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STRESS-STRAIN STATE OF METRO TUNNEL CONSTRUCTION UNDER SEISMIC IMPACTS

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Abstract

The article presents a study of the stress–strain state of the construction of a deep-laid subway distillation tunnel. The results of calculations of the tunnel lining taking into account the seismic impact of the soil are presented. Based on the above calculation results, the determination of 5 frequencies and forms of natural oscillations of the tunnel lining system with soil. The results of calculations showed that the first frequencies are low. They are taken into account when determining internal efforts and movements. It can be seen that with increasing depth of laying, horizontal and vertical movements over the tunnel decrease.

Keywords: tunnel, structure, typical circular lining, tubing, soil, seismic.

Аннотация

В статье приведено исследование напряженно–деформированного состояния конструкции перегонного тоннеля метрополитена глубокого заложения. Приведены результаты расчетов обделки тоннеля с учетом сейсмического воздействия грунта. На основе приведенных результатов расчета определения 5 частот и форм собственных колебаний системы обделки тоннеля с грунтом. Результаты расчетов показали, что первые частоты являются низкими. Они учитываются при определении внутренних усилий и перемещений. Видно, что с увеличением глубины заложения горизонтальные и вертикальные перемещения над тоннелем уменьшаются.

Ключевые слова: тоннель, сооружение, типовые круговая обделка, тюбинг, грунт, сейсмика.

Introduction

The development of the national economy of the Republic of Uzbekistan requires the constant expansion of the network of transport communications, in particular roads and railways. Today, by the Government of the Republic of Uzbekistan, the construction of metro lines in Tashkent is underway, since in the development of passenger transport, off-street highways are of particular importance, having the greatest carrying capacity [1].

A review of the literature and analysis of the work devoted to the design and construction of tunnels in seismically active areas showed that the most widespread class of metro structures are reinforced concrete ferry tunnels, which until now paid little attention to the problems of operation and monitoring of tunnels. This led to the fact that damage developed in tunnels, which led to emergency and pre-emergency situations. As a result, integrity was destroyed overlying earthen soil under seismic influences [2, 3, 4].

It should be noted that when seismic waves of compression-tension and shear propagating from the earthquake source pass through the soil mass, seismic stresses are formed in each element of the soil, in addition to the natural stress state. In places of contact of the soil with the contour of the tunnel (or other obstacle), when a flat seismic wave passes, a flat seismic wave occurs. Concentration of seismic stresses, which are an additional seismic contact load [5, 6, 7].

An important taskfor it is to assess the stress state of the tunnel lining from the action of a long wave of compression-tension and a wave of shear. Sequential analysis of the physical processes occurring at the same time makes it possible to sufficiently fully determine the basic patterns of interaction of the lining of tunnels together with the enclosing soil mass, as well as to develop recommendations for the design of elements, taking into account all features of the tunnels under seismic impacts.

In this regard, the development of a methodology for calculating the structures of the metro ferry tunnels of various shapes, taking into account the impact of seismic load, conducting numerical experiments and studying the effect of the interaction of the ground environment on the change in the bearing capacity and operability of structural elements is an urgent task today.

Materials and Methods

Based on the provisions of the dynamics of underground structures and the finite element method, we have developed a methodology for calculating seismic stresses for circular and non-circular tunnel linings of the metro [9, 10]. At the same time, two planar contact problems of the theory of elasticity for lining a tunnel are considered, reinforcing a cutout in an elastic medium and working under conditions of joint movements under the following boundary conditions: seismic waves are assumed to be elastic, harmonic with a flat propagation front, or non-standard, with a slight difference (in shape) of the real impulse from the sinusoidal one.

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Then, for such an environment, the system of equations of the finite element method (FEA) in the dynamic formulation can be written as

$$M\ddot{\vec{Z}}(t)+C\dot{\vec{Z}}(t)+K\vec{Z}(t)=-M\ddot{\vec{Z}}(t)_{\Gamma P} \quad (1)$$

where M, C and K are the matrix of masses, damping and stiffness of the finite element system, $\vec{Z}(t),\dot{\vec{Z}}(t),\ddot{\vec{Z}}(t),\ddot{\vec{Z}}(t)_{\Gamma P}$ - vectors of node movement, velocity and acceleration of the finite element system and known soil acceleration in the form of an earthquake acceleration.

