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# Comparative analysis of modelling methods of the tunnel construction harmful effect

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**Abstract.** The article presents a comparative analysis of the results of mathematical modeling of horizontal tunneling in the Plaxis 3D software package. Two main ways of modeling the tunnel lining were considered: models based on volumetric elements and using the Plate tool. An analysis was made of the distribution of displacements and deformations on the surface: subsidence, inclinations, curvature, horizontal deformations. Comparison of the maximum strain values showed an insignificant deviation (approximately 5%), which proved the applicability of the two models. For further work, a method using the Plate tool could be recommended as being more suitable in the case of complex models with a large number of intersections.

## 1. Introduction

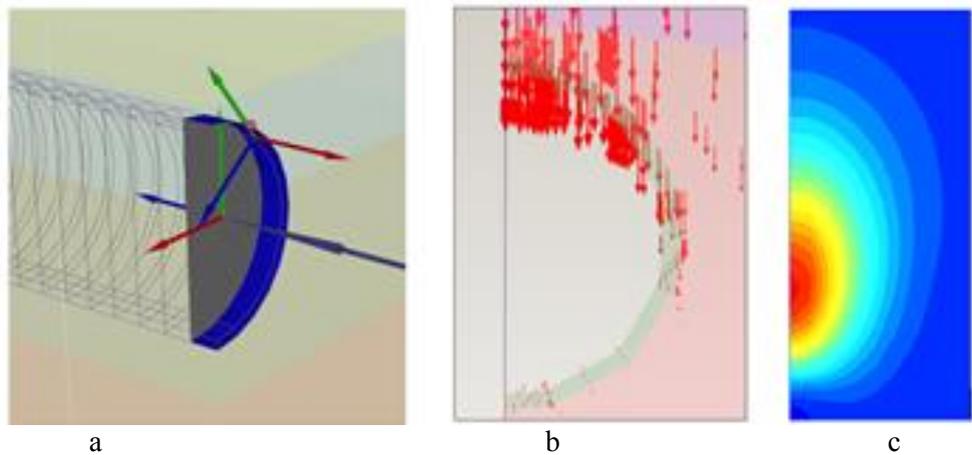
A large amount of underground construction at present in a densely built area requires the fullest possible and accurate prediction of the occurrence of displacements and deformations. The problems of assessing the harmful effects of underground work on the earth's surface and the surrounding massif are considered in the study of many Russian and foreign scientists [1–3]. Now there is no universal scientifically based approach to modeling geomechanical processes in the construction of tunnels. Thus, when creating a geometrical scheme for tunneling, various methods implemented in specialized software for constructing models can be used [4-9]. Comparison of methods for constructing models, their classification, and the establishment of boundary conditions for their use helps to make a choice of a modeling method for a particular structure. This, in turn, at the initial design phase will provide accurately assess the degree of harmful influence of underground construction on the soil massif and the earth's surface. Thus, the task of comparing various methods of constructing models is relevant.

The idea of the work is to improve the accuracy of forecasting geomechanical processes based on a comparison of modeling lining by volume elements and the Plate tool in Plaxis 3D.

## 2. Research methods

To solve the problem of choosing modeling tools for estimating the harmful effects of underground work on the earth's surface, we used the software “Plaxis 3D”. Using the example of horizontal tunneling, we considered two ways of achieving the total convergence of rocks in the tunnel crown: modeling of the lining with volumetric elements and setting the lining with the “Plate” tool. Figure 1 shows the main phases of modelling.





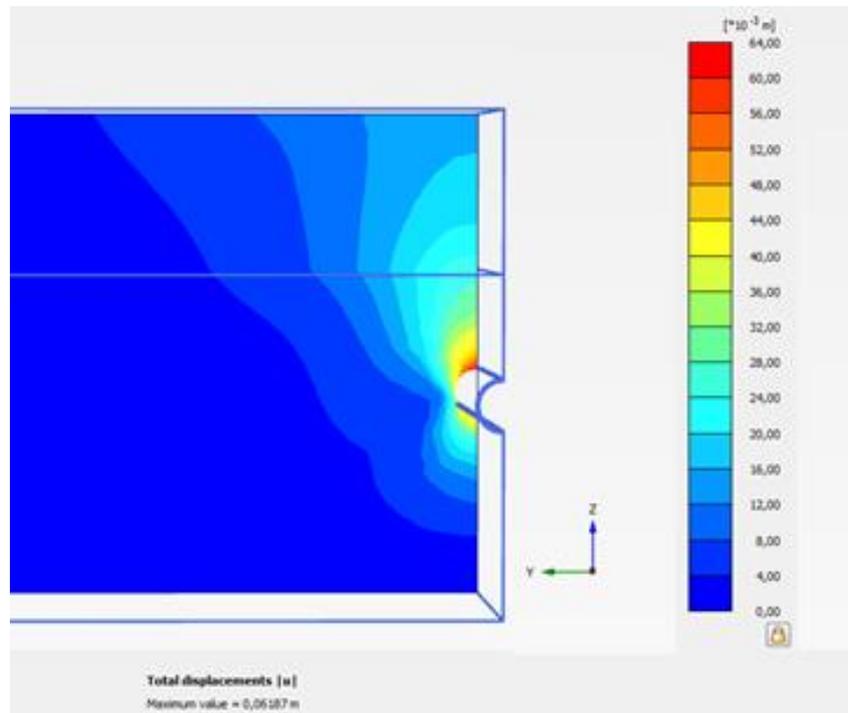
**Figure 1.** Modelling of the tunnel: a - sequential tunneling; b – subsidence in the main cross-section; c, d - subsidence trough.

