**Service Life Extension through Retrofit of the TEM2   
Shunting Locomotive Bogie Frame**

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**Abstract.** This study develops the regulatory, technical, and design documentation required to reinforce the bogie frame of TEM2 shunting locomotives in Uzbekistan’s rail network, which have been in service for over 50 years. The main objectives were to evaluate the frame’s structural strength and improve its reliability. To assess corrosion and material degradation resulting from long-term operation, ultrasonic thickness measurements were performed. Using these measurements, a detailed 3D finite element model of the bogie frame was created in SOLIDWORKS, and a strength analysis was conducted in accordance with Mode III of the GOST 34939 standard. The analysis revealed that stress levels in certain areas exceeded the allowable limit (160 MPa vs. 141 MPa), indicating fatigue cracking due to prolonged use. To address this, reinforcement design improvements were developed, and welding repairs were carried out at JSC “O‘ztemiryo‘lmashta’mir”. During the overhaul, reinforcing metal plates were fabricated and welded onto the bogie frame per the technical design. As a result, the calculated maximum stress was reduced to 121.8 MPa, and the safety factor improved from 2.2 to 2.6, demonstrating a notable enhancement in structural integrity. The study confirms that scientifically grounded modernization of locomotive frame structures nearing or past their service life is feasible. Strength-based reinforcement can effectively extend the operational lifespan of existing locomotives.

**Keywords:** Shunting locomotive of TEM2 type, bogie frame, bogie frame modernization, III-calculated mode, stress concentration, strength safety factor

# Introduction

The Republic of Uzbekistan is currently undergoing dynamic reforms aimed at modernizing its railway infrastructure and expanding new railway corridors. These initiatives are part of a broader national strategy focused on improving transport connectivity, increasing freight and passenger capacities, and supporting the region’s long-term economic development. As the railway network continues to grow, the demand for both shunting and mainline locomotives has significantly increased to ensure efficient operation on newly established routes.

In this context, the acquisition of modern, environmentally compliant locomotives has emerged as a national priority. At the same time, maintaining the operational reliability of the existing locomotive fleet remains a pressing concern. Prolonged service life of rolling stock necessitates consistent diagnostic assessments, timely overhauls, and preventive maintenance to guarantee safe and uninterrupted railway operations.

A strategic approach combining the gradual modernization of aging locomotives with the procurement of new units is considered essential for improving the overall performance and energy efficiency of the railway sector. These measures are expected to reduce operating costs, enhance service quality, and extend the useful life of the locomotive fleet.

According to statistical forecasts, by 2025, more than 70% of the locomotive fleet operated by JSC “O‘zbekiston temir yo‘llari” will consist of units that have exceeded 30 years of service, with TEM2-type shunting locomotives comprising a large portion. Many of these have been in continuous operation for over four decades [1]. Limited financial resources for purchasing new locomotives, along with an increasing number of technical failures and rising transport demand, have made the efficient use and life extension of aging locomotives an urgent priority [2], [3].

To address this challenge, comprehensive technical assessments are required to evaluate the current condition of long-serving locomotives, determine their residual lifespan, and explore methods for extending their operational capabilities. Under current railway regulations in Uzbekistan, the designated service life of TEM2 shunting locomotives is up to 50 years. During major overhauls, key components such as wheelsets, traction motors, and transformers are repaired or replaced. However, the structural frame—specifically the main and bogie frames—remains the core, non-replaceable element that defines the locomotive’s operational lifespan.

This article aims to provide a scientific basis for extending the service life of TEM2 locomotives by evaluating the residual resource of the bogie frame using strength analysis methods. The findings are intended to guide practical decision-making on modernization strategies for long-serving rolling stock.

# Literature review

Extensive research has been carried out by numerous scholars on the assessment of residual life in the frame structures of railway rolling stock, as well as on methods for extending the operational service life of these vehicles. These studies, including those referenced in provide valuable theoretical and practical foundations for evaluating structural durability and implementing life-extension strategies for aging rolling stock.