Assuming that there is no external influence, we come to the following equation.

$$M\ddot{\vec{Z}}(t)+K\vec{Z}(t)=0 \quad (2)$$

Assuming the solution is

$$\{Z\}=\{Z_0\}\cdot\cos(\omega t) \quad (3)$$

We get a frequency equation that has a solution if the following condition is met

$$([K]-\omega^2[M])\{Z_0\}=0 \quad (4)$$

This equality is possible only at certain values ω , which are called proper angular frequencies [11, 12].

Creating techniques and algorithms gives us:

1. Develop a tool for the calculation of tunnels of various configurations. As a result of the calculations, internal forces in the lining and stresses in the soil surrounding the lining are determined.
2. Set a serial calculation at different parameters of the tunnel to study the behavior of the structure.

According to FEA, the structure is divided by a finite number of elements [5, 6]. Elements are combined through anchor points. This procedure is called sampling. FEA is based on relatively simple mathematical models that lead to large arithmetic calculations that require the use of a computer to conduct them.

In the shell calculation program, the tunnel and the ground mass are modeled with 3 nodal flat finite elements (Fig. 1).

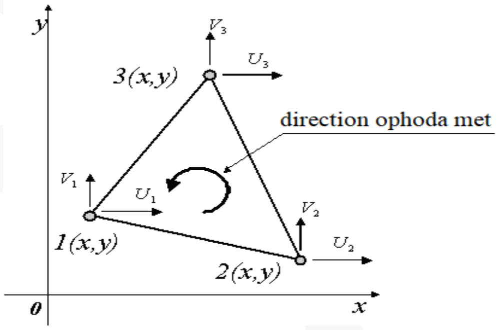

Figure - 1. Flat triangular finite element

The developed program is implemented as an "Excel-application" [13, 14, 15], i.e. all calculation modules are controlled from an Excel table.

Results and Their Discussion

To date, for the distillation tunnels of the Tashkent metro, prefabricated linings made of reinforced concrete blocks are widely used, where each ring consists of 8 blocks connected by radial joints. Also, tubing lining is strong, durable, easy to install and provides reliable waterproofing even with high groundwater pressure, but is expensive and metal-intensive. Therefore, if geological and hydrological conditions, tubing or block reinforced concrete lining is used. Reinforced concrete tubing consists of box-section elements that are connected in a ring by bolted ties (Fig. 2). The blocks that make up the trim ring rest freely (hingedly) at the longitudinal joints. Bending moments are minimized, and concrete works mainly on compression. In the design position, the blocks are fixed relative to each other with metal studs installed during the installation of the ring. Sealing of the lining and waterproofing of the joints are provided by embossing the seams with special mastics or by installing profile sealing sealants between the blocks.

Calculations are performed by the finite element method using the software package developed by us. The lining (rectangular cross-section b= 1 m, h = 0.2 m, hinged) is divided into 20 finite elements. And the system consists of 460 elements.

