**ORIGINAL ARTICLE**
DOI: https://doi.org/10.30932/1992-3252-2023-21-3-10

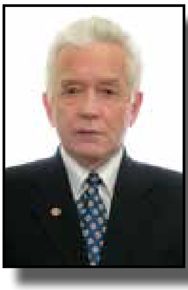
World of Transport and Transportation, 2023,
Vol. 21, Iss. 3 (106), pp. 254–262

# Regulatory Framework for Ensuring Safe Operation of Railway Equipment Based on the Service Life of Load-Bearing Structures

**Valery S. KOSSOV**

**Dmitry A. KNYAZEV**

**Nikolai F. KRASYUKOV**



**Nikolai A. MAKHUTOV**

**Mikhail M. GADENIN**

***Valery S. Kossov [1], Dmitry A. Knyazev [2], Nikolai F. Krasyukov [3], Nikolai A. Makhutov [4], Mikhail M. Gadenin [5]***

*[1, 2, 3]JSC «Research and Design-Technological Institute of Rolling Stock» (JSC «VNIKTI»), Kolomna, Russia.*
*[4, 5]Institute of Mechanical Engineering named after A. A. Blagonravov of Russian Academy of Sciences (IMASh RAS), Moscow, Russia.*
✉ [2] *knyazev-da@vnikti.com.*

## ABSTRACT

*Switching the operation of railway equipment to life cycle contracts and confirming its safety compliance with industry technical regulations in the absence of a legislative framework for the recall of substandard products entails the need for a more thorough analysis of resource indicators of structural components of rolling stock and track superstructure. From this point of view, the state of the existing regulatory framework for confirming the strength and service life criteria of load-bearing elements of rolling stock and track, the influence of the regulatory «guillotine» and the general transition from the system of Soviet state standards GOSTs and strength rules to modern approaches of certification and differentiation of such concepts as «standard» and «supporting standard».*

*Trends in moving away from classical bench testing methods towards introduction of a resource-based approach with defectiveness assessment are shown using examples of previously carried out research on safe operation of ER200 bogie frame and on the transition to domestic cassette bearings as part of import substitution, currently carried out for different types of rolling stock.*

*Based on the new methods and approaches, it is possible to consider longer periods of operation, reasonably assess the extension of service life, or introduce resource-restoring technology, ensuring further safe operation. As part of these new trends, a transition is being made to modern modelling methods for assessing product safety, concepts such as «virtual sensor» and «virtual train-track system» are being introduced. It is shown that a reasonable combination of full-scale operational tests and virtual digital modelling makes it possible to offer reliable estimates of service life and safety indicators at the design and operation stages in a short time.*

*Keywords: railway transport, strength, load, resource, rolling stock, full-scale bench and operational tests, virtual digital models and tests, safety confirmation.*

*For citation: Kossov, V. S., Knyazev, D. A., Krasyukov, N. F., Makhmutov, N. A., Gadenin, M. M. Regulatory Framework for Ensuring Safe Operation of Railway Equipment Based on the Service Life of Load-Bearing Structures. World of Transport and Transportation, 2023, Vol. 21, Iss. 3 (106), pp. 254–262. DOI: https://doi.org/10.30932/1992-3252-2023-21-3-10.*

***The text of the article originally written in Russian is published in the first part of the issue.***
***Текст статьи на русском языке публикуется в первой части данного выпуска.***

## INTRODUCTION

The introduction of the life cycle contracts to be used as basis of operation of railway equipment in the Russian Federation and the necessity to confirm the compliance of the safety of equipment with industry technical regulations in the absence of a legislative framework for the recall of faulty products entails the need for a more thorough analysis of resource indicators of structural components of rolling stock and track superstructure.

The development of a methodology for a comprehensive computational and experimental substantiation of reliability is carried out within the framework of an agreement between JSC Russian Railways and the Russian Academy of Sciences.

Of great importance are applied problems regarding the rolling stock which were solved by researchers from JSC VNIKTI, JSC VNIIZhT together with the Institute of Mechanical Engineering named after A. A. Blagonravov of Russian Academy of Sciences (IMASh RAS).

Since there is no law on the recall of substandard, faulty products, already at the stages of concluding life cycle contracts there is a need for resource analysis and further inclusion of these assessments in contracts and resource management process regarding operation of rolling stock and railway transport facilities through life cycle contracts. All this relates to the law on technical regulation,[1] from which technical regulations that set specific safety objectives organically follow. The concept of «risk» appears, assessed through a resource. In the standardisation law,[2] unfortunately, strength standards disappear.[3]

In this regard, JSC Russian Railways initiated research, during which JSC VNIKTI summarises industry experience in applying the strength standard rule [norm] and creates the basis for emergence of a new document, an information and technical directory, which is provided for by the law on standardization (Pic. 1) [3].