Do, Wu, Nguyen, and Do (2021) [4] proposed a hybrid method for assessing the fatigue and residual life of freight wagon bogie frames, combining finite element analysis with multi-body dynamic simulation. They evaluated service life by incorporating dynamic load histories into structural fatigue analysis. Xiu, Spiryagin, Wu, Yang, and Liu (2021) [5] further developed this approach by applying a virtual prototype method that integrated frame structures while accounting for traction, braking loads, and dynamics. Their research demonstrated that these longitudinal forces significantly reduce the fatigue life compared to vertical loading alone. Seo, Hur, Kwon, and Moon (2023) [6] focused on welded locomotive bogie frames, investigating how multiple welding repairs affect residual stresses and fatigue strength. Using modern engineering software, they assessed the distribution of residual stresses in the structure and the impact of repairs on fatigue life. Lan and Song (2021) [7] presented a methodology for simulating fatigue in locomotive bogie frames using the finite element method. They determined a preliminary assessment of the onset of fatigue damage to the structure based on its load history and Miner’s rule. This approach does not allow for a comprehensive assessment of the strength indicators of a full-scale model. In this study, we evaluate the static strength of the full-scale frame structure in the III-calculation mode in accordance with the requirements of GOST 34939 [8], which is the normative document. Through this, we determine the strength indicators and fatigue resistance of the bogie frame.

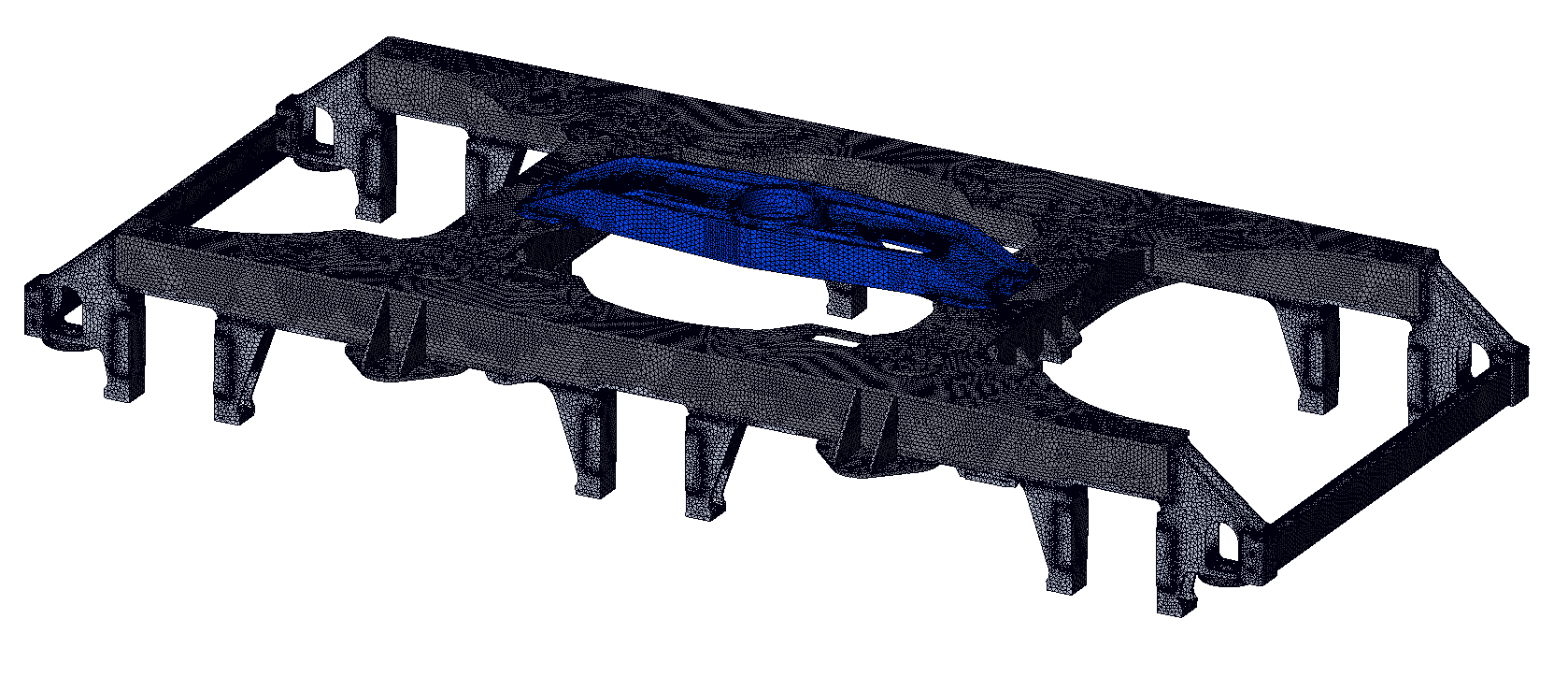
Researchers at Tashkent State Transport University have focused particularly on ensuring the operational safety of railway rolling stock, modernization, and improving the reliability characteristics of locomotives [9], [10], [11], [12], [13]. Their principal works have played a crucial role in assessing the service life of railway rolling stock and developing methodologies for extending its useful safe service life.

