International Journal of Innovative Research and Scientific Studies, 8(3) 2025, pages: 2534-2544

IJIRSS
International Journal of Innovative Research & Scientific Studies

ISSN: 2617-6548

URL: www.ijirss.com

The forces exerted by the TE33A locomotive on the switch elements

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Abstract

The article discusses the forces that arise when a TE-33A diesel locomotive moves through a switch. The analysis of dynamic loads acting on rail threads, crosspieces, and other switch elements is carried out. The purpose of this article is to determine the efforts of the TE-33A diesel locomotive acting on the main elements of the railway track switch. The measurements were carried out in accordance with the requirements using a strain gauge measuring and computing complex consisting of certified and verified measuring instruments from the world's leading manufacturers. As a result of theoretical analysis and experimental studies, the lateral and vertical forces transmitted by the wheels to the inner and outer rails of the transfer curve were determined when the TE-33A locomotive was moving along the R65 mark 1/11 switch. Possible causes of increased wear of the switch elements under the influence of the TE-33A diesel locomotive have been identified. Recommendations are proposed to reduce the negative impact on the switches, including optimizing driving modes. Based on the results obtained, diagrams of vertical and transverse forces were constructed, and indicators of the stress rate at maximum speed along the arrow of the locomotive in question were established.

Keywords: Edge stresses, Lateral forces, Rail, railway track, Test rolling stock.

DOI: 10.53894/ijirss.v8i3.7050
Funding: This study received no specific financial support.
History: Received: 12 March 2025 / **Revised:** 16 April 2025 / **Accepted:** 18 April 2025 / **Published:** 15 May 2025

Competing Interests: The authors declare that they have no competing interests.
Authors' Contributions: All authors contributed equally to the conception and design of the study. All authors have read and agreed to the published version of the manuscript.
Transparency: The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.
Publisher: Innovative Research Publishing

1. Introduction

Rail transport is one of the most important components of the transport system, providing transportation of goods and passengers over long distances. One of the key elements of the railway infrastructure is the switches, which allow for maneuvers and change the direction of movement of rolling stock. The reliability and durability of switches depend on many factors, among which dynamic loads that occur during the passage of rolling stock, in particular, diesel locomotives, play a special role [1].

The TE-33A diesel locomotive, belonging to the family of mainline locomotives, is widely used in the railway network due to its high power, efficiency, and operational reliability. However, the movement of heavy locomotives through the switches is accompanied by significant forces affecting their structural elements. These forces can cause wear on rail threads, crosspieces, wags, and other switch components, which requires comprehensive studies of their effects [2].

Due to the ever-growing need to increase the capacity of the existing railway network of the Republic of Kazakhstan, especially in the areas bordering the Russian Federation and *China*, the issue of improving the safety of operations for freight trains of increased weight and length is urgent. The commissioning of heavy-duty trains is a complex task associated with the use of more powerful locomotives, increased axle loads, reconstruction of track infrastructure and power supply, and improvement of the technology of the transportation process [1, 2].

In addition, an increase in train speeds with increasing road load demands an increase in the strength and stability of the track. The technical policy of JSC "National Company 'Kazakhstan Temir Zholy' " in Kazakhstan aims for a complete transition to a seamless track on a reinforced concrete base [3].

The use of reinforced concrete sleepers and heavy-duty rails, along with increasing the strength and reliability of the track, causes an increase in the modulus of elasticity of the sub-rail base and the rigidity of the track compared with wooden sleepers.

The issues of the dynamic impact of rolling stock on railway track elements are considered in the works of both domestic and foreign researchers. In the works of Rill and M. [1], Wan et al. [2] and Abdullayev et al. [3] and other specialists, the factors determining the load on the rail track are analyzed, including the geometry of the track, the design features of locomotives, the speed of movement, and the characteristics of the wheel-rail contact. Research shows that significant vertical and horizontal forces that occur when a locomotive moves through a switch can lead to accelerated wear and damage.

Modern research in the field of dynamics of the interaction of a wheelset with a rail aims to improve design solutions, increase the durability of the track, and reduce operating costs. The use of numerical modeling, laboratory, and field testing methods makes it possible to analyze in detail the distribution of loads in various operating conditions [3]. However, the specific effects of the TE-33A locomotive on the switches have not been sufficiently studied, which makes further research in this area relevant.

The relevance of this work is due to the need to increase the reliability and durability of switches, especially under conditions of increasing loads from a modern locomotive fleet. TE-33A diesel locomotives have a significant mass and high axial load, which requires a detailed analysis of their impact on the structural elements of the railway infrastructure [4]. The study of the forces that occur during the passage of the switch by this locomotive will reveal the main factors contributing to its wear and damage.

The practical significance of the study lies in the possibility of developing recommendations to reduce the negative impact of dynamic loads on switches. This may include optimizing traffic conditions, improving design solutions, or using new materials to increase the lifespan of the railway infrastructure.

The scientific novelty of the research consists of a comprehensive analysis of the forces arising during the movement of the TE33A diesel locomotive through the switches, using modern modeling methods and experimental measurements. Unlike previous studies, the focus is not only on the assessment of vertical and horizontal loads but also on the analysis of their impact on the durability of the switch elements. The data obtained will allow us to propose new approaches to the design and modernization of switches, taking into account the operating characteristics of the TE-33A diesel locomotive.

The purpose of this study is to analyze the dynamic forces that occur when the TE33A locomotive passes through the switch and to assess their impact on the operational characteristics of the switch elements.

