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STABILITY OF THE TUNNEL PASSING NEAR THE SLOPE TAKING INTO ACCOUNT THE GROUTING ZONE

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Abstract. Diversion tunnels of high head pressure hydropower plants usually pass near the gorge, which worsens the operating conditions of the "tunnel-massive" system, especially when seepage through the tunnel develops. When designing, it is necessary to determine the route of the tunnel with minimal depth and distance from the gorge surface. Solving this problem using classical solutions encounters well-known difficulties. In this regard, numerical methods have a great advantage. By analyzing the numerical results of alternative solutions, it is possible to achieve an acceptable location of the tunnel axis that provides safety conditions.

When solving assigned problems using finite element method (FEM), difficulties arise, mainly related to the development of calculation schemes for variant problems. In this regard, the boundary element method (BEM) has a great advantage. With a change in the location of the center of the tunnel, the design versions of the "tunnel-massive" system are rebuilt while maintaining the boundary element approximation of the edge contour.

The article provides some results of a numerical assessment of the stability of a slope in the presence of a tunnel, taking into account seepage through the lining.

Key words: Stability, system "tunnel-massof"; seepage; Boundary Element Method;

Introduction.

The track of the Engurhesi pressure tunnel mainly passes in the vicinity of the valley. The pressure tunnel (length 15 km, diameter 9.5 m) is designed with waterproof (non-crack resistant) concrete with limited parameters (number and opening) of equally distributed cracks. During the operation, there was a seepage

In general, according to the requirements of construction norms, the permissible seepage losses from the tunnel should not exceed 1% of the estimated cost of the HPP. Actually, the operation of HPPs showed that the value of seepage losses is much higher than allowed.

The pressure tunnel of Engurhesi passes through difficult geological conditions. The maximum pressure value at the beginning and end of the tunnel is 110-175 m, respectively, and the water level variation in the reservoir is 80 m.

An important feature of the construction of the Engurhesi derivation tunnel is that in the main part of its length it is presented as a single complex - concrete repair (0.5 m thick) with a reinforcing cement zone (6 m deep). Such a solution replaced more traditional constructions, e.g. reinforced concrete, composite or metal.

The monolithic array created by reinforcing cementation receives the pressure developed from the moles during the action of the pressure inside the tunnel. Thus, the performance of the repair is completely determined by the characteristic parameters of the strengthening cementation zone (elastic back pressure and water permeability), which must meet the design values. Thus, reinforcing cementation together with filling cementation is an integral part of the pressure tunnel, without which the normal operation of the facility is practically impossible.

In 2006, as a result of the rehabilitation works (grouting and 2-layer shotcrete) carried out in separate areas of the tunnel, seepage losses were temporarily reduced. Then the seepage costs increased again, which is related to the development of suffusion processes in the array.

Main part.

Evaluation of seepage parameters in the massive surrounding the tunnel

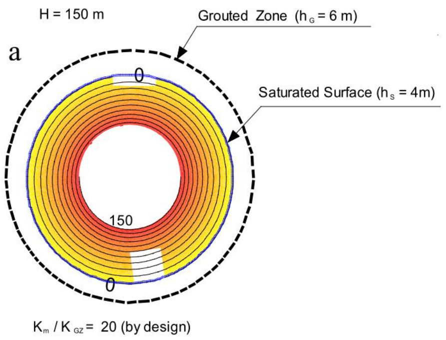
In general, individual areas of the massif surrounding the tunnel are also characterized by anisotropy.

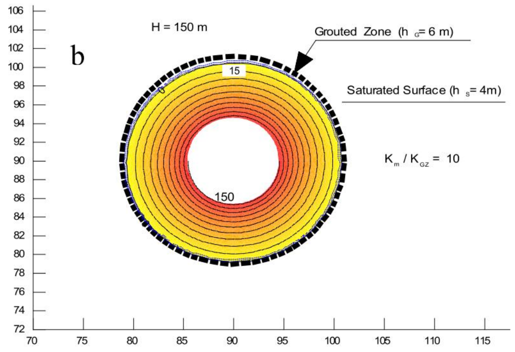
During the operation of the tunnel, filtering sources appeared in the valley, the regularity of the change of costs is correlated with the water reinforcing and filling cementing was not performed during the construction, or a suffusion process developed during the operation period. In this regard, it is expected that the anisotropy of the massif would be preserved in the conditions of the low-quality cementation zone.

