METHOD OF SELECTING OPTIMAL PARAMETERS OF SEISMIC-PROOF BEARING PARTS OF BRIDGES AND OVERPASSES ON HIGH- SPEED RAILWAY LINES

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Abstract: ***The article deals with the issues of ensuring seismic stability of high-speed railway overpasses, taking into account the experience of their design and construction in developed foreign countries. The review of technical solutions for ensuring earthquake resistance of overpasses and bridges located on high- speed and high- speed railway lines in the world and in the Republic of Uzbekistan is carried out. The method of selecting the optimal parameters of earthquake-proof bearing parts of bridges and overpasses on high-speed railway lines is presented. The article proposed a new solution of dynamic oscillation damping of the bridges, wherein the dampening mass (superstructure) is located between the two protected objects (supports) and dampens their oscillation. Thanks to this approach, several times reduces the seismic load on the supports of the girder bridges in high-speed lines.***
Keywords: ***Bridges, overpasses, design, construction, transport networks, high-speed Railways, seismic resistance, system "superstructure-support", seismic resistance of supports.***

1. INTRODUCTION. Starting from the 60s of the XX century in the developed countries of Europe, America and Asia, the construction and operation of high-speed railways (HSR), designed both for the transport of passengers and goods, has been going on. these transport facilities fully fit into the spirit and need of modern realities and have shown their relevance and effectiveness (Fig. 1)

At present, HSR networks are created on the railways of Japan, China, France, Germany, Italy, Spain, and Great Britain. Western European countries have combined their high-speed highway networks into a common system with a total length of about 15 thousand km, and in China, at present, the length of the high-speed highway network reaches more than 40 thousand km. On these highways, traffic is usually carried out at an average speed of 250–300 km/h [1].

Figure1. High-speed railway on the overpass (PRC. 2010)

2. MAIN PART. In high-speed highways, in contrast to the usual non-high-speed traffic, it is required to use a powerful upper track structure (including on bridges and overpasses) with long length jointless rail lashes. The need to use a welded jointless path on bridges is explained by the desire to improve the conditions for the interaction of the track and rolling stock, reduce the vibrodynamic effects on bridges or overpasses due to the presence of rail joints, and increase the comfort and safety of travel [2-4].

As is known, the territory of the Republic of Uzbekistan is a seismic hazard zone. With the introduction of new high-speed railway lines in the country, it became necessary to ensure not only the bearing capacity, but also the seismic resistance of bridge structures.

In the regional conditions of the Republic of Uzbekistan, among the problems posed by high-speed traffic to design and scientific organizations, a large place is occupied by the problem of the dynamic behavior of railway bridges and overpasses under the vertical and horizontal effects of train loadsin combination with seismic impact.

Taking into account the experience of building high-speed rail in developed foreign countries, it can be stated that holding high-speed rail at a certain height (20-40 m) above the earth’s surface, i.e. on overpasses, may be the most rational and efficient in economic terms. Such a solution will meet modern requirements in the field of construction of transport facilities [7,11-13].

In bridge structures, under the influence of rolling stock, oscillations occur, characterized by amplitude, frequency, speed and other parameters. The nature of the oscillatory process depends on the type, condition and properties of the soil of the subgrade, the design of the upper track structure, speed, axial, linear loads and other factors [5, 6].

It should be noted that the more vulnerable part of the bridges is the supports. For this, in order to maintain bridge supports from seismic loads, it is necessary to correctly select the settings of the absorbers (seismic insulating bearing parts) [9].

Bridges, overpasses, as well as other artificial structures on railways, are among the so-called barrier objects, and their anti-seismic reinforcement is given priority. The requirements for the seismic resistance of bridges, overpasses and other transport structures are set forth in the current standards of all countries subject to seismic influences, including our country.

An analysis of foreign earthquake-resistant transport construction showed that one of the most seismically hazardous areas is Japan. The result of the proper quality of the design and construction of the HF of Japan was that the vast majority of their structures and devices did not receive serious damage during the strong earthquake of 2011. Nevertheless, its consequences for high-speed highways were carefully studied. Based on the analysis, to date, Japan has developed new, more stringent standards for the design and construction of transport facilities on the high-speed rail.

In parallel with the tightening of design standards and improving the quality of construction in Japan, in recent years, measures have been taken to equip high-speed rolling stock and the HSR track complex with various devices designed to reduce the negative consequence scar derailment due to seismic shocks or other reasons.

