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IDENTIFYING THE INFLUENCE OF MICRO PROFILE OF RURAL ROADS ON THE DURABILITY OF BUS BODY WHEN CARRYING PASSENGERS

Dmytro Ruban
Corresponding author
Doctor of Technical Sciences, Associate Professor*
E-mail: ruban_dimon@ukr.net
Lybomyr Krainyk
Doctor of Technical Sciences, Professor*
Hanna Ruban**
Stepan Khimka
PhD*
Oleg Sukach
PhD, Associate Professor*
Vladyslav Khotunov
PhD, Associate Professor
Department of Computer Engineering and Information Technologies**
Viktor Shevchuk
PhD, Associate Professor
Department of Vehicle Operation and Fire-Rescue Equipment
Lviv State University of Life Safety
Kleparivska str., 35, Lviv, Ukraine, 79000
Ihor Dufanets
Department of Automobiles and Tractors
Stepan Gzhytskyi National University
of Veterinary Medicine and Biotechnologies of Lviv
Pekarska str., 50, Lviv, Ukraine, 79010
Olexandr Artyukh
PhD, Associate Professor
Department of Automobiles, Heat Engines and Hybrid Power Plants
National University "Zaporizhzhia Polytechnic"
Zhukovskoho str., 64, Zaporizhzhia, Ukraine, 69063
*Department of Automobiles and Tractors
Lviv National University of Nature Management
V. Velykoho str., 1, Dublyany, Ukraine, 80381
**Cherkasy State Business College
V. Chornovola str., 243, Cherkasy, Ukraine, 18028

The object of this study is the durability of a bus body when passengers are transported on rural roads.

According to the European classification, the total length of roads in Ukraine that correspond to the first category does not exceed 5 %. That is, all other 95 % of roads have a quality level that does not meet the regulatory operating conditions. In particular, in rural areas, buses are operated both on worn asphalt-concrete surfaces and on dirt and gravel roads. Such operating conditions additionally lead to intensive wear of buses and significantly worsen the durability of their bodies. The task to determine the influence of worn and dirt roads on the durability of the bus body during passenger transportation in rural areas could be solved by the durability assessment procedure proposed in this paper.

The current work presents patterns that make it possible to predict the degradation of the bus body material that affect the durability of the body. The factors of influence during the operation of buses on rural routes have been substantiated and presented. The simulation results show that when operating buses on rural roads, cracks in the body frame of the body occur at runs that are 3.8–13.1 times less than under regulatory operating conditions.

The proposed procedure for assessing the durability of a bus body when transporting passengers on rural roads makes it possible to predict the deterioration of the physical and mechanical properties of the elements of the bus body frame and take measures at the design stage to increase their reliability and durability

Keywords: bus body durability, simulation modeling, passenger, rural roads, road micro profile

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1. Introduction

The safety of public transport passengers directly depends on the durability of the bus body throughout its entire service life. The formation of the body resource and its verification for compliance with passive safety requirements is one of the most important tasks of bus manufacturers. Therefore, at the design and production stage, buses are certified according to Rules [1] using a full-scale experiment, in which the bus is tipped over on its side and the deformations of the body

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pillars are determined. The results of such an experiment determined the permissible deformations of the body walls, which limit the living space of the passenger compartment of the bus. However, such a method requires significant costs, and in the case of non-compliance with the requirements of the UNECE Rules No. 66, it becomes necessary to adopt new technical solutions and manufacture a new bus sample for the subsequent experiment using the destructive method of conformity assessment. This approach also requires a lot of work and time to achieve the desired result.

Thus, there is a need to devise a procedure for assessing the durability of a bus body during operation on worn and dirt roads, which is typical for rural areas. It is important when devising this procedure to take into account the following road micro profiles: asphalt concrete pavement, low-quality paving (with depressions and bumps, which corresponds to critically worn asphalt concrete pavement), dirt road. Moreover, the percentage of the length of each type of road micro profile has a significant impact on the accumulation of fatigue fracture sites in the bus body. Also, during operation of a bus on rural roads, the evolution of corrosion, passenger loading, and driving modes will be case-specific.

The results of studies could allow operating organizations to predict the durability of the bus body during its operation in rural areas and predict the mileage before the body needs to be repaired or the bus itself is decommissioned. For manufacturers, such studies would allow them to adjust the structure of the bus at the design stage in order to ensure the desired durability of the bus body when operating on rural roads.

2. Literature review and problem statement

The authors of work [2], in accordance with UNECE Regulations No. 66, proposed a method using simulation modeling that allows for bus certification without destroying the body. This method allows for proper testing of the bus body for passenger transportation at the design stage. It should be noted that within the limits of the durability of the bus, it is important to maintain the structurally established passive safety of passenger transportation throughout the entire service life. Therefore, the authors of work [3] proposed to check bus bodies for compliance with the requirements of UNECE Regulations No. 66 during operation. Such studies [3] showed that during bus operation, the physical and mechanical properties of the body frame elements deteriorate [4]. Therefore, after 5–8 years of operation, such a bus will no longer comply with UNECE Regulations No. 66 and will need to be scrapped. Moreover, such studies were conducted on road surfaces under urban conditions. Let us assume that during the operation of buses on rural roads, the situation may be even worse. However, studies on the durability of bodies and passive safety have not yet been conducted. In addition, to perform simulation modeling, which makes it possible to determine the degradation of the bus body according to the methodology reported in [5], a study of micro profiles of roads with different surfaces [6], including low-quality roads and dirt roads, was previously conducted. In [2], a methodology for calculating bus bodies is described, taking into account their passive safety at the design stage using simulation modeling according to UNECE regulations No. 66 [1]. It is shown that using modern automated design tools, it has become possible to check the compliance of the passive safety of new bus bodies at the design stage using non-destructive methods, in contrast to UNECE regulations No. 66, which require the destruction of the bus body. However, issues related to the assessment of the durability of the bus body during operation remain unresolved. A likely reason is the incorporation of the characteristics of the new material into the simulation model. An option for solving the problem of taking into account the deterioration of the properties of the body material is to introduce into the simulation model the mechanical characteristics of the body frame pipes that have degraded during operation. This is the approach used in [2]; but the features of bus operation on rural roads are not taken into account there. All this allows us to argue that it is advisable to conduct a study aimed at taking into account the features of bus operation on rural roads. This will show how such operation would affect the degradation of the bus body material and, accordingly, its durability.

