PAPER • OPEN ACCESS

Research of dynamic indicators and influence of different types of rolling stock on railway track

View the article online for updates and enhancements.

Research of dynamic indicators and influence of different types of rolling stock on railway track

A O Shvets[1,3,4]**, O M Bolotov**[2,3]**, A K Percevoj**[2,3]**, V V Ghlukhov**[2,3]**, O O Bolotov**[2,3] **and L S Saparova**[2,3]

[1]Department «Theoretical and Structural Mechanics»
[2]Department «Branch Research Laboratory of The Dynamics and Strength of Rolling Stock»
[3]Dnipro National University of Railway Transport named after Academician V. Lazaryan, Lazaryan St., 2, Dnipro, Ukraine, 49010

[4]angela_Shvets@ua.fm

Abstract. The technical level of rolling stock of railway transport directly affects the economic indicators of the transport industry and the economy of the country as a whole, which leads to the need for improvement of the control, quantitative assessment of the dynamic loading of rolling stock to ensure safe and reliable communication at the railways. Therefore, in the process of designing and operating the rolling stock the quantitative assessment of dynamic loadings is a relevant scientific and technical problem. The purpose of this work is to study the influence of different types of rolling stock, taking into account the speed of movement on their main dynamic indicators and indicators of interaction of track and rolling stock. The basis of the research is the method of mathematical and computer simulation of the dynamic loading of a freight car using the model of spatial variations of the coupling of five cars and a software complex developed in the branch research laboratory of dynamics and strength of rolling stock (BRL DSRS). Theoretical studies have been carried out under condition of movement of several types of freight cars: a gondola car of the model 12-532, a hopper car for coal transportation of the model 12-4034 and a flat car with a long cargo of the model 13-401 and typical bogies 18-100 with the speeds from 50 to 90 km/h in the curves with radii 350 and 600 m, with superelevation 130 and 120 mm, correspondingly.

1. Introduction

Among the main directions of activity of the railway industry are the following: the development of high-speed trains; increased traffic safety; development of a new rolling stock and modernization of the existing fleet. The safety of freight trains, the values of permissible speeds and load capacity, the costs for maintenance of rolling stock and track facilities, increase of the runs between repairs essentially depend on the design of the freight rolling stock of the railways [1-3].

Increasing the speed of railway carriages will allow strengthening the integration processes between countries, satisfying the demand of the population in transportation, reducing the electricity and resources consumption, using the production capacity of the leading industries. However, this leads to the need for improvement of the control, quantitative assessment of the dynamic loading of rolling stock to ensure safe and reliable communication at the railways. Therefore, in the design process of rolling stock quantitative assessment of dynamic loadings is a relevant scientific and technical problem. Operation of the morally obsolete rolling stock with low dynamic properties is one

of the reasons for insufficient safety level of train traffic and high operating costs due to increased repairs, as well as increased energy consumption for traction of trains [4-6].

The purpose of this work is to study the influence of various types of rolling stock, taking into account the loading mode and the movement speed on their main dynamic indicators and indicators of interaction of the track and rolling stock.

2. Methodology

During operation of trains, primarily the ones with increased length and weight, particular attention is paid to the assessment of dynamic performance of carriages, among which the most important is the indicator characterizing the traffic safety of the carriage – the derailment stability coefficient of the wheel. In order to do this, the mathematical models of spatial oscillations of the car (or group of cars) moving in a train are used. The models of the rolling stock, as a rule, represent the variations of the system of differential equations in the second-order partial derivatives compiled according to the Lagrange–d'Alembert principle, which correspond to the set task. Using such models, the problem can be found analytically. Mathematical modeling makes it possible to determine the dynamic indicators of cars during their movement along the straight and curved track sections with real irregularities in the vertical and horizontal planes, taking into account the actual rolling surface of the wheel and the rail head profile [7-9].

The oscillations of a single car and its interaction with the railway track are considered on sufficiently full calculation schemes. Figure 1 presents the calculation scheme of a freight cat and shows positive directions for all displacements and rotation angles [10-12].
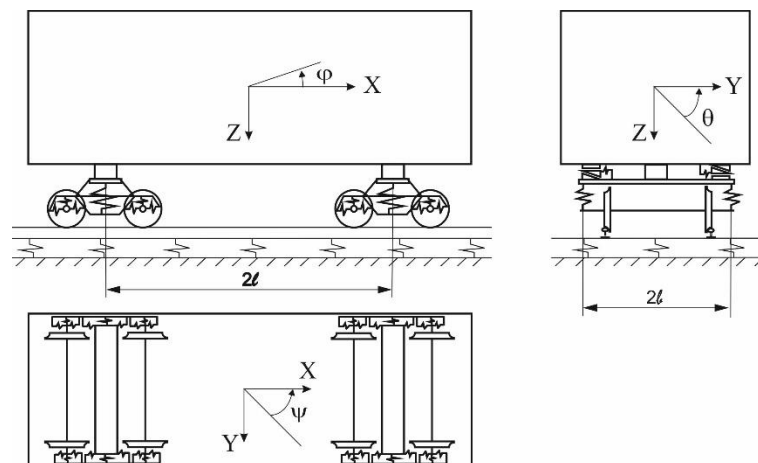

Figure 1. Calculation scheme of 4-axle gondola car.

