Seismic stress state of "Earth bed - foundation" system

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Abstract. This article presents research results in seismic resistance of transport structures, anti-seismic design of roads, and the stability of slopes of railway subgrade embankments. The use of modern methods of wave mechanics for the correct assessment of the seismic resistance of the subgrade of the railway track and the determination of the most constructive optimal solutions are considered. The results of multivariate numerical experiments on studying the seismic stress state of the "subgrade-foundation" system are given. One of the most effective ways to determine ground motion is to use the accelerogram of a past earthquake. The analysis of the isoline of the components of seismic displacements and stresses in the subgrade body from the action of the horizontal and vertical components of the accelerogram has been carried out.

1 Introduction

The work of the railway network of the countries of Central Asia is characterized by a high degree of intensity of their use. This determines the freight traffic on railways, which continues to increase yearly, on average over the network and in terms of the highest value on especially loaded highways [1, 2].

All this causes a corresponding increase in the requirements for all branches of the railway economy, including the railway track, in terms of increasing its reliability, strength, and stability, as well as efficiency and reducing the labor intensity of maintenance and repair.

All elements of the track construction work in close interaction and interdependence from each other; the failure of one element adversely affects the condition and operation of others. Therefore, to ensure the normal operation of the track as a whole throughout its entire length, the strength and stability of the subgrade, its structures, and its devices are of great importance. The subgrade is constructed and operated in a variety of, in several areas, complex, hydrogeological, and seismic conditions.

Regulatory documents [3, 4] regulate the procedure and conditions for maintaining the railway network's subgrade, drainage, fortification, and protective structures to ensure the uninterrupted and safe movement of trains at set speeds. The good condition of the subgrade and its structures is ensured by the conformity of its structures, the existing loads,

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and the implementation of scheduled preventive repairs and is based on continuous current maintenance and periodic overhaul.

The main task of maintaining the subgrade is to ensure the health of the state of all its elements, prevent malfunctions, eliminate them in a timely manner, and eliminate the causes that cause malfunctions [3, 4].

The subgrade of the railway track serves as the basis for the superstructure of the track and consists of a complex of engineering structures designed for long service life. The main goal is to ensure the good condition of the subgrade, fortification, drainage structures, and protective and seismic devices during their operation and current maintenance.

A vast area associated with the peculiarity of calculating railway track structures for dynamic effects has not yet been studied. Many issues require further theoretical and experimental verification and study.

Railways are of vital importance, and their failure as a result of an earthquake entails not only significant material damage but also disruption of the normal functioning of individual settlements and industrial enterprises or regions as a whole. Therefore, much attention is paid to research in the field of seismic resistance of transport structures. In areas with seismicity of 7-9 points, the design of the subgrade of railways should be carried out, considering seismic effects. In a devastating earthquake zone, railways must provide not only ordinary household needs but also rescue, emergency, and restoration work, and, if necessary, the evacuation of the population.

For the first time, Professor Zschocher V.O., in 1929, conducted special studies on the issue of the anti-seismic design of roads, the stability of the slopes of the embankments of the railway subgrade in connection with the design of the Turkestan-Siberian railway. The results of these experimental studies became the basis for normalizing the steepness of the slopes of the subgrade in seismic areas.

The main requirements in the design of railway subgrades include the route choice, considering seismic zoning data. In highly seismic regions, it should bypass areas that are especially unfavorable in engineering and geological terms, in particular, zones of possible collapses, landslides, and avalanches.

Observing the requirements of the standards [3, 4] in the design, it must be taken into account that the severity of the consequences of the failure of the subgrade is far from the same. This circumstance is considered by the magnitude of the calculated seismicity, which, when designing the subgrade, can be much less than the strength of the maximum possible earthquake at a given construction site.