The objective of the research is to summarise the results of development of a methodology of comprehensive computational and experimental substantiation of reliability and of a legal and regulatory base for safe operation of rail equipment as for service life of load-bearing structures

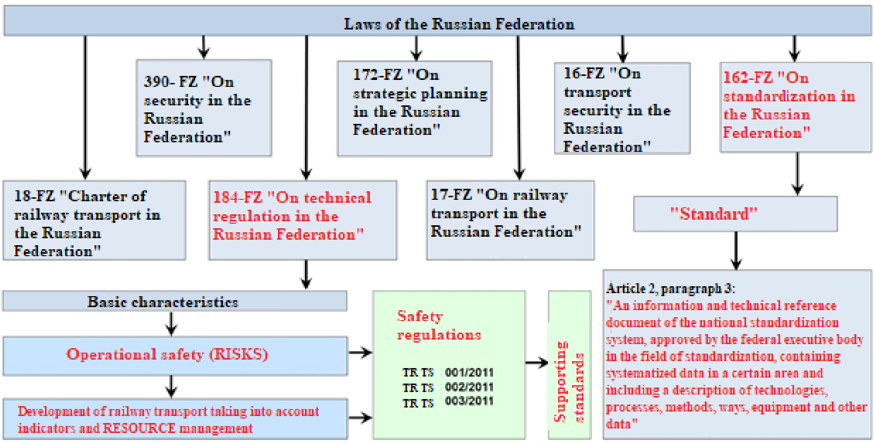
## RESULTS

Service life and safety must be confirmed based on calculations and tests using proven methods (Pic. 2). Also, it is necessary to be able to qualitatively, with an assessment of probability, calculate the service life at the design stage. This should be laid down during production regarding the technological base and tools and be supported at the operation stage by all methods of diagnostics and maintenance.

[1]. Federal Law «On technical regulation» № 184-FZ, dated December 27, 2002, 129 p. [Electronic resource]: https://www.consultant.ru/document/cons_doc_LAW_40241/?ysclid=lnbusufwwa679963992. Last accessed 24.05.2023.

[2] Federal Law закон «On standardization in the Russian Federation» № 162-FZ, dated June 29, 2015, 74 p. [Electronic resource]: https://www.consultant.ru/document/cons_doc_LAW_181810/?ysclid=lnbuuhjtmn504679735. Last accessed 24.05.2023.

[3] Standard rules [norms] for calculating and assessing the strength of load-bearing elements, dynamic qualities and the impact on the track of the undercarriage of locomotives on 1520 mm gauge railways of the Ministry of Railways of the Russian Federation. Moscow, Ministry of Railways, 1998, 145 p.




*Pic. 1. Structural diagram of the relationship between legislative and regulatory acts on transport safety and security [here and after pictures have been developed with participation of the authors].*

**Table 1**

**Analysis of the state of state standards [GOST] that support technical regulations for railway facilities subject to technical regulation (TRF), based on availability of reliability indicators and methods for assessing the service life of TRF**

| Technical regulations of the Customs Union | Supporting standards | | TRF (quantity) | | |
|---|---|---|---|---|---|
| | Technical requirements | Control methods | | | |
| TR TS 001/2011 | 173 | 167 | Rolling stock (17) | Components of rolling stock (44) | – |
| TR TS 002/2011 | 98 | 116 | Components of infrastructure (20) | Elements of components of infrastructure (54) | Components of high-speed rolling stock (67) |
| TR TS 003/2011 | 76 | 84 | Components of infrastructure (30) | Elements of components of infrastructure (64) | |
| Total | 347 | 367 | 67 | 162 | 67 |
| | 714 | | 296 | | |

In table 1, within the framework of existing approaches to certification and acceptance testing, the concepts of «standard» and «supporting standard» are highlighted. A supporting standard contains certification requirements. It is being implemented through the 710th decision of the Interstate Commission of the Customs Union.[4] In total there have been developed about 900 standards, while only 24 of them concern reliability, 18 – strength and service life, and almost none concern methods and methodology. The regulatory «guillotine» cut off the strength standard rules [norms] and many state standards [GOST] that existed in ex-Soviet Union. Hence, a necessity to come back to those issues, which is what the joint work of JSC «VNIKTI» with IMASh RAS is aimed at.

Basic standards for testing and regarding strength and service life of railway equipment:

1. GOST 16504–81. System of state testing of products. Testing and quality control of products. Basic terms and definitions.

2. GOST R 53076–2008. Rail transport. Requirements for the strength of railway rolling stock bodies.

3. GOST 31373–2008. Wheel sets of locomotives and multiple-unit rolling stock. Calculations and strength tests.

4. GOST 31846–2012. Special rolling stock. Requirements for the strength of load-bearing structures and dynamic properties.