To achieve this goal, the following tasks are being solved:

- To review existing research in the field of dynamic interaction of locomotives with switches.
- To develop a methodology for the experimental study of loads arising from the movement of a TE33A diesel locomotive through a switch.
- To determine the relationship between the parameters of the movement of the locomotive and the loads transmitted to the switch.
- To develop recommendations for reducing the negative impact of loads on the switch elements.

The results of this study can be utilized in the design and modernization of switches, as well as in the development of measures aimed at enhancing their operational reliability.

2. Materials and Methods

The accuracy and correctness of the applied experimental methods for assessing the force effects of wheels on the track play an important role in analyzing the safety of the operation of freight composite trains. The reliability of the data obtained makes it possible to determine the main parameters of the interaction between wheels and rails, assess the level of loads, and identify possible risks associated with the operation of railway rolling stock. One of the key factors determining the strength of rails is edge stresses, which are caused by bending and torsion of the rail under the influence of vertical and horizontal loads from rolling stock [2].

Edge stresses play an important role in assessing the durability and safety of a rail track. They make it possible to quantify the effect of dynamic loads on track elements and identify possible critical stress zones. The half-sum of edge stresses characterizes the level of vertical impact on the path, while the half-difference indicates the intensity of the lateral force. In addition, edge stresses allow for the analysis of the influence of the moments of forces arising from lateral loads, as well as the assessment of the degree of displacement of the conditional center of the contact spot between the wheel and the rail head [4]. Thus, the accuracy of determining edge stresses is an essential aspect of predicting the durability of the rail bed and preventing premature wear.

During the study, measurements were carried out in accordance with established standards and requirements using modern high-precision measuring systems. In particular, a strain gauge measuring and computing complex was used, which includes certified and trusted devices from the world's leading manufacturers. This complex made it possible to accurately record the force effects of the wheels on the rail track, as well as to identify patterns of load distribution in various modes of movement of the locomotive through the switch [3, 5].

An analysis of the data obtained showed that the greatest lateral force in the forward reach of the frame rail is observed when the switchboard passes through. It is registered in the rectilinear section of the frame rail under the first wheelset of the locomotive and reaches 114 kN at a speed of 50 km/h. This indicator is close to the permissible limit, which is 113.8 kN [5]. Throughout the studied speed range, the lateral force acting on the rail from the first wheelset varies from 90 to 114 kN, indicating its significant effect on the condition of the track.

It is important to note that the measured lateral forces from the second wheelset turned out to be significantly lower—by 1.4 to 2 times compared with the first wheelset. The lateral forces from the third wheelset were even lower. A similar trend is observed for the wheelsets of the second trolley, although their values are slightly lower compared to the first trolley (Figure 1).

When the locomotive is moving against the wind through the switch, the magnitude of the lateral forces is significantly reduced. The maximum recorded value was 22.3 kN, which is significantly lower compared to the rough passage [4, 5]. Approximately at the same level are the lateral forces acting on the forward reach of the curved frame rail in both directions of movement of the locomotive. This fact indicates a significant difference in the loads that occur in different directions of movement, which must be taken into account when designing and upgrading the switch elements.

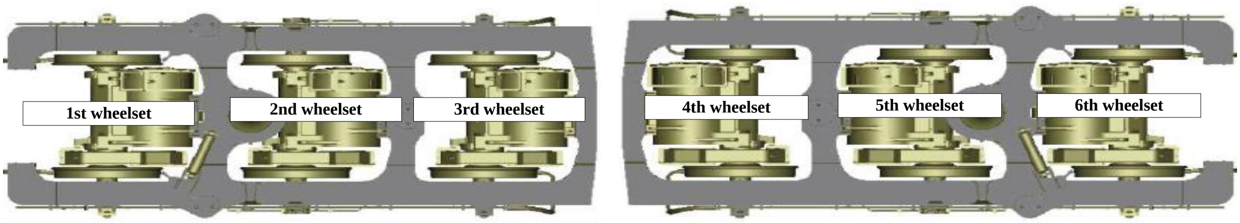

Figure 1.
The location and serial number of the wheelsets on the locomotive.

3. Results

The experimental data obtained allow us to draw a number of important conclusions. Firstly, the maximum lateral forces occur in the forward reach of the frame rail during the rough movement of the locomotive, while their values can reach critical limits at a speed of 50 km/h. Secondly, the magnitude of the lateral forces from the first wheelset significantly exceeds similar values for subsequent wheelsets, which indicates an uneven load distribution [5]. Thirdly, with anti-rough movement, the lateral forces are significantly lower, which makes this mode less loaded in terms of impact on the rail track.

Figure 2 shows the measured values of the lateral forces in the forward reach of the rectilinear frame rail during the rolling motion of the locomotive. Analyzing the data obtained, it can be noted that up to a speed of 40 km/h, the maximum values of lateral forces do not exceed 112 kN, which corresponds to the established regulatory requirements. However, when the speed increases to 50 km/h, there is a slight excess of the permissible level – by 0.2%. This result indicates a possible risk of exceeding the maximum permissible loads at high speeds, which requires additional study and possible revision of the operating modes of the locomotive through the switches.

In the future, further research should focus on a more detailed analysis of the factors influencing the magnitude of lateral forces, including the influence of the profile of the wheels, the condition of the track, and the design features of the switches. The results obtained can be used to optimize traffic modes, develop new design solutions, and increase the service life of railway infrastructure elements.