2 Objects and methods of research

An assessment of the subgrade's bearing capacity is necessary to decide on the possibility of their further use or strengthening. This assessment is carried out by an engineering survey of the object, followed by a verification calculation based on the data obtained. Calculating the subgrade for the action of surface seismic waves is a difficult problem in the dynamics of structures. The practical importance of this problem leads to the fact that many countries of the world are working on its solution. The problem of seismology, the choice and calculation of the design of the railway track were devoted to research by prominent scientific specialists in our country and abroad [5-11].

Despite this, several issues in this area are still awaiting resolution. The main task now, thanks to the general development of this field of science, is the use of modern methods of wave mechanics for the correct assessment of the seismic resistance of the subgrade of the railway track and the determination of the most constructive optimal solutions.

At the same time, the territory of the Central Asian countries is distinguished by complex geomorphology, hydrogeology, and neotectonics and is characterized by a seismic background of 9-10 points.

An analysis of the consequences of destructive earthquakes shows the need for fundamental research and the adoption of progressive construction technology focused on reducing damage from strong seismic effects described in [12]. From the analysis of actual data on damage to railways, it can be seen that the subgrade is characterized by deformations of uneven settlement, buckling and creeping of slopes, leading to distortion of the transverse profile, cracks and ruptures, spreading of water-saturated soils, and curvature of the axis in profile and plan. Railway rails bend depending on the subgrade's degree and direction of deformation. The types of deformation of the roadbed, along with other factors, depend on the design of the subgrade.

Important initial information for the study and practical implementation of the issues of seismic resistance of the "subgrade-base" system is, of course, kinematic data on the earthquake itself. Strong seismic movements that cause sufficiently intense ground vibrations have parameters that are too large to be recorded using typical instruments used in seismology. Therefore, the three ground motion components recorded by the accelerograph represent a complete description of the intensity of an earthquake that affects the subgrade at the same site. The most important recording parameters of each component, from the point of view of the design calculation, are amplitude, frequency content, and duration [13–18].

The amplitude is usually characterized by the peak value of the acceleration or, sometimes, by the number of peaks that exceed a certain level. Ground motion velocity can be a more representative measure of intensity than acceleration, but velocity records are usually unavailable unless additional calculations are performed. The frequency composition can roughly represent the number of zero line crossings per second on the accelerogram and the duration by the time interval between the first and last peaks exceeding a given level [19-22]. It is obvious that the last quantitative characteristics together give an approximate description of the process of ground vibrations and do not reflect their potential danger to the subgrade.

An important point in calculating the seismic resistance of the subgrade is the choice of the characteristics of the input seismic action for which it should be calculated. Seismic loads are special of all types of external loads that must be considered in design since a large earthquake usually causes greater stresses and movements in critical sections of the subgrade than all other loads combined.

One of the most effective ways to determine ground motion is to use the accelerogram of a past earthquake. Obviously, the calculation for a given accelerogram will be a more reasonable and most effective method for studying the seismic stress state of the "subgrade-base" system.

The object of calculation of the dynamic analysis is the cross-section of the subgrade in the form of a trapezoid with the slope of the sides in the ratios: k_1=1:2; k_2=1:1.75; k_3=1:1.5 and heights h_1=11.0 m, h_2=6.0 m, h_3=6.0 m, shown in Fig. 1. The total height of the subgrade $H=h_1+h_2+h_3$=23.0 m. The elastic and density parameters of the subgrade and base are shown in Table 1. The main area of the subgrade has a width of b=11.0 m. The size of the lower base of the embankment at the assumed heights and slopes of the sides is $a=b+2(k_1\cdot h_1+ k_2\cdot h_2+ k_3\cdot h_3)$ = 94.0m.

