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ABOUT ROCK PRESSURE LOADS ON TUNNEL LININGS CONSTRUCTED USING TRENCHLESS METHOD

Konstantin P. BESRODNY, Mikhail O. LEBEDEV
OJSC NIPII «Lenmetrogiprotrans», Saint-Petersburg, Russia

Data contained in requirements documents concerning recommended methods of loads calculation on tunnel linings and results of field studies of stress-strain state of the system «tunnel linings – rock» obtained during geotechnical monitoring when tunnels were constructed in various geological engineering conditions were considered in this paper.

Recommendations about using methods of calculation on the basis of roof arch are provided by requirements documents regarding calculation of tunnel linings; at the same time natural stress field and stress-train performance of soil body, which influence to a great extent on stress-strain state of linings and supports are usually not taken into account. According to the results of field studies that were led in the framework of geotechnical monitoring during transport tunnels construction using technologies providing avoidance of tunnel face front and tunnel contour displacements, soil continuity is preserved and thus, a possibility of aching is avoided. Also this concerns water-saturated quaternary deposits during construction of running and escalator tunnels of underground rapid transit system of Saint-Petersburg with the help of hydraulic and earth-pressure balance-tunnel boring machines.

In many cases of tunnels construction for different purposes when soil body displacements do not influence on continuity the calculations of linings and supports should be made with the help of continuum mechanics methods.

Key words: requirements documents, rock mass, tunnels, loads, geotechnical monitoring, transducers, stresses, calculations.

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Introduction. Recommendations about using methods of calculations on the basis of roof arch are provided by requirements documents regarding calculation of tunnel linings (Code Specification SP 122.13330.2012 «Railroad and highway tunnels», revised edition of Building regulations SNiP 32-04-97).

In unstable soils where arching processes are not possible (water-saturated noncohesive and soft clayish soils) loads on tunnel linings must be calculated taking into account soil column pressure over tunnel construction.

Approaches provided by requirements documents do not consider either natural stress field or stress-strain performance of soil body, which to a great extent influence on stress-strain state of linings and supports. According to field studies results which are led as a part of geotechnical monitoring [1, 3-7, 11, 12], during transport tunnels construction using technologies providing avoidance of tunnel face front and tunnel contour displacements, soil continuity is preserved and thus, a possibility of arching is avoided.

Also this concerns water-saturated quaternary deposits during construction of running and escalator tunnels of underground rapid transit system of Saint-Petersburg with the help of hydraulic and earth-pressure balance-tunnel boring machines. Studies led during construction of railroad tunnels of Baikal-Amur Mainline in rocky soils, transport tunnels along Olympic highway «Adler – Mountain climate resort Alpika-Service» and construction of tunnels of Petersburg underground rapid transit system showed that roof arches have no influence on linings [1, 6, 8].

The study of stress-strain state of tunnel linings in various engineering geological conditions may be given as example in this paper.

Research method. During manufacturing of iron-concrete lining blocks in plant or during lining concreting (sprayed concrete) vibrating wire linear displacement transducers were directly embedded.

Vibrating wire linear displacement transducers allow to measure period (frequency) of a wire depending on its tension, then, having information about calibrating characteristics of transducers relative deformations of linings material may be defined. A special methodic was developed to determine stresses in concrete (sprayed concrete) constructions on the basis of measures deformations including concrete early-age loading.

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Stresses in concrete in any considered moment with respect to concrete creep may be determined according to formula

$$\sigma(t) = \varepsilon(t)E(t) - \int_{t_0}^{t} K(t,\tau)\,\sigma(\tau),$$

where $E(t)$ – concrete elasticity modulus in a considered time moment t; $\varepsilon(t)$ – strains in a considered time moment; $\sigma(\tau)$ – stresses of elastic component of strain of concrete; $K(t, \tau)$ – creep memory function

$$K(t,\tau) = E(t)(1/E(\tau) + c(t)),$$

$c(t)$ – concrete creep degree (ref. table).