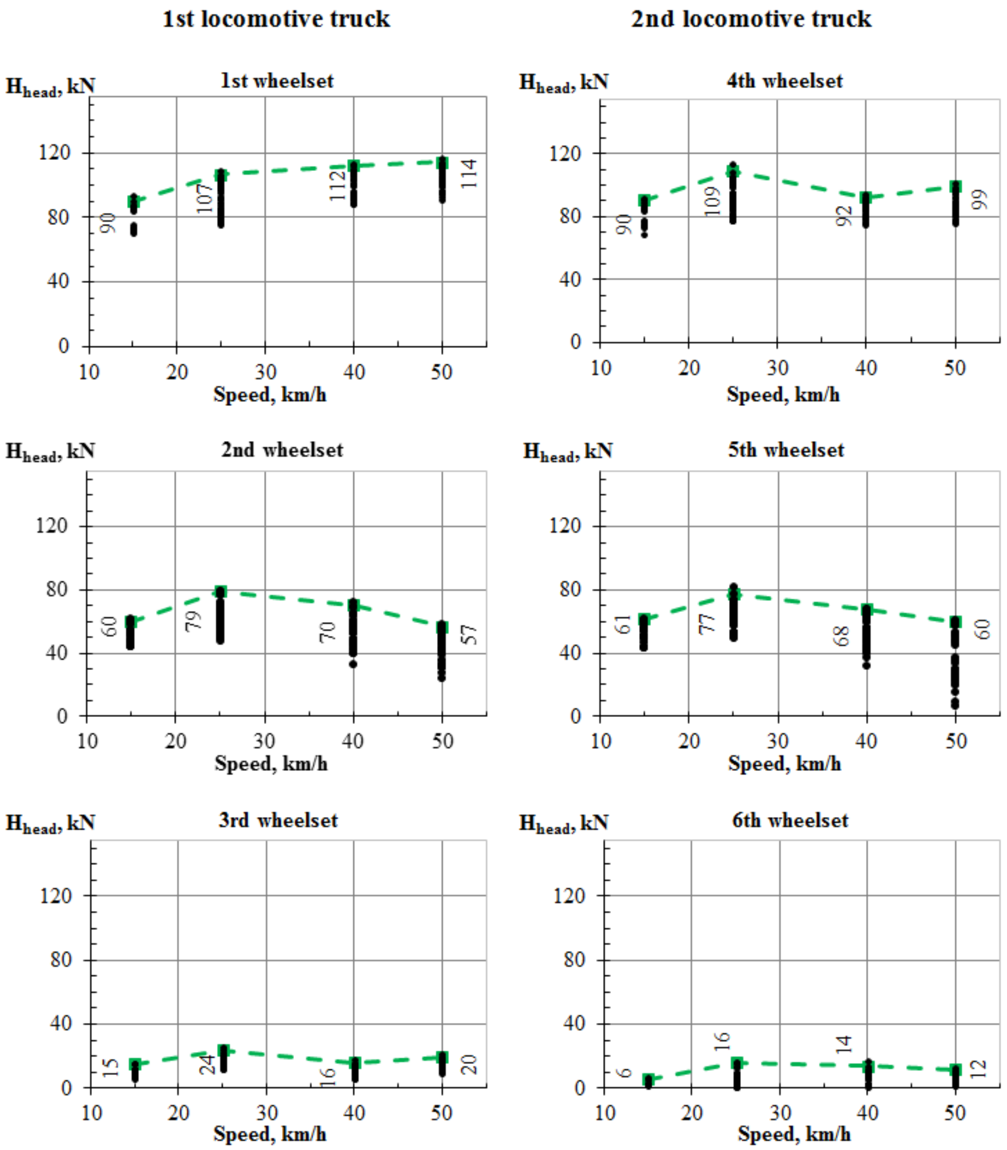

Figure 2.
Lateral forces from the wheel to the rectilinear frame rail when the TE33A locomotive moves along the 1/11 grade R65 switch in the opposite direction.

The dependence of the vertical forces transmitted from the wheel to the rail, measured in the forward reach of the rectilinear frame rail, is shown in Figure 3. Data analysis shows that the level of these forces practically does not change depending on the speed and direction of movement of the locomotive. This indicates the stability of the contact interactions between the wheel and the rail under these conditions, as well as the fact that the effect of speed on vertical loads is not significant when passing this section of the track.

However, when moving through the switch in the opposite direction, a slightly different picture is observed. In the forward reach of a curved frame rail, the level of vertical forces transmitted from the wheels to the rails tends to decrease with increasing speed. This phenomenon can be explained by an increase in the outstanding acceleration resulting from the dynamic features of the movement of the wheelset in a curved section of the track. In particular, an increase in speed leads to a change in the load distribution between the wheels and rails, as well as to possible additional vibrations of the trolley, which partially reduces the transmitted vertical load [6, 7].

Thus, data analysis shows that in straight sections of the track, the effect of speed on vertical forces is minimal, while in curved areas of the switch, it becomes more noticeable. It is important to take this into account when designing railway tracks and choosing operating modes of movement.

