks automated design system (version 2021). The model was then exported to ANSYS Workbench (version 2021), where a refined finite-element model (FEM) was created on its basis. A strength analysis using FEM was conducted in accordance with Standards [9] and the State Standard (GOST) 34093-2017 [10]. The developed FEM made it possible to determine the stress-strain state of the structure under static and dynamic loads. To analyse stresses and identify areas that require reinforcement, the model included cross-sections with virtual measurement points, which helped obtain local stress values and perform a detailed analysis of the stress loading on the body.

The computations produced maximum stress values at virtual measurement points. The distribution diagrams for equivalent Von Mises stresses arising from a longitudinal force of 2.5 MN (compression) are shown in *Fig. 1*.

An analysis of the resulting dependencies of maximum stresses arising in elements of the coach body has shown that an increase in longitudinal loads produces insignificant changes in stress in areas of the side and end walls, as well as of the roof; however, in certain parts of the carriage frame elements, stresses exceed the permissible values, which indicates that these areas require improvement in terms of design. In this connection, further research was focused directly on the design of the carriage frame. The study included further calculations where the length of the carriage was incrementally increased in the range from 500 to 2,500 mm with a 500 mm increment. The distribution diagrams for equivalent Von Mises stresses in frame elements from longitudinal forces are shown in *Fig. 2*.

Thus, when the carriage length is increased by 2,500 mm, the maximum equivalent stresses reach 688.75 MPa in the centre sill and 661.13 MPa in the side sills, which significantly exceeds the permissible value of 293.25 MPa. This means that the frame needs to be structurally reinforced in order to ensure safe operation and increase the capacity of an extended coach.

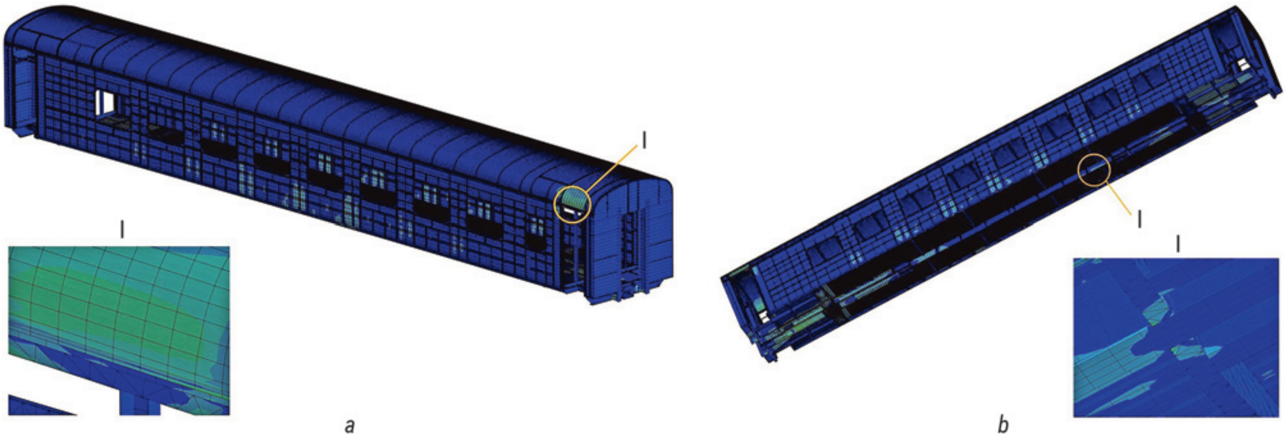

Fig. 1. Distribution field of equivalent stresses (Von Mises stress) in the coach body under the action of a longitudinal compressive force of 2.5 MN: *a* — top view; *b* — bottom view