In [7], the results of calculating compliance with the requirements of passive safety of buses at the certification stage are reported. However, the degradation of the metal of the bus body during operation was not taken into account, which has a significant impact on the durability of the body.

In [8], the methodology and results of tests for the durability of polyurethane adhesive joints are described. This methodology could also be used with further improvement to study the durability of bus bodies with a body frame cladding made of composite materials.

In [9], the results of experimental studies of the durability of bus bodies on real urban routes are reported. It is shown that driving on urban roads with cobblestones leads to the accumulation of fatigue fracture sites in the bus body. Such studies confirm that during the operation of buses, the material degrades, which would inevitably lead to a limitation of durability and deterioration of passenger transportation safety. But the issues related to the movement of buses on rural roads and the impact of such roads on the durability of the body when transporting passengers remained unresolved. In addition, the results of road tests that are reported in [9] require significant material costs. Thus, there is a need to conduct research using computer modeling to simulate the movement of a bus on a road surface corresponding to rural roads.

The results of studies of individual elements of the frame of bus and trolleybus bodies on fatigue in laboratory conditions are reported in [10]. However, it is unclear what conditions of bus movement correspond to the assumed values of frequencies and amplitudes of loads in laboratory studies. Simulation modeling would make it possible to obtain initial data for laboratory tests and take into account different modes of bus movement, including on rural roads.

In [11] it is proven that accelerated durability tests of buses could allow design engineers to take into account the peculiarities of bus traffic on roads of different quality at the design stage. However, accelerated field tests also require significant costs, unlike simulation modeling. Such studies confirm the importance of determining the durability of bus bodies during passenger transportation on roads of different quality, including rural roads, but when using simulation modeling.

In [12], a study of the failure tolerance of vehicle frames was conducted. Such studies additionally confirm the importance of predicting the durability of bus bodies, but, unlike [12], the use of simulation modeling would reduce the time and cost of the studies.

Our review of the literature demonstrates that the foregoing studies did not take into account the peculiarities of operation on rural roads and did not take into account the share of bus traffic on roads of different quality, including unpaved ones.

However, passenger transportation in rural areas is of great importance in the transport infrastructure of each country and also requires a forecast of the durability of the bus body. Therefore, it is advisable to conduct a study into the durability of buses when transporting passengers on rural roads.

3. The aim and objectives of the study

The purpose of our study is to assess the durability of bus bodies during passenger transportation, taking into account the degradation of body frame elements when driving on rural roads. This will make it possible to take into account the operation of buses on rural roads and predict the possible negative consequences of the impact of low-quality roads on durability, taking into account the degradation of the bus body material.

To achieve the goal, the following tasks were set:

– to devise a procedure for assessing the durability of a bus body during passenger transportation on rural roads;

– to conduct simulation modeling of bus movement on rural roads, which makes it possible to determine increased stresses in the non-load-bearing elements of the body due to a decrease in the wall thickness of the frame pipes and material degradation and to assess the durability of the bus body under given operating parameters.

4. The study materials and methods

The object of our study is the durability of the bus body during passenger transportation on rural roads.

The main hypothesis of the study assumes that the assessment of the durability of the bus body during its operation on rural roads could make it possible to obtain data for the possibility of forming the resource of the bus body at the design stage in accordance with the condition of the road surface. Such operation is associated with the possibility of bus movement in villages on unpaved roads. Therefore, first of all, it is necessary to take into account the micro profiles of roads that are characteristic of rural areas, namely: asphalt concrete pavement (minimum length), low-quality asphalt roads (they can be equated to low-quality paving stones), and unpaved roads. Spectral densities and corresponding coefficients for calculation in MATLAB Simulink (USA) [13] were given in [3, 14].

Table 1 gives coefficients of the autocorrelation functions of the micro profile of roads, which make it possible to calculate the real values of the micro profile of roads during bus movement.

Table 1

Approximation coefficients of autocorrelation functions for road micro profiles [3, 14]

Road micro profile	Approximation coefficients					
	σ_x	A_1	A_2	α_1	α_2	β_2
Asphalt concrete surface	1.03	0.85	0.15	–0.2	–0.05	0.6
Evenly paved paving	2.32	1.0	0	0.45	–	–
Low quality paving	2.32	0.85	0.15	–0.5	–0.2	1.0
Unpaved road	2.12	–	1.0	–	0.58	0.63

To transfer shocks from irregularities created by the micro profile of the road surface, the known spectral density dependences [3] were used. The dependences [15] were converted into specific micro profile values using the following formula:

$$x(t)=\zeta(t)\times \times\left[\begin{array}{l}\dfrac{A_1\cdot\sqrt{2\cdot\sigma_x^2\cdot\alpha_1/h}}{s+\alpha_1}+ \\ +\dfrac{A_2\cdot\sqrt{2\cdot\sigma_x^2\cdot\alpha_2/h}\cdot s+A_2\cdot\sqrt{2\cdot\sigma_x^2\cdot\alpha_2/h}\cdot\sqrt{\alpha_2^2+\beta_2^2}}{s^2+2\cdot\alpha_2\cdot s+\alpha_2^2+\beta_2^2}\end{array}\right], \quad (1)$$

where $\zeta(t)$ is discrete white noise; h is the integration step; s is the differentiation operator.