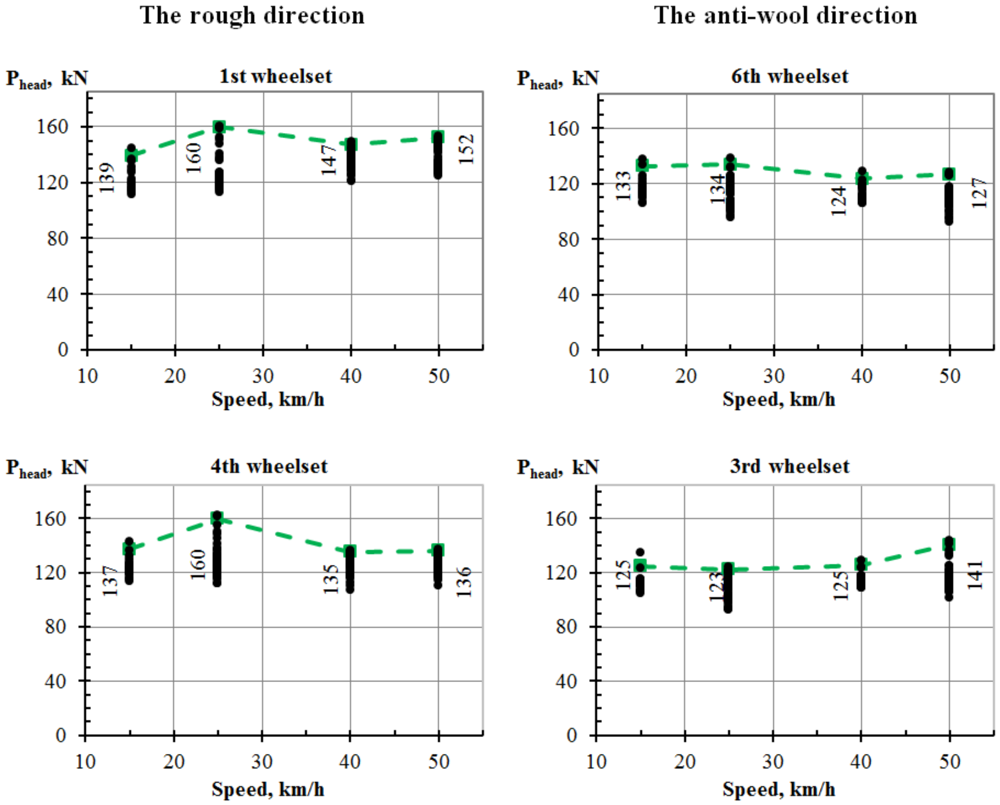

Figure 3.
Vertical forces from the wheel to the rectilinear frame rail when the TE33A locomotive is moving along the R65 mark 1/11 switch.

The greatest lateral forces transmitted from the wheel to the rail in the transfer curve of the switch are observed on the outer rail under the guiding wheelsets of the trolleys. These forces have a significant impact on rail wear, track stability, and rolling stock safety. As can be seen from Figure 4, the dependence of the level of lateral forces on velocity is linear and practically independent of the direction of movement [8]. This confirms that an increase in speed in this section of the track leads to a proportional increase in lateral loads.

The maximum observed value of the lateral forces at a speed of 50 km/h is approaching the maximum permissible value (113.8 kN), and when the switchboard is running roughly, it exceeds this limit by 10.7%. This fact requires special attention when operating rolling stock, as exceeding the permissible loads can lead to increased wear of the switch elements and an increase in the probability of failures.

As in the forward reach of the frame rail, in this section of the track, the greatest level of lateral forces is observed from the first wheelset. In all studied speed modes, it demonstrates values that are in the upper range of acceptable standards [9]. At the same time, the lateral forces from the second wheelsets of trolleys are slightly lower than those from the first. The difference is 1.36–1.67 times for the first cart and 1.15–1.58 times for the second. The lateral forces from the third wheelsets are significantly lower and do not exceed 53 kN.

An analysis of the measurements shows that the most intense lateral loads occur on the first pair of wheels, and exceeding the permissible values during rough driving requires additional measures to reduce the load on the track and ensure traffic safety.

