SAFETY ON A BRIDGE AT HIGH SPEEDS

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ABSTRACT

The article investigates a problem of steady movement of wheels of rolling stock of high-speed rail in the area of bridge crossing at speeds up to 350 km / h. The author justifies the use of a mathematical model that considers as elements the rolling stock, track superstructure, spans and adjoining track on the roadbed. It is shown that high-speed rail specifically requires an integrated approach to structures of both bridge spans, and track superstructure to ensure the safety and preservation of the dynamic properties of engineering structures and the machinery used.

ENGLISH SUMMARY

Background. *Force of interaction between wheel and rail is an important indicator of traffic safety. When there is an insufficient vertical force pressing the wheel to the rail wheel flange may roll in the rail head under the influence of lateral forces, which can result in derailing. At high speeds it will lead to the collapse with severe consequences, especially in the area of the bridge.*

In studies of bridge spans fluctuations, a relatively simple model is used, which presents vehicles and beams of span structures. Such a model is still used [6] and its application to the study of oscillations of superstructures could be justified. However, the absence of a rail in the model makes it impossible to study the stability of the wheel movement and the evaluation of transport safety. Therefore, MIIT University has developed a detailed mathematical model that includes beam spans, track superstructure, vehicles with two-level springing (BTV system) [1, 2, 3].

Objective. *The objective of the author is to investigate a problem of steady movement of wheels of rolling stock of high-speed rail in the area of bridge crossing at speeds up to 350 km / h.*

Methods. *The author uses analysis, mathematical modeling, descriptive method, numerical experiment, and comparison.*

Results. *Evaluation of safety of entering of the wheel flange on the rail is proposed in [1], based on [4]. According to the latest work force ratio of vertical and horizontal wheel and rail interaction determining the sustainability of the wheel on the rail must be considered with account of the time of unfavorable combination of these forces, as well as other factors. It is established [4] that for locomotives at a ratio of lateral force to vertical of less than 1,48 traffic safety is ensured, regardless of the duration of unfavorable combination; index over 9,56 means that the safety is not provided in case of an arbitrarily small duration of unfavorable combination. In [1] it is shown that the same safety, for example, for rolling stock EPS-2, is available at the value of the vertical force of not less than 56,25 kN, regardless of the exposure duration. If a vertical force is less than 23,814 kN derailment is inevitable.*

It is generally accepted that an increase in the rigidity of superstructures, leading to a decrease in their deflections under load, has a positive effect on the interaction of rolling stock and track (both upper and lower superstructures). Pic. 1, which demonstrates the results of numerical experiments of passage of 6-car high-speed train through the single-span bridge, clearly shows that by increasing the stiffness factor of the span by 2,5 times (stiffness factor has been increased from 4 to 10) dynamic deflections are reduced from 24 mm (L / 750) to 4,2 mm (L / 4300).

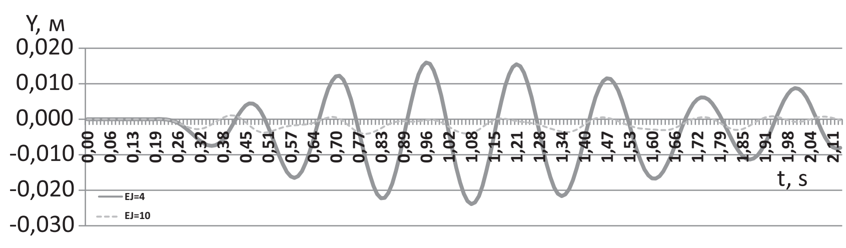
The natural frequencies of the first vibration modes for the beam spans with the length of 18–33 m are 4–10 Hz [5], for the vehicle body they are 2–3,5 Hz [4], the excitation frequency of the oscillations reaches 3,8 Hz (with a vehicle length of 26 m and speed of 97 m /s). For one block of a model span with a length of 18 m stiffness factor, i. e. the product of the modulus of elasticity for the reduced moment of inertia without exponent, is EJ = 4 and the first natural frequency will be 4,3 Hz – this option is considered as the base for comparison. A similar span with EJ = 10 has the first natural frequency of 6, 8 Hz.

Fluctuations in the middle of the span of different stiffness in case of the passage of 6 cars at a speed of 97 m / s are shown in Pic. 1. As it can be noted, the increase in stiffness of the superstructure has led to an increase in the frequency of natural oscillations of the first form, the removal of the mode of oscillations from the resonance zone of amplitude-frequency characteristics of the superstructure and reduction of the oscillations amplitude. Does it mean an increase in safety?

We consider safety conditions for different vehicles. Table 1 presents maximum and minimum values of the vertical force between wheel and rail for individual units of a train, consisting of 6 cars, and Pic. 2 shows force in the contact of one of the wheels with the rail.

As it can be seen from the table, safety conditions set forth in this article, are not observed for 2–5 cars at span EJ = 4 and 3–5 cars at span EJ = 10, since the force between wheel and rail is below 23,814 kN.

Thus, tightening deflections standards of superstructures does not give a positive effect in terms of traffic safety. Solution should be sought in together in complex dynamical parameters and track superstructures.



Pic. 1. Fluctuations in the middle of the span of different stiffness in case of the passage of 6 cars at a speed of 97 m/s.

