Design of pressure tunnel with consideration of construction sequence influence

Alex Miminoshvili
Georgian Technical University, Tbilisi, Georgia, 77, M. Kostava St. 0160
lexomiminoshvili@gmail.com

DOI: https://doi.org/10.52340/building.2025.71.27

Abstract The paper presents a study of the stress state of the "tunnel-surrounding massif" unified system taking into account the technological scheme of tunnel construction.

During tunnel construction, during the staged development of the ground, there will be a gradual development of mining loads on the existing tunnel lining. Unlike the sudden construction scheme, such a scheme is close to the correct assessment of the loads developed on the lining and, accordingly, the calculation of the lining structure.

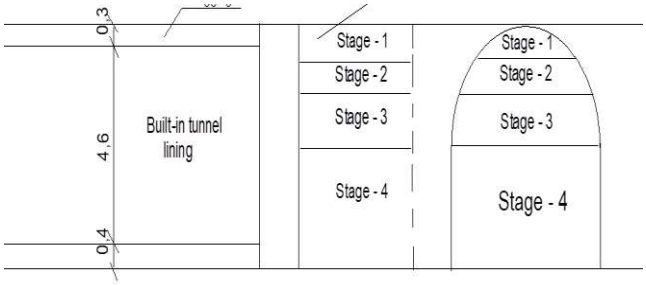
On the basis of the numerical calculation carried out for the design solution of the Aspindza HPP pressure tunnel, the stress state parameters reflecting the joint operation of the "tunnel-surrounding massif" system were obtained, taking into account the differentiated influence of the construction technology (sudden construction and staged construction). In particular, the vertical normal stresses in the lining cross-section increased insignificantly, while the horizontal normal stresses decreased by 25%. In the cross-section of the foundation, the compressive stresses increased in the construction state (up to 20%), while in the operational state, the compressive stresses decreased (up to 30%).

INTRODUCTION

In general, tunnels are calculated using the "sudden construction scheme" - within the framework of superposition. In reality, the tunnel is constructed in stages along its longitudinal axis, which deviates from the superposition approach.

During the tunneling process, as the ground is gradually worked out, there will be a gradual development of mining loads on the existing tunnel lining. Unlike the sudden construction scheme, such a scheme is closer to the correct assessment of the loads developed on the lining and, accordingly, to the calculation of the lining structure.

The study of the joint operation of the tunnel surrounding the array system, taking into account the construction stages, was carried out in 4 main stages (processing zones 6, 7, 8, 9 are given in the drawing (Fig. 1).



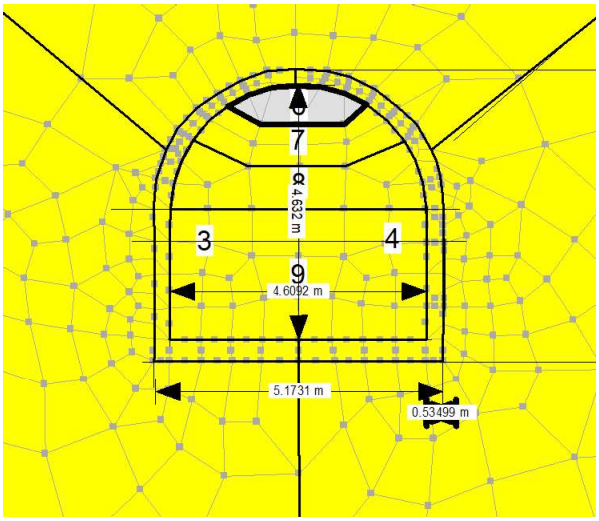


Fig. 1 Scheme of the phased construction of the tunnel.Fig. 2 Calculation scheme of the "Tunnel

Surrounding Array" system. Stages of tunnel development.

During the calculation, in accordance with the presented calculation scheme, at each stage of the array processing in accordance with the tunnel construction stages, the corresponding elements of the excavated area are removed from the calculation scheme. As a result, at each stage of the calculation, the stresses are redistributed from the removed elements to neighboring elements.

- Calculation of the stress state of the tunnel construction

Taking into account the construction stages

As a result of the calculation, the results of the stress state of the tunnel construction were obtained for all stages of construction and are given in the drawings below.