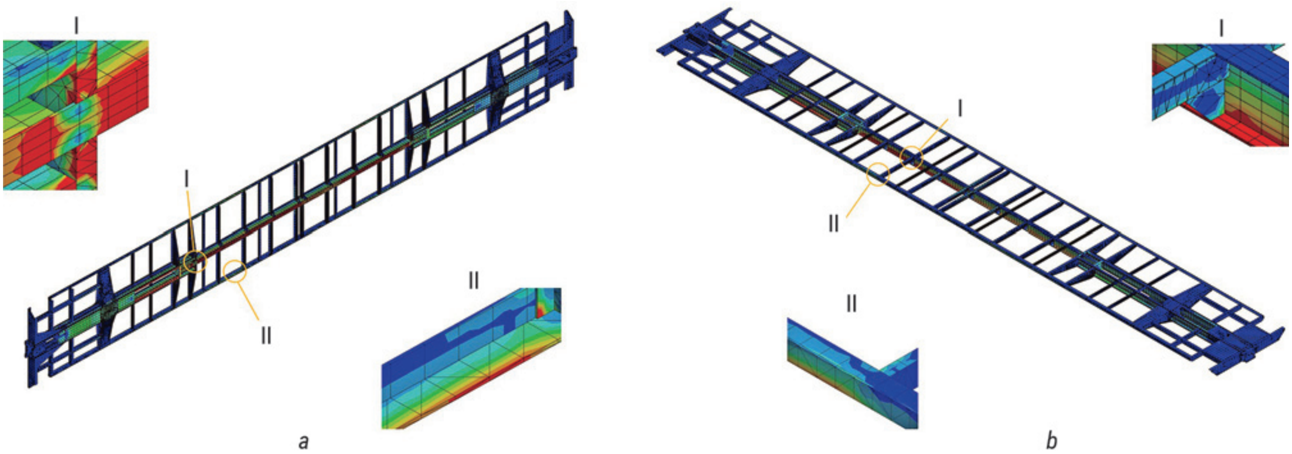

Fig. 2. Distribution fields of equivalent stresses in frame elements from longitudinal forces: *a* — top view; *b* — bottom view

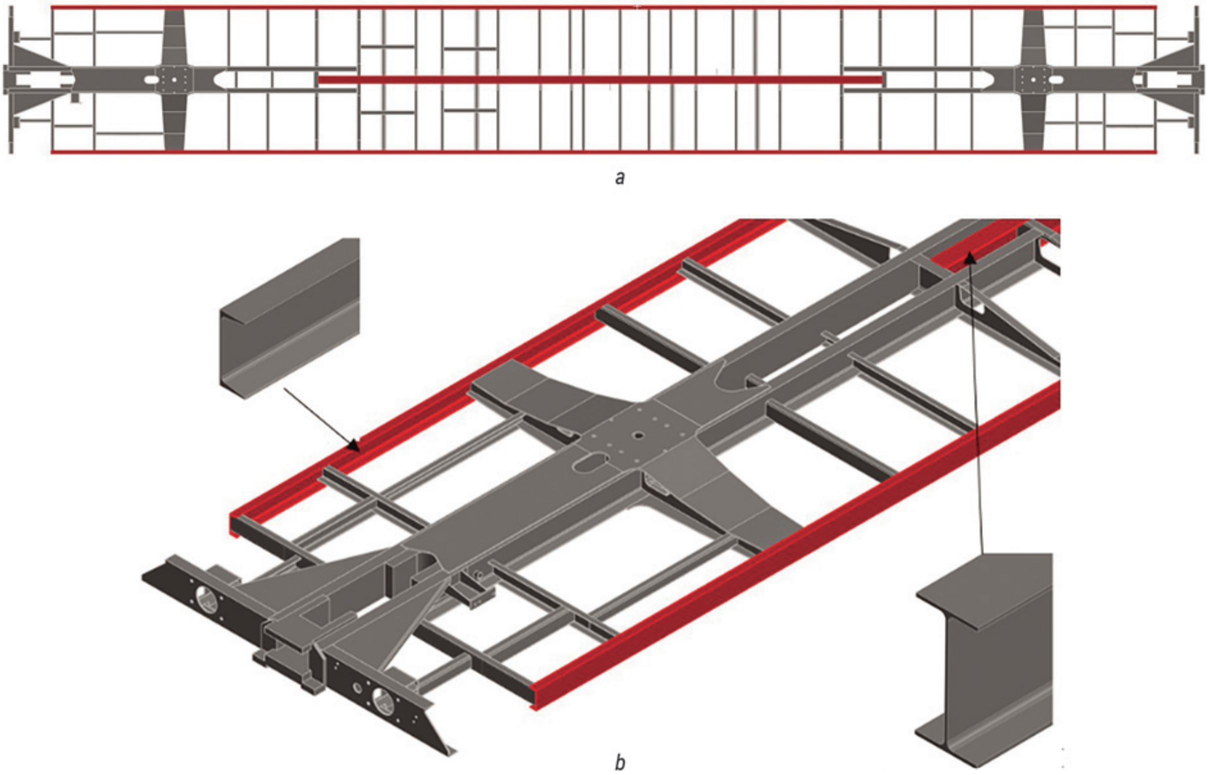

Fig. 3. Frame of an extended coach with reinforcement parts: *a* — general view; *b* — reinforced elements (centre sill and side sills)

The desktop study has shown that in order to meet structural strength requirements, the width of beam flanges in the middle section of the centre sill of the frame made of an I-beam No. 30 should be increased from 135 mm to 150 mm. In addition, to improve the structural strength, it is recommended to use C-channels No. 18 as the side sills to replace the original L-bars. It has been found that with a wheelbase extended to 18,000 mm and a 1,500 mm longer overall length, the coach design meets the requirements for automatic coupling. The improved design of the carriage frame is shown in *Fig. 3*.

After validating the chosen parameters for the extended coach design, stress was calculated in accordance with the requirements[3] for three design conditions[4] using the software package for FEM analysis and numerical modelling. The calculation results are given in *Table 1*.

