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Determination of state of avalanche protection gallery during seismic impact and avalanches

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Abstract. The article considers the definitions of the state of the avalanche protection gallery under seismic impact and avalanches. Determined emerging horizontal and vertical vibrations of the entire structure. A calculation scheme was developed to study the dynamics of loose bodies. The scheme of vibrations of a reinforced concrete gallery with an arch covering with backfill soil during a possible earthquake in the OYZ plane is considered. The main type of vibration is lateral, vertical dynamic forces in the ground backfill. The dependence of horizontal forces on the snow layer, the dependence of the force Fr on the gallery on the speed of avalanche movement, the dependence of the force Fr on the unevenness of the backfill soil, and the change in the frequency characteristics of the gallery on the speed of avalanche movement were determined.

1 Introduction

The railway transport of the Republic of Uzbekistan carries freight and mass passenger traffic both within the republic and in interstate traffic [1].

Construction is one of the most complex and labor-intensive branches of the national economy, characterized by high dynamism, i.e., constant changes in time of both production conditions and the construction objects themselves [2].

Over the past period, in Uzbekistan, due to the state policy in the transport sector, large-scale work has been carried out to organize an effective transport system that meets the demands of the economy and the population in transport services with all types of transport [3].

External physical causes of the destruction of coastal supports can be the impact of loads, vibrations, and other extreme events, such as earthquakes.

Analysis of the actual data on the survey of the consequences of destructive earthquakes shows that the earthquake's intensity depends on the engineering-geological, hydrogeological, and geomorphological structure of the area [4].

The railway works in difficult conditions. Being influenced by mobile loads, natural phenomena, and the organic world, it must serve at any time of the year, day or night, ensuring the continuity and safety of trains with set speeds.

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The planned large-scale construction of new transit railways in Uzbekistan, which should ensure the creation of an alternative and efficient transport corridor connecting the Middle East and Central Asian regions with dynamically developing China, requires the creation of artificial structures with high strength and earthquake resistance, which is most relevant in Uzbekistan. To optimize the load-bearing capacity of the gallery, i.e., to reduce dynamic impacts, it was proposed to use structures that allow you to dump an avalanche passing over a snow protection gallery.

In areas of terrain with a horizontal surface, a more accurate method for calculating natural stresses is adopted based on known compression dependencies. For hillside terrain, the location of the subgrade may apply approximate methods of calculation [5].

When rebuilding existing railways and designing and building new ones for high-speed traffic, solving a whole range of technical and economic problems is necessary. It is primarily the issues of ensuring the safety of train traffic, associated with the increase of the forces of interaction of way and rolling stock, with more vibration, more intensive accumulation of residual strain, and reduction of service life of the main elements of the permanent way, to increase the volume of works on routine maintenance and repairs of the way [6, 8, 9].

As a result of changes in the physical and mechanical properties of the soil and an increase in the vibration frequencies under the influence of vibrodynamic forces, various deformations, and destructions occur in structures [7].

2 Objects and methods of research

The objects of the study are avalanche protection galleries. When avalanches descend, and seismic effects occur in the gallery structures, horizontal and vertical vibrations of the entire structure occur together with the backfill soil and a layer of snow. The avalanche protection gallery is a complex dynamic system: a concrete structure, a filling ground, and a layer of moving snow [16-20]. Its calculation scheme can be presented and developed for the study of the dynamics of bulk solids, and inertial characteristics can be determined by the formulas of N.E. Zhukovsky [15].

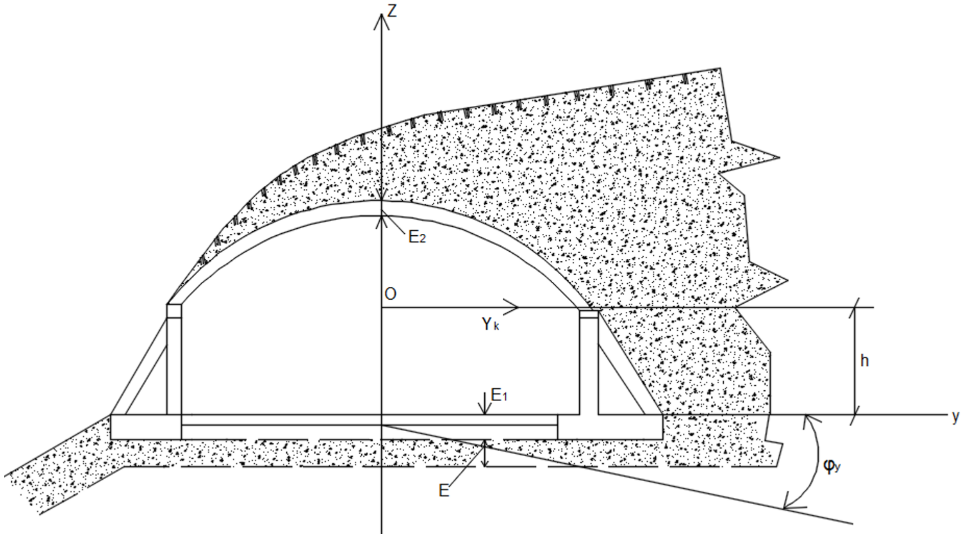

Fig. 1. Design scheme of the gallery.