The work [12] proposes a mathematical model describing the spatial oscillations of the car coupling in a train (Figure 2), one rail carriage of which is considered according to the fullest calculation scheme (called "zero"), and the calculation schemes of neighboring cars, depending on the task setting, are simplified as further is the distance from the "zero" carriage on both sides. A mechanical system with 58 degrees of freedom is taken as a calculation scheme of the "zero" carriage. The cars, adjacent to the "zero" one, are represented by a system with 12 degrees of freedom. In the calculation schemes describing the oscillations of these cars, the main features of freight car bogies are preserved – the side frames lozenging.

During the study of spatial oscillations of cars adjacent to the "zero" one, considered by the simplified calculation scheme, the following assumptions are introduced. It is assumed that the cars have single-stage spring suspension. Each of them consists of eleven solid bodies: a body, two bolsters, four side frames of a bogie and four-wheel sets. Unlike "zero" car, the track under adjacent cars is considered to be absolutely rigid in the vertical direction and elastic in the horizontal transverse direction. This assumption does not lead to increase in the number of degrees of freedom, since the

speed of rails displacement in the expressions for transverse forces can be neglected. Outer cars of coupling, these cars are the systems with six degrees of freedom.
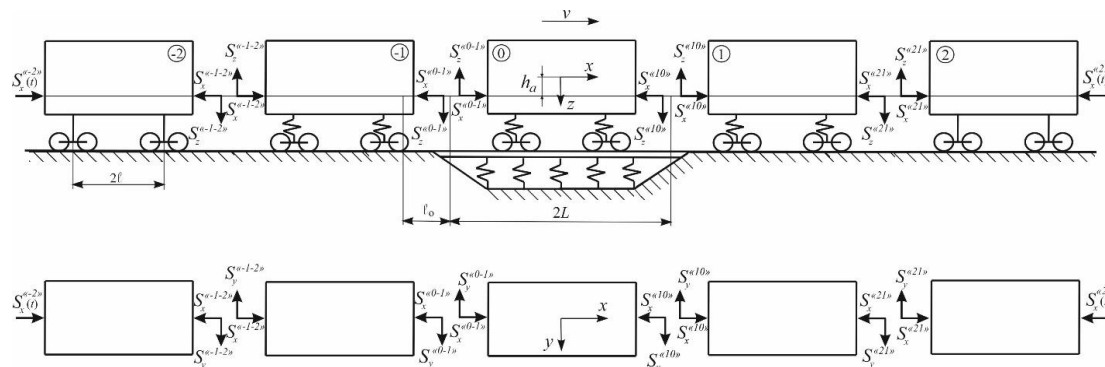

Figure 2. The forces arising from the action of longitudinal forces in the auto-coupling of cars.

The complement of the mathematical models of spatial oscillations by the initial data with the specified inertial characteristics of the car and cargo elements makes it possible to approximate the results of calculations to the real state of objects and thereby increase the objectivity of mathematical and computer simulation. It was for solving this problem that the "Software complex for determining the moments of inertia of car bodies" was created [11, 13].

Several types of freight cars are considered: gondola car of the model 12-532, hopper car for coal transportation of the model 12-4034 and flat car with a long cargo of the model 13-401 on typical bogies 18-100 under different loading conditions. In this case, the weight of the cars, the inertia moments of the body I_x, I_y, I_z and the height of the mass center of the body h above the level of rail heads (LRH) vary. Preparatory calculations, which are given in Table 1, are carried out with the help of "Software complex for determining the moments of inertia of car bodies".

Table 1. Inertia and geometric characteristics of cars at different loading modes.

