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Calculation of the Lining of Construction of the Shallow Subway Tunnel

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Abstract. The alternative from the normative method for numerical calculating the construction of the lining of the shallow subway tunnel for standard loads are proposed in this issue. The most important drawback of existing regulatory models and calculation methods is the use linear properties of a material. Applying in practice of new materials, new types of reinforcement, including composite materials, require the use of a more advanced approach for calculation and design of newly constructed structures. It is vital when structures is constructed in seismic prone regions, where it is necessary to take into account seismic loads, as well as reserves of the bearing capability of materials. The proposed method is directed to use real loading diagrams of concrete and reinforcement steel specifications. This approach also allows us to trace the deformation's character of a reinforced concrete structure in each site of it. By applying proposed below approach a more detailed analysis of the stress and strain state of various elements of the structure are shown here.

Keywords. Subway, stress, strain, structure, reinforcement

1. Introduction

Shallow tunnels often have to be built in unfavourable engineering and geological conditions. Besides, it can be located in seismic prone zones, and the influence of surface waves should be taken into account, which can make a significant contribution to the design loads according to the standards. The ground conditions around such structures may typically consist of fine-grained water-saturated soils also.

There are wide spectra theoretical, numerical or experimental investigation for identification of subway tunnel's damages, seismic response by using finite or boundary element analysis are provided [1-6]. These investigations generally includes case study. However, building codes applied in practice.

As rule, the underground tunnel consists of reinforced concrete blocks. The internal dimensions of the cross-section of passageway tunnels are regulated by the clearance of the passage in the tunnel. The average length of the subway tunnel is from 800 m up to 2000 m. The tunnel construction elements are subject to calculation. Generally, the construction of subway tunnels can be with vaulted lining and tunnels with flat ceilings.

At the same time, they can be single- or double-vaulted with single, double or multi-spans. As a rule, the lining of the subway tunnels are closed structures and either

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prefabricated from reinforced concrete or concrete elements or cast-iron tubings, or monolithic from reinforced concrete and concrete. In our case for shallow subway tunnel, a prefabricated reinforced concrete lining of four flat elements and a rectangular all-section lining in the form of a closed finished tunnel link were used.

2. Numerical Approach and Calculation

The whole-sectional lining (figure 1) as rule is 3D reinforced concrete or composite frame. The general standard proportions of the whole-sectional lining construction are: height is 4.61m, width – 4.15m; gauge of the lining elements at a backfill height above the tunnel from 1m up to 7m and level of groundwater up to 1m below the day surface are taken as for the beams are 0.25m, flumes are 0.22mm, walls are 0.19m. The concrete grade for the lining with unified dimensions was taken as for compressive strength concrete (Rc) not less than 14.8MPa (B25 grade), for tensile strength (Rct) not less than 1.07MPa, Young's modulus (Ec) is 30000MPa. The lining is reinforced with welded meshes and steel A-I, A-II, and A-III grade frames. The thickness of the protective layer of working reinforcement is taken 15mm, and the spacing of working reinforcements from 0.10m up to 0.15m.

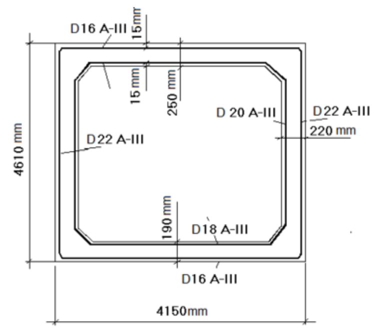

Figure 1. Standard of a whole-sectional lining design.

By approach proposed in [7], the numerical computation of a standard lining design (figure 1) is calculated for primary combinations of external forces. It is symmetric loading on the lining design by the surface traffic located above the tunnel [8]. The lining design is subject to standard permanent vertical and horizontal loads from the weight from above the tunnel space. It is includes the backfill soil, the hydrostatic pressure of subsurface liquid up to the flume axis level, the lining's own weight, and soil pressure, etc. (figure 2).

The intensity of the standard load from wheeled or automobile transport on the road's surface have to be taken as greatest load at the level of the lining beam axis [3]. In accordance with the requirements of standards [7] and other norms [10, 11] the external loads for tunnel design were calculated by the "Tashmetroproekt" with using the following data:

Soil was loam with standard volumetric weight γ=0.018*MPa/m*;

Normative angle of internal friction of soil is accepted as $\varphi=24^0$;

The maximum groundwater level was located 1m below the ground surface;

Soil elastic modulus is *E=50MPa*;

Soil pressure is R, bed coefficient (modulus of subgrade response) – *k=5MPa/m*;

Depth of tunnel relative to the ground surface is *H=4m;*

Thickness of road coat was *0.2m*.