5. GOST R 55495–2013. Motorised rolling stock. Requirements for strength and dynamic properties.

6. GOST R 55513–2013. Locomotives. Requirements for strength and dynamic properties.

7. GOST R 55514–2013 Locomotives. Methodology of dynamic strength tests.

8. GOST 33211–2014. Cargo wagons. Requirements for strength and dynamic properties.

9. GOST 33788–2016. Cargo and passenger wagons. Test method for strength and dynamic properties.

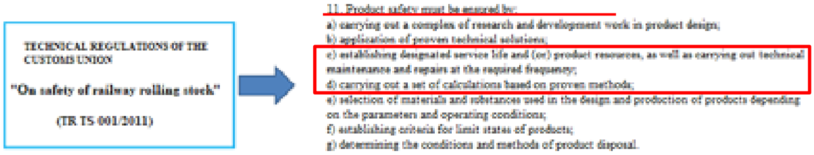
10. GOST 33272–2015. Safety of machines and equipment. Procedure for establishing and renewing assigned resources, service life and storage period. Basic provisions.

11. GOST R 57445–2017. Railway technical means. General requirements for residual life determination methods.

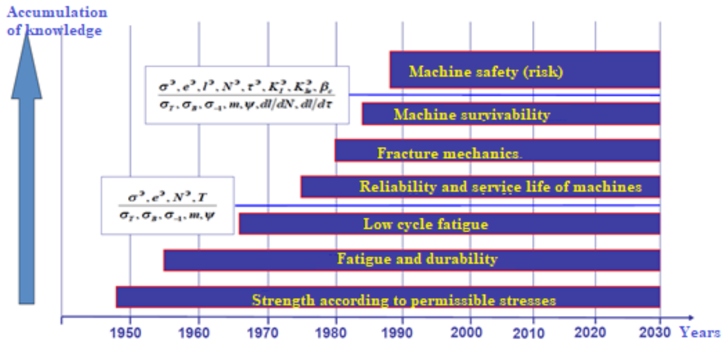
12. GOST R 15700.10–2018. Numerical modelling of physical processes. Determination of stress-strain state. Verification and validation of numerical models of complex structural elements in the elastic domain.

Any of these standards, if compared with previously existing strength standards[3], is much shorter. The strength standard rules are a document of about 200 pages instead of 30–50 pages of standards. They provide only the main criterion relationships, but the entire methodological base is missing. Previously, the structure of industry was homogeneous, managed by the USSR Council of Ministers, but now, due to the emergence of competition among companies, the issue of calculation rules and comparison of calculations is becoming increasingly relevant. It is necessary for both the manufacturing plant employee, the

[4] Decision of the Customs Union Commission «On the adoption of technical regulations of the Customs Union «On safety of railway rolling stock», «On safety of high-speed railway transport» and «On safety of railway transport infrastructure» No. 710, dated July 15, 2011, 82 p. [Electronic resource]: https://www.alta.ru/tamdoc/11sr0710/?ysclid=lncutwnj2j999365223. Last accessed 24.05.2023




*Pic. 2. Initial provisions of TR TS 001/2011*
*[Translation of official text in Russian is for exemplification only].*
*Note: Technical Regulations of the Customs Union 001/2011 «On safety in railway transport» (TR TS 001/2011). Adopted by EEC decision No. 710 of July 15, 2011, 59 p. [Electronic resource]: https://www.rst.gov.ru/portal/gost/home/standarts/technicalregulationses?portal: isSecure=true&navigationalstate=JBPNS_rO0ABXdSAAZhY3Rpb24AAAABABJjaGFuZ2VTa2luVmlzdWFsbHkABXRoZW1lAAAAAQAcbG93LWJsYWNrLXNob3ctcHRzYW5zLWxzWmVybwAHX19FT0ZfXw**&portal: componentId=abfaa8e6–70cc-47aa-8946–0fd2b2df47b3. Last accessed 24.05.2023.*




*Pic. 3. Current state and stages of development of scientific disciplines of strength, resource and safety.*

scientist, and the operation employee of JSC Russian Railways to consider the issues of the life cycle and its provision according to approximately the same rules.

Thus, tests have now been completed on five cassette-type axle-box bearings, including three of Chinese manufacturers and two of domestic manufacturers. Positive test results have been obtained based on reproduction of 400 thousand km of mileage. Testing of cassette bearings on electric locomotives 2ES6 produced by Ural Locomotives LLC is currently underway, as well as tests of cassette-type bearings on cargo cars wagons which are almost completely equipped with domestic units and parts (inner and outer rings, fasteners, lubrication). In 2023, tests of cassette bearings for cargo cars with a load of 25 tf fully manufactured in Russia will be carried out, tests of bearings for high-speed domestic rolling stock will be tested through reproducing 600 thousand km of mileage, and bearings of the high-speed electric locomotive EP20 will be tested as well.

Based on the identified trends, methods will be developed that will allow analysing the resource at all stages of the life cycle.[5]

Pic. 3 presents the history [1] of development of the science on the strength of machine structures, starting from the strength of materials, the development of its models, the theory of elasticity, to issues of survivability, safety, risks and assessment of these parameters.