The assumptions accepted in the study show that corrosion damage to the body would occur during operation. At the same time, body corrosion during operation in rural areas would differ from corrosion on urban routes. Such differences are that in rural areas, unlike cities, a minimum amount of road de-icing agents are used. Experience was also previously accumulated in operating buses in small (up to 1 million inhabitants) and large (over 1 million inhabitants) cities. Accordingly, the characteristics of the reduction in the thickness of the frame pipes under the influence of corrosion were obtained depending on the mileage and population of the city in which the bus is operated [3, 15]. The simplifications adopted in the study are that the corrosion intensity in rural areas is taken equal to the corrosion intensity that occurs during the movement of buses on the roads of small cities [15]. Thus, when modeling the accumulation of fatigue damage centers, the operation of buses on roads that are typical for rural areas is taken into account.

To perform calculations in MATLAB Simulink, formulas were derived based on the Lagrange equation of the second kind and on the basis of the calculation scheme (Fig. 1) [3]; a simulation model was also built in the MATLAB Simulink software environment [3, 13].

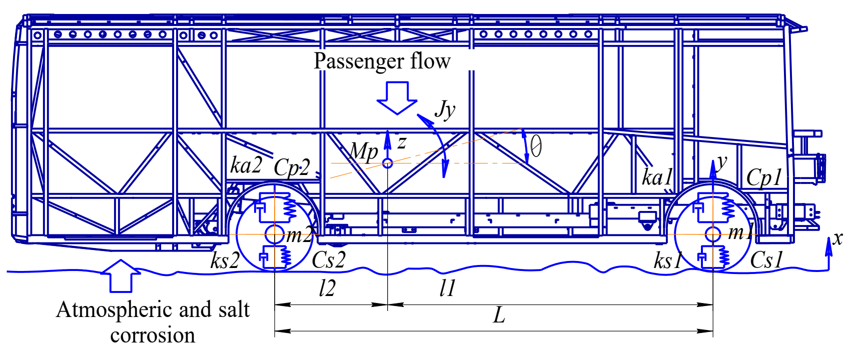


Fig. 1. Calculation scheme [3]

The calculation scheme shown in Fig. 1 describes the vertical and longitudinal-angular oscillations of the bus sprung masses M_P and the unsprung masses m_1 and m_2 relative to static equilibrium according to the calculation scheme (Fig. 1). The scheme shows l_1 and l_2 – the distance from the vertical axis of the center of mass of the bus to the vertical axis of the front and rear wheels, respectively; $L=l_1+l_2$; J_y – moment of inertia of the sprung mass of the bus, which performs longitudinal-angular oscillations; Θ is the angle by which the bus deviates from the horizontal axis during longitudinal-angular oscillations.

The numerical characteristics of the parameters of the Ataman A092N6 bus and the characteristics of the material endurance (Steel 20) [3, 4] were entered into the MATLAB Simulink workspace. This mathematical model is described in [3, 5, 15, 16] in which its adequacy was checked. Thus, the following initial data were selected for simulation modeling:

1. Characteristics of the bus "Ataman" A092N6.
2. Passenger load – 83 passengers.
3. Average speed – 40 km/h.
4. Characteristics of the endurance curve for the material Steel 20 (Table 2).

Table 2

Steel 20 material endurance characteristics [17]

Material	f, Hz	R_σ	σ_m, τ_m, MPa	N, cycle	σ_R, τ_R, MPa	N_G, cycle	m_N
Steel 20	50	–1	0	10^7	210	$3{\cdot}10^6$	12.2

In Table 2: f – frequency of cycles during testing; R_σ – stress cycle asymmetry coefficient; σ_m, τ_m – average stress of the cycle; N – basic number of cycles; σ_R, τ_R – endurance limit; N_G – abscissa of the fatigue curve break point; m_N – fatigue curve slope index.

5. Results of assessing the durability of a bus body when transporting passengers on rural roads

5. 1. Procedure for assessing the durability of a bus body when transporting passengers on rural roads

The proposed procedure for assessing the durability of a bus body on unpaved roads is represented in the form of a structural diagram in Fig. 2.

According to the above structural diagram (Fig. 1), the approximation coefficients of the autocorrelation functions of the micro profile of the unpaved road are additionally introduced into the working area of the implemented mathematical model in MATLAB Simulink. Then, using modeling in MATLAB Simulink, specific values of the micro profile of the road are determined. In the latest versions of MATLAB Simulink (for example: R2024a), it became possible to obtain numerical values of the micro profiles of roads with different coatings from the built-in MATLAB library. However, MATLAB Simulink still does not have the characteristics of the micro profile of an unpaved road. Then, accelerations are calculated in the studied section. In this case, the distributed masses of the bus, elastic and damping characteristics of the suspensions are taken into account. Such a calculation is carried out on the basis of the theory of suspension. It became possible to implement this model in the process of solving a system of equations based on the Lagrange equation [3, 15, 16]. Having found the reduced mass of the bus body in the studied section, the force is determined based on Newton's second law. The thickness of the body frame walls in the studied section is determined taking into account the characteristics of the decrease in the thickness of the pipes under the influence of corrosion (Fig. 3). Corrosion processes are taken into account based on the experience of operation in small cities (Fig. 3).

Based on the plot in Fig. 3, the coefficients were calculated and the mathematical dependence of the reduction in the thickness of the walls of the bus body base when driving on rural roads was obtained: $\Delta_P=-2.856{\cdot}10^{-6}L+3.57$. The resulting dependence will also correspond to driving on roads in small towns [3, 15] since in small towns the sprinkling of roads with sand-salt mixtures is much less (compared to cities with a million inhabitants) or is absent altogether.