The cumulative vertical standard and computed dead loads for the primary limit states with load combination as:

- The external load applied at the beam plane (surface pressure, the backfill gravity, additional vertical pressure due to the presence of groundwater, the own beam’s weight, the magnitude of the live load according to the norms scheme (NK-80)

$$q_{s,normative} = 0{,}09351 MPa \, , \; q_{s,calc.} = 0{,}10719 MPa$$

horizontal pressure applied to the lining at the level of the axes of the beam and flume:

$$P_{ah1,normative} = 0{,}0112 MPa \, , \; P_{ah1,calc.} = 0{,}02215 MPa$$

$$P_{ah2,normative} = 0{,}0448 MPA \, , \; P_{ah2,calc.} = 0{,}05277 MPa$$

magnitude of additional horizontal pressure due to the presence of groundwater:

$$P_{hw1,normative} = 0{,}01858 MPa \, , \; P_{hw1,calc.} = 0{,}01974 MPa$$

$$P_{hw2,normative} = 0{,}04762 MPa \, , \; P_{hw2,calc.} = 0{,}05058 MPa$$

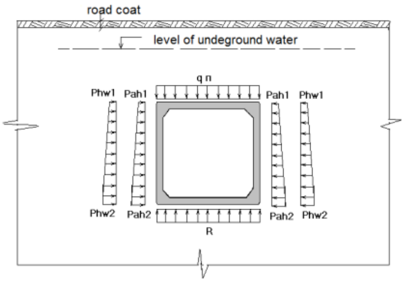

Figure 2. Scheme for primary loads, according to norms [9].

Two calculation schemes were used to calculate the tunnel lining:

a) According to the existing scheme - the “ZNIIS model” used by the Tashmetroproekt Institute (figure 3);
b) According to the scheme of the methodology and program developed by FEM (figure 4).

The linear layout for deafining of internal loads by “ZNIIS model” [7] is used here.

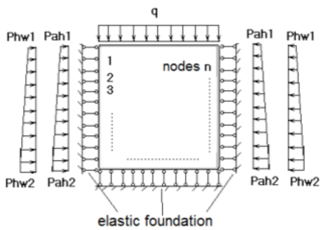

Figure 3. Calculation scheme according to the ZNIIS model.

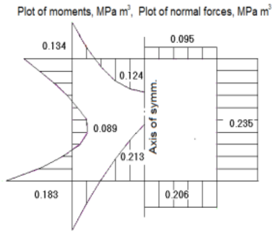

Figure 4. Normal forces and moment diagrams by the “ZNIIS model”.

By calculating of internal forces according Baikov SD [12], the compressed zone height is defined as (figure 5):

$$x = (R_S A_S - R_{SC} A_S^{/}) / R_c b$$

here, R_c is the design strength of concrete in compression, R_{sc} is design strength of reinforcement in compression, R_s is design resistance of reinforcement at tension, A_s, A'_s are the cross-sectional areas of reinforcement in tension and compressed zone. The following condition must be met $\xi \le \xi_R$, $\xi = x/h_o$, $\xi_R = \dfrac{\omega}{1 + \dfrac{\sigma_{SR}}{400}(1 - \dfrac{\omega}{1{,}1})}$, ω is the characteristic of the concrete compressed zone defined as $\omega = 0.85 - 0.008R_c$, here $\sigma_{SR} = R_s$, $a^{/}$ are the distances from the acting forces in the reinforcement to the nearest edge of the section. The strength of the each section is provided in case when the calculated bending moment from the external loads does not exceed the computed bending moment of internal forces. Bending moments calculated for the gravity centre of tensioned or compressed zone of concrete relatively (figure 5).

$$M \le R_c bx(h_0 - 0.5x) + R_{sc} A_s^{/}(h_0 - a^{/})$$

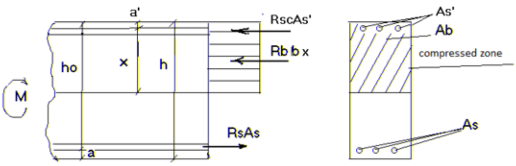

Figure 5. Cross section at limiting state for double reinforcing structure.

In the table 1 the calculated data according to the above formulas, to test the strength in a standard beam, wall and flume are presented.

Table 1. Calculated values.