- Tunnel crown section (1-1)

σy - The distribution of stresses in the vertical section of the intact massif was reflected in the epigraph with a linear regularity. At each subsequent stage of massif processing, there is a decrease in loads at the crown section of archt.

During tunneling, the stresses σx in the direction of the cross-section of the clit (vertical cross-section direction) gradually increase and reach their maximum value when the tunnel is completely finished. This indicates the appearance of the arch effect.

The regularity of the stress distribution was clearly evident in the section of the repair cleft. During the stage-by-stage processing of the tunnel, the compressive horizontal normal stresses gradually decrease, and during the complete processing of the tunnel section, they transition into tensile stresses.

- Toe and wall sections (2-2, 3-3) of tunnel

During the staged processing of the tunnel, the distribution of stresses at the heel and wall intersections develops according to the following regularity (fig. 2):

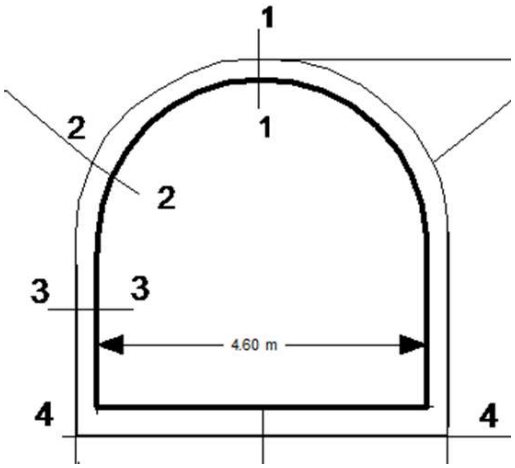


Fig. 3. Sections under consideration for tunnel construction.

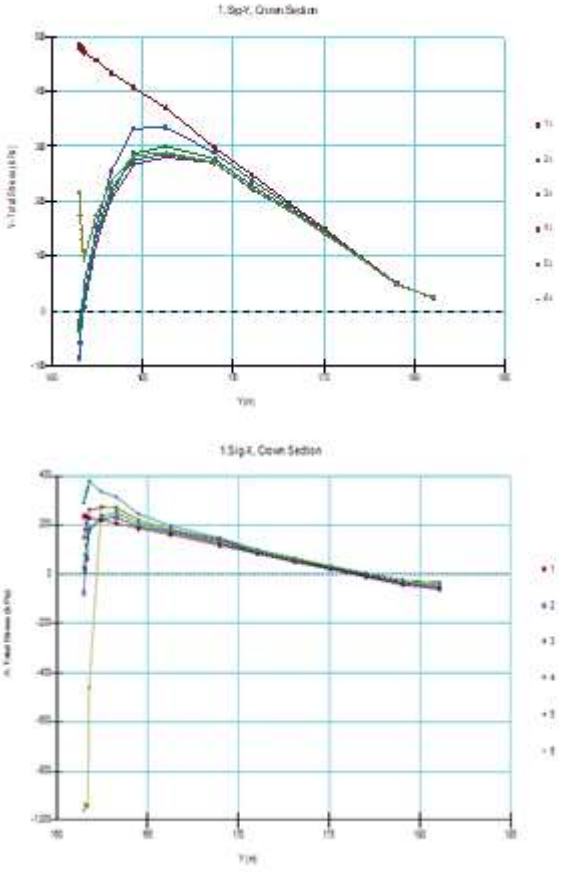


Fig. 4. Distribution of the normal stresses in the vertical cross-section of the tunnel.
a. vertical normal stresses;
b. horizontal normal stresses

- The vertical normal stresses σ_y in the direction of the array's construction gradually increase, and at the heel

intersection the stresses reach their maximum. Under the action of hydrostatic pressure, tensile stresses appear in the structure, the maximum value of which at the heel intersection reaches -68 kPa.

– During tunneling, the stresses σ_x in the direction of the cross-section of the clit (vertical cross-section) gradually increase and reach their maximum value during the complete tunneling (Fig. 2.2.4 2).