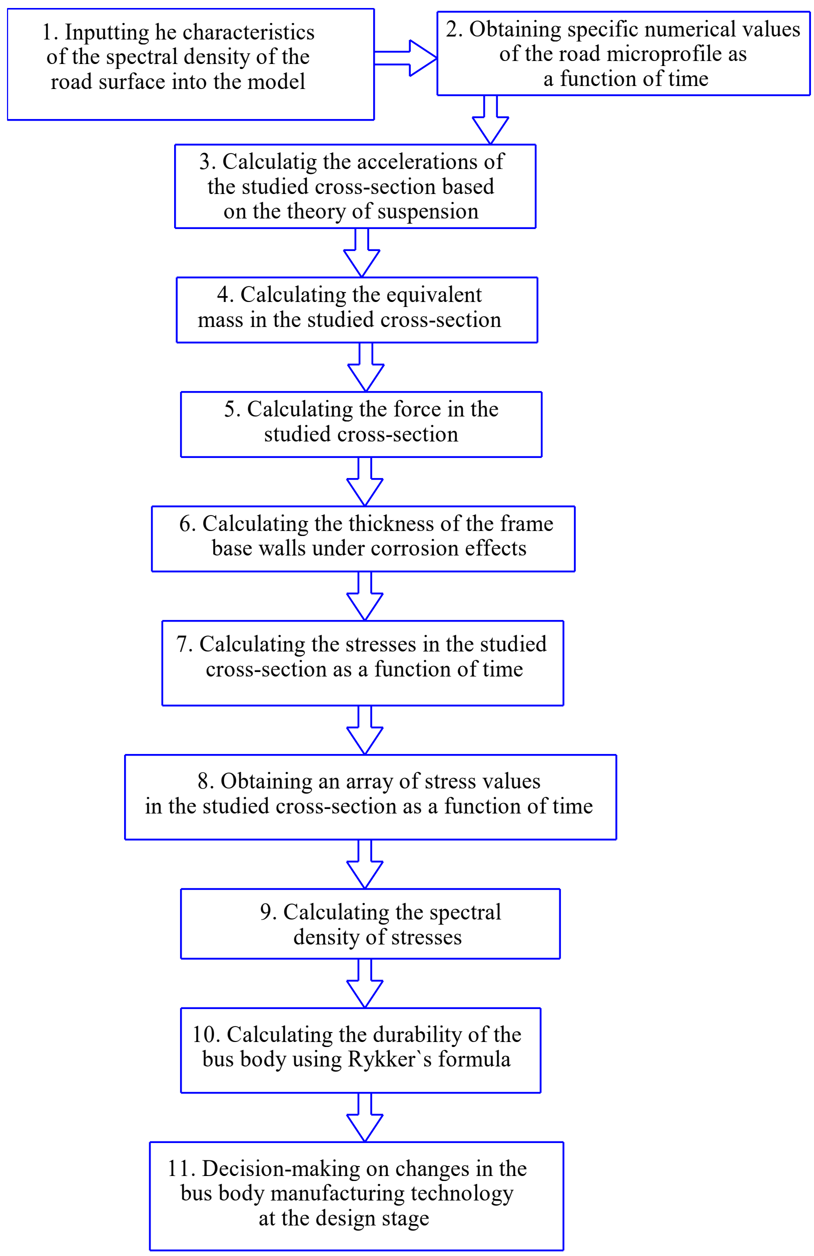


Fig. 2. Flowchart of the procedure for assessing the durability of a bus body when operating on unpaved roads

Dividing the force by the cross-sectional area at the corresponding moment of the bus wheels passing over the micro profile of the road, an array of stresses in the studied section is built. The numerical data on the array are entered into the MATLAB Simulink workspace. The calculation of the spectral density of stresses $S(\omega)$ in the studied section is carried out on the basis of the obtained array.

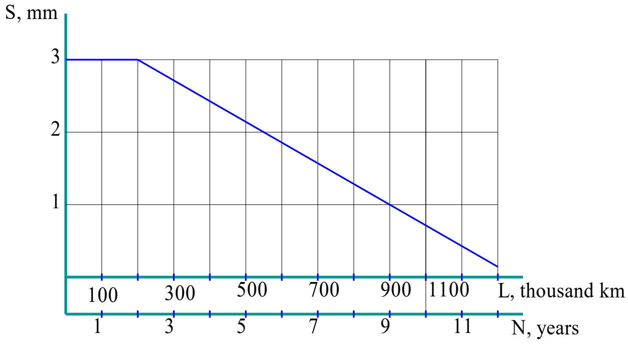


Fig. 3. Reducing the wall thickness of the bus body base pipes when operating in rural areas

Thus, it became possible to determine the durability of the bus body according to the hypothesis from [3, 15, 16] in units of mileage:

$$S = V_a \cdot \frac{2 \cdot \pi \cdot A}{\Delta^{m_N} \cdot \left(\sqrt{2}\right)^{m_N} \cdot \Gamma\left(\frac{m_N + 2}{2}\right) \cdot \left(\int\limits_{\omega} S_0(\omega) \cdot \omega^{\frac{2}{m_N}} d\omega\right)^{\frac{m_N}{2}}}, \quad (2)$$

where V_a is the average speed of the bus; $\Delta = \sqrt{D}$ – deviation in the numerical values of stresses σ_i obtained during the simulation; D is the variance; $S_0(\omega) = S(\omega)/D$ – reduced spectral density of stresses σ_i in the studied section, determined on the basis of simulation modeling in MATLAB Simulink in accordance with the selected conditions of bus movement; $\Gamma\left(\frac{m_N + 2}{2}\right)$ – gamma function; A and m_N are the characteristics of the endurance curve (Table 2) $\left(A = N \cdot \sigma_a^{m_N}\right)$.