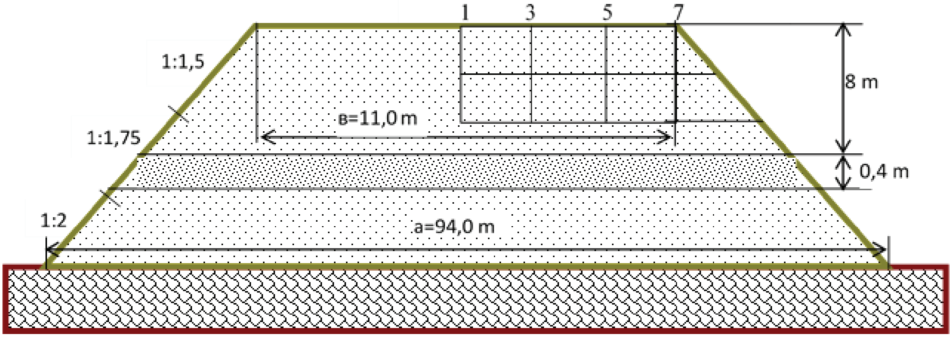

Fig. 1. Calculation scheme

The base of the computational domain is assumed to be rigid, i.e., the displacements are zero in the horizontal and vertical directions. The computational domain is divided into 212 isoparametric quadrangular quadratic elements with a total number of nodes of 711. Within each element, the material is homogeneous.

Table 1. Elastic and density parameters of subgrade and foundation

	Elastic and density parameters			
	E, MPa	**ν**	**G, MPa**	**γ, t/m³**
Subgrade	32	30	24	14
Base	30	26	25	19

As external force factors of seismic motion, a real accelerogram of a 9-point Gazli earthquake (05/17/1976) with a duration of 1.38 seconds was used. For direct calculation, the most intense part of the horizontal (ax) and vertical (ay) components of the accelerograms was taken (Fig. 2). The adopted specific time step does not lose the maxima of the given values of accelerations and their abrupt fluctuations.

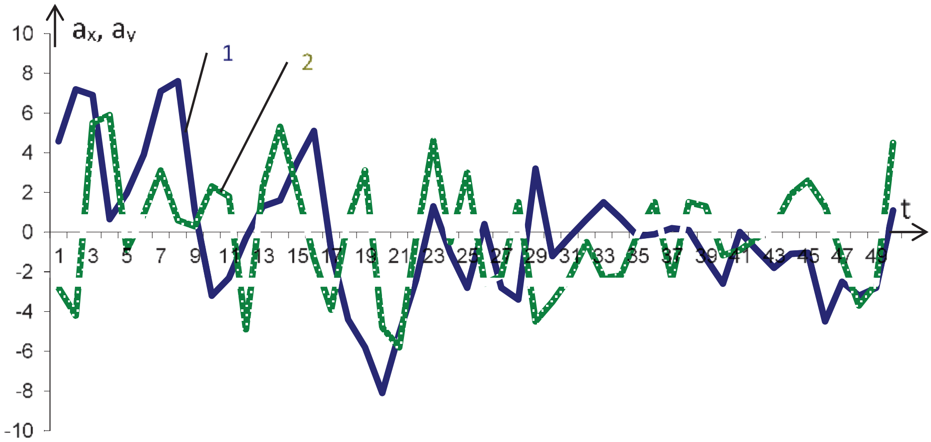

Fig. 2. Diagram of changes over time of the horizontal (ax) and vertical (ay) components of the accelerograms. Duration 1.38 seconds $(0 \le t \le 50\Delta t)$. Curve 1 corresponds to a_x, 2 to a_y.

3 Results and discussion

Below are some important numerical results of multivariate numerical experiments on studying the seismic stress state of the "subgrade-base" system.

Fig. 3-6 contain isolines of the components of seismic displacements and stresses in the subgrade body from the action of the horizontal and vertical components of the accelerogram.