№	beam	wall	flume
h, m	0.25	0.22	0.19
b, m	1	1	1
a, m	0.025	0.025	0.025
a', m	0.025	0.025	0.025
h_o, m	0.225	0.195	0.165
R_c, *MPa*	14.8	14.8	14.8
ω	0.7316	0.7316	0.7316
ξ_R	0.560353	0.560353	0.560353
Rs, *MPa*	365	365	365
Rsc, *MPa*	365	365	365
As, m^2	0.002512	0.00266	0.004832
A's, m^2	0.001206	0.002512	0.00201
x	0.032215	0.00364	0.069618
ξ	0.43176	0.018665	0.421926
M, *MPa* m^3	0.187616	0.166276	0.236832

The section's strength according to highest value for moment obtained by the "ZNIIS model" we can write:

For beam 0,134 $MPa\ m^3$< 0,187616 $MPa\ m^3$
For wall 0,089 $MPa\ m^3$< 0,166276 $MPa\ m^3$
For beam 0,213 $MPa\ m^3$< 0,236832 $MPa\ m^3$

Next step is lining calculation by design scheme (figure 6.). Here the non-linear deformation (by taking into account all weights for strength limits) was taken for computing.

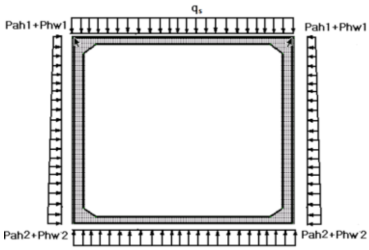

Figure 6. FE design scheme "concrete-reinforcement" according to the developed methodology and program.

Figure 7 shows the deformation of the structure under the action of a symmetric loads. On figure 8 are presented calculated stresses when the tensile stresses in concrete sites exceed or not theirs limit values.

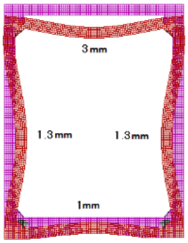

Figure 7. Deformation of the structure.

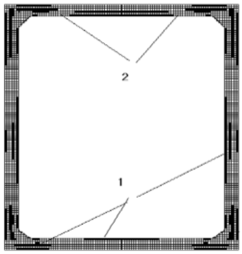

Figure 8. Calculation results: 1) sites where tensile stresses are above the limit value, 2) sites where compressive stresses are below the limit value.

3. Conclusion

By calculation was revealed that in a reinforced concrete structure the largest compressive stresses arise basically at the junctions of various inwall elements with each other (floor with wall, wall with flume). In described problem the maximum value for clenched stresses zone was 10.889MPa, and it's did not achieved the strength limit which is 14.8MPa for this case. So effect was due to the presence of lengthwise reinforcements. Even in destroyed sites of concrete the tensile stresses values in the steel reinforcement did not exceed 16.43MPa. On the figures 9 and 10 the averaged calculated values for principal stresses are presented. On these figures, the sites of maximal stress magnitudes are shown. In general, the data obtained confirm the results of "ZNIIS model"; however, it's have to be underlined that values for bending moments calculated by the proposed model (figure 11) in inelastic calculation turned out to be 20-25% less than those shown in figure 4 (elastic model).

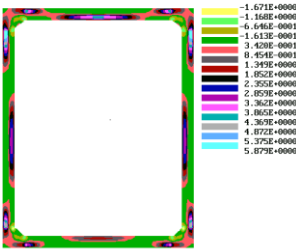

Figure 9. Isochromes of principal stresses σ_1 in a structure.

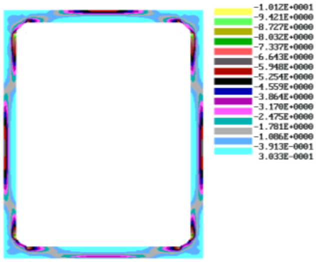

Figure 10. Isochromes of principal stresses σ_2 in a structure.

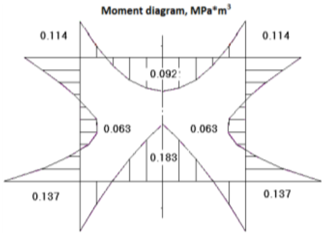

Figure 11. Diagram of the bending moment obtained according by inelastic model.

The principal lack or disadvantage of the “ZNIIS model” is using the internal forces extracted from the elastic calculation in the strength calculations.

The principal vantage of presented calculation approach is using the real stress-strain curve for concrete and reinforcement. This also allows for civil engineers the visual view, track of strain pattern of each site of reinforced concrete structure and find path to develop strengthening measures if necessary.

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