The array of stress values in the body frame elements when driving on low-quality roads (paving with depressions and bumps, unpaved road) takes up larger volumes and, accordingly, requires more time to process the result and requires more computer resources. Unlike the algorithm in the methodology for predictive assessment of bus resource durability [5], in which the calculation of durability was carried out using a single model, the proposed durability assessment procedure is divided into two separate models. This has made it possible to simplify model debugging and implement the model with existing computer resources.

Fig. 4 shows, for example, the implementation of subitem 10 (the second module of the model, which receives data from the working area after calculating the first part of the model) of the structural diagram shown in Fig. 2, in the MATLAB Simulink software environment. Thus, sequential modeling based on two parts of the model makes it possible to speed up the calculation of durability and relieve the computer.

Comparing the desired bus mileage with that calculated by Reicher's hypothesis, it is concluded that changes need to be made to the bus structure at the design stage. If the calculated durability value is less than the desired bus mileage, changes are made to the bus design that could increase the durability of the body. With proper body durability, there is no need to improve the design and manufacturing technology, as this would inevitably lead to an increase in the cost of the bus.

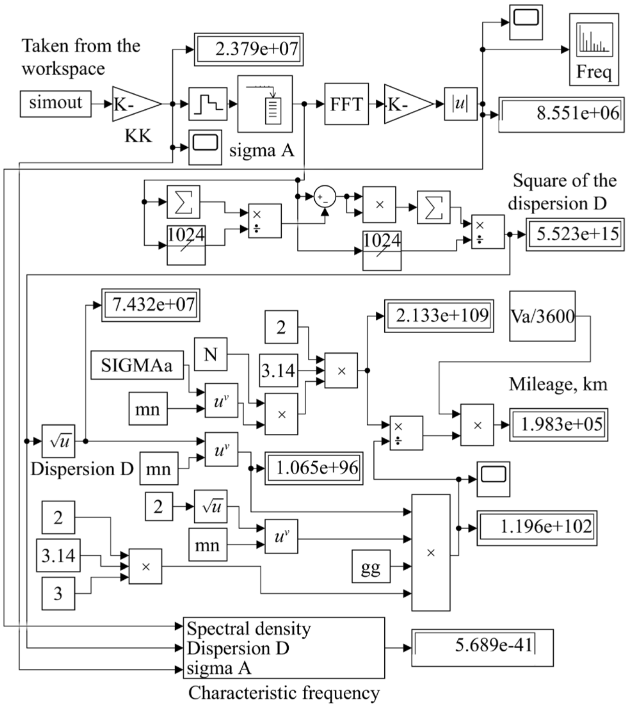


Fig. 4. MATLAB Simulink durability calculation model

5. 2. Simulation results, which determined the increased stresses in the non-load-bearing elements of the body and its durability under specified operating parameters

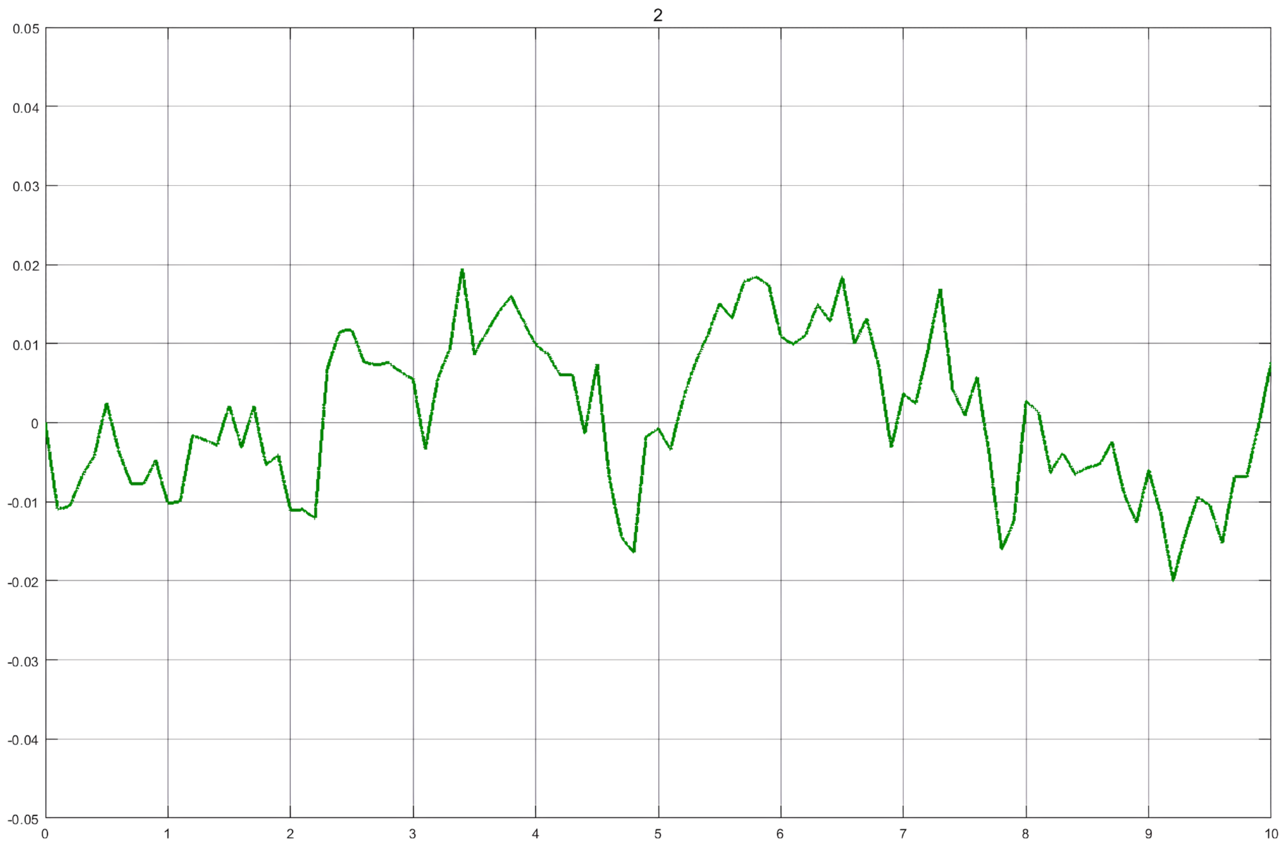
Using the approximation coefficients of the autocorrelation functions of the road micro profile (Table 1) and based on dependence (1), specific values of the deviation of the road micro profiles were calculated. For example, the time diagrams of the deviation of the road surface micro profile are shown in Fig. 5.