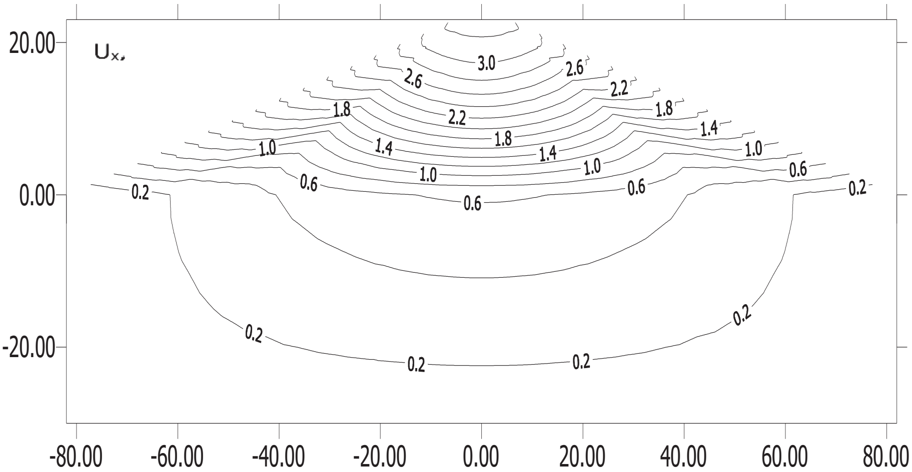

Fig. 3. Change of isolines of displacements U_x in the subgrade body under the influence of the horizontal component of the accelerogram a_x.

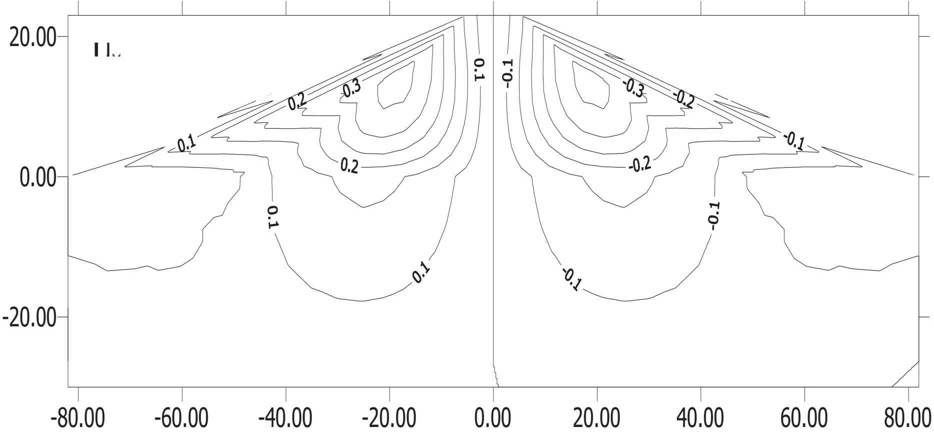

Fig. 4. Change of displacement isolines U_y in the subgrade body under the influence of the horizontal component of the accelerogram a_x.

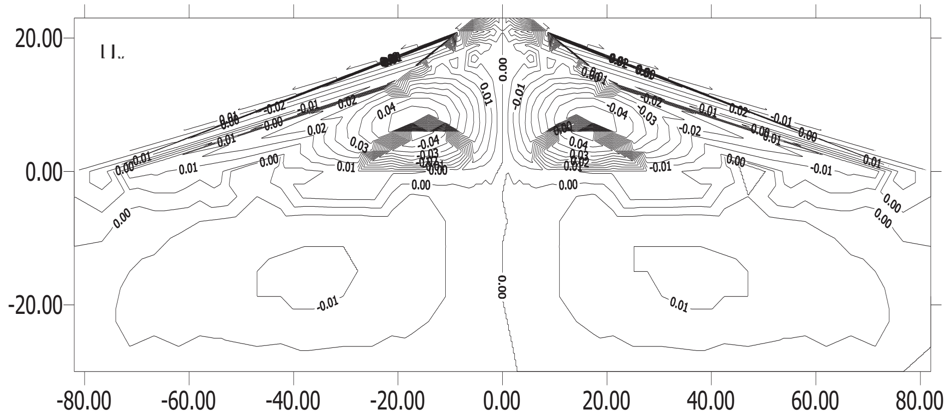

Fig. 5. Change of displacement isolines U_x in the subgrade body under the influence of the vertical component of the accelerogram a_y.