Parameters	Designations	Name of cars		
		Gondola car of the model 12-532	Hopper for coal of the model 12-4034	Flat car of the model 13-401
Car base	$2L$, m	8.66	7.84	9.72
Car weight	M_o, t	76.5 (13.3)*	88.34 (18.72)	63.6 (13.6)
Inertia moments	I_x, t·m^2	75 (20)	160 (33.6)	22 (13.5)
	I_y, t·m^2	1050 (300)	1190 (300)	1194 (240)
	I_z, t·m^2	1100 (300)	1245 (307)	1223 (260)
Mass center height above the LRH	h, m	1.843 (1.6)	2.7 (1.77)	2.1 (1.1)

* – in brackets the values of cars` parameters in the empty mode are specified

3. Calculation results

Calculations can be made with sufficient accuracy for practice, limited to consideration of the movement of a group of five cars (Figure 2). The basis of the research is the method of mathematical simulation using the model of spatial oscillations of the coupling of five cars and a software complex developed by the BRL DSRS of the Dnipro National University of Railway Transport named after Academician V. Lazaryan. Theoretical studies have been carried out under the condition of movement of several types of freight cars: gondola car of the model 12-532, hopper car for coal transportation of

the model 12-4034 and flat car with a long cargo of the model 13-401 on typical bogies 18-100 with speeds in the range from 50 to 90 km/h along the curves with radii 350 and 600 m, with superelevation 130 and 120 mm, correspondingly. The rails – P65, wooden sleepers, broken stone ballast [13, 14].

In this study, the influence of several types of freight rolling stock on the railway track at different loading modes was considered. The graphs of changes of indicators under analysis when moving in the curved track sections of $R = 600$ m and 350 m are presented in Figure 3-6.
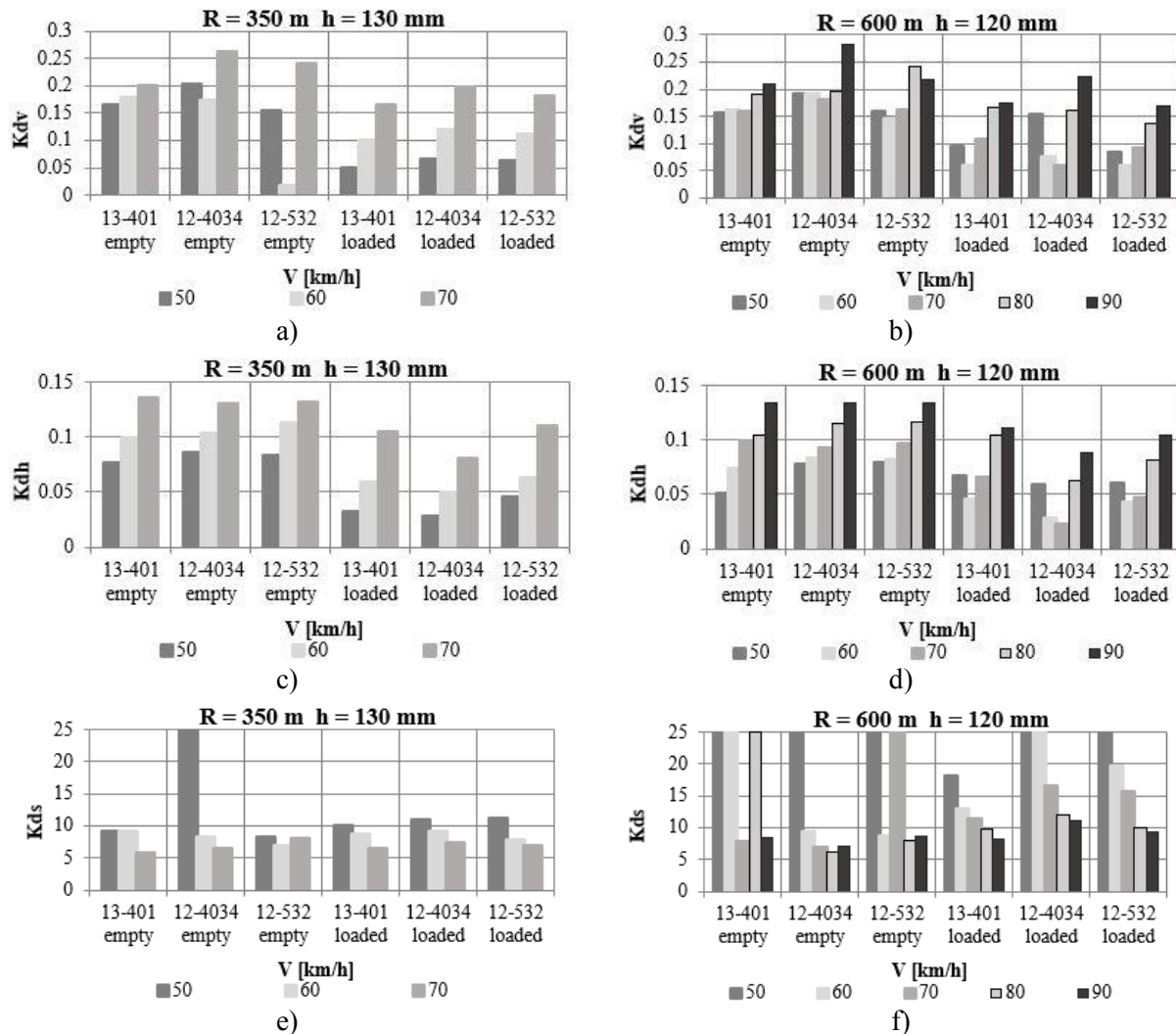

Figure 3. Dependence graphs on the loading mode when moving in the corresponding curve (a, b) coefficients of vertical dynamics; (c, d) coefficients of horizontal dynamics; (e, f) derailment stability coefficient.