Concrete elasticity modulus is closely related to gain in strength during its early-age loading (monolithic concrete linings, sprayed concrete linings and supports) and may be determined with help of approximation:

$$E(t) = E_0(1 - \alpha_1 e^{-\beta_1\tau} - \alpha_2 e^{-\beta_2\tau}),$$

where E_0 – concrete elasticity modulus; α_1, α_2, β_1, β_2 – parameters found on the basis of experimental data.

Degree of concrete creep in time and age loading pattern

Concrete creep characteristics							
Age of loading, days	Concrete creep degree $c(t, t_1)\times10^{-5}$ MPa under duration of loading (t, t_0), days						
	10	25	50	100	200	500	1000
0,125	10	16	20	24	27	31	32
10	1.1	1,76	2.23	2,67	3,06	3,48	3,6
30	0,85	1,41	1,8	2,18	2,52	2,89	3
112	0,5	0,8	1.18	1,45	1,7	1,92	1,98
205	0,35	0,67	0,89	1,09	1,26	1,42	1,46
512	0,21	0,46	0,65	0,8	0,91	0,98	1

In the process of stress calculations the following allowances were taken:
- strains and stresses in reinforcing steel bars are bonded with Hooke's law;
- reinforcing bars deform together with concrete;
- concrete is represented as linearly elasto-creeping material;
- within cross-section concrete is homogenous in composition and age;
- flat cross-section hypothesis is applied.

A construction of running tunnels of prefabricated waterproof modular concrete lining of 7.6 m external diameter with the help of tunnel-boring machines with hydraulic pressure of tunnel face in completely unstable water-saturated quaternary deposits when hydrostatic pressure reaches values up to 0.5 MPa was realized between «Lesnaya» и «Pl.Muzhestva» stations of Petersburg rapid transit system.

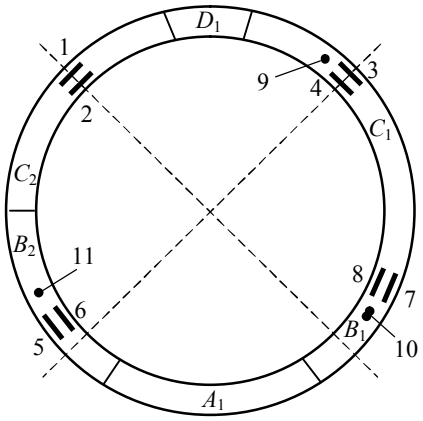


Fig.1. Scheme of transducers installation in the circle (keyblock in vault head)
1-8 – transducers in shear direction;
9-11 – transducers along tunnel axis

Study of static effect on the tunnels in plane normal to its axis was performed with the help of vibrating wire linear displacement transducers for concrete PLDS-400 (wire transducer of linear deformations with measurement range of 400 mm), which were fixed in concrete body of lining blocks during manufacturing process.

Each of four blocks within each circle is equipped with a transducer: B1, B2, C1 and C2 (Fig.1) and 11 transducers were installed: 8 pcs were fixed in the direction normal to tunnel axis, 3 pcs were fixed in the direction parallel to tunnel axis.

Totally, there were installed ten circles with blocks equipped with transducers.

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Fig.2 presents a graph of stresses behavior in block C1 of circle № 308; it is considered to be typical for all normal shear stresses in studied circles.

Maximal value of normal shear stresses fixed in a point of test circle № 420 is equal to 25.8 MPa, which is low in comparison with uniaxial compressive strength of 65 MPa.

In all blocks equipped with transducers normal shear stresses are compressive.

Next example presents results of study of stress-strain state of escalator tunnel lining of «Admiralteyskaya» station in Petersburg underground constructed in quarterly water-saturated soils using earth-pressure balance-tunnel boring machine.

Fig.3 shows engineering geological section of escalator tunnel; lining circles equipped with transducers are fixed on the route of tunnel. Fig.4 demonstrates a scheme of lining with embedded wire transducers for measurements of normal shear stresses and stresses along tunnel axis. As an example fig.5 presents graphs of normal shear stresses in one of lining blocks. Typical situation was revealed for all blocks equipped with transducers: normal shear stresses are compressive with similar development tendency.