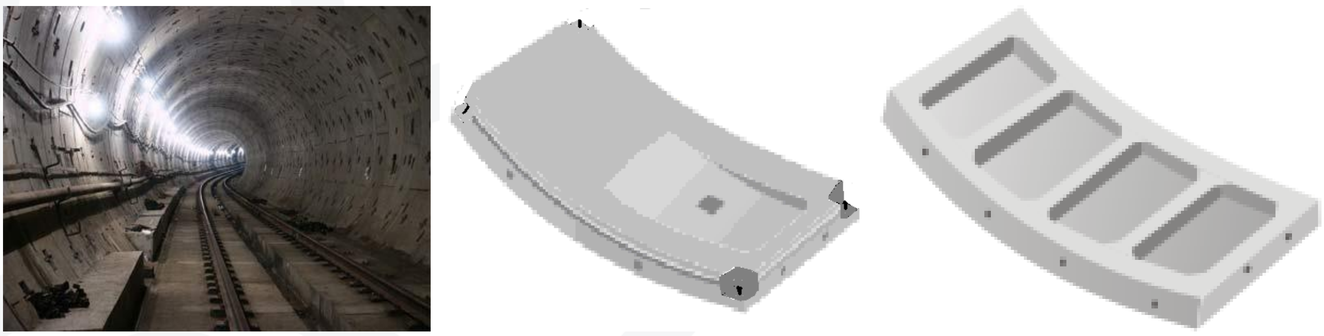

Figure – 2. Deep tunnel with lining of reinforced concrete tubing and blocks

For cladding, the design class of concrete for compressive strength is adopted - B25, R_b = 14.8 MPa, for tensile strength - R_{bt} = 1.07 MPa, modulus of elasticity - E_b =30000 MPa. Lining is reinforced with welded meshes and frames of reinforcement of class A-I, A-II and A-III. The thickness of the protective layer for the working fittings is 15 mm, the pitch of the working reinforcements is 0.10 - 0.15 m.

The given seismic load should be taken in the form of $\ddot{U}(t)_{ГР} = U_0 * e^{-\varepsilon_0 t} \sin \theta t$ in the horizontal direction, soil - loam, normative volumetric weight - $\gamma = 0{,}018 МПа/м$, the normative angle of internal friction of the soil – $\varphi = 24^\circ$, the maximum groundwater

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level is located 1 m below the surface of the earth, the depth of the tunnel relative to the surface of the earth H = 22 m. Fig. 3 shows a finite element scheme for calculating the tunnel together with the soil massif.

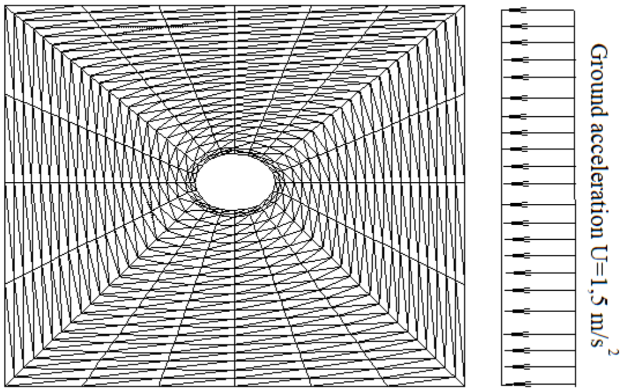
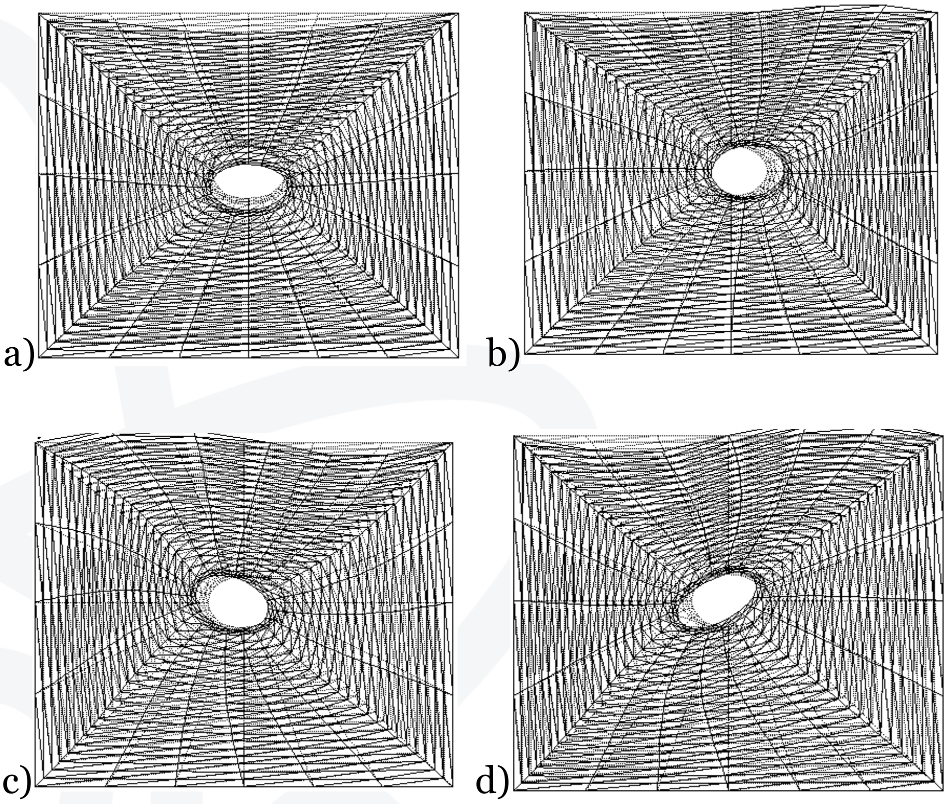