As one can see from Figure 3 (a, b), in general, the coefficients of vertical dynamics increase. Thus, in the whole range of investigated speeds, the indicators K_{dv} in both loading modes do not exceed the permissible norm both in the curve of $R = 600$ m and in the curve of $R = 350$ m. The level of assessment in both curves corresponds to the "excellent" one. Only a gondola car in the curve of $R = 350$ m at the speed of 60 km/h has a much better vertical dynamic. Figure 3 (e, f), presents the coefficients of horizontal dynamics K_{dh} when moving in curves with a radius $R = 350$ m and 600 m, correspondingly. One can see that with increasing speed and loading mode, the coefficients of horizontal dynamics K_{dh} increase and remain in the curve of $R = 600$ m and in the curve $R = 350$ m

at the excellent level of assessment [14]. The loaded hopper car has the best coefficients of horizontal dynamics in both curves.

The coefficients of the derailment stability in the curve of $R = 350$ m (Figure 3, d) have little dependence on the loading mode, in contrast to the curve of $R = 600$ m (Figure 3, f), but in both cases do not exceed the minimum permissible value determined by the norms [1]. It follows from the obtained results, that the loaded hopper car in case of increase in the movement speed has higher indicators of coefficients K_{ds}, which can be explained by the increased car weight. In the curve of $R = 350$ m, the coefficient of derailment stability for hopper car at the speed of 50 km/h is the greatest. Flat car has the smallest indicators K_{ds}, which is explained by the large car base, which worsens curve negotiation.

Figure 4 presents the coefficients of vertical K_{vdt} and horizontal dynamics K_{hdt} of the track for the forces of interaction of wheels and rails, as well as the displacement stability coefficient of track panel when moving in the corresponding curved track sections.
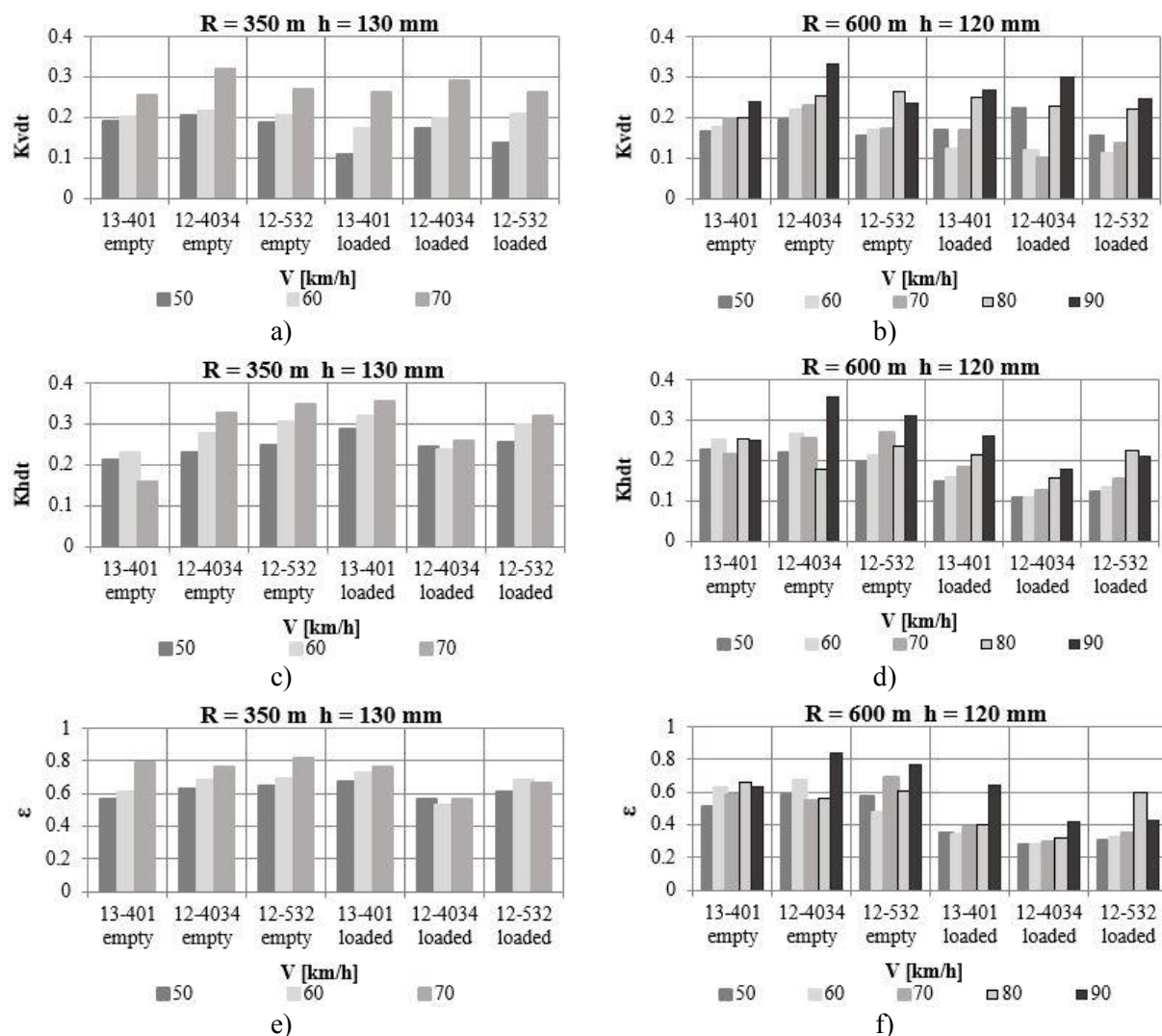