Fig. 5 demonstrates that in 10 s of movement, the bus at a speed of 40 km/h travels approximately 111 m, and on asphalt concrete pavement, the deviations of irregularities do not exceed 2 cm. When moving on an unpaved road, the deviations already increase by more than 2 times.

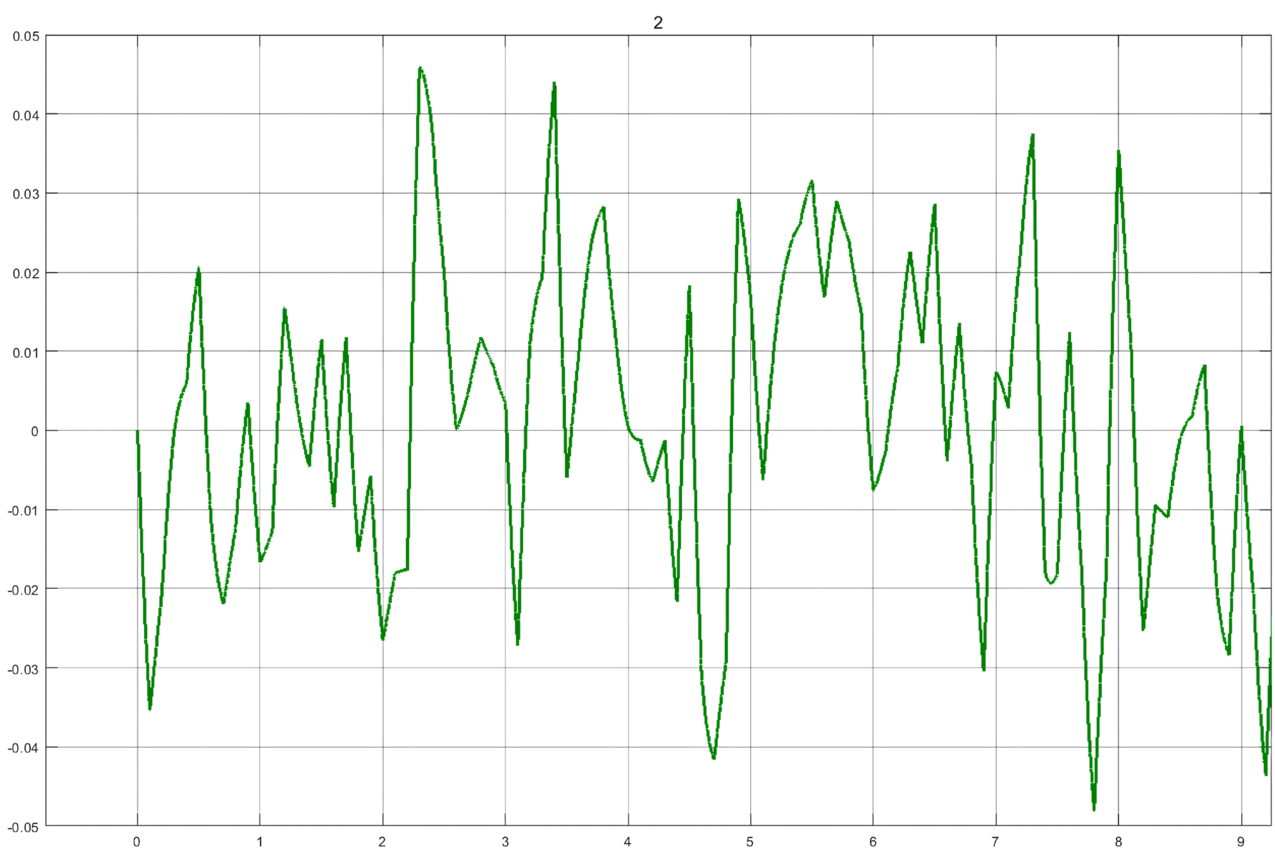
Then, as a result of further calculations according to the algorithm block diagram (Fig. 1, items 3–7), the stress in the studied section is determined. For example, the time diagrams of stresses in the studied section are shown in Fig. 6.

From the time diagrams (Fig. 6) it is clear that when driving on an asphalt-concrete surface, the stresses in the studied section do not exceed 30 MPa. When driving on an unpaved road, the stresses reach 100 MPa.