Table 2 presents an assessment of strength and service life based on permissible stresses and safety factors. At the stages of design, preliminary design development, decisions on dimensions, and engineering vision of the project, such an assessment is necessary [2].

The resource should then be assessed. To do this, it is necessary to construct a fatigue curve with determination of the endurance limit and assessment of damageability [2] (Pic. 4). Calculation of the resource assumes accumulation of damage as the part is used and the destructive number of cycles is reached. Next, it is possible to proceed to estimating the resource in years of operation. But this is only at the stage of development of the resource approach.

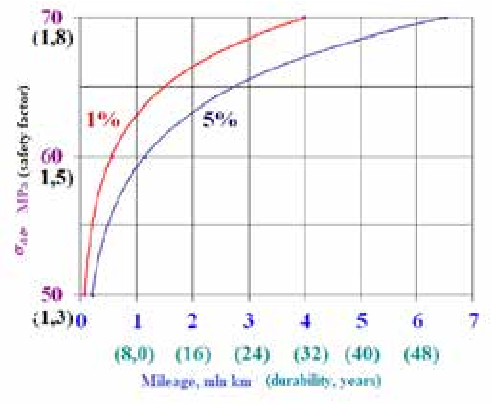
The development of the approach is that defects also need to be assessed. There is no large wagon casting without defects. Pic. 5 shows an example of a fracture mechanics model with development of a crack-like defect, and corresponding estimates are given. Here elements of defect modelling, load studies, considering developments in the field of mechanics of a deformed body, fracture mechanics with an assessment of the number of cycles, mileage and conversion to years of operation are given (Table 3).

[5] GOST 57445-2017. Railway technical means. General requirements for resource determination methods. Moscow, Standartinform publ., 2017, 26 p. [Electronic resource]: https://files.stroyinf.ru/Data2/1/4293746/4293746291.pdf?ysclid=lncv2au9ff644715443. Last accessed 24.05.2023.

Table 2

**Strength conditions according to current standards**

| Rolling stock type | Static strength assessment as for permissible stresses | | Fatigue resistance rating as for permissible safety factor n |
|---|---|---|---|
| | I mode | III mode | |
| Locomotives | $\sigma_T \leq [\sigma] = 0,90 \cdot \sigma$ | $\sigma_T \leq [\sigma] = 0,55 \cdot \sigma$ | $n = \frac{\sigma_{-1}}{K_\sigma \cdot \sigma_a + \psi \cdot \sigma_m} \geq 2$ |
| Wagons | | $\sigma_T \leq [\sigma] = 0,60 \cdot \sigma$ | $n = \frac{\sigma_{-1}}{K_\sigma \cdot \sigma_{ae}} \geq 1,4...1,8$ |




*Pic. 4. Assessment of the resource of the side frame of a cargo car at the design stage: 1 %, 5 % – damageability.*

Pic. 6 shows the complex of works carried out on the frame of the ER200 bogie during the period when the issue of ensuring safe operation of the electric train was acute for 2–3 years before the introduction of Sapsan trains into operation. This work was successfully carried out by JSC VNIKTI together with JSC VNIIZhT and IMASh RAS. A histogram of operational load was generated, a calculation was carried out, the most loaded zones were identified, concentrators were installed, and the levels of residual stresses were determined. For the stated conditions, an estimate was made of the number of trips of the ER200 electric train depending on the magnitude of the residual stresses (Table 4). Subsequently, these bogie frames were constantly inspected, monitored, and promptly restored (repaired) or removed.

Switching to the resource approach, researchers have already started to move away from the classical approaches of material strength and fatigue curves with a horizontal right branch due to the fact that even with testing period comparable to forty years of operation and above, approaches based on unlimited endurance of the part do not work (Pic. 7). Then the right branch of the fatigue graph has a slope and enters the gigacycle fatigue zone. As an example of assessment, trips of Sapsan train on Moscow-St. Petersburg route were studied. For this train, the service life according to specifications is set at 15 million km of mileage or 30 years of operation. The full loading cycle for the specified service life is the number of wheel revolutions ($5x10^9$). Such a volume of operating time, even in bench conditions, means years of testing with the existing technical capabilities. Over 65 years, JSC VNIKTI tested only about five samples of axles based on $10^8$, which made it possible to estimate the angle of inclination of the right branch of the fatigue curve [3]. And now, based on these developments, we can state about long periods of operation and reasonably assess the extension of service life or assign resource-restoring technology and ensure further safe operation.