Figure 4. Graphs of dependence on the loading mode when moving in the corresponding curve: (a, b) coefficient of vertical dynamics of the track for the forces of interaction of wheels and rails; (c, d) coefficient of horizontal dynamics of the track for the forces of interaction of wheels and rails; (e, f) displacement stability coefficient of the track panel.

Permissible value of the vertical dynamics coefficient of the track K_{vdt} is calculated in accordance with the permissible dynamic loading per unit length on the railway track from the group of axles of the bogie 168 kN/m and for these types of rolling stock on the bogies of the model 18-100 is $[K_{vdt}] = 0.45$ [1]. The coefficient of vertical dynamics of the track K_{vdt} in Figure 4 (a, b) does not exceed the permissible value in curves with radius $R = 350$ m and 600 m.

The coefficient of horizontal dynamics of the track K_{hdt} in Figure 4 (d, e), which is considered a safety criterion for the displacement of track panel, does not exceed the permissible value $[K_{hdt}] = 0.4$ in the curves with a radius $R = 350$ m and 600 m.

The value of the stability coefficient of the track panel ε (Figure 4, c, d) in the track with broken stone ballast is much less than the permissible value. One should take $[\varepsilon]$ for the track with broken stone ballast at normal speeds of movement $[\varepsilon] = 0.85$ [14].

Figure 5 shows the influence of the speed on the indicators of interaction with the rolling stock in the curves with $R = 350$ m and $R = 600$ m, correspondingly – the side force acting from the track on the wheel, the edge stress at the rail base, the wear factor of the side edge of the wheel tread.
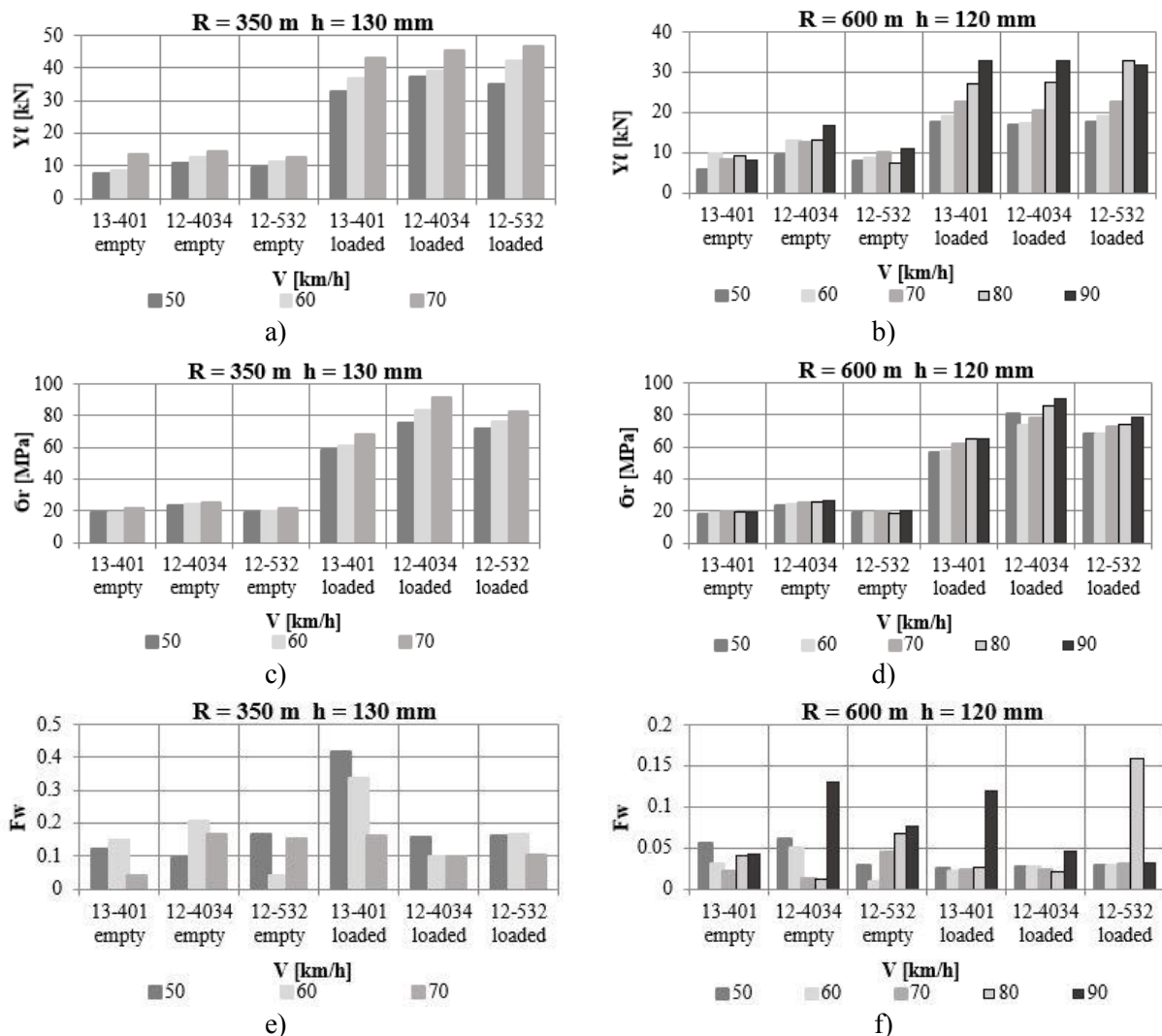