One of the most important tasks in this situation is to keep the rolling stock within the rail gauge, to prevent it from reaching the oncoming path or overturning. At present, several designs of devices designed for this purpose have become widespread in Japan. one of them provides for the installation on steel axle boxes of wagons of wagons of steel safety, restrictive elbows (Fig. 2), which, in the event of a wheel pair coming off the rails, rest against the rail and do not allow the wheel pair to go beyond the sleepers (plates) [1].

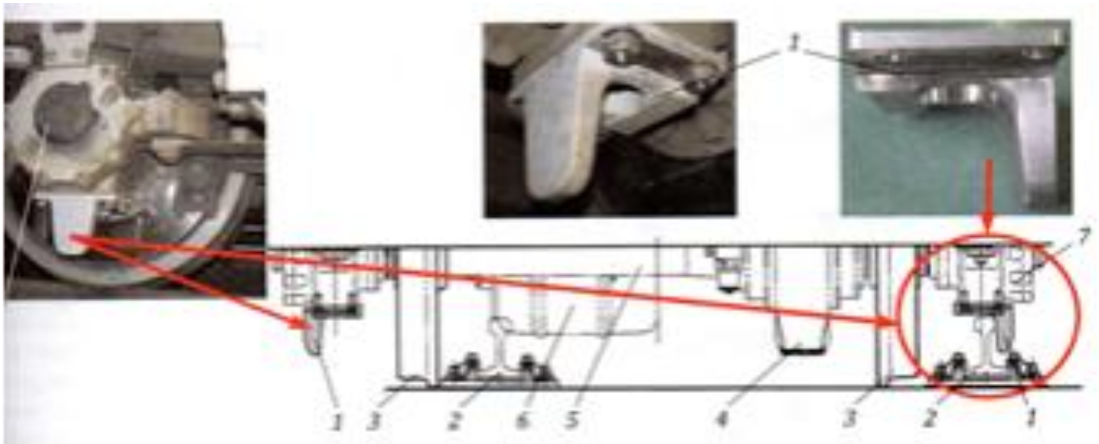

Figure 2. Safety, restrictive squares on the axle boxes of carriages of high-speed Japanese train cars/

1-restrictive elbow; 2–rail; 3–wheel; 4–traction reducer on the axis of the wheel set; 5–axis of the wheel set; b–traction engine; 7–axle box

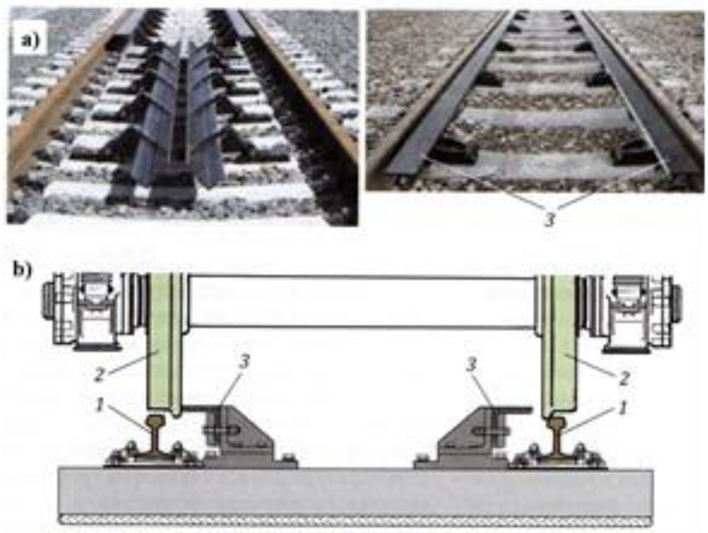

Figure 3. Counter rails in the form of corners on the Japanese high-speed rail:
a – general view of the path; b – transverse section: 1 – rails; 2-wheel pair;

3 - counter rails in the form of corners, reclining to the center during the performance of work on maintenance of the track

In some cases, counter rails, well known in world practice, are installed between the rails in the form of a longitudinal structure from a corner profile (Fig. 3), which prevent the wheel from rolling out onto the rail head. The descent of the rolling stock from the rails, its exit onto the oncoming track is a dangerous possible consequence of a seismic shock [1].