Table 1

Stresses in elements of the extended coach body

Structural element	Design conditions		
	I	II	III
Frame elements	219 MPa (74% of the permissible value)	237 MPa (80% of the permissible value)	96 MPa (51% of the permissible value)
Side wall framework elements	135 MPa (46% of the permissible value)	117 MPa (40% of the permissible value)	107 MPa (56% of the permissible value)
End wall framework elements	114 MPa (39% of the permissible value)	97 MPa (33% of the permissible value)	39 MPa (21% of the permissible value)
Roof framework elements	128 MPa (44% of the permissible value)	117 MPa (40% of the permissible value)	105 MPa (55% of the permissible value)

[3] Standards for the calculation and design of new and upgraded 1,520 mm gauge (non-self-propelled) carriages on railways of the Ministry of Railways. Effective October 01, 1984. Moscow. VNIIV-VNIIZhT. 1983:260.
[4] GOST 34093-2017. Passenger cars on locomotive traction. Requirements for structural strength and dynamic qualities. Moscow. Standartinform. 2017:45.

Table 2

Stability safety factors for coach body elements

Design conditions	Buckling failure zone	Stability factor	
		design	permissible
I (compression)	Floor sheet at the tail end of the carriage	2.22	1.1
I (impact)	Floor sheet at the tail end of the carriage	2.75	1.1
II (tensile)	Roof covering in the middle part of the carriage	2.90	1.3
II (jerk)	Roof covering at the tail end of the carriage	2.38	1.3
III (compression)	Floor sheet at the tail end of the carriage	1.61	1.5
III (tensile)	Corrugated sheets of the floor	2.29	1.5

Thus, in all the design conditions, the values of stress in elements are within the permissible limits, which confirms that the structure is structurally safe in terms of its strength.

The stability of elements of the extended body was assessed using the estimated safety factors.

The results summarized in *Table 2* have shown a sufficient safety margin and conformity of the design to standards.

STATIC AND DYNAMIC PERFORMANCE TESTING

For the purposes of experimental evaluation of the developed extended coach design, a preproduction prototype was fabricated and subject to static and dynamic performance testing[5].

The purpose of the static tests was to assess the stress-strain state of elements of the body metal structures at the reference points upon the exposure to statically applied compression and tensile loads.

The product was tested at the facilities of TVSRZ JSC. A special static loading fixture for carriages was used to create longitudinal forces. Deformations were registered using resistive strain gauges connected to a MIC-185 measuring and computing system and the measurement processes were recorded with a personal computer. Before the tests, strain gauges corresponding to the most heavily loaded sections identified by the preliminary FEM calculations were glued at the predetermined reference points of load-bearing body elements. The tests involved applying a static longitudinal force of 1.5 MN (tensile) and 2.5 MN (compression) via automatic coupler elements with the use of jacks installed on a loading fixture.

As a result of the static tests of the extended coach prototype, the maximum stress reached 230.1 MPa in the central part of the centre sill and 83.1 MPa in the side sill, which does not exceed the permissible level of 293.25 MPa.

At the next stage, the extended carriage prototype underwent dynamic tests on the Tukimachi-Angren section. The following results were registered: vertical dynamics coefficient: 0.24 (with the design and permissible values being 0.21 and 0.35, respectively); stability factor against wheel derailment: 2.1 (design and permissible values: 2.7 and 2.0, respectively); and stability against overturning: 3.13 (design and permissible values: 1.92 and 1.4, respectively). As a result, the dynamic reliability of the design was confirmed.

Testing the impact of the extended coach on the railway track according to GOST 34759-2021 has confirmed that the track strength characteristics meet regulatory requirements for the operation of the coach. The tests were conducted at a temperature of 26–36 °C, humidity of 16–30 %, and a pressure of 100.2 kPa.

The developed design increases the passenger capacity compared to the base model (48 seats). In Class I and II extended coaches, the number of seats was increased by 50 % to reach 72 seats, and in Class III coaches, it was increased by 87 % to 90 seats.

CONCLUSION

Thus, the research has shown the effectiveness of the structural solutions designed to increase the passenger capacity while maintaining the levels of the carriage strength and safety. The modelling and testing have shown that the developed extended design of the body with a reinforced frame meets regulatory requirements. The comprehensive approach confirmed the soundness of the design in terms of strength and dynamic performance. The optimized interior layout made it possible to increase the number of seats to 72 (Classes I–II) and 90 (Class III), contributing to better cost-effectiveness of passenger services. The design has been successfully adapted to being manufactured by TVSRZ JSC and to the operating conditions in the Republic of Uzbekistan.

[5] GOST 33788-2016. Freight and passenger railcars. Methods of testing structural strength and dynamic performance. Moscow. Standartinform. 2016:41.

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