Soil massif with a sufficient degree of approximation is presented as a simplified version - two horizontal layers of soils. A horizontal tunnel with an outer diameter of 5.5 m is constructed at a depth of 57 m. The characteristics of soil layers and the lining material are presented in Table 1. The differences of the models are in the method of constructing the tunnel: in one of them the tunnel is formed by the “Plate” tool (the lining of the tunnel represents a surface with specified deformation characteristics), in another tunnel lining is modeled with three-dimensional elements - rings of 0.5 m thick [10]. After the construction of structural elements is completed, we create a grid that completes the finite element model. In this case, the massif model consists of a medium size network, including more than 17000 elements and 26000 nodes. To calculate displacements and deformations in the model, we used the Coulomb – Mohr model, which can present a first approximation to describe the behavior of soils. In addition, for the modelling the tunnel lining we used linear-elastic model.

**Table 1.** Material properties

Parameter	Plastic clay	Clay	Tunnel lining
Material model	Mohr-Coulomb	Mohr-Coulomb	Linear-elastic
Modulus of deformation, E, kN/m <sup>2</sup>	12 230	200 000	150 000
Poisson's ratio, $\nu$	0.34	0.35	0.15
Internal friction angle, $\varphi$ , °	19.2	22	-
Cohesion, c, kN/m <sup>2</sup>	17.0	150	-

Verification of the models was carried out based on the value of maximum subsidence on the surface above the axis of the tunnel (25 mm in this example). Subsidence and horizontal deformations are automatically calculated in Plaxis 3D. Figure 2 shows an example of the distribution of total displacements in the massif.



**Figure 2.** Distribution of total displacements in the model of tunnel driving

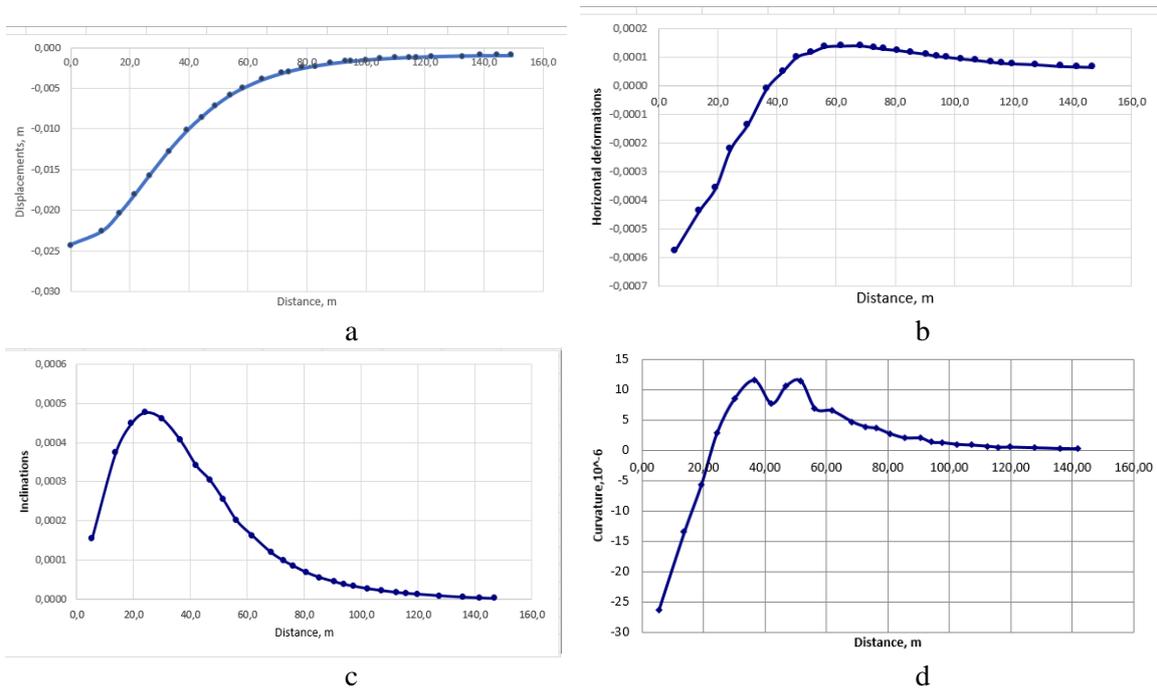
We calculated deformations of the inclinations and curvatures using the obtained subsidence with MS Excel. Table 2 presents a comparative analysis of displacement trough size based on various simulation results.