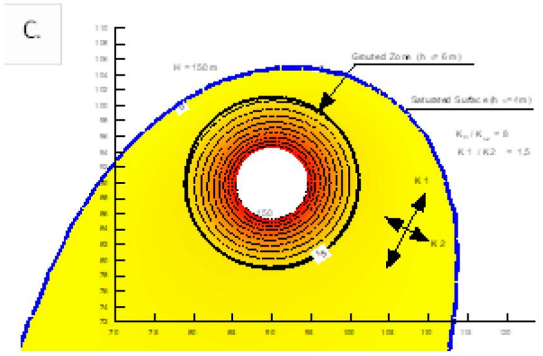
level in the reservoir. According to the results of the observations, the tendency of the increase in the cost of individual sources was revealed over the years. Judging from the above, it can be assumed that proper quality

In order to predict the processes developed during operation, a series of studies were conducted, during which the design and also the increased the grouting zone permability, were taken into account:

$K_m / K_{gz} =$ 20,10, 9, 8, ... , 3.







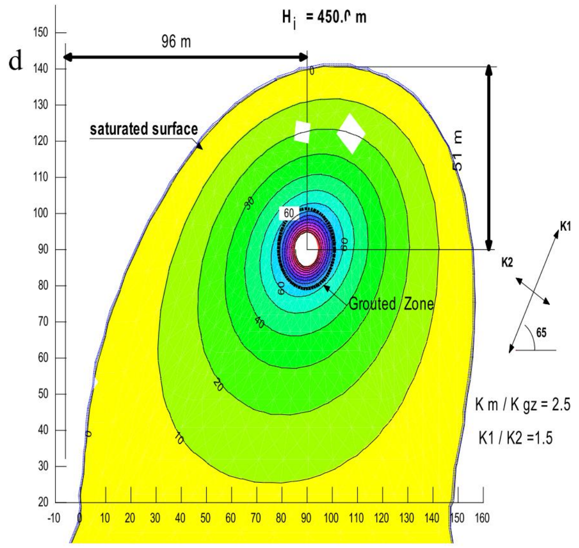


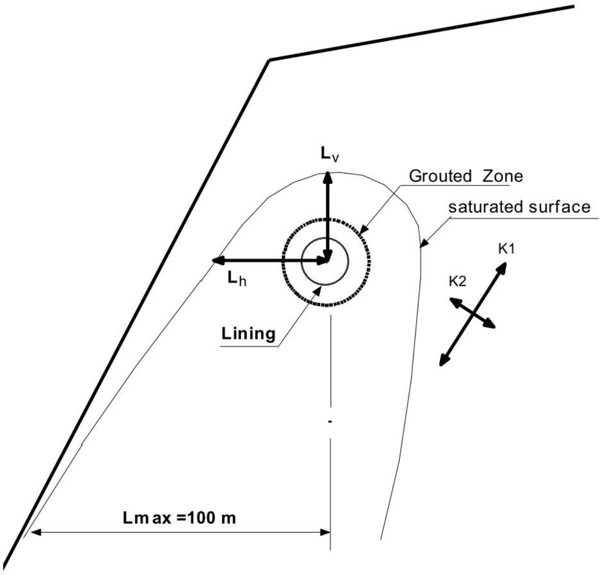
Fig. 1. Distribution of seepage pressures in the surrounding tunnel:

a. for the design condition;

b. The phreatic surface is placed within the grouting zone when Km/Kgz=10;

c. in case when grouting zone is a with low quality;

d. due to the anisotropy of the massif, the phreatic surface approaches the slope



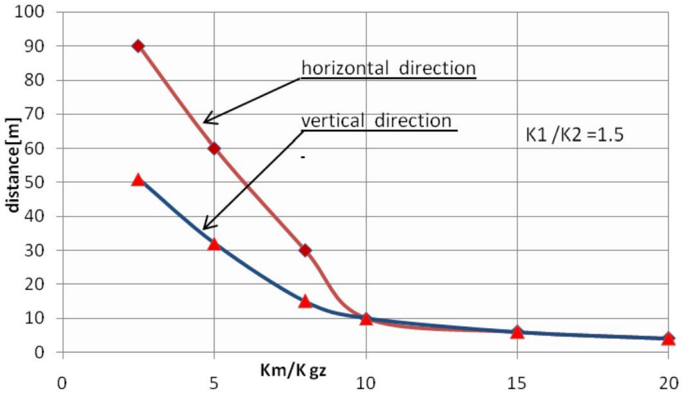


Fig. 2 phreatic surface curves spreading in horizontal and vertical directions.