Table 1

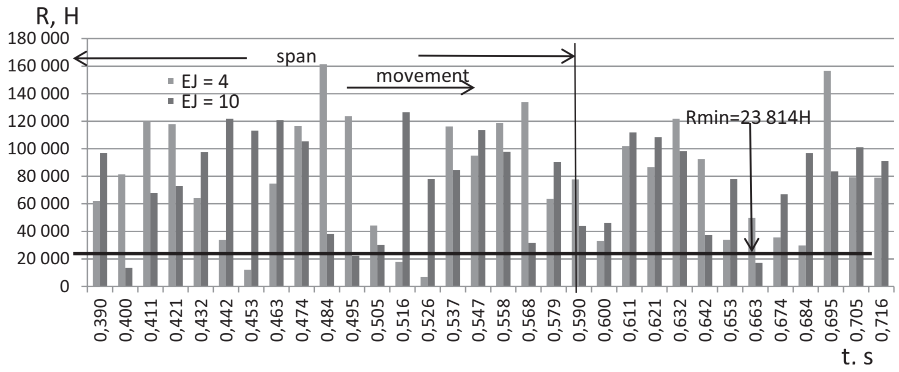
Extreme values of forces between wheel and rail when passing through a single-span bridge, kN

Car №	1	2	3	4	5	6
Superstructure EJ=4						
Rmin	34,5	20,6	15,9	18,4	17,3	31,5
Rmax	116,2	133,0	139,1	161,7	184,4	161,3
Superstructure EJ=10						
Rмin	44,3	32,2	17,5	15,5	21,8	27,7
Rмax	115,9	147,7	142,7	148,2	157,2	196,8

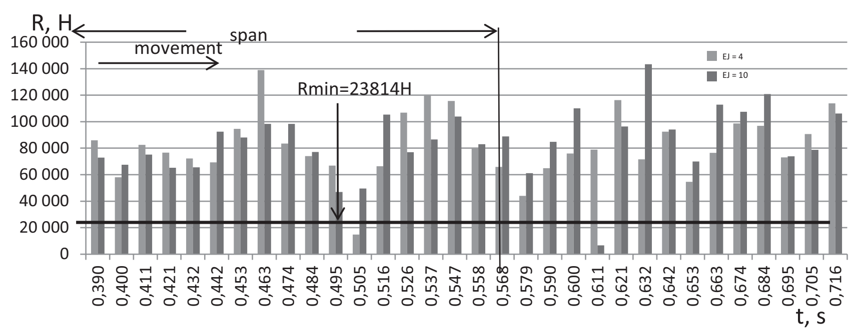
Table 2

Extreme values of forces between wheel and rail when passing through a single-span bridge with a ride on the ballast, kN

Car №	1	2	3	4	5	6
Base version						
Rmin	34,5	20,6	15,9	18,4	17,3	31,5
Rmax	116,2	133,0	139,1	161,7	184,4	161,3
Version with a check rail						
Rmin	47,8	29,4	32,0	38,2	31,7	19,3
Rmax	118,8	119,6	125,0	135,9	138,5	139,7



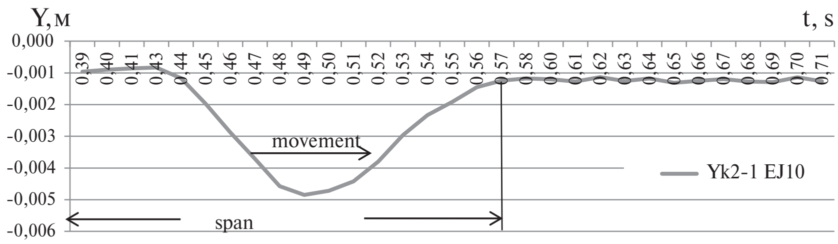
Pic. 2. Force in the contact area of one of the wheels with the rail if the stiffness of bridge girders differs.



Pic.3. Force in the contact area of the wheel and the rail in around the flange rail if stiffness of bridge ginders differs.

In [1] the authors developed a theory of optimal control of dynamic processes by means of fixed options for changing track parameters along the length of the bridge. Local change in stiffness of a rail bar is an example of such a control. Technically stiffening of a rail bar is achieved by setting check rails having a hard clamp to sleepers. In the required places the flexural rigidity of a check rail may be zero if there are no joints of check rails.

Application of check rails significantly improves stability of a wheel on a rail (Table 2). However, it is impossible to completely solve the problem of safety:



Pic. 4. Oscillations of the wheel №2 while passing the bridge.

for the sixth car vertical force of interaction between wheel and rail is not enough to prevent the rise of the wheel flange on the rail, because it is less than 23,814 kN.

Pic. 3 and 4 illustrate forces in the contact of one of wheels with the rail regarding different stiffness of the superstructure and the wheel oscillations during passage through the bridge with the beam stiffness EJ = 10. See Pic. 3 it is clear that increase in the stiffness of the span significantly reduces the variability of the force in the contact of a wheel and a rail, although in both cases there is one time interval of 0,01 seconds when safety conditions are violated. Comparison with Pic. 2, where the violation of safety conditions is repeated in the interval to 0,02 seconds, shows that the proposed measure improves the interaction of the wheel and the rail.

Pic. 4 shows the stability of methods of numerical experiments; wheel oscillations die out. It is also notable that when entering the superstructure within the time interval of 0,39–0,44 s wheel lifting (Y values are less than 1 mm) occurs due to the phase of the oscillation of the superstructure (see fragment of Pic. 1 for on the same interval).

Conclusion. *The described results prove that the solution of the high-speed traffic safety problem can be achieved by the joint optimization of dynamic properties of both bridge spans and track superstructure.*

Keywords: railway, high-speed rail trains, bridge spans, roadbed, traffic safety, mathematical model, engineering calculation.

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