**Table 2.** Dimensions of the trough in the main cross section using different boundary criteria

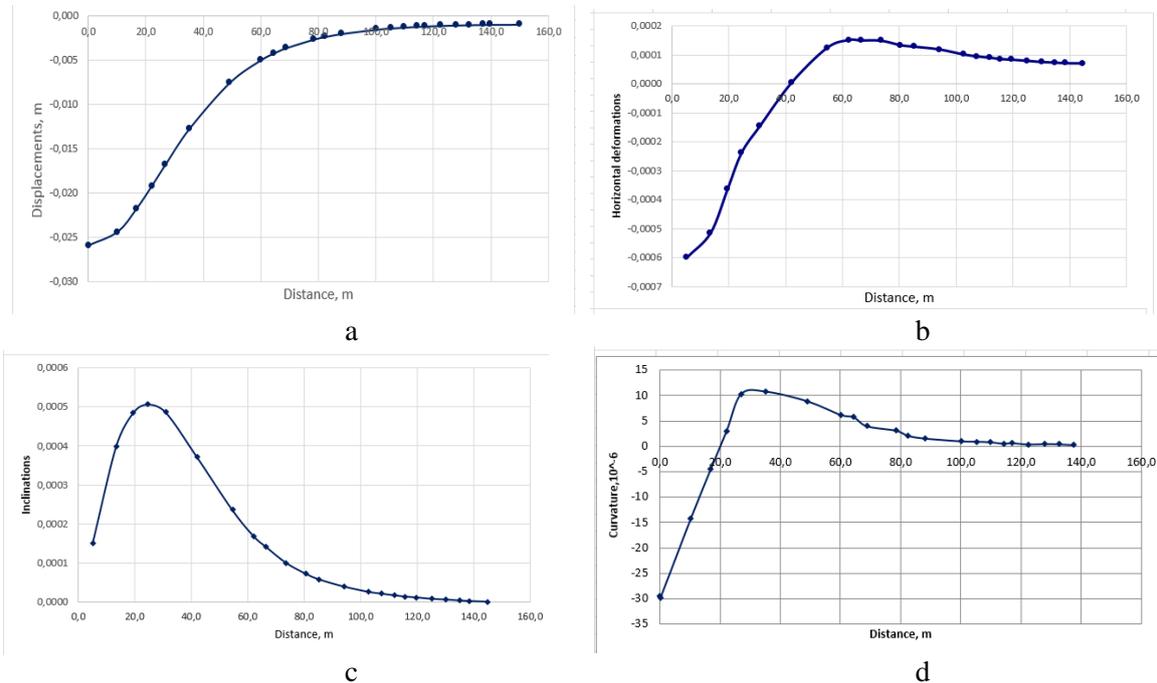
Model	Subsidence, 5 mm	Inclination, $i=0,2 \cdot 10^{-3}$	Horizontal deformations,
			$\varepsilon=-0,2 \cdot 10^{-3}$
Volumetric	58.4	54.1	22.6
Plate	60.1	55.4	24.0

### 3. Results and discussion

As a result, we calculated values of the main displacements and deformations on the earth's surface: subsidence, inclination and curvature deformations, and horizontal deformations. The graphs of displacement and deformations in the displacement trough on the surface are shown in Figures 3 and 4. Thus, the deviations of the sizes of the troughs for different boundary criteria turned out to be insignificant (maximum value is 1.7 m).



**Figure 3.** Distribution of deformations in the displacement trough when modeling lining by volume elements: a – displacements, b - horizontal deformations, c – inclinations, d - curvatures



**Figure 4.** Distribution of deformations in the displacement trough when modeling lining using the “Plate” tool: a – displacements, b - horizontal deformations, c – inclinations, d - curvatures

Based on the plotted distributions of deformations in the trough, we made a comparison of the maximum values of the functions (Table 3).

**Table 3.** Maximum displacements and deformation values in the trough

Model	Subsidence, mm	Inclination	Curvature	Horizontal deformations
Volumetric	24	0.00048	0.000027	0.00016
Plate	26	0.00052	0.000032	0.00016

#### 4. Conclusion

Based on the conducted studies, it can be concluded that there are insignificant differences in the amplitude values (5%) and the nature of the distribution of displacements and deformations in troughs. The values of the inclinations and horizontal deformations, as can be seen from the table, also differ insignificantly (less than 5%). The discrepancy between the curvature values of the two models was about 15%. Therefore, both modeling options can be applied. For further work, we can recommend the method using the Plate tool as the least time consuming and convenient in the case of model elements intersection with further complication of the geometric scheme of the model.

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