# Materials and Methods

## Object of Research

This scientific research study focuses on the bogie frame, which is the main structural component of the TEM2 type shunting locomotive currently in use on the railways of the Republic of Uzbekistan. Ultrasonic thickness measurements of the bogie frame metal were carried out using a calibrated UT-1M ultrasonic thickness gauge. The measurements considered the uniformly distributed corrosion factors observed on two TEM2 locomotives: unit No. 473 from the “Termiz” locomotive depot of JSC “O‘zbekiston temir yo‘llari,” and unit No. 784 operated by the state enterprise “Navoi Uran.” Both locomotives have been in continuous operation for over 50 years. Based on the measurement results, the most severely corroded sections of the bogie frames were identified, and the extent of material degradation in these areas was assessed [14]. These findings were then used to develop a finite element model that closely replicates the actual structural condition of the bogie frames, utilizing modern computer-aided engineering software.

The finite element model of the TEM2 bogie frame was constructed using advanced engineering tools and consists of 726,614 finite elements and 1,277,692 nodes. The mesh generated for this model is a high-resolution “solid body mesh,” specifically tailored for analyzing structures with complex geometric features [15]. This meshing approach automatically refines the mesh density in regions with inclined surfaces, bends, and curvatures, enabling more accurate stress distribution analysis. Figure 1 illustrates the finite element model of the bogie frame structure developed for the TEM2 shunting locomotive.



**FIGURE 1.** Computational model of the bogie frame structure for a TEM2 type shunting locomotive

The structural strength analysis of the computational model of the bogie frame was carried out in accordance with the requirements of the widely recognized standard GOST 34939 [8], which governs the strength assessment of railway transport components. These standard outlines established methodological approaches for evaluating the structural integrity of locomotive frame elements under various static and dynamic loading scenarios. By adhering to this standard, the analysis ensures consistency with industry practices and provides a reliable basis for assessing the safety and durability of long-serving locomotive frames.

Table 1, compiled in accordance with the GOST 34939 standard [8], defines the permissible stress limits for locomotive frame structures under both normal operational and extreme loading conditions. These limits are determined by considering the mechanical properties of the structural materials, the geometry of the frame, and the dynamic loads experienced during locomotive operation. Adherence to these standardized values ensures that the strength assessment is performed within a rigorous and regulated engineering framework, enhancing the reliability and validity of the study’s findings.

**TABLE 1.** Allowable stresses for the main frame and bogie frame components of locomotives [8] (as per GOST 34939)

|  |  |  |  |
| --- | --- | --- | --- |
| **Calculation modes** | | **Distribution of permissible stresses in the frame structure of locomotives** | |
| **Main frame** | **Bogie frame** |
| **Mode I** | **Ia** | 0,9 *σ0,2* | |
| **Ib** | 0,9 *σ0,2*\* | 0,9 *σ0,2* |
| **Mode II** |  | 0,6 *σ0,2* | |
| **Mode III** |  | 0,6 *σ0,2* | |
| **Mode IV** |  | 0,9 *σ0,2* | |
| \*The value *σ0,2* is used when conducting tests.  Note - *σ0,2* is the conventional yield strength of the material, obtained from reference data or determined according to GOST 1497. | | | |