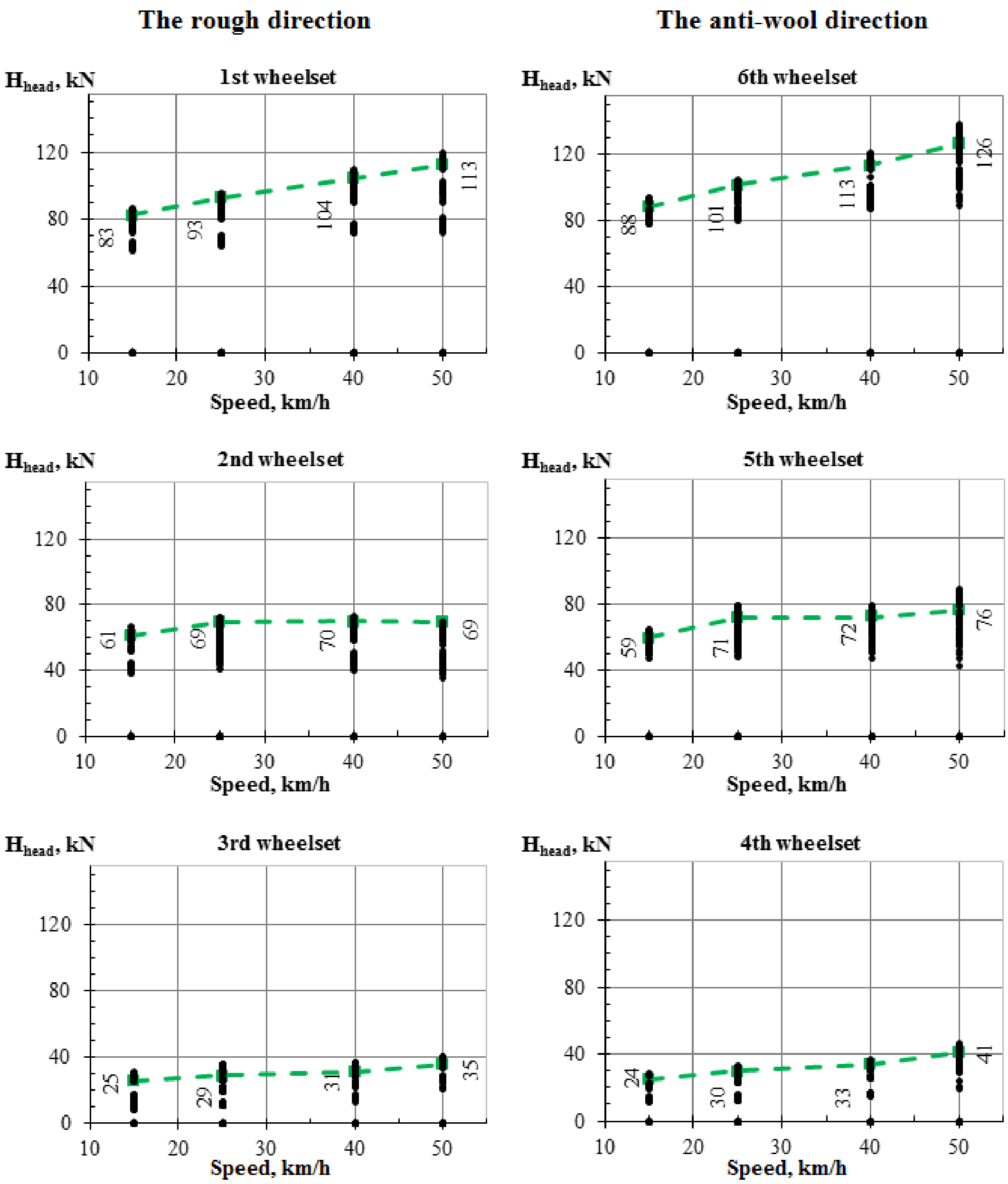

Figure 4.
Lateral forces from the wheel to the outer rail of the transfer curve when the TE33A3 locomotive moves along the P65 mark 1/11 switch.

The lateral forces acting on the inner rail of the transfer curve are important for assessing the dynamics of rolling stock movement and the stability of the track. Analysis of the measured data shows that the level of these forces does not depend on the direction of movement of the locomotive. However, the dependence on the speed of movement is manifested primarily for the guiding wheel sets of trolleys, which is due to the peculiarities of their interaction with the rail track.

Compared to the lateral forces measured on the outer rail of the transfer curve, these loads are significantly lower. This is explained by the fact that the main force action during the passage of the switch falls on the outer rail, while the inner rail perceives only part of the lateral loads. The greatest lateral forces were recorded during the passage of the first wheel sets of trolleys, reaching 53 kN [10]. The lateral forces from the middle wheel sets of trolleys are slightly lower; their level is about 80% of the maximum value, which corresponds to a 20% reduction in load.

Under the third wheelsets, the lateral forces are even lower and do not exceed 26 kN. This load distribution indicates a gradual decrease in the impact on the inner rail as the wheel sets of bogies pass through. Figure 5 shows the measured values of the lateral forces acting on the inner rail of the transfer curve from the first truck of the locomotive, which clearly confirms the above patterns.