It was obtained by calculations (fig. 1, 2) that:

- In the range, the depression surface remains within the cementation zone;
- in the presence of a low quality of the cementation zone (or in the presence of a suffusion process), when the material partially repeats the anisotropy of the array, the depression surface already passes from the cementation zone;
- It represents the critical value of the depression surface (it departs significantly from the axis of the tunnel and begins to wet the slope of the valley), for which it has not yet been reached (fig. 2).

Thus, we can assume that the reinforcement is more realistic for the current state of the cementation zone.

Estimation of the stability of the slope of the gorge with the presence of a tunnel and seepage

The stress state of the massif around the high-pressure tunnel is characterized by significant tensile (hoop) and compressive radial stresses. The concentration of specified stress is still increased when there is a non-reinforced finish. In this case, the zone of shear failure (η≤1) may exceed the zone of arching (determining the calculation of massif pressure on the lining) when designing tunnels, according to guideline [1]

Boundary-element approximation of the studied area is carried out according to the solving equation in the form of the method of seepage loads [2,3}:

$$\left.\begin{aligned} b_S^i &= \sum_{j=1}^{N} C_{ss}^{ij} P_S^j + \sum_{j=1}^{N} C_{sn}^{ij} P_n^j \\ b_n^i &= \sum_{j=1}^{N} C_{ns}^{ij} P_S^j + \sum_{j=1}^{N} C_{nn}^{ij} P_n^j \end{aligned}\right\} \quad i=1, \ldots, N$$

where: b_s^i and b_n^i denote known boundary conditions on the contour by effort or displacement; $\sum_{j=1}^{N} C_{ns}^{ij}$, . . . ,$\sum_{j=1}^{N} C_{nn}^{ij}$, generalized boundary coefficients of influence or tension or displacement; P_S^j, P_n^j, seepage fors.

For the “tunnel-massif” calculation system, the following boundary conditions are specified:

- along vertical edges - $\sigma_s = 0$; $U_n = 0$;
- for the bottom face – Us = 0; Un = 0;
- for a slope σ_s 0; $\sigma_n = 0$;
- for the upper face, the load from the own weight of the overlying part of the array is taken into account.

As a numerical example, below we consider the joint operation of a Enguri tunnel (with a diameter of 9.5 m), with an unreinforced lining with a massif, using boundary elements method BEM (fig. 3).

The shear strength of the rock mass was assessed using safety factors according to the dependence [4]:

$$\eta = \frac{\tau_{\alpha пр}}{\tau_{\alpha}},$$

where: $\tau_{\alpha пр}$ - limiting resistance to shear of the rock mass along dangerous shearing areas; τ_{α} is the effective shear stress over the same areas.

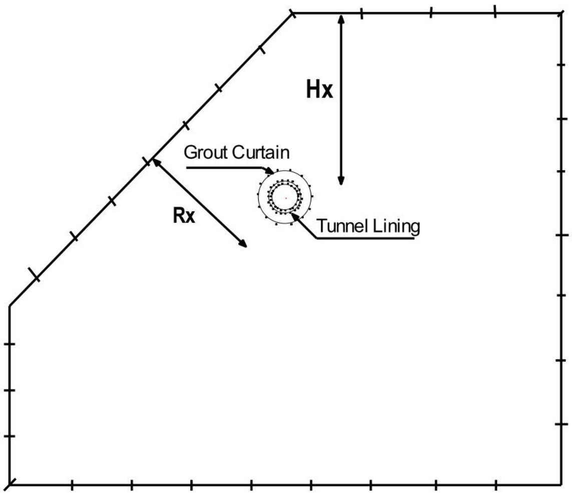


Fig. 3 Calculation scheme of the "tunnel-massife" system using BEM.