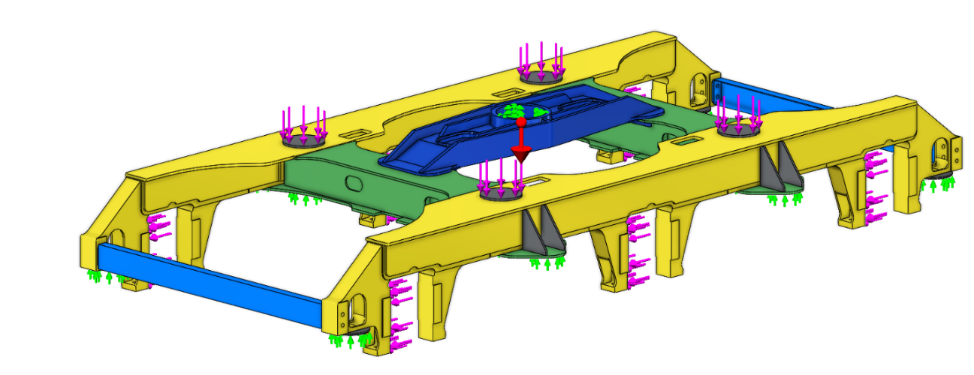
The main frame structure, with its parts made of St3 grade steel through welding, has a yield strength of   
*σ0,2* =235MPa according to its mechanical properties. The strength calculation work is carried out based on Mode III, where the permissible stress should not exceed 141 MPa, as specified in GOST. The following Table 2 presents the main initial data for the TEM2 type shunting locomotive.

**TABLE 2.** Basic initial data for a TEM2 type shunting locomotive

|  |  |
| --- | --- |
| Mass of the locomotive PL, ton | 120 |
| Mass of the bogie frame PB, kg | 23 573 |
| Continuous traction force F, kgf | 20 400 |
| Fuel capacity, kg | 5 440 |
| Mass of diesel generator (water+oil), kg | 22 800 |
| Number of arrows | 6 |
| **Distribution of forces acting on the structure** | |
| Force acting on the supporting structures of the bogie frame, ton | (PL - PB)/4 |
| Force acting on the jaws of the bogie frame, ton | F/ 6 |

# Results and Discussion

According to the results of the strength analysis, the equivalent overall stress values must not exceed the allowable limits specified in Table 1. Based on the parameters outlined in Table 2, the corresponding loading scheme applied to the bogie frame structure is illustrated in Figure 2.



**FIGURE 2.** Loading diagram for the bogie frame

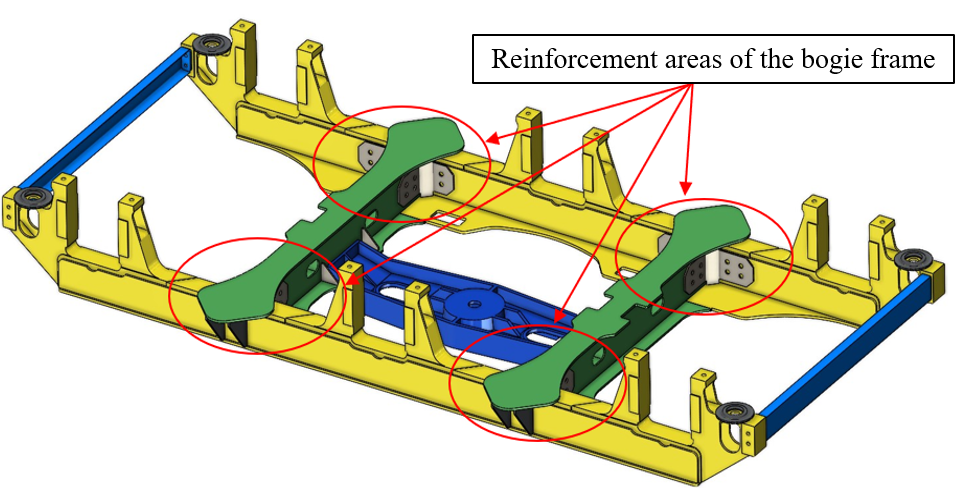
The strength test results of the bogie frame’s simulation model under the third loading condition are illustrated in Figure 3 below.

|  |  |
| --- | --- |
| *а)* |  |
| *b)* |  |

**FIGURE 3.** Strength calculation of the bogie frame; a) stress-strain state, b) safety margin

Based on the strength calculation results, critical high-stress zones on the locomotive’s bogie frame were identified. These findings revealed structurally vulnerable areas characterized by elevated stress–strain concentrations. As a result, reinforcement work has been planned for these zones during the overhaul of TEM2-type shunting locomotives, which have been in operation for more than 50 years on the Uzbekistan railway network [16]. The primary objective is to enhance the structural strength and extend the service life of the bogie frames.