Another example – construction of underground infrastructure and ventilation tunnel from mine shaft in Proterozoic clays during construction of Petersburg underground system. Advanced heading was used during tunnel excavation– screen of tubes and placing of shear reinforcement of soil body with rigid arch concrete support with the help of fiberglass injection anchors. These measures allowed to reduce displacements of entry contour almost to zero.

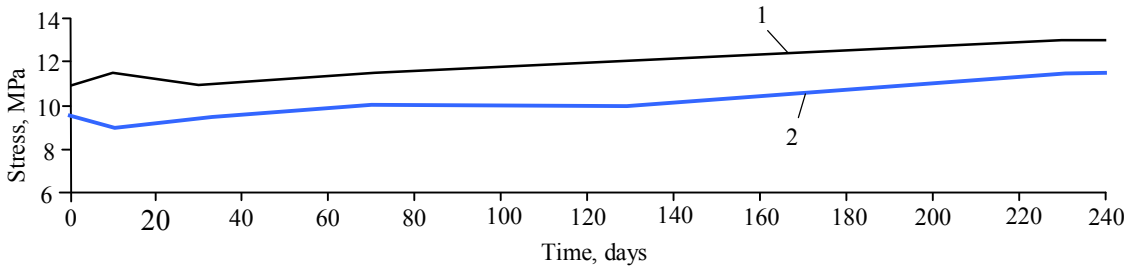


Fig.2. Development of stresses in time in C1 block of circle 308 in tunnel № 1
1 – transducer 3; 2 – transducer 4