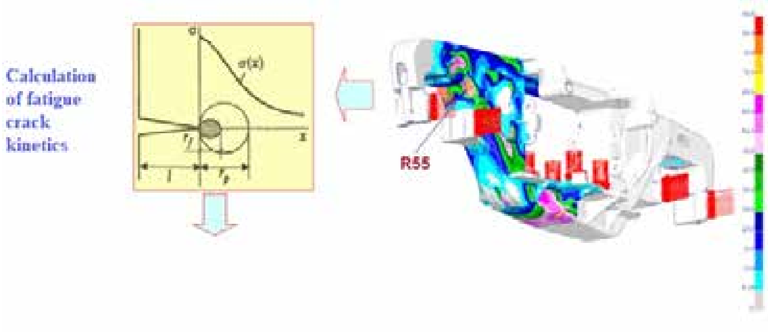
JSC VNIKTI together with IMASh RAS has developed a problem-oriented state standard[5], which offers guidelines and shows the main directions of work and determines the requirements for calculating the resource. It states that, first of all, the issue of determining the load-bearing and power systems is important (Pic. 8). The resource is determined by all the features of operation, that is, it is necessary to solve a technical and economic problem: some objects must provide an absolute resource and can be safely operated, while others must be promptly removed, repaired, or disposed of. But in any case, the facility must operate reliably between scheduled repairs.

All complex computation programs have the concept of «virtual sensor». By placing it in any zone of interest, and this is, first, the zone of stress concentrations, the most loaded zone, at the virtual modelling stage we obtain a virtual load. This load can be converted into stress blocks, and by comparing them with the fatigue curves of materials or objects, parts, the service life can be assessed with the required accuracy. Sufficient accuracy with the required probability of non-destruction is ensured by comparing numerical virtual experiments with accumulated

**Table 3**

**Dependence of resource on various defects in cast elements**

| List of factors under study | Resource | | |
|---|---|---|---|
| | Number of cycles | Mileage | Years (mileage is assumed as 120 thous. km/year) |
| Reduced ductility of cast steel 20GL:<br>– relative elongation 7…16 % instead of 18 %;<br>– relative narrowing 8…19 % instead of 25 % | $2{,}70x10^9$ | 3118 | 26 |
| No heat treatment when welding casting defects within a radius of R55 | $279x10^6$ | 322 | 2,7 |
| Presence of internal casting defects (gas pore, crack) in the R55 zone | $13{,}8x10^6$ | 153 | 1,3 |

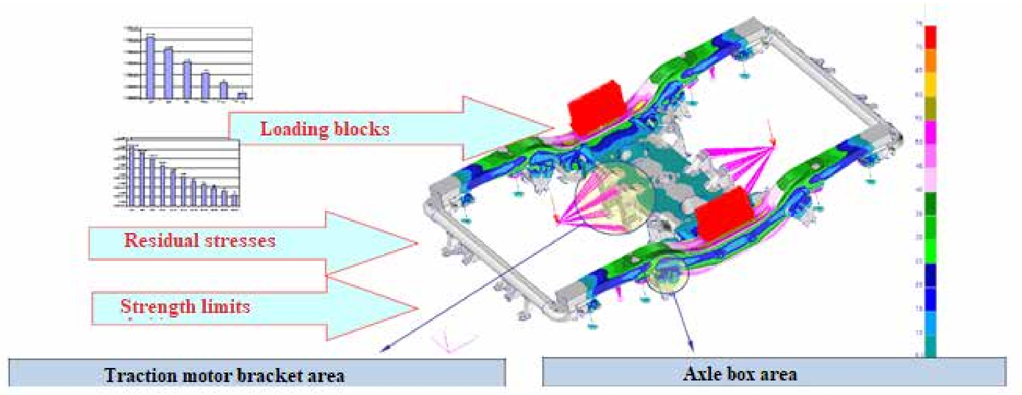



*Pic. 5. Life study of the cast side frame of a cargo wagon bogie.*

**Table 4**

**Values of maximum residual stresses**

| Traction motor bracket area | | | Axle box area | | |
|---|---|---|---|---|---|
| Residual stresses, MPa | Resource | | Residual stresses, MPa | Resource | |
| | Number of trips | Years | | Number of trips | Years |
| 240 | 320 | 3,1 | 240 | 308 | 3,0 |
| 200 | 460 | 4,4 | 200 | 420 | 4,0 |
| 150 | 852 | 8,0 | 150 | 544 | 5,0 |

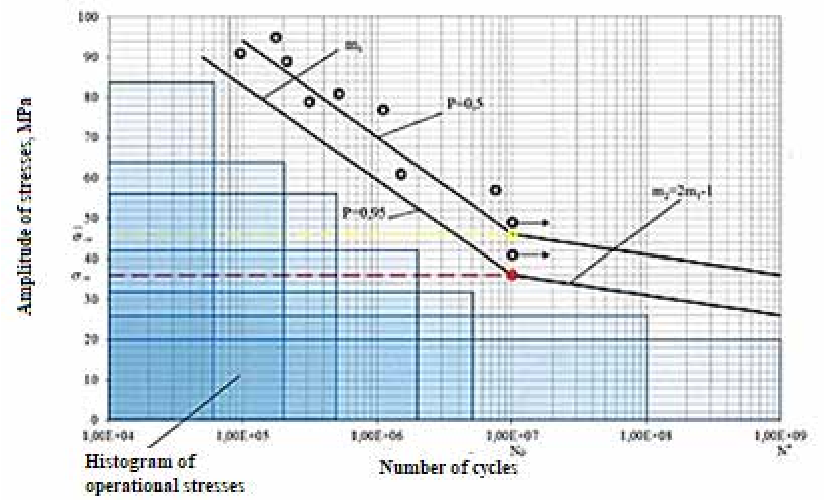



*Pic. 6. Estimation of the residual life of ER200 bogie frames as for St. Petersburg–Moscow section.*