0

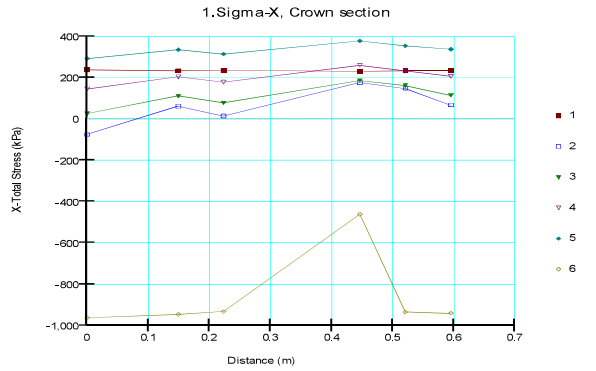


Fig. 5. Distribution of horizontal normal (σ_x) stresses in the arch crown section

– Distribution of vertical normal stresses in the vertical cross-section of the clit of the tunnel. σx Distribution of horizontal normal stresses in the cross-section of the repair arch. c). This indicates the occurrence of the arch effect.

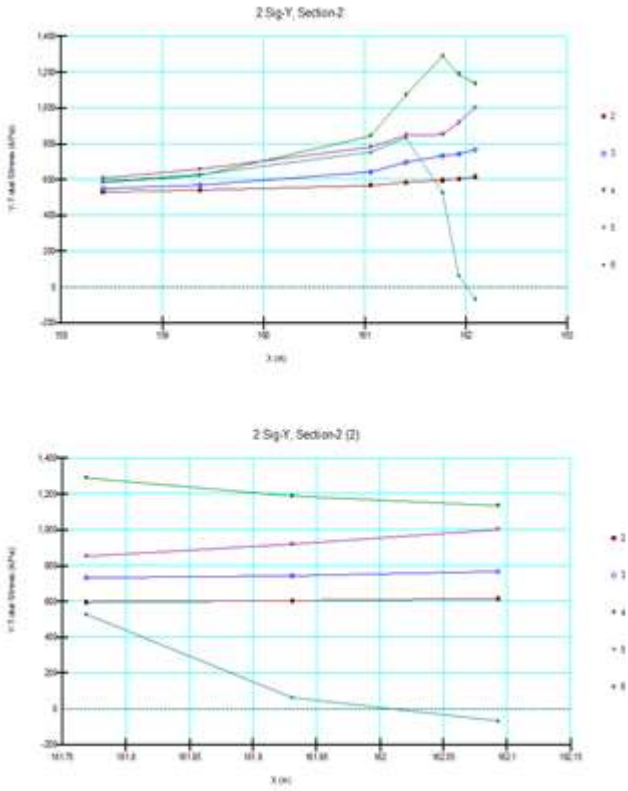
➢ Tunnel arch heel and wall sections (2-2, 3-3)

During the gradual development of a tunnel, the stress distribution at the heel and wall intersections develops according to the following regularity (fig. 3,4):

– σy vertical normal stresses occur with a gradual increase in the fibers. Obviously, the stresses reach their maximum value at the heel section. Under the action of hydrostatic pressure, tensile stresses appear in the structure, the maximum value of which at the heel section reaches -68 kPa.

– The distribution of horizontal normal stresses σx in the massif is increasing, and on the contrary, it decreases along the repair section.

– As a result of the pressure from inside the tunnel, the stresses in the section decrease,



which is reflected in the values of the stresses σx and σy.

Fig. 6. Distribution of vertical normal stresses in the vertical cross-section of the tunnel

➢ Tunnel base section (4 - 4)

The gradual processing of the tunnel was also reflected in the contact section of the tunnel lining and the base (Fig. 2.2.4 6 σ_xhorizontal and σ_y vertical normal stresses distribution at the contact section of the tunnel lining and the base,. In particular,

The distribution of σx horizontal normal stresses is mainly of an increasing nature, and during the

complete processing of the tunnel section, on the contrary, the stresses decrease in the central part, and towards the heel sections, the stresses increase.

The distribution of σy vertical normal stresses during the gradual processing of the tunnel has a decreasing nature and reaches a minimum value (0.32 kPa) during the complete processing of the tunnel section, while towards the heel sections, the stresses increase and reach a maximum value (958 kPa).