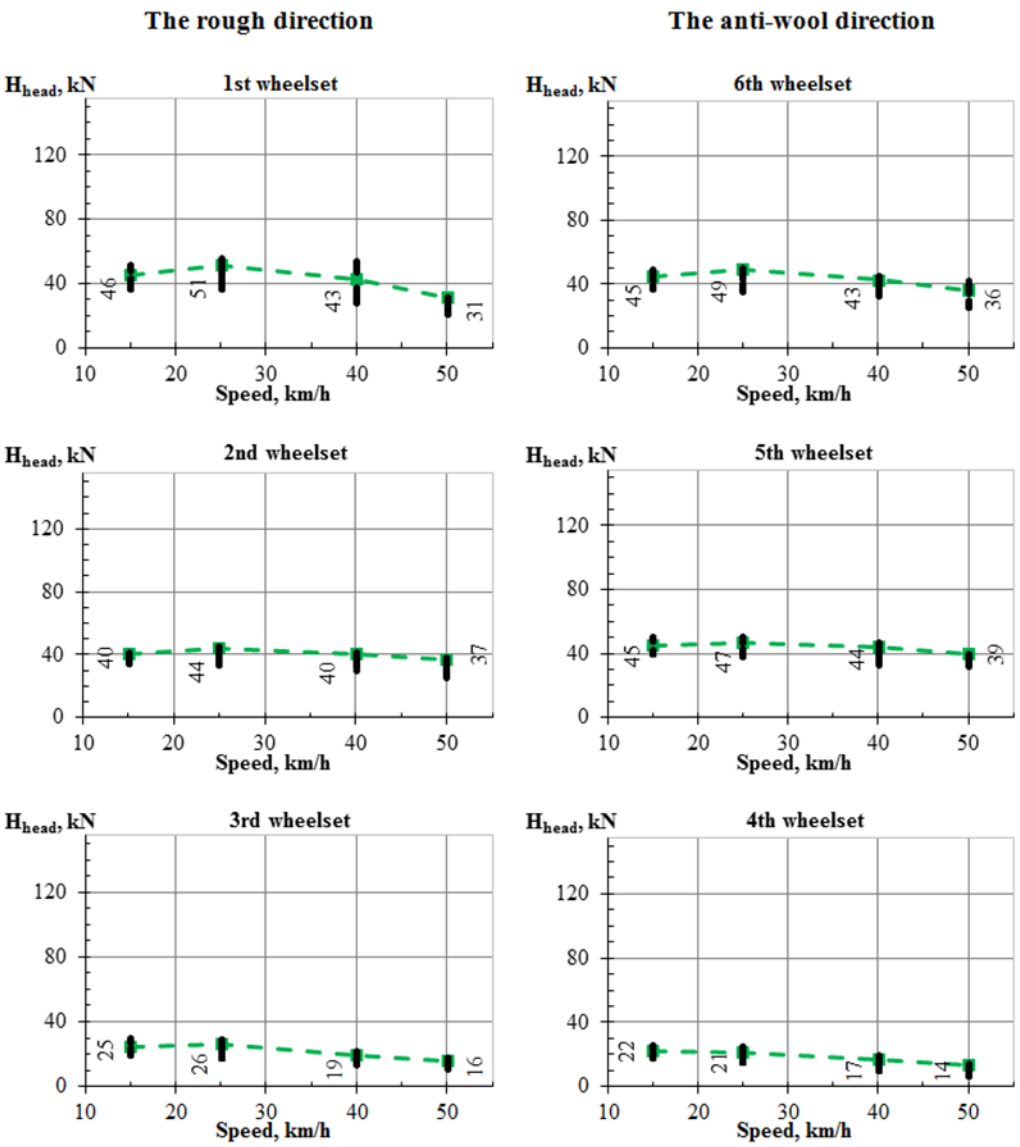

Figure 5.
Lateral forces from the wheel to the inner rail of the transfer curve when the TE33A locomotive moves along the R65 mark 1/11 switch.

The lateral forces generated on the external guide of the transfer curve of the switch type R65 grade 1/11 are a key parameter determining the safety and stability of rolling stock movement. These forces are formed under the influence of dynamic factors such as the speed of movement, the weight of the locomotive and wagons, the design features of the bogies, as well as the geometric parameters of the switch.

The maximum observed values of transverse forces are recorded in areas of intense interaction between wheelsets and guide rails, especially when passing rolling stock with high lateral loads. The external guide of the transfer curve of the switch experiences significant loads during rough and anti-rough movement, particularly at high speeds or with insufficient smoothness of the track profile [9].

Studies show that an increase in speed leads to an increase in transverse loads, and critical values can reach maximum permissible limits. In particular, on switches of the R65 type of the 1/11 brand, the maximum transverse forces can range from 90 to 115 kN, which requires special monitoring by railway transport specialists.

To reduce lateral forces, it is necessary to take into account the design features of the running gear of the rolling stock, adjust the operating parameters, and ensure timely diagnosis of the condition of the switches. The introduction of modern load control methods will improve the reliability and durability of the railway infrastructure. Tables 1 and 2 show the maximum observed values of the lateral forces acting on the transfer curve.

Table 1.
Maximum observed values of lateral forces in the outer rail of the transfer curve of the switch type R65 mark 1/11, kN.

The direction of movement	Speed, km/h	Wheel sets						Maximum
		1	2	3	4	5	6	
Woolly	15	83	61	25	68	59	30	83
	25	93	69	29	76	64	35	93
	40	104	70	31	81	64	43	104
	50	113	69	35	88	58	53	113
Facing	15	88	59	24	80	59	24	88
	25	101	71	30	91	69	29	101
	40	113	72	33	102	69	33	113
	50	126	76	41	112	71	44	126

Table 2.
Maximum observed values of lateral forces in the inner rail of the transfer curve of the switch type R65 mark 1/11, kN.

The direction of movement	Speed, km/h	Wheel sets						Maximum
		1	2	3	4	5	6	
Woolly	15	46	40	25	48	43	17	48
	25	51	44	26	53	45	16	53
	40	43	40	19	46	42	9	46
	50	31	37	16	39	34	4	39
Facing	15	45	45	22	44	42	21	45
	25	49	47	21	50	45	23	50
	40	43	44	17	43	41	16	44
	50	36	39	14	36	33	10	39

Figures 6 and 7 show the results of measurements of the vertical forces transmitted from the wheel to the rail in the transfer curve of the switch for the first trolley during the course of movement. These forces play an important role in assessing the dynamic interaction of wheelsets with the track and determine the load distribution in the rolling stock–track system.

The vertical forces measured under the first trolley make it possible to analyze the patterns of load on the rail track during the passage of the switch. The measurement data show that the level of vertical forces on this section of the track can vary depending on the speed of movement, the mass of the train, and the design features of the wheelsets. At the same time, there is a tendency to maintain the general nature of the load distribution during the movement of the second trolley, which indicates the stability of the dynamic characteristics of the interaction of trolleys with the rail.

The greatest vertical forces are recorded at the moments of contact of the wheelsets with the rail at the critical points of the transfer curve, where loads are redistributed between the rail strands. As the speed of movement increases, slight fluctuations in the values of vertical forces are possible, which are associated with dynamic effects such as vibrations of the trolley and the shock-absorbing properties of the undercarriage of the rolling stock.

The measurement results confirm the need for a thorough analysis of the force effects on the rail track, especially under conditions of intensive operation of switches. This data can be used to optimize the designs of rail elements, improve operational conditions, and increase the reliability of railway infrastructure.