Currently operated high-speed and high-speed railway lines in the Republic of Uzbekistan combine conventional transportation, i.e. these highways are also used for non-high-speed freight and passenger trains (Fig. 4). This situation of railway networks does not meet the international standards set by the HSR. In this regard, the issue of designing and building a separate railway line is currently relevant (Fig. 5), intended only for high-speed traffic and located on reinforced concrete overpasses. Of course, the construction of this overpass should be designed taking into account the seismic conditions of the Republic of Uzbekistan, as well as taking into account the world experience in the field of earthquake-resistant transport construction [3-4,14-17].

Figure 4. High-speed electric train "Afrosiyob" (Talgo, Spain)

It is known that the consideration of seismic conditions in the design of the overpass structure consists in the development of optimal solutions for the structural elements of the overpass – supports and superstructures. In addition to them, the bearing parts that transmit static and dynamic loads to the supports, as well as the rolling stock that causes forced vibrations of the superstructures, participate in the work. This is the system that is subject to seismic impact. Therefore, it is very important and relevant to select the optimal parameters of the bearing parts intended to increase the seismic resistance of the overpass structure. In this regard, the developed methodology for selecting the optimal parameters of earthquake-proof bearing parts of bridges and overpasses on high-speed Railways is described below.

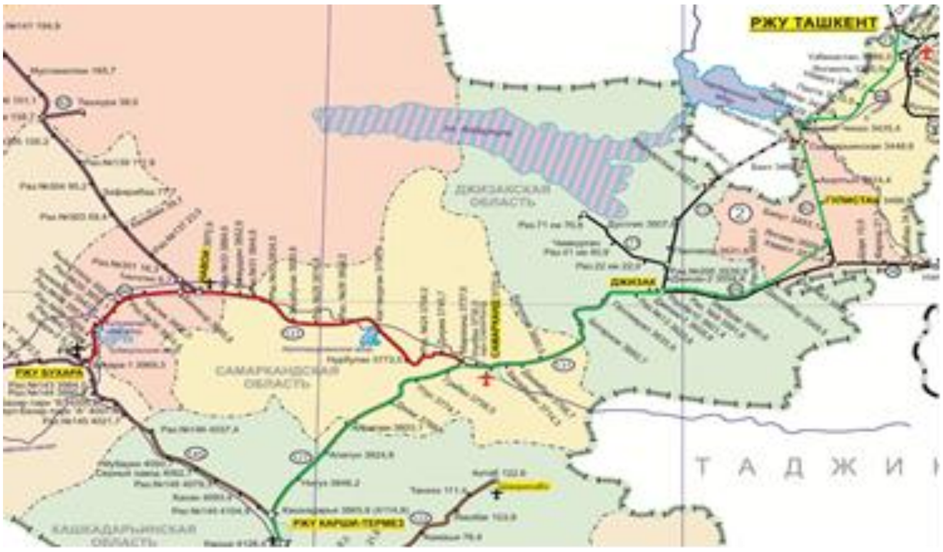

Figure 5. High-speed railway scheme of the Republic of Uzbekistan

Tashkent- Samarqand – Karshi high-speed line (500 км)

Tashkent – Bukhara high-speed line (592 км)

3. METHOD OF SOLVING THE PROBLEM. Considering the overpass as a single system "rolling stock-span - support" implies the need to analyze the work of not only the spans, but also the supports.

The new solution of the three – mass system problem presented in this article is a modification of the two-mass system. Currently, the three-mass system is the optimal solution for increasing the seismic resistance of transport structures using dynamic vibration dampers. It makes it possible to solve the problem of optimal selection of flexible connections, i.e. the selection of optimal characteristics of the system components ' stiffness. The proposed system is a new solution for dynamic damping of bridge support vibrations, where the damping mass is a superstructure located between two protective objects, i.e. supports and dampens their vibrations.

The three-mass system includes the abutments and the Central part, characterized in that each of the parts is combined into a separate temperature-continuous system, and the Central part is connected to the abutments by a malleable connection. In this case, the Central part does not have fixed bearing parts, and the rigidity of the flexible joints is selected according to the proposed method below. The design scheme of the three-mass system is shown in Fig. 6.