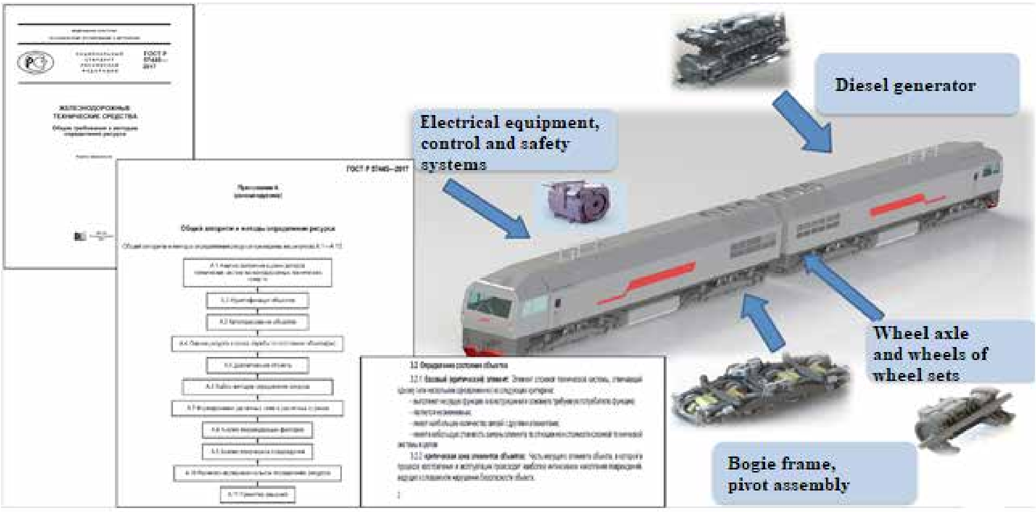
experimental data based on the results of bench and train tests.

When modelling, along with the solid components of the rolling stock, finite element elastic models of the structures under study (bodies, frames, parts, traction drive, etc.) are created that sufficiently fully reflect the power flow of the supporting system or the transmission of traction force.

Pic. 9 shows a general view of the load blocks formed for computations and their development [4], obtained in model and full-scale experiments. The «train – track» interaction, combined with the impact of unevenness, deviations, track alignments, and wheel damage actually measured at the operating site, for example, the Eastern segment of the railway network, makes it possible to obtain the real load and achieve the

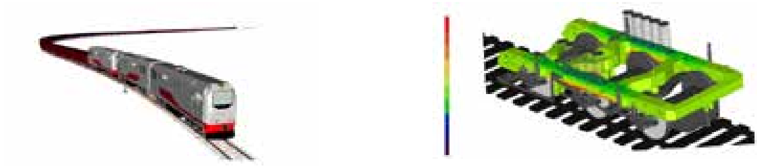



*Pic. 7. An example of calculating the service life of a bogie frame sidewall: m1 and m2 – indicators of the slope angle of the fatigue curve; P – probability of destruction; N0, N* – test bases; σ – endurance limits of the part.*

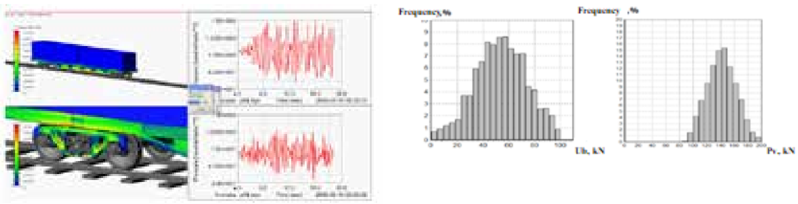



*Pic. 8. Basic elements that determine the service life and operational safety of a locomotive.*

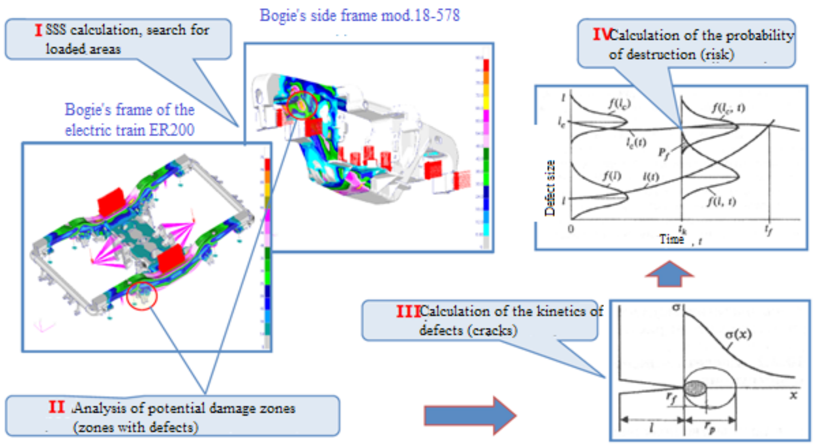
a) b)



c) d)