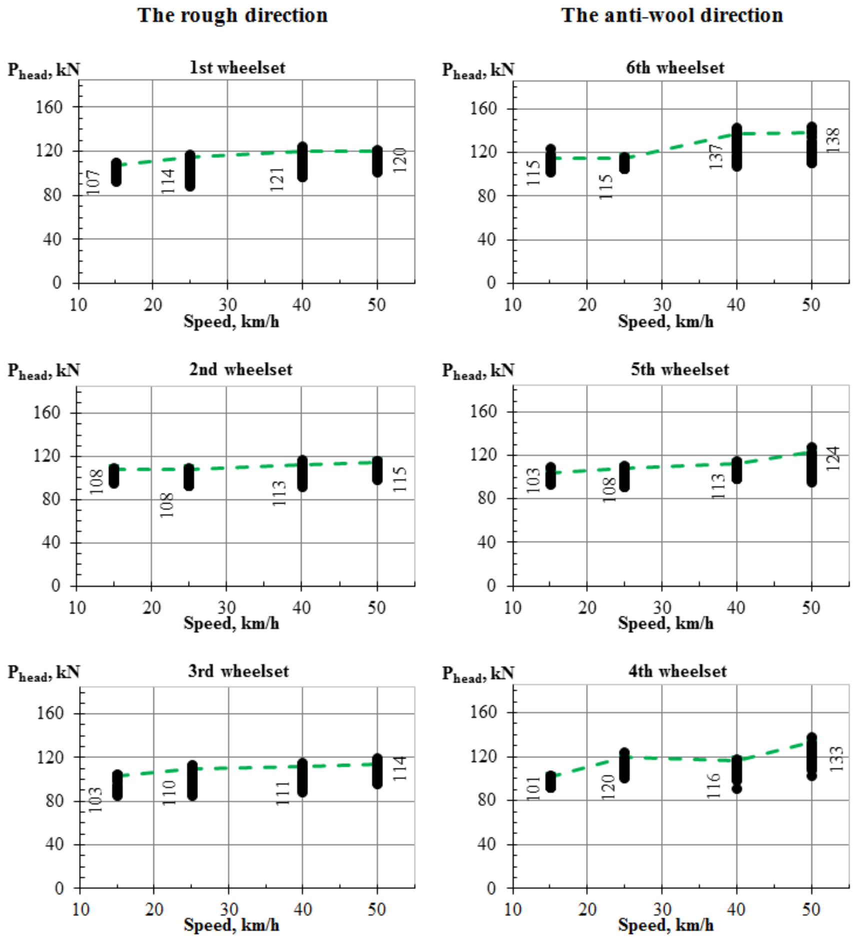

Figure 6.
Vertical forces from the wheel to the outer rail of the transfer curve when the TE33A locomotive moves along the R65 mark 1/11 switch.

On the outer rail of the switchboard, under conditions of rough movement, the level of vertical forces remains almost constant at all speeds, indicating the absence of significant vertical dynamic processes at the point of contact between the wheel and the rail. This means that in this mode of rolling stock movement, the vertical loads on the rail structure do not undergo significant changes, which indicates a stable interaction between the wheelset and the rail. These results confirm the correct functioning of the wheelsets and their interaction with the track under conditions of stable movement, which is critically important to ensure the safe operation of the switches, especially at high speeds [11, 12].

However, when moving in the opposite direction, there is a slight increase in vertical forces with increasing speed. This is due to a change in the nature of the load distribution between the wheelset and the track, which may be attributed to increased depreciation or a change in the trajectory of the trolleys. This effect requires attention, as at high speeds it can contribute to additional loads on the switch elements, which, in turn, can affect their wear and durability.

As for the inner rail, as the speed increases, the vertical forces transmitted from the wheel to the rail decrease slightly. This effect is especially pronounced when passing the switch in the opposite direction. A decrease in vertical forces on the inner rail indicates a redistribution of load to the outer side of the curve, which is typical for most switches and is also associated with dynamic processes occurring in the body of the rolling stock [13, 14].