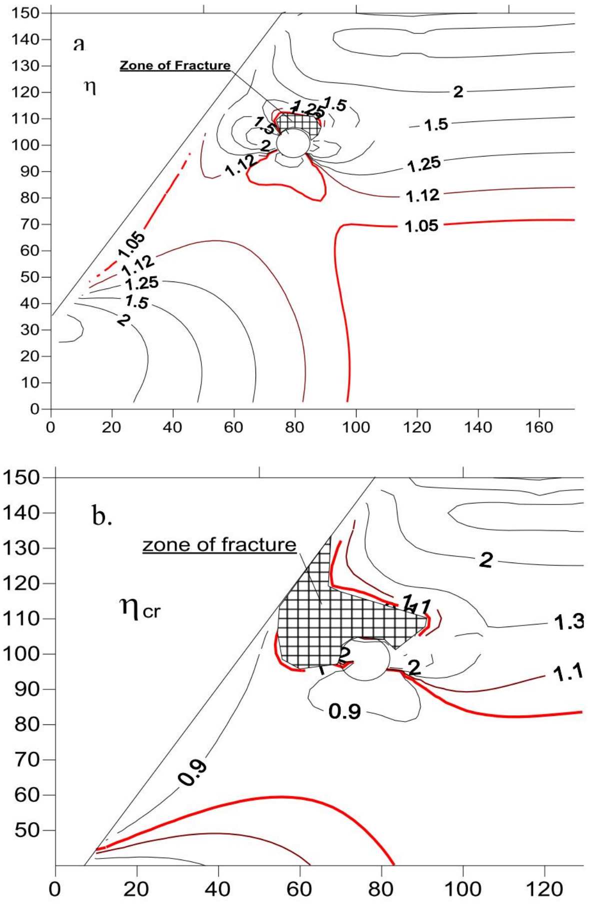


Fig. 4 Isolines of safety factors of the tunnel-massif system.taking into account:

a the presence of a destruction area (η≤1), at Rx=30 m;

b. limit state of the tunnel- massif system, at Rx=20 m.

When η>1 the massif has a shear strength margin; when η≤1 the strength of the array is exhausted, a limiting state occurs.

The pewswnt work considered 2 calculation options: a) an isotropic massif and b) an anisotropic massif with overlapping layers along the expected shear. The latter considers the most unfavorable arrangement of layers - close to perpendicular to the slope. By analogy with the Enguri hydroelectric power station massif, the ratio of deformation moduli along and across the layers was adopted: ${E_1}/{E_2}$=1.6 (E_1 and E_2 deformation modulus along and across the layers).

According to the calculation results, it was found that:

- under conditions of massif isotropy when:
  - Rx=30m (the distance of the tunnel axis to the slope), the destruction area above the tunnel was 6.3m (Fig.4). At the same time, the zone of tensile stresses spread in the height of the massif up to 7 m;
  - Rx=25m, a limiting state occurs in the array. In this case, there is a complete rupture of the massif towards the slope of the gorge (Fig. 5).
- under conditions of anisotropy, shear safety factors decreased by an average of 25% (Fig. 5).

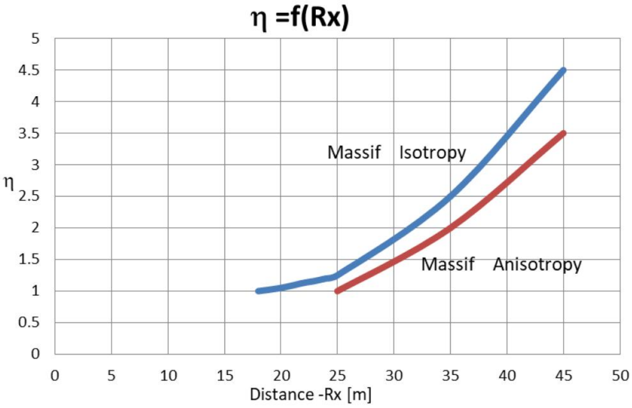


Fig 5. Diagram connecting safety factors with the distance between the tunnel axis and the slope.

Conclusion

Based on the conducted research, the following conclusions can be drawn:

- Developed methodology based on BEM:
  - characterized by the simplicity of the calculation scheme, which gives an advantage over FEM. By simply changing the location of the center of the tunnel, rebuilding the design schemes of the "tunnel-array" system while maintaining the boundary element approximation of the edge contour of the system, a variety of research options is achieved;
  - allows you to justify the route of the diversion tunnel (according to the tensile and shear strength of the base material) taking into account the topographic and geological structure of the massif;
- When designing pressure tunnels, zones of destruction caused by internal pressure, which may exceed the zone of arch formation, which determines the calculated rock pressure according to SNiPs on the lining. Therefore, the above should be taken into account when designing tunnels;
- Anisotropy of the massif (when the layers are located close to perpendicular to the slope) significantly (on average by 25%) reduces the safety factors.

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