Figure – 3. Finite element design model of lining with soil



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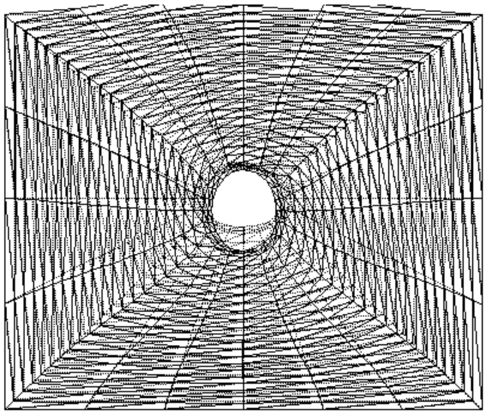


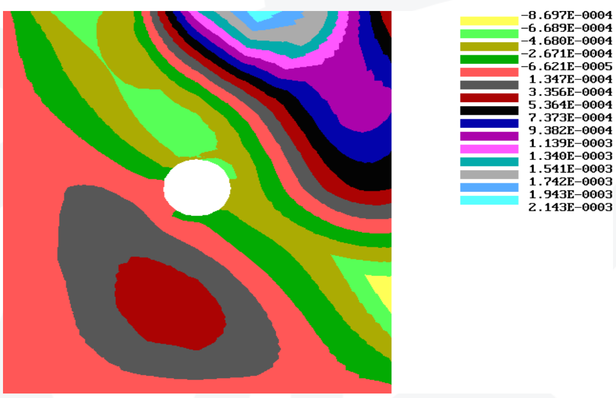
e)

Figure – 4. Derived from the calculation of the first forms and 5 frequencies Intrinsic oscillation system: a) $\omega_1 = 16,2Hz,$; b) $\omega_2 = 16,2Hz,$; c) $\omega_3 = 16,2Hz,$; d) $\omega_4 = 16,2Hz$; e) $\omega_5 = 16,2Hz$.

In Fig. 4 shows the results of calculations for the determination of 5 frequencies and forms of natural oscillations of the system. From the analysis of the results, we can say that the first frequencies are low. They are taken into account in determining internal efforts and movements.

In Fig. 5 shows the plots obtained from the calculation - isochromes of horizontal and vertical movements of the region. From the drawings it can be seen that with increasing depth, both horizontal and vertical movements over the tunnel decrease. However, horizontal movements are smaller than vertical ones. This is due to the direction of the external load in the horizontal direction.

a)



b)

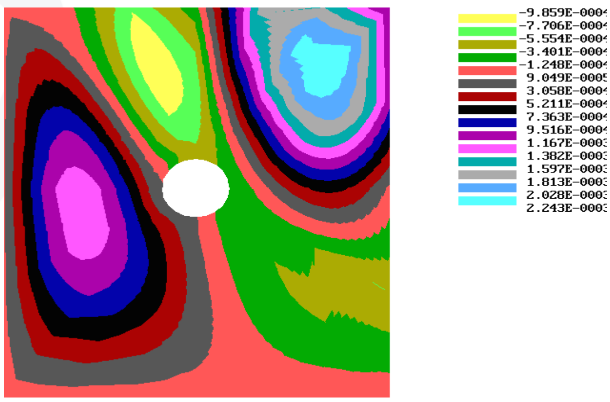


Figure – 5. Obtained from the calculation of isochrome of movements, m.: a) horizontal, b) vertical.