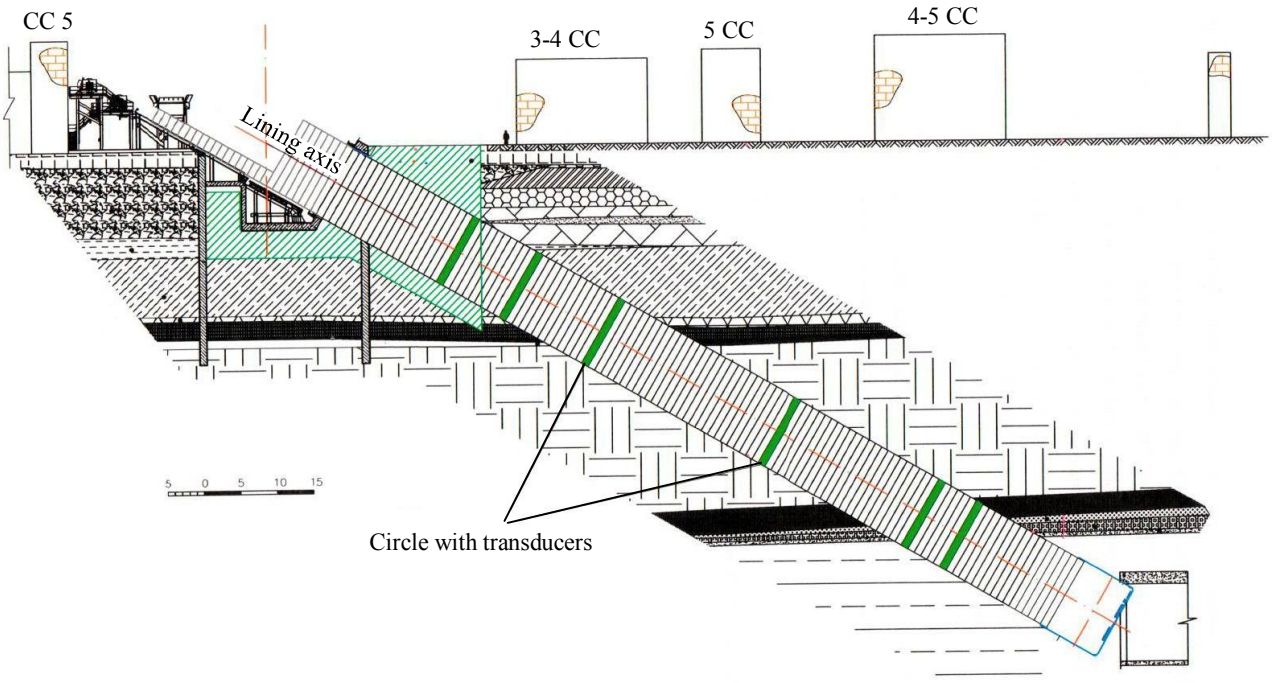


Fig.3. Placement of lining circles with transducers along tunnel route

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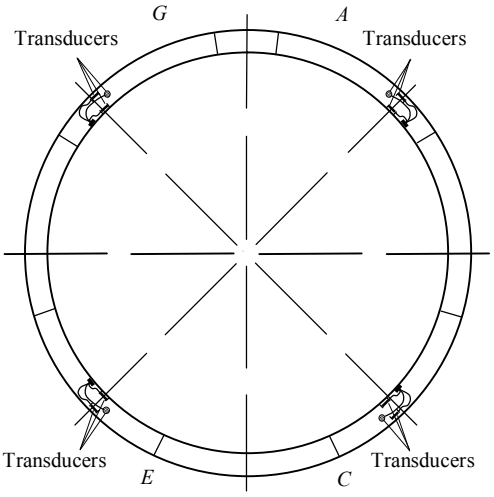


Fig.4. Scheme of transducers placement in escalator tunnel

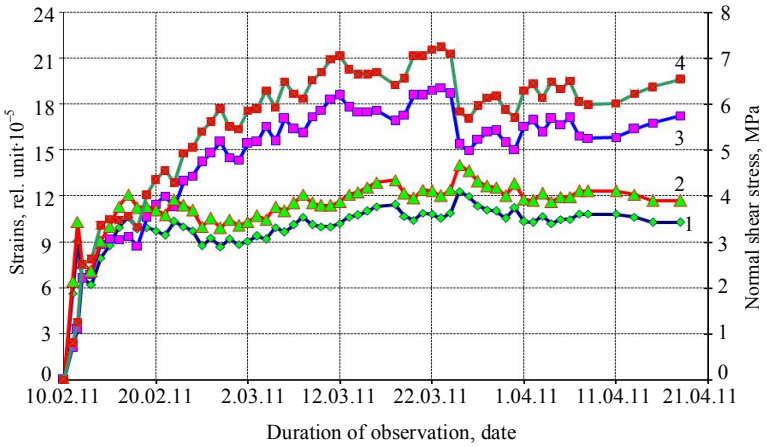


Fig.5. Graph of stresses in one of lining blocks on external (1, 2) and internal (3, 4) contour

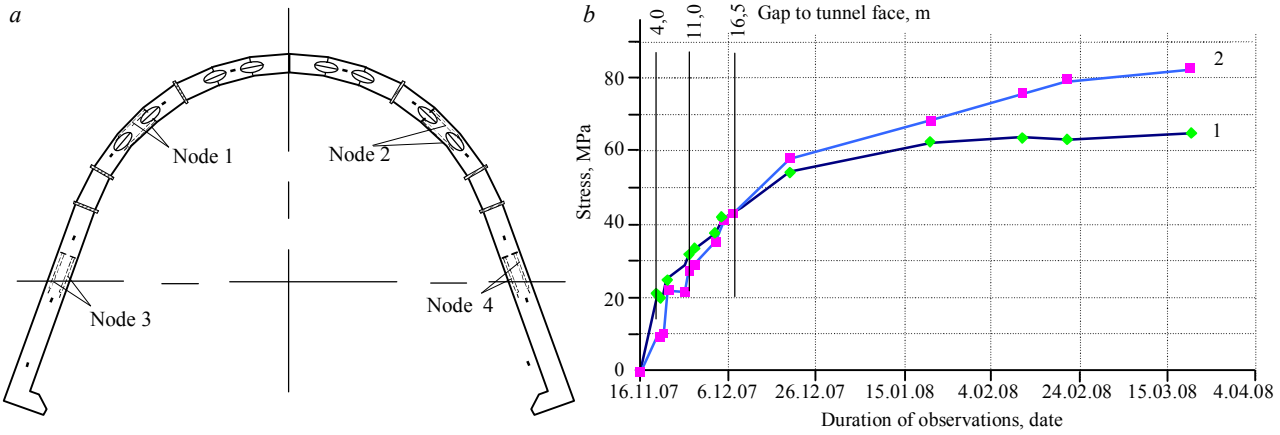


Fig.6. Implementation of control and measurement equipment to steel arch in nodes 1-4 (*a*) and graph of normal shear stresses in one of nodes in perimeter of support on external (1) and internal (2) contour (*b*)