Let's take a fixed coordinate system of *OXY*. The vertical axis *OZ* will be directed perpendicular to the axis of the gallery. Relative to this coordinate system, the gallery's position is determined by - n coordinates.

Let us consider the scheme of vibrations of a reinforced concrete gallery with an arched covering with a filling ground in case of a possible earthquake in the *OYZ* plane during the movement of an avalanche.

Figure 1 shows the design scheme of the gallery, the construction of which is considered absolutely rigid, and elasticity is included in the corresponding characteristics of the surrounding soil. The filling soil can rotate – φ_z, relative to the vertical axis, a transverse displacement – $y_{m,}$ and a rotation relative to the gallery axis – φ_k. The connection between the galleries and the ground is carried out in the vertical direction by stiffness – E, in the transverse direction – E_1, and when turning by linear elastic stiffness – E_2.

3 Results and discussion

The free surface of moving snow can be represented as a series:

$$Z = \sum_{n=1}^{\infty} f_n(t)\varphi_n(x)\,\psi_n(y) \qquad (1)$$

where: $f_n(t)$ is unknown time functions characterizing the fluctuations of the snow layer on the surface of the filling ground; $\psi_n(y)$ is the known complete orthonormal system of the function.

It follows from equation (1) that there will be two types of vibrations in the gallery – along the axis – *OX* and along the axis *OY*, and in each of them, there are two types of waves – even and odd, corresponding to even and odd values – n.

Studies have shown that the main types of vibrations are lateral, vertical dynamic forces in the filling ground caused by these vibrations, which account for up to 40% of the rest [10, 11, 12, 13, 14]. Suppose the natural frequencies of longitudinal vibrations from the snow mass are located in the sphere of changes from an earthquake. In that case, it is possible that the oscillations coincide, which will destroy the entire engineering structure.

As coordinates, we take:

$$\Theta_\kappa,\ y_k,\ \varphi_z,\ y_m,\ \varphi_x$$

The kinematic energy of the system under consideration is equal to:

$$T = \frac{1}{2}\mathcal{J}_0\theta_k^2 + \frac{1}{2}m_k(\dot{y}_k + h_1\dot{\theta}_k)^2 + \frac{1}{2}m_k\dot{y}_m{}^2 + \frac{1}{2}\mathcal{J}_z\dot{\varphi}_z{}^2 + \frac{1}{2}\mathcal{J}_m\dot{\varphi}_x \qquad (2)$$

where: m_k is the mass of the gallery with the filling soil; h_1 is the height of the center of mass from the axis of transverse vibrations of the gallery; $\mathcal{J}_m$ is the mass of the filling soil involved in joint fluctuations with he gallery.

Total moment of inertia:

$$\mathcal{J}_0 = \mathcal{J}_0^k + \mathcal{J}_0^b$$

where $\mathcal{J}_0^k$ is the moment of inertia of the gallery structure; $\mathcal{J}_0^b$ is the moment of inertia of the avalanche, replaced by the moment of inertia of the equivalent layer relative to the transverse axis of the gallery; $\mathcal{J}_z$, $\mathcal{J}_x$ are the moment of inertia of the filling soil relative to the axes *OZ* and *OX*.

The potential energy of the ground filling system and gallery structures:

$$P = \frac{1}{2}\mathrm{E}(-\theta_k \mathrm{b} + \mathrm{b}\varphi_{\mathrm{x}})^2 + \frac{1}{2}\mathrm{E}(\theta_k \mathrm{b} + \mathrm{b}\varphi_{\mathrm{x}})^2 + \frac{1}{2}\mathrm{E}_1(y_k - y_m)^2 - \frac{1}{2}m_k \mathrm{g} \mathrm{L}\theta_k^2 + \frac{1}{2}\mathrm{E}_2(L\varphi_{\mathrm{x}} - L\theta_0)^2 \quad (3)$$

where: E is the vertical modulus of elasticity of the soil; E_1 is horizontal modulus of soil elasticity; E_2 is modulus of elasticity of the gallery body; 2L is gallery width; 2b is the width of the filling ground surface.