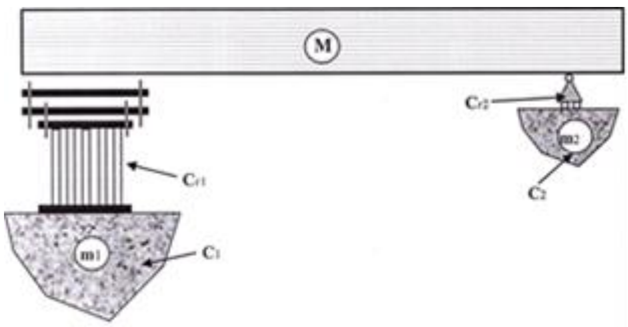

Figure 6 - The design scheme of the three-mass system

C_1 – the rigidity of the support of the left abutment; C_2 – rigidity of support of the right foundation;

$C_г$, $C_{г2}$ – respectively, the stiffness of the vibration damper; m_1 – is the mass of the left abutment;
m_2 – mass of the right abutment; M – is the mass of the central part, i.e. the superstructure.

In the accepted notation, the diagonal matrix of masses of oscillations of the system takes the form

$$M = \begin{Vmatrix} M & 0 & 0 \\ 0 & m_1 & 0 \\ 0 & 0 & m_2 \end{Vmatrix}; \quad (1)$$

From the above mass scheme, we construct the stiffness matrix

$$C = \begin{Vmatrix} C_{г1} + C_{г2} & -C_{г1} & -C_{г2} \\ -C_{г1} & C_1 + C_{г1} & 0 \\ -C_{г2} & 0 & C_2 + C_{г2} \end{Vmatrix}; \quad (2)$$

From the above mass scheme, we construct the stiffness matrix

$$\begin{cases} \ddot{q}_1 + (k_{г1}^2 + k_{г2}^2)q_1 - k_{г1}^2 q_2 - k_{2г}^2 q_3 = -\ddot{y}_o \\ \mu_1 \ddot{q}_2 - k_{г1}^2 q_1 + (k_1^2 + k_{г1}^2)q_2 = -\mu_1 \ddot{y}_o \\ \mu_2 \ddot{q}_3 - k_{г2}^2 q_1 + (k_2^2 + k_{г2}^2)q_3 = -\mu_2 \ddot{y}_o \end{cases} \quad (3)$$

We denote the natural frequencies of the fundamental tone of the oscillations of the right and left abutment

$$\frac{C_1}{m_1} = k_{10}^2; \qquad \frac{C_2}{m_2} = k_{20}^2; \quad (4)$$

And the natural frequencies of the damper of the central part are equal

$$k_{г1}^2 = \frac{C_{г1}}{M}; \qquad k_{г2}^2 = \frac{C_{г2}}{M}; \quad (5)$$

In the formula (3) we replace k_1^2 и k_2^2 and, as follows

$$k_1^2 = \frac{C_1}{M} = \frac{C_1}{m_1} \cdot \frac{m_1}{M} = k_{10}^2 \mu_1; \qquad k_2^2 = \frac{C_2}{M} = \frac{C_2}{m_2} \cdot \frac{m_2}{M} = k_{20}^2 \mu_1; \quad (6)$$

where, $\mu_1 = \dfrac{m_1}{M}$; $\mu_2 = \dfrac{m_2}{M}$ – mass ratio of inertia.

The setting of dynamic oscillation dampers is determined by the ratio of the natural frequencies of the main vibration tone of the dampener (superstructure) and the natural frequencies of the main vibration tone of the support (right and left abutment) [8-10]:

$$\left(\frac{k_{г1}}{k_{10}}\right) = f_1; \qquad \left(\frac{k_{г2}}{k_{10}}\right) = f_2; \quad (7)$$

The solution for the three-mass system was found in dimensionless form, while the mass matrix and stiffness matrix are written as follows

$$M = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \mu_1 & 0 \\ 0 & 0 & \mu_2 \end{pmatrix} \quad (8) \qquad R = \begin{pmatrix} f_1^2 + f_2^2 & -f_1^2 & -f_2^2 \\ -f_1^2 & \mu_1 + f_1^2 & 0 \\ -f_2^2 & 0 & \kappa^2 \cdot \mu_2 + f_2^2 \end{pmatrix} \quad (9)$$