As a result of further implementation of the model for calculating the durability of the bus body in MATLAB Simulink (Fig. 4), the durability of the bus body was determined on unpaved roads, which amounted to S=198310 km of mileage. Table 3 gives the results in comparison with driving on a road with an asphalt-concrete surface and on low-quality paving stones with depressions and bumps.



a



b

Fig. 5. Time diagrams of deviation in the micro profile of the road surface corresponding to the movement of a bus in rural areas (along the abscissa axis in seconds (s); along the ordinate axis in meters (m)): *a* – asphalt concrete surface; *b* – unpaved road

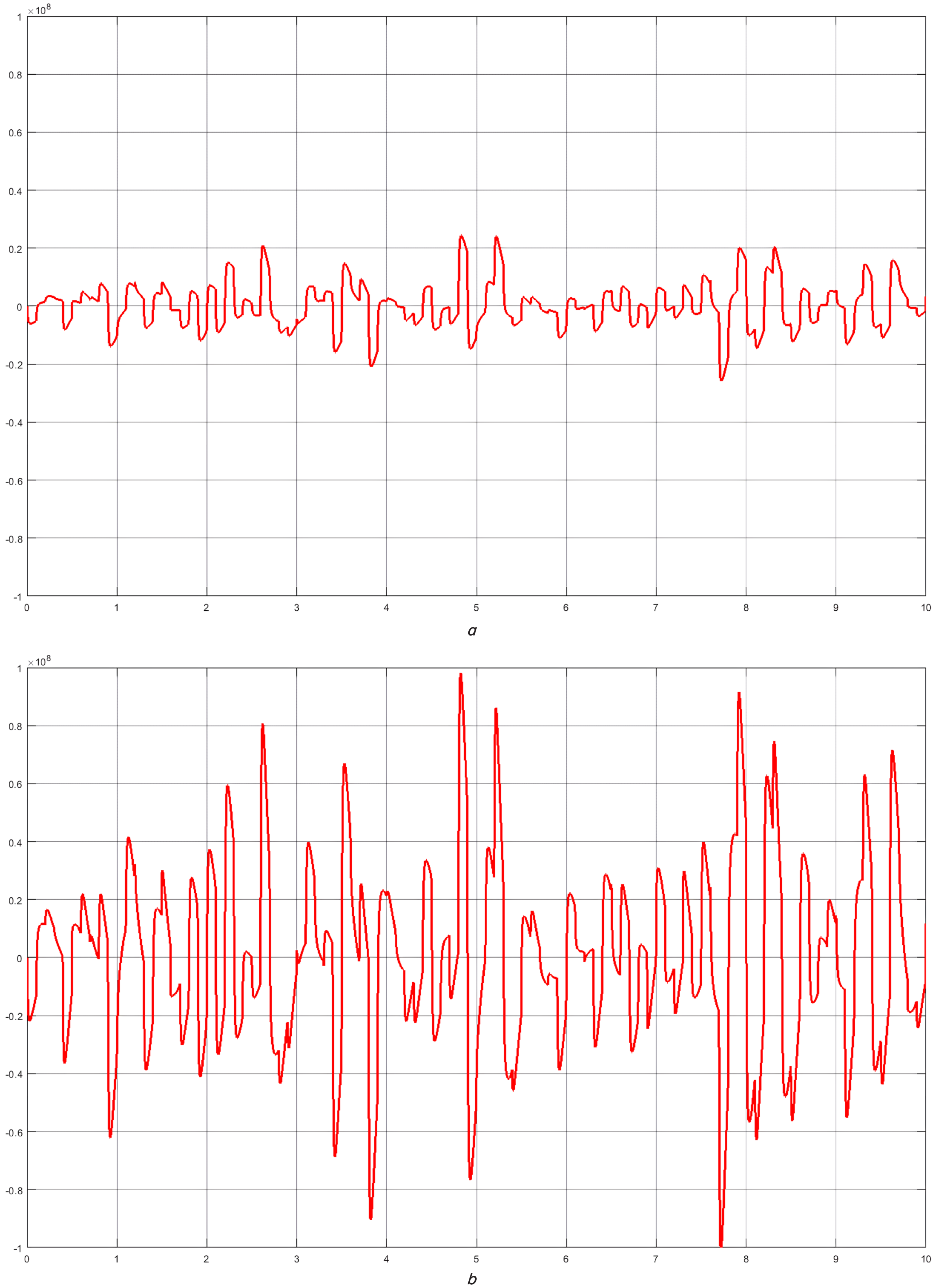


Fig. 6. Time diagrams of stresses in the studied cross-section, corresponding to the movement of a bus through rural areas (along the abscissa axis in seconds (s); along the ordinate axis in pascals (Pa)): *a* – asphalt concrete pavement; *b* – unpaved road

Table 3

Comparison of bus mileage on roads with different surfaces

Road surface	Durability S, km
Asphalt concrete	756,321
Cobblestone with depressions and bumps	57,523
Unpaved road	198,310

From Table 3, one can see that the durability of the bus body (mileage before the destruction of the body frame elements) will be in the range from 57,523 to 756,321 km.

That is, during the study, it was established that when operating a bus on cobblestones with depressions and bumps, the durability of the bus body would be the lowest and would be 57,523 km. On an unpaved road, the durability is 198,310 km. On an asphalt concrete surface, the durability will be maximum – 198,310 km. For a more objective assessment of the durability of the body, it should be taken into account that in real operation the bus can move on roads of different quality. In this case, there is no difference where the buses are operated: in the city, outside the city, or in rural areas. Accordingly, as the realities of operation show, the share of roads corresponding to category I – II roads in Ukraine is 5 %. That is, this is an asphalt concrete surface. All other roads (95 %) are low-quality roads. These include cobblestones with depressions and bumps and unpaved roads. Thus, assuming that in rural areas the length of cobblestones with depressions and bumps (47.5 %) and unpaved roads (47.5 %) is the same, then we can obtain the total mileage on rural roads of different quality according to the following formula [3]:

$$S_{\Sigma} = \frac{1}{\dfrac{\alpha_1}{100S_1} + \dfrac{\alpha_2}{100S_2} + \ldots + \dfrac{\alpha_n}{100S_n}}, \qquad (3)$$

where S_i is the durability of the bus body on a specific road surface in km; α_i is the percentage of bus operation on a road with a specific surface in %.