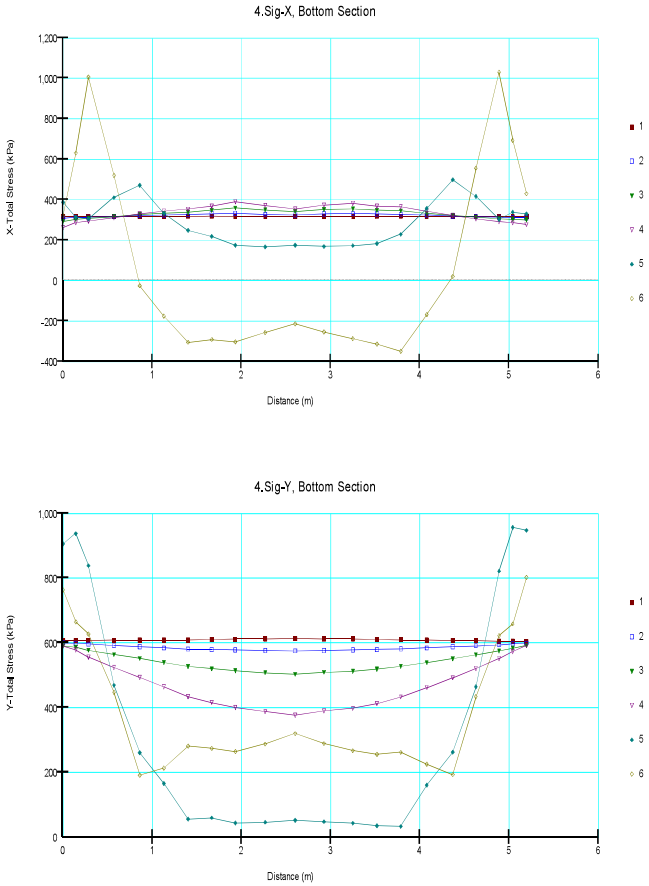


Fig. 7 Distribution of σx horizontal and σy vertical normal stresses at the contact section of the tunnel lining and base.

The contact section of the lining and the base under the action of internal pressure At the intersection: σx, the tensile horizontal normal stresses increase significantly and reach -350 kPa, while towards the heel intersections, on the contrary, the compressive stresses increase and reach 100 kPa.

Below is an analysis of the stress state of the tunnel lining (based on the results of the principal stresses) taking into account the construction stages in the empty state and as a result of the action of internal pressure (fig. .

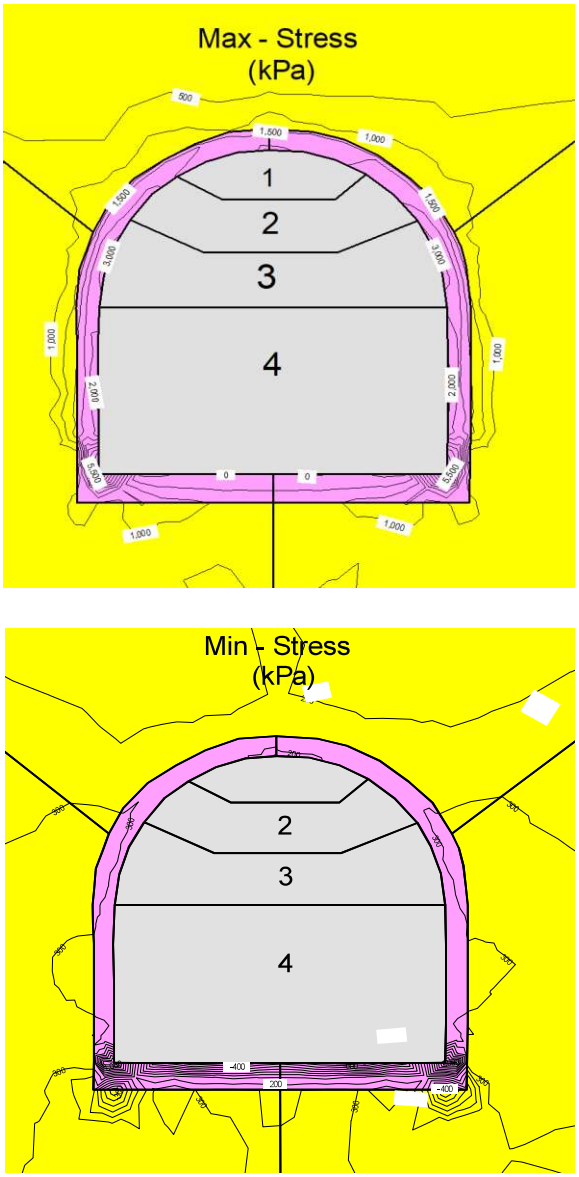


Fig. 8. Distribution of maximum and minimum principal stresses in tunnel lining after completion of construction (empty tunnel).