Figure 5. Graphs of dependence on the loading mode when moving in the corresponding curve: (a, b) side force acting from the track side on the wheel; (c, d) edge stress at the rail base; (e, f) the wear factor of the side edge of the wheel tread.

The side forces acting from the track on the wheel (horizontal forces) Y_L (Figure 5, a, b) increase and, in comparison with the permissible values of 100 kN, have no excess. The values Y_L for the gondola in both curves are on average higher than the corresponding values for the flat car and hopper.

The dynamic influence of rolling stock on the track increases with increasing the speeds of train movement, and, as a result, the stresses at the rail edges increase (Figure 5, c, d). The maximum stresses occurring at the edges of the rail bases are used as a criterion for establishing the permissible speeds and should not exceed 240 MPa for the track with rails P65 [14].

According to the results of calculations, the edge stresses increase with increasing the movement speed and do not exceed the permissible values for both loading modes in curves with a radius of $R = 350$ m and 600 m. The largest edge stresses arise when a hopper car moves in both empty and loaded state.

In the curve of $R = 350$ m at the speed of movement 50-60 km/h, the wear factor of the side edge of the wheel tread of the loaded flat car increases significantly. At the speed of 80 km/h, the wear factor of the side edge of the wheel tread F_w significantly increases for a gondola in the curve of $R = 600$ m. In turn, there is a significant F_w increase at the speed of 90 km/h in the curve $R = 600$ m for an empty hopper and a loaded flat car.

The wear factor of the side edge of the wheel tread F_w is determined as a characteristic equal to the product of the guiding force Y_d at the angle of hunting (climbing) ψ_{ws} of the wheel on the rail. Figure 6 shows the influence of speed on the indicators of rolling stock interaction with the track in the curves of $R = 350$ m and $R = 600$ m, correspondingly, guiding force acting on the wheel from the track side on the wheel and the wheel set hunting.