Having performed the calculation according to formula (3), substituting the durability values from Table 3, taking into account the above realities of operation, the total mileage of the bus before the destruction of the body base on rural roads is $S_{\Sigma}=91{,}702$ km.

At mileages greater than those obtained during modeling, the body resource would be exhausted, and the bus could no longer provide proper safety for passenger transportation since fatigue cracks would begin to form in the frame of the body base.

6. Discussion of results based on modeling that assessed the durability of the bus body when driving on rural roads

Our results showed that when driving on rural roads, the durability of the bus body would be 91,702 km – formula (3). This is explained by the fact that rural roads are mainly 95 % composed of unpaved roads and critically worn asphalt concrete roads, which can be equated to paving with depressions and bumps. If we compare the mileage of the bus purely on unpaved roads (Table 3) and on paving with depressions and bumps (Table 3), then the durability of the bus body would be 3.4 times higher.

The increased service life of the bus is explained by the soft structure of the unpaved road and the absence of sharp drops, unlike a critically worn asphalt concrete road. However, it should not be assumed that unpaved roads have an absolute advantage over worn asphalt concrete pavement. A significant disadvantage of operating a bus on unpaved roads is increased contamination of the bus bodies and increased wear of disc brakes, especially on the rear axle. As real experience of operation on rural roads (especially on sandy-clay-gravel roads) shows, there is intensive wear of the rear brake disks and pads. Therefore, under such operating conditions, the durability of brake pads does not exceed 10 thousand km of mileage. Therefore, in the design of buses that are planned to be operated mainly on rural roads, it is more expedient to use drum brake mechanisms that are more protected from dirt and, given the low speed of operation on these roads, the effect of overheating of the brake mechanisms is unlikely. When modeling, it is not necessary to take into account the influence of forces that arise during braking and can negatively affect the strength of the body structure after prolonged use since when driving on rural roads, which are usually unpaved or with poor pavement, the coefficient of adhesion of the tire to the road is quite low. It is evident that when driving on asphalt concrete pavement (category I roads), the mileage before the destruction of the body frame base would be maximum; it is 756,321 km (Table 3). Accordingly, the excess mileage, in contrast to the critically worn road surface (Table 3), is 13.1 times. The highest durability when driving on category I roads is explained by the minimum deviations of the road micro profile. Category I and II roads are the operating conditions prescribed in the operating instructions for public transport buses.

Unlike [3], in which the durability of a bus in the city is calculated, our result – the mileage of the bus before the destruction of the body base when operating on rural roads – allows us to estimate the durability of the bus body in the country. This becomes possible due to the consideration of the features of operation on rural roads. Namely, during the modeling in MATLAB Simulink, unpaved roads were taken into account, which are described by the corresponding autocorrelation function of the road micro profile, the approximation coefficients of which are given in Table 1 [3, 14]. The share of roads with different types of road surfaces in rural areas was also taken into account using formula (2).

The devised procedure allowed us to estimate the durability of the bus body when transporting passengers on rural roads, taking into account the following surfaces: asphalt concrete; paving stones with depressions and bumps; and unpaved roads, taking into account their share. Based on the simulation modeling of bus movement on unpaved roads, the stresses in the non-bearing elements of the body were obtained due to the decrease in the wall thickness of the frame pipes and material degradation, and it was shown that the durability of the bus body is 198,310 km (Table 3). However, taking into account the fact that a significant proportion of buses also travel on broken asphalt concrete pavement, the durability decreased to 91,702 km (Table 3) when operating the bus on different types of roads in rural areas.

The limitation of this study is that the shares of bus movement on rural roads are taken on average for Ukraine (roads of I–II categories – 5 %; cobblestones with depressions and hills – 47.5 %; unpaved road – 47.5 %). Therefore, the percentage of mileage in a specific village would differ.

The disadvantage of our study is the lack of information on the distribution of the share of roads with different surfaces in other villages of Ukraine and other countries. There are also villages (especially in EU countries) in which there are no unpaved roads at all. In addition to the studied road surfaces, there may be roads with evenly paved cobblestones.

To get closer to the realities of operation in a particular village, the development of this study should focus on measuring the length of roads with different types of surfaces within a given village. It would also be advisable to accumulate statistical data for each individual village to understand the need for road rehabilitation, which has a significant impact not only on the durability of buses but also the safety of passenger transportation. It is also possible to take a micro profile of the road in rural areas on a specific route to obtain an array of the micro profile of the road. Such additional studies could allow us to bring the results of the work as close as possible to the realities of operation in a particular village. In addition, this would simplify part of the model and eliminate the need to use formula (2).

7. Conclusions

1. A procedure for assessing the durability of a bus body during passenger transportation on rural roads has been devised. Taking into account the micro profile of an unpaved road, it has become possible to fully assess the durability of the bus body during passenger transportation in rural areas. The share of bus operation on all types of roads (asphalt concrete pavement, paving with depressions and bumps, and unpaved road) has been taken into account, which fully allows us to bring the results of simulation modeling closer to the realities of operation.

2. A simulation modeling of bus movement on rural roads has been carried out, which made it possible to determine the bus mileage before the destruction of the body frame elements, which limits its durability. If we consider each road surface separately, then when operating on asphalt concrete pavement, the mileage before the destruction of the base frame would be the largest and could equal to 756,321 km. The average result is when driving on unpaved roads: 198,310 km. On cobblestones with depressions and bumps, the durability would be the lowest – 57,523 km. It has been established that the average durability when transporting passengers on rural roads is 91,702 km of mileage, with the length of the asphalt concrete coating being 5 %, and the other two coatings in equal parts (47.5 % – cobblestones with depressions and bumps; 47.5 % – unpaved road).

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study, as well as the results reported in this paper.

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Data availability

All data are available, either in numerical or graphical form, in the main text of the manuscript.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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