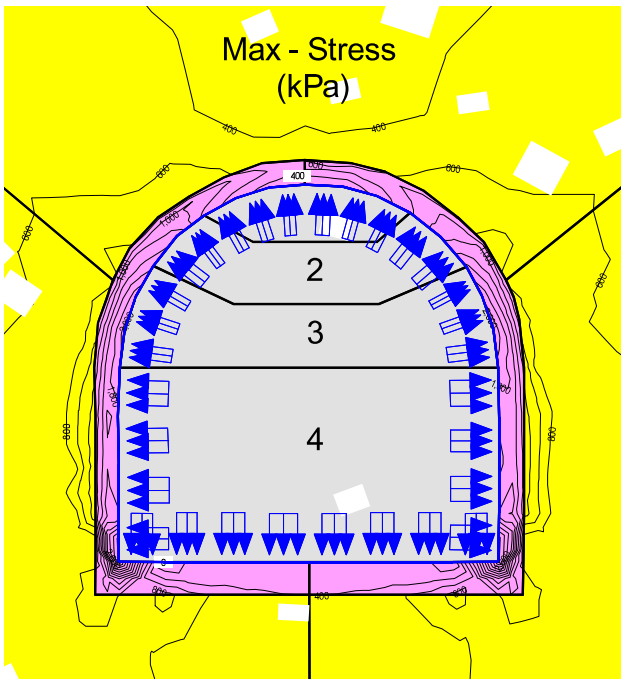


Fig. 9 Distribution of maximum principal stresses in tunnel construction (operational condition).

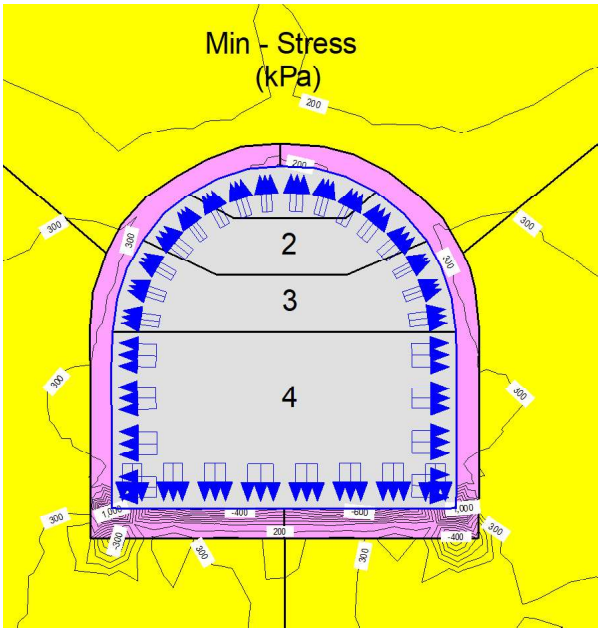


Fig. 10 Distribution of minimum principal stresses in tunnel construction (operational condition).

hBased on numerical calculations, the parameters of the stress state reflecting the joint operation of the "tunnel array" system were obtained, taking into account the differentiated influence of the construction technology (sudden construction and gradual construction).

- During the construction of the tunnel, the gradual processing of the soil was regularly reflected in the nature of the distribution of stresses in the structure and the surrounding area. The zone of collapse of the rock soil (vertical mining pressure) was specified according to the vertical normal stresses (σy) developed at the tunnel cleft section.
- The vertical load acting on the arch, during the gradual processing of the tunnel (compared to the sudden tunnel construction scheme), decreased insignificantly (up to 4%), while the stresses in the horizontal direction increased up to 8%.
- In crown section of tunnel, the vertical normal stresses increased by 5%, and the horizontal normal stresses decreased by 25%.
- In the bottom section of tunnel, the compressive stresses increased in the construction state (up to 20%), while in the operational state, the compressive stresses decreased (up to 30%);

References

1. Franklin, J.A., Hoek, E.: Developments in triaxial testing technique. Rock Mechanics, 2(4), pp.223-228 (1970).
2. Handin, J., Heard, H.C., Magouirk, J.N.: Effects of the intermediate principal stress on the failure of limestone, dolomite, and glass at different temperatures and strain rates. Journal of Geophysical Research, 72(2), 611– 640 (1967).