Guiding forces acting on the wheel Y_d from the track (Figure 6, a, b), with increasing the movement speed, significantly increase in the curve of $R = 350$ m and, on average, have identical values for all types of rolling stock. The values Y_d in the curve of $R = 600$ m at the speeds of 80-90 km/h vary significantly for all types of studied rolling stock.
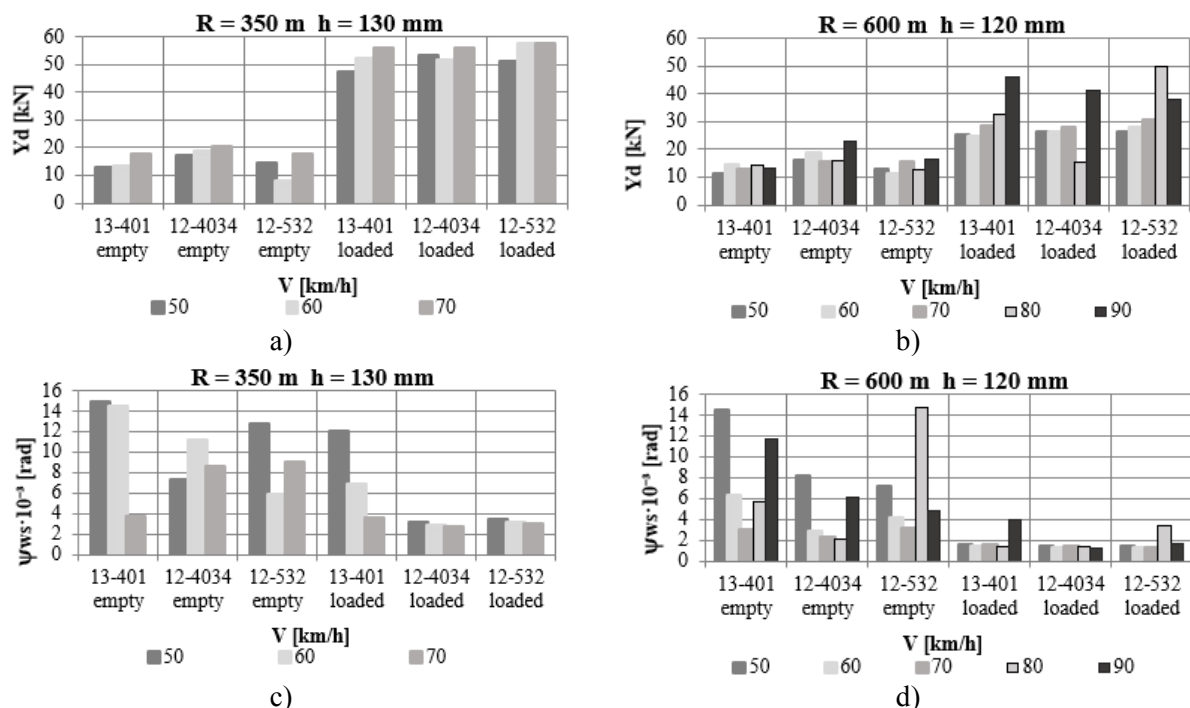

Figure 6. Graphs of dependence on the loading mode when moving in the corresponding curve: (a, b) guiding force acting from the track side on the wheel; (c, d) wheel set hunting.

The results of calculations show (Figure 6, c, d) that in the curves of $R = 350$ m and $R = 600$ m in the empty mode, at the speeds up to 90 km/h, a flat car has the largest angle of wheel set hunting ψ_{ws}. At the speeds of 80 km/h in the curves of the average radius $R = 600$ m, the values ψ_{ws} increase for the gondola and significantly differ from the other range of the investigated speeds. For gondola-cars on the bogies of the model 18-100, the speed of 80 km/h is critical and associated with the loss of movement stability, when the dynamic transverse oscillations of the hunting of the car parts stop damping, becoming steady (self-oscillations) [15].

4. Conclusions

In papers presents an analysis of theoretical studies of dynamic qualities of various types of rolling stock; the calculations were performed with the use of a package of applied programs. Based on the study, the following conclusions can be made:

- in all range of speeds the indicators K_{dv} and K_{dh} in both loading modes increase and do not exceed the permissible norm both in the curve of $R = 600$ m and in the curve of $R = 350$ m. The gondola in the curve of $R = 350$ m at the speed of 60 km/h has considerably better vertical dynamics, and the loaded hopper car has better coefficients of the horizontal dynamics in both curves;

- the derailment stability coefficients of the wheels in the curve have little dependence on the loading mode, in contrast to the curve of $R = 600$ m, but in both cases they do not exceed the minimum permissible value determined by the norms. The loaded hopper car, in case of the speed increase, has higher indicators of the coefficients K_{ds} which can be explained by the increased car weight. In the curve of $R = 350$ m, the derailment stability coefficient of the wheels for hopper at the speed of 50 km/h is the greatest. Flat car has the smallest indicators K_{ds} which is explained by the large car base that worsens curve negotiation;

- the coefficients of the vertical K_{vdt} and horizontal dynamics K_{hdt} of the track do not exceed the permissible value in the curves with radius of $R = 350$ m and 600 m. The loaded flat car has the smallest values of the track panel`s stability coefficient ε in the track with broken stone ballast;

- side forces Y_L increase linearly and have no excess, and the values Y_L for gondola cars in both curves on average are larger than the corresponding values for the flat car and hopper;

- edge stresses increase with increasing speed and do not exceed the permissible values for both modes of loading in the curves with radius of $R = 350$ m and 600 m. The largest edge stresses arise when hopper car moves in both empty and loaded condition;