*Pic. 9. A schematic example of implementation of the approach using digital models to determine the operational load: a – solid-state model of a moving train; b – elastic FE model of a locomotive bogie; c – elastic FE model of a cargo car; d – distribution of lateral (Yb) and vertical (Pv) forces from the wheels to the rails.*




*Pic. 10. Generalised scheme of risk analysis of load-bearing elements of rolling stock.*

*а)*  *б)* 

*Pic. 11. Equipment for testing axles and wheels for fatigue by cyclically changing circular bending: a) general view of the full-scale stand; b) a virtual analogue of a «wheel-axle» test bench.*

**Table 5**

**Comparison of regulatory documents regarding testing base**

| Standard requirements in Europe | | Standard requirements in Russia | |
|---|---|---|---|
| Test base | Regulatory documents | Test base | Regulatory documents |
| Confirmation of the endurance limit of axles on the base $10^7$ | DIN EN 13260 | Confirmation of the endurance limit of axles on the base $10^7$ | GOST 33783<br>GOST 11018<br>GOST 4835 |
| Confirmation of the endurance limit of wheels on the base $10^7$ | DIN EN 13262 | Confirmation of the endurance limit of wheels on the base $10^7$ | |

required probability of estimating resource indicators.

In Pic. 10, two objects are considered: the sidewall of the cargo wagon bogie and the bogie frame of the ER200 electric train. This approach is now being actively implemented at JSC VNIKTI using the above models and integrating them into digital technology.

In 2023 and further on, it would be advisable for JSC VNIKTI to focus on identifying the deep relationship between the finite element (FE), truly mechanistic approach and statistical models, including neural networks. Mechanical models themselves are a source of big data, but they need to be compared and adjusted in accordance with operational data [5].

Pic. 11 shows an example of testing axles and wheels and how it is possible to develop virtual stands and tests [6, pp. 61–65].

Table 5 shows estimates of the number of cycles before failure and a comparison of the results obtained with the regulatory framework.

## CONCLUSIONS

Based on the foregoing, we can conclude that virtual testing of railway equipment through numerical modelling (development and research of adequate digital models) is important for traffic safety, allowing to achieve the goals [7, pp 69–72; 8, pp. 27–29] of:

– Assessment of running and dynamic qualities, strength, service life and safety of rolling stock (RS),

– Study of the characteristics and performance of the track.

– Study of the interaction of RS, tracks, their load.

Besides, virtual tests help solve the following problems:

– Study of the stress-strain state of structures of large-sized and heavily loaded objects.

– Study of stress concentration (including using virtual sensors) in structural elements, welded and cast parts.

– Modelling and simulation of extreme and emergency conditions and types of object loading.

– Modelling of joint and individual components and types of impacts for complexly loaded objects (mechanical, thermal, etc.).

Methods of using software:

– Selection and justification of models depending on formulation of the problem (statics, kinematics, dynamics) and the solution area.

– Creation of finite element 3D models of the objects under study.

– Fine-tuning of FE models taking into account the design features of the object (rods, plates, shells, etc.).

– Selection and justification of the FE mesh.

– Confirmation of the model's compliance with the task and study of the limits of applicability of the solution.

– Verification and validation of the model and results.

## REFERENCES

1 Oganyan, E. S., Volokhov, G. M. Calculations and strength tests of locomotive load-bearing structures [Raschety i ispytaniya na prochnost nesushchikh konstruktsii lokomotivov]. Moscow, TMC for railway education, 2013, 326 p. ISBN: 978–5–89035–618–5.

2. Makhutov, N. A., Gapanovich, V. A., Kossov, V. S., Oganyan, E. S., Krasyukov, N. F., Volokhov, G. M. Methods for determining the service life and cyclic strength of locomotive underframe structures. Transport: nauka, tekhnika, upravlenie, 2016, Iss. 10, pp. 3–12. [Electronic resource]: https://www.elibrary.ru/item.asp?id=27180774&ysclid=lnbggnup2j283492649. Last accessed 17.04.2023.