In Fig. Figure 6 also shows the isochromes of the horizontal and vertical stresses of the region.

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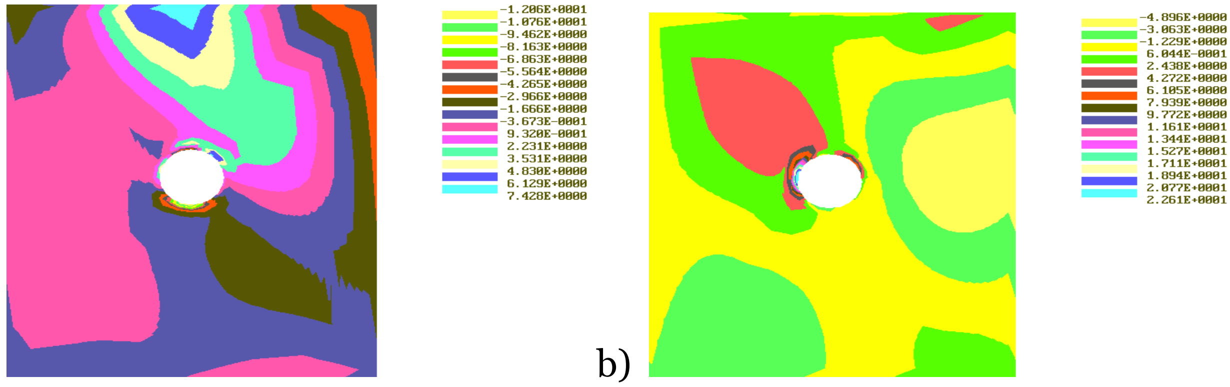

Figure – 6. Based voltage isochromes, kN/m²: a) horizontal; b) vertical.