We introduce a parameter χ equal to the ratio of the natural frequencies of the Central part of the extinguisher:

$$\frac{k_{г2}}{k_{г1}} = \chi \qquad f_2 = \frac{k_{г2}}{\omega} = \frac{k_{г2}}{k_{г1}} \cdot \frac{k_{г1}}{\omega} = \chi \cdot f_1 \qquad (10)$$

Using the parameter χ, we bring system (9) to the form

$$\begin{pmatrix} f_1^2 + \chi^2 f_1^2 - 1 & -f_1^2 & -\chi^2 f_1^2 \\ -f_1^2 & f_1^2 & 0 \\ -\chi^2 f_1^2 & 0 & \kappa^2 \mu_2 + \chi^2 f_1^2 - \mu_2 \end{pmatrix} = 0 \qquad (11)$$

When analyzing seismic vibrations of bridges, it becomes necessary to take into account damping parameters for each structural element.

In matrix form, the system of equations of vibration with damping takes the form

$$\mathbf{M\ddot{H}} + \mathbf{RH} + \mathbf{B\dot{H}} = -\mathbf{M\ddot{Y}}_0, \qquad (12)$$

where, M = (m1, m2 ... m_n (is the diagonal inertia matrix, R is the stiffness matrix.

H – is the vector of generalized coordinates; $\ddot{\bar{y}}_0$ – Is the vector of kinematic perturbations, $\ddot{\bar{y}}_0 = V_p \cdot \ddot{y}_0$; $\ddot{y}_0$ – acceleration of the base;

B – is a viscous damping matrix of the system composed of damping coefficients; b_{ij} ;

$V_p = \begin{pmatrix} 1 \\ 1 \\ 1 \end{pmatrix}$ - a vector of projections of effects on the directions of generalized coordinates [2, 3].

The hysteresis damping matrix for the system in question is as follows

$$\boldsymbol{B_c} = \begin{pmatrix} f_1^2 \cdot \gamma_1 + f_2^2 \cdot \gamma_2 & -f_1^2 \cdot \gamma_1 & -f_2^2 \cdot \gamma_2 \\ -f_1^2 \cdot \gamma_1 & \mu_1 \cdot \gamma_1 + f_1^2 \cdot \gamma_1 & 0 \\ -f_2^2 \cdot \gamma_2 & 0 & \kappa^2 \cdot \mu_2 \cdot \gamma_2 + f_2^2 \cdot \gamma_2 \end{pmatrix} \qquad (13)$$

As a result of the solution, the author obtained the settings of the seismic protective bearing parts, which have the following form:

$$f_1 = \sqrt{\frac{Cг_1^2\left(C_2^2 m_1^2 - C_1^2 m_2^2\right)}{Cг_2^2 \cdot (C_2^2 m_1^2 - C_1^2 m_2^2 - MC_1^2 m_2)}} \ ; \quad f_2 = \chi\sqrt{\frac{Cг_1^2\left(C_2^2 m_1^2 - C_1^2 m_2^2\right)}{Cг_2^2 \cdot (C_2^2 m_1^2 - C_1^2 m_2^2 - MC_1^2 m_2)}} \qquad (14)$$

So, according to the formula (14), it is possible to determine the values of the settings of the dynamic vibration dampener of the left and right abutments and in accordance with them to select the stiffness characteristics of the elements of the three – mass system “rolling stock-superstructure-support”.

CONCLUSIONS. Reviewed in improving the earthquake resistance of viaducts for high speed railway lines, as well as the technique of selection of optimal parameters seismic bearing parts reference parts racks allows you to make the following conclusions:

1. The three-mass system is a new solution for dynamic damping of bridge support vibrations, where the damping mass is a superstructure located between two protective objects, i.e. supports and dampens their vibrations.

2. The three-mass system “rolling stock-superstructure-support” is the optimal solution in increasing the seismic resistance of transport structures, which makes it possible to solve

the question of optimal selection of flexible connections, i.e., the selection of optimal characteristics of the stiffness of the components of the system.

3. The developed method of selecting the optimal parameters of earthquake-proof bearing parts of overpasses allows you to more accurately select the parameters of the bearing parts and optimize these parameters for stiffness and damping for use in the selection of dynamic vibration dampers of bridge supports.

4. The approach to solving the problem and making constructive decisions proposed in this article significantly increases the seismic stability of the structure, since the seismic load on the supports of bridges and overpasses on high-speed railway lines is reduced several times.

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