3. Volokhov, G. M., Oguenko, V. V., Timakov, M. V. Linear approximation of the fatigue curve of full-scale axles of rolling stock wheel sets in the gigacycle range [Lineinaya approksimatsiya krivoi ustalosti naturnykh osei kolesnykh par podvizhnogo sostava v gigatsiklovom diapazone]. Rolling stock of XXI century: ideas, requirements, projects. Abstracts of VIII International scientific-technical conference (St. Petersburg, July 3–7, 2013). St. Petersburg, PGUPS publ., 2013, pp. 38–41. [Electronic resource]: https://drive.google.com/file/d/13Q9KxaPJpqgYS90tkcIunpyeSGEh4uQ1/view [full text of materials of the conference]. Last accessed 17.04.2023.

4. Volokhov, G. M., Knyazev, D. A., Timakov, M. V. Using a generated block of wheel pair loads of high-speed rolling stock when calculating axle survivability [Ispolzovanie generirovannogo bloka nagruzok kolesnoi pary vysokoskorostnogo podvizhnogo sostava pri raschete zhivuchesti osi]. Rolling stock of XXI century: ideas, requirements, projects. Materials of XII International scientific-practical conference (St. Petersburg, July 5–9, 2017). St. Petersburg, PGUPS publ., 2017, 190 p. pp. 128–130. ISBN 978-5-7641-0908-4. [Electronic resource]: https://drive.google.com/file/d/1xL6JI2sKUTOLcL0G04YKxY6kLR3bHD4E/view [full text of materials of the conference]. Last accessed 17.04.2023.

5. Oganyan, E. S., Volokhov, G. M., Gasyuk, A. S., Fazliakhmetov, D. M., Muravlev, E. V. Safe operation of locomotives based on the service life of their basic parts. Bezopasnost truda v promyshlennosti, 2017, Iss. 6, pp. 54–57. DOI: 10.24000/0409-2961-2017-6-54-58.

6. Volokhov, G. M., Knyazev, D. A., Timakov, M. V. Simulation of crack growth on the hollow axle of a motor wheel set of high-speed rolling stock [Modelirovanie rosta treshchiny na polnoi osi motornoi kolesnoi pary vysokoskorostnogo podvizhnogo sostava]. Locomotives. Transport and technological complexes. XXI Century. Collection of materials of V International scientific-technical conference dedicated to the 180th anniversary of Russian railways (St. Petersburg, November 14–16, 2017). St. Petersburg, PGUPS publ., 2017, 455 p., pp. 61–65. ISBN: 978-5-7641-1098-1.

7. Oganyan, E. S., Volokhov, G. M., Gadzhimetov, G. I. On the issue of the procedure for updating the fleet and extending the service life of operating locomotives in the light of the requirements of TR TS 001/2011 [K voprosu o poryadke obnovleniya parka i prodleniya srokov sluzhny ekspluatituyushchikhsya lokomotivov v svete trebovanii TR TS 001/2011]. Locomotives. Transport and technological complexes. XXI Century. Proceedings of V International scientific and technical conference dedicated to the 180th anniversary of Russian railways (St. Petersburg, November 14–16, 2017). St. Petersburg, PGUPS publ., 2017, 455 p., pp. 69–72. ISBN: 978-5-7641-1098-1.

8. Volokhov, G. M., Ovechnikov, M. N., Knyazev, D. A., Timakov, M. V. Simulation of crack growth in railway rolling stock axles [Modelirovanie rosta treshchiny v osyakh zheleznodorozhnogo podvizhnogo sostava]. Computer modelling in railway transport: dynamics, strength, wear. IV scientific and technical seminar (Bryansk, April 3–4, 2018). Bryansk, BSTU publl., 2018, 78 p., pp. 27–29. ISBN: 978-5-906967-87- 9.

*Information about the authors:*

***Kossov, Valery S.,*** *D.Sc. (Eng), Professor, General Director of JSC «Research and Design-Technological Institute of Rolling Stock» (JSC «VNIKTI»), Kolomna, Russia, vskossov@icloud.com.*

***Knyazev, Dmitry A.,*** *Ph.D. (Eng), Deputy Head of the Department of JSC «Research and Design-Technological Institute of Rolling Stock» (JSC «VNIKTI»), Kolomna, Russia, knyazev-da@vnikti.com.*

***Krasyukov, Nikolai F.,*** *Ph.D. (Eng), Leading Researcher of JSC «Research and Design-Technological Institute of Rolling Stock» (JSC «VNIKTI»), Kolomna, Russia, timakov-mv@vnikti.com.*

***Makhutov, Nikolai A.,*** *D.Sc. (Eng), Professor, Corresponding member of RAS, Senior Researcher at the Institute of Mechanical Engineering named after A. A. Blagonravov of Russian Academy of Sciences (IMASh RAS), Moscow, Russia, kei51@mail.ru.*

***Gadenin, Mikhail M.,*** *D.Sc. (Eng), Senior Researcher at the Institute of Mechanical Engineering named after A. A. Blagonravov of Russian Academy of Sciences (IMASh RAS), Moscow, Russia, safety@imash.ru.*

*Article received 06.03.2023, approved25.05.2023, accepted 19,06,2023.*