In frame support wire transducers – strainmeters PLDS-400 – were used to study its stress-strain state. Transducers installation on steel frames was performed according to scheme showed in fig.6, *a*. Transducers were installed on the internal and external contours in each node of frame perimeter. Fig.6, *b* shows graphs of normal shear stresses development in time in cross-sections of concrete arch support, which are considered to be typical for experimental areas.

The most intensive growth of stresses was revealed during 2 weeks. Within this period of time a gap to tunnel face was equal to 15 m. In the end of this period the value of stresses was equal to 40 MPa. Further the increment of stresses was not so significant and the speed of increment gradually decreases.

Results of studies that were led during ventilation tunneling excavation showed the following:

• stresses in frame support do not exceed 50 % of its load bearing capacity, which provides possibility on the stage of design to decrease specific consumption of materials for support construction or to increase setting increment of frames regarding the same engineering and technical conditions;

• normal shear stresses both on the internal and external contours are compressive.

The results of studies showed that in conditions of interaction between linings (supports) and adjacent soil body its continuity was preserved. That is the reason why for all presented experimental areas calculations were made using continuum mechanics methods [2]; use of these methods showed close convergence in contrast to results of calculation using fixed loads method, in which normal tensile shear stresses appear almost in all cases.

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In this method a plane contact problem of elasticity theory for a circle of optional form (one symmetry axis) reinforcing an opening in the linearly elastic homogenous isotropic medium (Fig.7). A circle S_1 simulates a support and is limited by contours L, L_1, has stress-strain properties E_1, ν_1 (elasticity modulus and Poisson ratio of support material relatively) and works jointly with medium S_0 which simulates rock mass with the characteristics E_0, ν_0, i.e. vectors of stresses and strains along the contact line L are continuous.

A medium has initial stress state which generally may be characterized by principal stresses N_1 and N_2, acting under optional angle $\tilde{\alpha}$ to vertical and horizontal lines. An inclined position of principal axes may be provoked by tectonic forces action in rock mass.

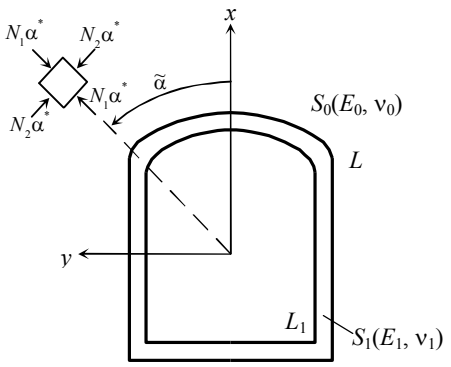


Fig.7. Design diagram for contact problem of interaction between support and soil body

Conclusion. Multi-year research of stress-strain forming in transport tunnels and other underground constructions linings allow to make a conclusion that in many cases of different purpose tunnels construction where strains of soil body do not influence on adjacent soil body continuity calculations of supports and linings should be made on the basis of continuum mechanics methods. Methods of stress-strain calculations closed to underground constructions with respect to limit state of rock mass are given in papers [9, 13, 14].

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Authors: **Konstantin P. Besrodny**, *Doctor of Engineering Sciences, advisor of general director in research scientific work, besrodny@lenmetro.ru (OJSC NIPII «Lenmetrogiprotrans», Saint-Petersburg, Russia)*, **Mikhail O. Lebedev**, *Candidate of Engineering Sciences, deputy general director in research scientific work, lebedev-lmgt@yandex.ru (OJSC NIPII «Lenmetrogiprotrans», Saint-Petersburg, Russia)*.

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