To support this effort, regulatory and technical documentation, along with detailed design drawings, were developed to guide the reinforcement process and ensure the long-term reliability of the frame [17]. Figure 4 highlights in red the specific regions of the bogie frame structure targeted for reinforcement.



**FIGURE 4.** Points where the bogie frame is reinforced

The work on extending the service life of TEM2-type shunting locomotives No. 473, No. 846, No. 932, No. 1109, No. 1105, No. 2159, No. 2170, No. 2306, No. 2308, No. 2309, No. 2310, No. 2393, and No. 2557 belonging to JSC “O‘zbekiston temir yo‘llari” as well as No. 784 on the balance sheet of the state enterprise “Navoi uran” was carried out at the locomotive repair facility of JSC “O‘ztemiryo’lmashta’mir” as shown in Figure 5. These works were performed by welding reinforcing plates to the bogie frame in accordance with regulatory and technical documentation and design drawings [18].

|  |  |
| --- | --- |
|  |  |

**FIGURE 5.** Welded state of reinforcing plates on the strengthened areas of the bogie frame

The reinforcement of the bogie frame was performed in accordance with the developed normative-technical and design documentation [19]. Following the reinforcement, the structure was re-evaluated for strength in compliance with the requirements of GOST 34939. The results of the post-reinforcement strength analysis are presented in Figure 6 below.

|  |  |
| --- | --- |
| *а)* |  |
| *b)* |  |

**FIGURE 6.** Strength calculation for enhancing the durability of the bogie frame, taking into account reinforcing elements; a) stress-strain state, b) safety margin

The results of the strength analysis for the bogie frame of a shunting locomotive with an expired service life, along with the evaluation of the effectiveness of the applied reinforcement measures, are summarized in Table 3. This table presents the comparative strength calculation outcomes before and after the application of the strengthening technologies [20].

**TABLE 3.** Results of strength calculations for the bogie frame

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Structural condition of the bogie frame** | **Nominal stress, MPa** | **Stress concentration factor** | **Stress considering the stress concentration factor, MPa** | | **Allowable stress, MPa** | **Strength safety factor** |
| Before reinforcement | 100 | 1,6 | | 160 | 141 | 2,2 |
| After reinforcement | 87 | 1,4 | | 121,8 | 141 | 2,6 |

As shown in the analysis of Table 3, the nominal stress in the bogie frame prior to reinforcement was 100 MPa, while the stress value adjusted for the stress concentration coefficient reached 160 MPa. This value exceeds the allowable stress limit of 141 MPa, indicating a reduction in the structural durability and a limited margin for safe operation. The corresponding safety factor in this state was 2.2.

Following the reinforcement measures, the nominal stress was reduced to 87 MPa, and the stress considering the concentration coefficient decreased to 121.8 MPa, which is safely below the permissible limit (121.8 < 141 MPa). These results confirm the effectiveness of the reinforcement in improving the structural integrity and extending the service life of the bogie frame.

# Conclusion

The conducted scientific study confirms the practical importance of assessing the current technical condition of main structural components—specifically, the bogie frames—that play a critical role in determining the service life of TEM2-type shunting locomotives, many of which have been operating in Uzbekistan for over five decades. The research highlights the necessity of evaluating the residual structural resource of these components based on strength calculations and supports extending their operational life through targeted modernization.

As a result of this approach, the service life of several locomotives from the JSC “O‘zbekiston temir yo‘llari” fleet—namely units No. 473, 846, 932, 1105, 1109, 2159, 2170, 2306, 2308, 2309, 2310, 2393, and 2557—as well as units No. 784 and 1526 from JSC “Navoi Mining and Metallurgical Combine” was successfully extended to 57 years following repair and modernization works carried out at JSC “O‘ztemiryo‘lmashta’mir.”

This extension has resulted in significant economic benefits, with an estimated cost savings of 1.85 billion Uzbek soums per locomotive annually. Furthermore, the implementation of welding operations based on well-developed normative-technical and design documentation has demonstrated a substantial improvement in the reliability and structural integrity of locomotives previously deemed decommissioned.

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