Skew angle of the gallery body:

$$\theta_0 = \frac{\eta_l - \eta_r}{2L} \quad (4)$$

$$\eta_l = \frac{1}{2}\sum_{i=1}^{r} \eta_i^r; \quad \eta_r = \frac{1}{2}\sum_{i=1}^{r} \eta_i^l$$

where: η_i^l is the friction from the avalanche in the left part of the backfill ground of the gallery; η_i^r is friction from an avalanche in the right part of the backfill ground of the gallery.

The values – P can be taken equal to 2, 3, and 4, depending on the design of the butt joints of the gallery coating.

Generalized forces – Q and moments of generalized forces corresponding to generalized coordinates – θ_k and y_k equal:

$$Q\theta_k = F_{fr,b} bLign(-\dot{\theta}_k b - b\dot{\varphi}_{\mathrm{x}}) - F_{fr,b} bLign(\dot{\theta}_k b - b\dot{\varphi}_{\mathrm{x}})$$
$$Qy_k = -F_{fr,b} bLign(\dot{y}_k - b\dot{y}_m) - F_{fr,b} bLign(\dot{\theta}_k b - b\dot{\varphi}_{\mathrm{x}}) \quad (5)$$

The gravitational force is a horizontal component of the normal avalanche forces on the backfilling ground, part of which is transmitted to the gallery:

$$F_{grav} = \frac{\mathrm{P}_{st}}{R_c - R_r} \quad (6)$$

where: P_{st} is static load of the filling soil on the gallery; R_c, R_r are the radii of curvature of the gallery covering in transverse and longitudinal sections.

$$\begin{cases} Qy_m = -2F_{\mathrm{p}} y_m - 4F_y \varepsilon_m - 2F_{\mathrm{p}} y_m - 2\,F_{fr,y} Lign(\dot{y}_k - \dot{y}_m); \\ Q\varphi_x = -F_{fr,b} bLign(-\dot{\theta}_k b - b\dot{\varphi}_k) + F_{fr,b} bLign(-\dot{\theta}_k b - b\dot{\varphi}_{\mathrm{x}}); \end{cases} \quad (7)$$

Using the Lagrange equation of the second order, we obtain a system of differential equations:

$$\begin{cases} (\mathcal{I}_0 + m_k h_1^2)\dot{\theta}_k + m_k h_1 \ddot{y}_k + (2Eb^2 - m_k g h_1)\theta_k - F_{fr,b} bLign(-\dot{\theta}_k b + b\dot{\varphi}_{\mathrm{x}}) + \\ F_{fr,b} bLign(\dot{\theta}_k b + b\dot{\varphi}_{\mathrm{x}}) - 2Eb^2 \varphi_{\mathrm{x}} = 0; \\ m_k y_k + m_k h_1 \ddot{\theta}_k + \mathrm{E}_1 y_k + 2\,F_{fr} Lign(\dot{y}_k - \dot{y}_m) - \mathrm{E}_1 y_1 = 0; \\ m_k \ddot{y}_k + m_k h_1 \ddot{\theta}_k + \mathrm{E}_1 y_k + 2\,F_{fr} Lign(\dot{y}_k - \dot{y}_m) - \mathrm{E}_1 y_m = 0; \\ \mathcal{I}_x \ddot{\varphi}_k + (2Eb^2 + 2\mathrm{E}_2 L^2)\varphi_{\mathrm{x}} - 2Eb^2\theta_k + 2\beta_2 L^2 \dot{\varphi}_{\mathrm{x}} + F_{fr,b} bLign(\dot{\theta}_k b - b\dot{\varphi}_{\mathrm{x}}) \\ -2\mathrm{E}_2 L^2 \theta_0 - 2\beta_2 L^2 \dot{\theta}_0 = 0; \\ m_m \ddot{y}_m + 2\mathrm{E}_2 y_1 + 2\,F_{fr,b} bLign(\dot{y}_k - \dot{y}_m) + \frac{2\mathrm{P}}{R_c - R_r} + 2F_y \varepsilon_y + F_{\mathrm{p}} y_m; \end{cases} \quad (8)$$

The solution of equation (8) allows theoretical addition and the unevenness of the sliding surface of the filling soil on the avalanche impact force on the gallery. It is also possible to determine changes in frequency characteristics that occur depending on the speed and density of the snow mass.