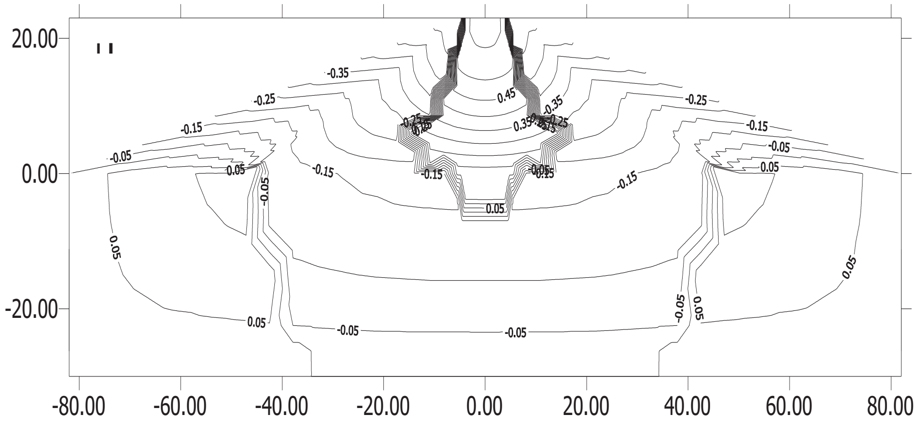

Fig. 6. Change of isolines of displacements U_y in the body of subgrade under impact.

Fig. 3–6 indicate a uniform distribution of the seismic stress and displacement component in the subgrade body from the action of the horizontal component of the accelerogram. It should be noted that the area under the main platform is deformed to a certain depth under the influence of the vertical component of the accelerogram, and a similar pattern is observed in the distribution of seismic stresses.

Of great interest for analysis is the knowledge of the process of oscillations in the time sweep. Graphically, it is difficult to present such results in general for the entire region. Therefore, one has to confine oneself to the consideration and analysis of stresses and displacements of individual characteristic points of the subgrade. These points are indicated in (Fig. 7).

Fig. 7, 8 show diagrams of changes over time in seismic displacements and stresses from the action of the horizontal and vertical components of the accelerogram at $0 \leq t \leq 50\Delta t$.

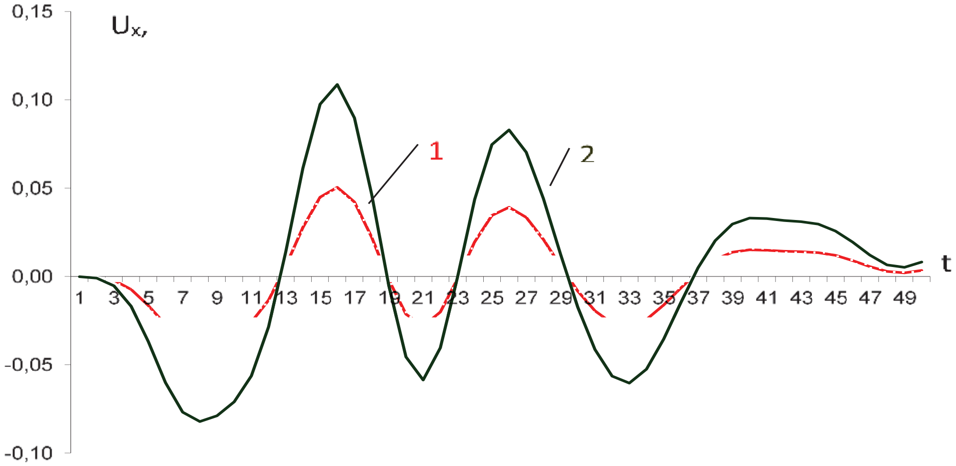

Fig. 7. Diagram of change in displacement U_x over time from the horizontal component of the accelerogram a_x. Curve 1 – point 3, curve 2 – point 7.