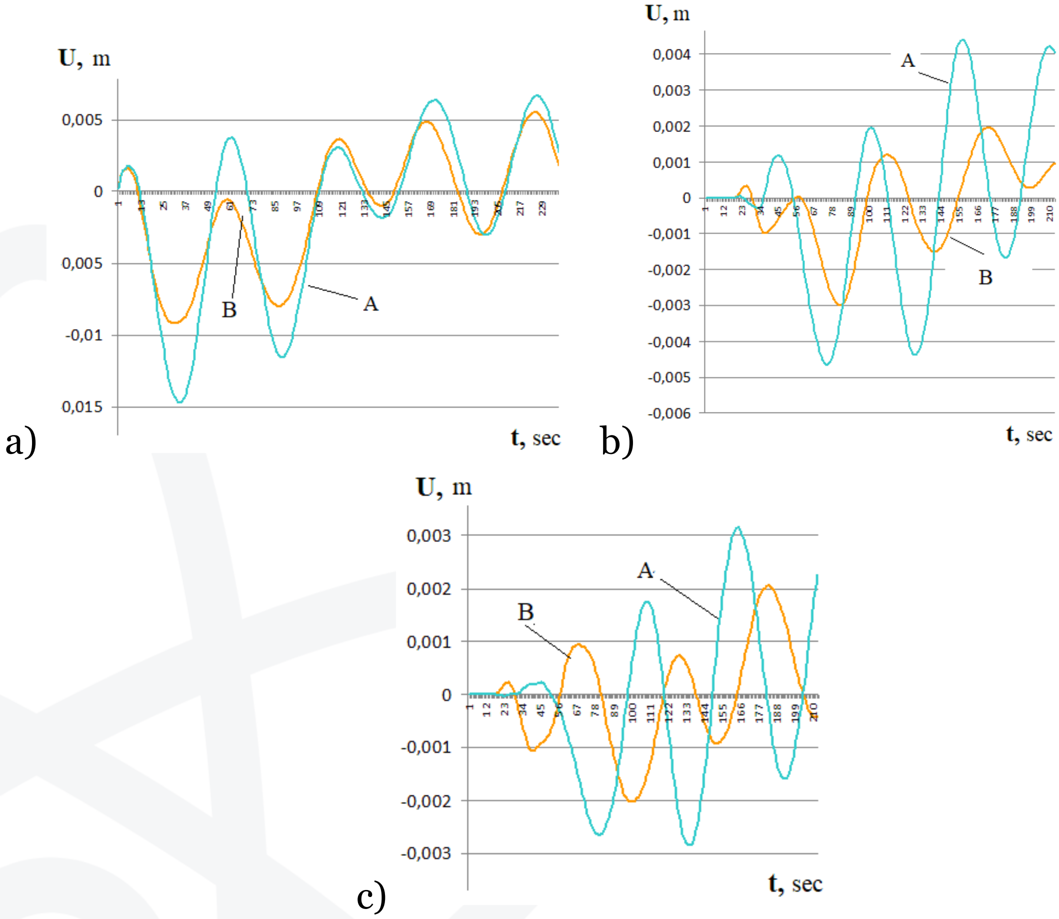

Figure – 7. The resulting changes in time travel: A – horizontal; B – vertical.
a) On the surface of the ground; b) over the tunnel; c) below the tunnel.

Analysis of the results showed (Fig. 7, 8) that the stresses increasing in depth in the soil are of the same nature, but in the tunnel they change their sign and have maximum values.

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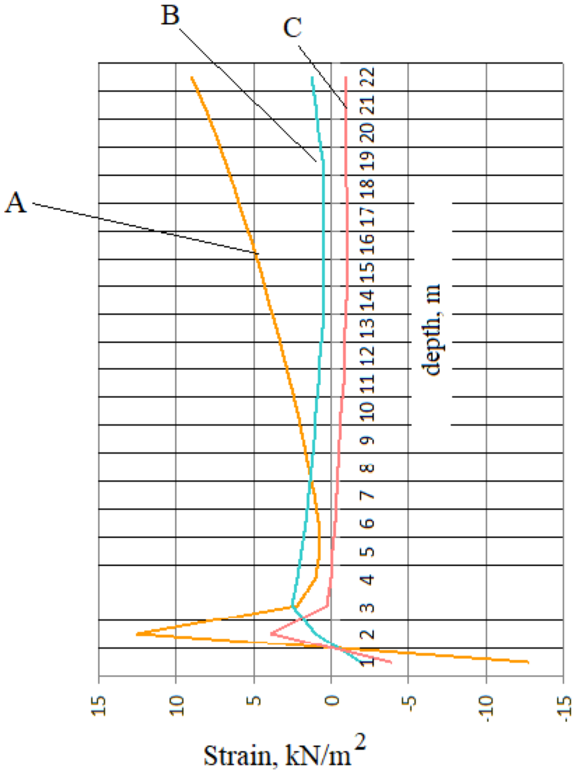

A – horizontal, B – vertical, C – tangents.
Figure – 8. The resulting voltage change from magnification in depth, m.

Conclusion

Based on the provisions of the dynamics of underground structures and the finite element method, a methodology for calculating seismic stresses for circular and non-circular tunnel linings of the metro has been developed. Based on the results of the calculation for the determination of 5 frequencies and forms of natural oscillations of the system, we can say that the first frequencies are low. These frequencies were taken into account when determining the internal forces and movements in the sections of the lining. It can be seen that with an increase in the depth of laying, horizontal and vertical movements over the tunnel decrease. However, horizontal movements are less than vertical. This is due to the impact of external load in the horizontal direction. Stresses, increasing in depth in the ground are of the same nature in their value, but in the tunnel they change their sign and have a high value.

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