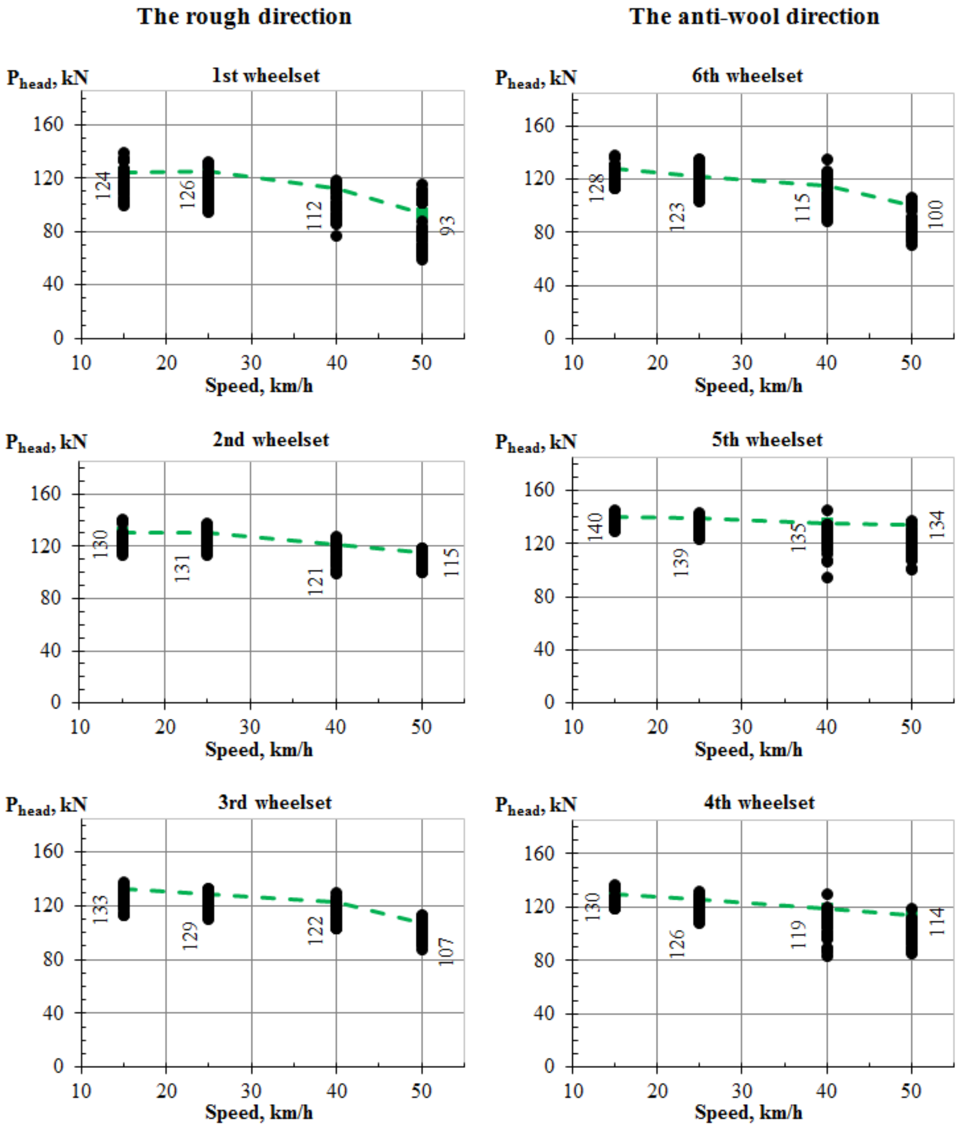

Figure 7.
Vertical forces from the wheel to the inner rail of the transfer curve when the TE33A locomotive moves along the P65 mark 1/11 switch.

4. Discussion

The analysis of the force effects of the TE-33A locomotive on the switch elements revealed the key patterns of their distribution. The measurement results showed that the greatest lateral forces act on the outer rail of the transfer curve, especially in the area of contact with the first wheelsets of the trolleys. These forces increase with increasing speed and can reach extreme values, which requires special attention when operating this type of locomotive on difficult sections of track [8].

The vertical forces transmitted from the wheels to the rail remain relatively stable depending on the speed and direction of movement; however, in curved switch areas, they may decrease slightly due to dynamic effects. The lateral forces acting on the inner rail are significantly lower than those on the outer rail and decrease as the wheelsets of the trolleys pass through, indicating a redistribution of loads during movement.

Exceeding the permissible values of lateral forces during the rough passage of the switch indicates the need to adjust the operating conditions to ensure safe movement. In particular, speed limits are possible in certain areas of the track, as well as improving the design of trolleys to reduce side loads.

The conducted research confirms the importance of taking dynamic factors into account when designing and operating a railway track. The results obtained can be used to optimize the technical condition of the switches and increase the reliability of rolling stock movement.

5. Conclusions

The study of the force effects of the TE-33A locomotive on the switch elements revealed the main patterns of load distribution and their impact on the operational reliability of the track. An analysis of the measured parameters showed that the greatest lateral forces act on the outer rail of the transfer curve, especially in the area of contact with the guide wheelsets of the trolleys. These forces increase with increasing speed and can reach extreme values, which must be taken into account when organizing the operation of railway transport.

The vertical forces transmitted from the wheels to the rail demonstrate relative stability regardless of the speed and direction of movement. However, there is a slight decrease in vertical loads in the curved sections of the switch, which is explained by dynamic processes associated with the weight redistribution of rolling stock. The lateral forces acting on the inner rail are significantly lower than those on the outer rail and gradually decrease as the wheelsets pass through.

The recorded cases of exceeding the permissible lateral loads during the rough passage of the switch indicate the need to adjust operational parameters, including possible speed limits in critical areas and optimization of the design of the chassis of the locomotive. The introduction of modern methods for monitoring loads and the condition of track infrastructure will improve traffic safety and extend the service life of rail elements.

In the course of the experimental study, the following results were obtained:

1. An overview of the specifics of the establishment and location of railway switches in the territory of Kazakhstan is provided.

2. To achieve this goal, the lateral and vertical forces acting on the inner and outer rails of the switches were determined experimentally, and graphs of the dependence of the voltage of each wheelset of a locomotive on the speed of movement were constructed.

3. As a result of the analysis of the above dependencies, it was found that the dynamic tensile stresses (the maximum probable value) at the edges of the sole of the rail in the modes under consideration do not exceed:

Thus, the lateral forces in the switch type R65 mark 1/11 in the front reach of the frame rail and in the transfer curve, in terms of the maximum observed values up to a speed of 40 km/h, meet the permissible standards, and at a speed of 50 km/h, exceed the permissible standards.

The results of the study can be used in the design and modernization of switches, as well as to optimize the operational modes of locomotives, which ultimately contribute to improving the safety and efficiency of railway transport.

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