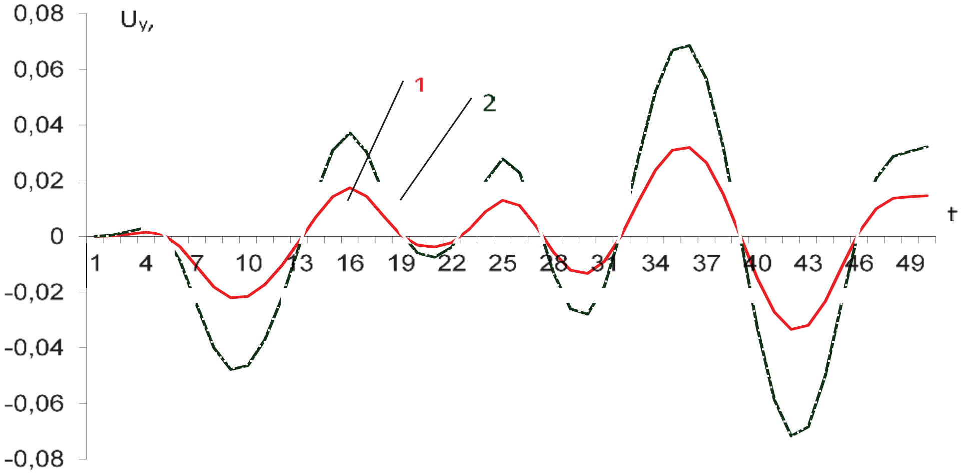

Fig. 8. Diagram of change in displacement U_x over time from the vertical component of the accelerogram a_y. Curve 1 – point 3, curve 2 – point 7.

Fig. 3–6 indicate a uniform distribution of the seismic stress and displacement component in the subgrade body from the action of the horizontal component of the accelerogram. It should be noted that the area under the main platform is deformed to a certain depth under the influence of the vertical component of the accelerogram, and a similar pattern is observed in the distribution of seismic stresses.

Of great interest for analysis is the knowledge of the process of oscillations in the time sweep. Graphically, it is difficult to present such results in general for the entire region. Therefore, one has to confine oneself to the consideration and analysis of stresses and displacements of individual characteristic points of the subgrade. These points are indicated in (Fig. 7).

Fig. 7, 8 show diagrams of changes over time in seismic displacements and stresses from the action of the horizontal and vertical components of the accelerogram at $0 \leq t \leq 50\Delta t$.

As can be seen, the maxima of seismic displacements and stresses do not always coincide with the maxima of seismic accelerations a_x and a_x.

As can be seen from Fig. 3-6, the components of the accelerogram a_x, a_y create completely different seismic stress states of the subgrade-base system. Therefore, to obtain a complete picture of the seismically stressed state of the subgrade, it is necessary to consider the contribution of each component of the accelerogram to it.

4 Conclusion

1. The results of experimental studies on the issue of the anti-seismic design of roads and the stability of the slopes of the embankments of the railway subgrade became the basis for normalizing the steepness of the slopes of the subgrade in seismic areas.
2. Calculating the subgrade for the action of surface seismic waves is a difficult task in the dynamics of structures. The practical importance of this task is the use of modern methods of wave mechanics for correctly assessing the seismic resistance of the railway track's subgrade and determining the most constructive optimal solutions.
3. The seismic stress state of the subgrade-base system was studied. Based on the analysis of the results of numerical experiments, it was found that to obtain a complete picture of the seismically stressed state of the subgrade, it is necessary to take into account the contribution of each component of the accelerogram of a real earthquake to it.

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