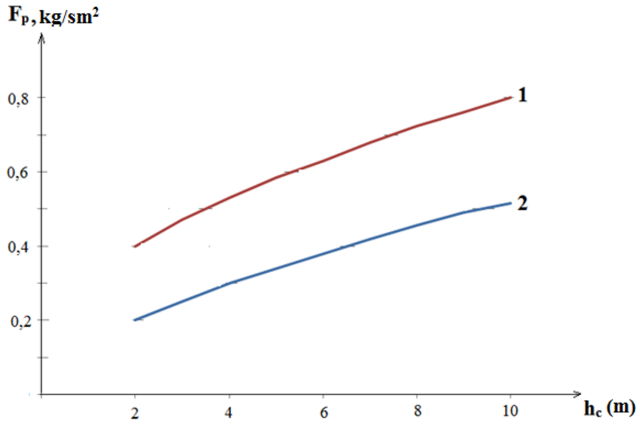

Fig. 2. Dependence of horizontal forces on the snow layer: 1 is dense snow, 2 is loose snow.

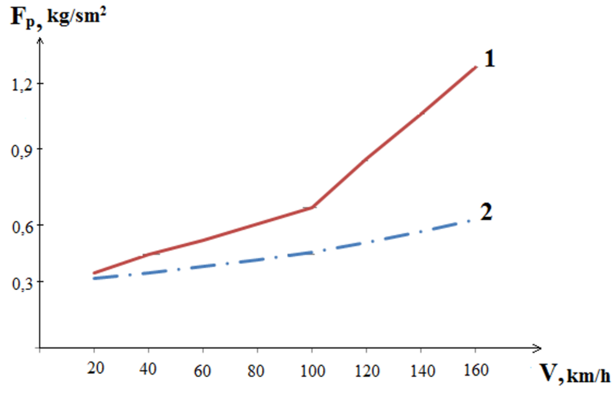

Fig. 3. Dependence of the force Fr on the gallery on the speed of avalanches: 1 is dense snow, 2 is loose snow.

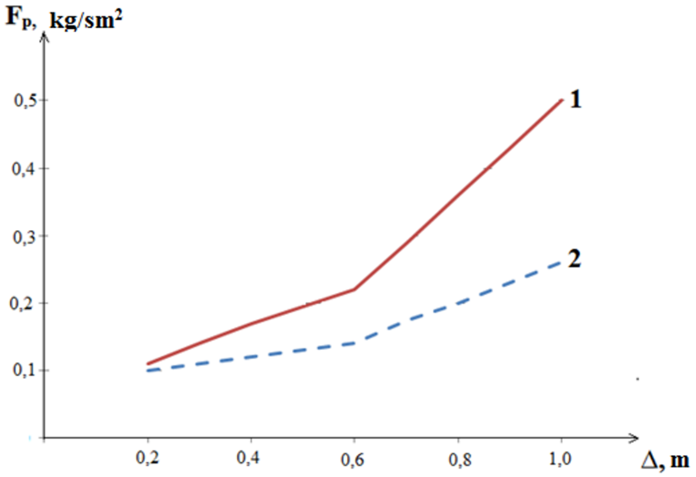

Fig. 4. Dependence of the force Fr on the unevenness of the filling ground: 1 is dense snow, 2 is loose snow.

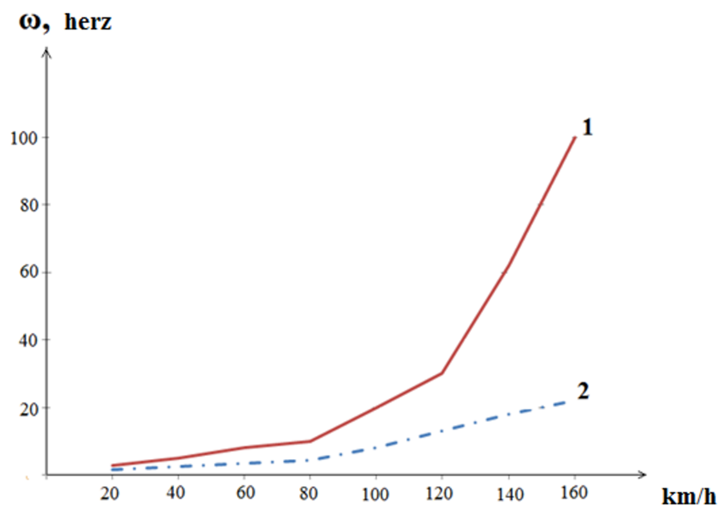

Fig. 5. Changing the frequency characteristics of the gallery from the speed of the avalanche:1 is dense snow, 2 is loose snow.

4 Conclusion

Conclusions follow from the analysis of the graphs Fig. 2-5:
1. The amount of force on the gallery depends on the density of avalanche snow.
2. The speed of the avalanche movement affects the forces transmitted by the gallery structure and its frequency characteristics.
3. The backfill soil of the gallery must be constructed smoothly because irregularities dramatically increase the forces from an avalanche.

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