- the wear factor of the wheel tread`s side edge of the loaded flat car significantly increases in the curve of $R = 350$ m at the speed of 50-60 km/h. The wear factor $F_w$ of the wheel tread`s side edge significantly increases for gondola car in the curve of $R = 600$ m at the speed of 80 km/h. In turn, there is a significant F_w increase for the empty hopper and the loaded flat car at the speed of 90 km/h in the curve of $R = 600$;

- guiding forces acting on the wheel from the track side Y_d significantly increase with the speed increasing in the curve of $R = 350$ m and have on average equal values for all types of rolling stock. The values Y_d in the curve of $R = 600$ m at the speeds of 80-90 km/h vary considerably for all types of the studied rolling stock;

- flat car has the largest angles of wheel set hunting ψ_{ws} in the curves of $R = 350$ m and $R = 600$ m in the empty mode at the speeds up to 90 km/h. At the speeds of 80 km/h in the curves of the average radius $R = 600$ m, the values ψ_{ws} increase for the gondola car and significantly differ from the other range of the studied speeds.

The paper presents an analysis of theoretical studies of dynamic qualities of various types of rolling stock; the calculations were performed with the use of a package of applied programs.

The obtained results have a practical orientation. During the theoretical studies and after the simulation, taking into account the oscillation processes of freight car, the dependences of the main dynamic indicators and interaction indicators of rolling stock and track, taking into account the speed and loading mode, were obtained. Application of the obtained results will increase the traffic safety of freight cars and will improve the technical and economic performance of railway transport.

References

[1]   Pshinko O, Ursulyak L, Kostrytsia S, Fedorov Ye and Shvets A 2019 The influence of the «train-track» system parameters on the maximum longitudinal forces' level *Transport Problems* **4** 14 pp 161–172

[2]   Kurhan M B and Kurhan D M Providing the Railway Transit Traffic Ukraine–European Union *Pollack Periodica* **14** 2 pp 27–38

[3]   McKinnon A C 2016 Freight Transport Deceleration: Its Possible Contribution to the Decarbonisation of Logistics *Transport Reviews* **36** 4 pp 418–436

[4]   Kostritsa S A, Sobolevska Y H, Kuzyshyn A Y and Batih A V 2018 Mathematical model of DPKR-2 dyzel train car *Science and Transport Progress* **1** 73 pp 56–65

[5]   Shvets A O 2020 Stability of freight cars under the action of compressive longitudinal forces *Science and Transport Progress* **1** 85 pp 119–137

[6]   Lunys O, Neduzha L and Tatarinova V 2019 Stability research of the main-line locomotive movement *Proc. of the 23rd Int. Sci. Conf. Transport Means 2019* pt III (Palanga, Lithuania: Kaunas Univ. of Techn.) pp 1341–1345

[7]   Kurhan D 2016 Determination of Load for Quasi-static Calculations of Railway Track Stress-strain State *Acta Technica Jaurinensis* **9** 1 pp 83–96

[8]   Ursulyak L V and Shvets A A 2017 Improvement of Mathematical Models for Estimation of Train Dynamics *Science and Transport Progress* **6** 72 pp 67–79

[9]   Klimenko I, Černiauskaite L, Neduzha L and Ochkasov O 2018. Mathematical Simulation of Spatial Oscillations of the "Underframe-Track" System Interaction *Proc. of 12th Int. Conf. ITELMS'2018* (Panevèžysm, Lithuania: Kaunas Univ. of Techn.) pp 105–114

[10]   Myamlin S, Neduzha L and Urbutis Ž 2016 Research of Innovations of Diesel Locomotives and Bogies *Proc. Eng.* **134** (Vilnius, Lithuania: Vilnius Gediminas Techn. Univ.) pp 469–474

[11]   Shvets A O and Bolotov O O 2019 Influence of loads from the axis of a gondola car on its dynamic indicators and railroad tracks *Science and Transport Progress* **1** 79 pp 151–166

[12]   Danovich V D and Malysheva A A 1998 Mathematical model of spatial oscillations of the coupling of five cars moving along a rectilinear section of the track *Transport. Stress loading and durability of a rolling stock* (Dnepropetrovsk: Dnipro National University of Railway Transport named after Academician V. Lazaryan) pp 62–69

[13]   Shatunov O V and Shvets A O 2019 Study of dynamic indicators of flat wagon with load centre shift *Science and Transport Progress* **2** 80 pp 127–143

[14]   Danilenko E I 2010 *Railway track [Zaliznychna kolija]* (Kiev: Inpres) p 456

[15]   Lazaryan V A, Dlugach L A and Korotenko M L 1972 *Ustoychivost dvizheniya relsovykh ekipazhey* (Kiev: Naukova dumka) p 197