Tunneling by the cut-and-cover method is practiced widely at industrial plants for laying utility lines. Rectangular all-sectional linings and constructions of precast planar members are most effective for such tunnels. Experience gained in the construction and operation of such tunnels indicates that their working conditions have been inadequately studied, especially when tunneling in clays. To refine the characteristics of the joint action of tunnel design and soil, extensive investigations were carried out at the Ural branch of the State Planning Institute for General Construction and Sanitary Engineering Planning of Industrial Plants (Promstroiniproekt) under laboratory and field conditions. Large-scale models (1:3) of two static schemes — closed rectangular frames and two hinged systems were tested on a stand [1], the behavior of the tunnels being modeled in made ground and in a trench.

Under field conditions we measured the soil pressure on a rectangular tunnel measuring 2.2 x 2-m in cross section under trench conditions [2]. The experiments established the character of deformations of the fill and structures and revealed the regularities of the distribution of pressure on the tunnel contour and the dynamics of the change of contact pressures by stages of stress of the structures of the different static schemes (Fig. 1).

The experiments showed that deformations of the structure have the greatest effect on the pressure distribution. It was established that deflection of the ceiling causes the formation of a load-relieving soil arch above the tunnel.

Closed blocks (Fig. 1a, b) are characterized by increased stiffness in the corners, and considerable deflections of the ceiling occur only in the middle zone. Different deformation over the width of the tunnel leads to a concentration of pressure on the corner portions of the frame and to its decreases in the central part of the span. The pressure diagram has a characteristic saddle-shape (see Fig. 1a, b). The coefficient of nonuniformity of the vertical pressure (ratio of the maximum stress to the minimum) varies within 1.3-2; the maximum values are obtained at loads close to the critical with respect to the strength of the structures. At pressures not exceeding the standard loads the coefficient of nonuniformity had values 1.3-1.5. Upon a change of the soil pressure under field conditions the coefficients of nonuniformity for the ceiling were equal to 1.26-1.8 [2].

In tunnels with free support of the slabs on the walls the ceiling (Fig. 1c) is deflected over the entire width of the structure. Measurements of layerwise deformations of the fill, on the basis of markers placed in the soil and of the vertical and horizontal stresses in the fill showed that the soil arch formed in this case extends beyond the limits of the structures, which determines the more uniform distribution of the pressure over the ceiling.

The distribution of the reaction pressure along the foot of the tunnels is governed by the concentrated transmission of forces from the walls to the bottom and depends to a considerable extent on the strength properties of the soil. In the presence of weak bases (plastic clays, loose sands, made ground) the pressure distribution obeys the laws of linearly deformable bases only in the case of small loads — up to the start of development of plastic deformation zones under the edges of the bottom (see Fig. 1a). With the
development of plastic deformations the diagram approaches a parabolic shape. However, at loads close to the critical with respect to the material of the structures the pressure in the middle decreases slightly owing to deflection of the slab and appearance of cracks in the concrete (formation of a plastic hinge). In dense clays a marked concentration of pressure on the corner portions (see Fig. 1b, c) is observed at all stages of work of the structures, which leads to a considerable decrease of forces in the bottom.

Experiments established that a linear increase of the intensity of the horizontal pressure to one-half the height of the wall is observed for tunnels made of closed blocks. The pressure drops in the lower part and amounts to no more than 50% of the maximum values. For structures with a hinged support of the ceiling the ordinates of the diagrams of lateral earth pressure within the limits of the installed pressure cells decrease downward, duplicating the strain curve of the tunnel walls.

The experimental data were compared with the theoretical values of the vertical pressures calculated with consideration of friction of the fill on the trench walls [3, 4], the following assumptions being made:

- Sliding of the fill located over the structure occurs along vertical planes passing through the slope of the trench at the level of the tunnel ceiling;
- the pressure in any horizontal section is distributed uniformly over the width of the trench;
- the ratio between the horizontal and vertical stresses in the fill is a constant.

The comparison of the theoretical and experimental values of pressure on the ceiling of tunnels made of closed blocks showed (Fig. 2) that at a load on the ground surface equal to 0.45 kg/cm² and more, the experimental data are close to the theoretical obtained with consideration of cohesion of the clay. At smaller loads the experimental data approximate to the theoretical determined without consideration of cohesion of the clay fill (c = 0). The experimental values of the vertical pressure on the two-hinged tunnel scheme are less than the calculated values, the maximum divergences amounting to 15%.

This indicates that a part of the cohesion lost in excavating the clay is restored as the fill is compacted and thus the joint action of the tunnel and enclosing soil improves.

The data of measuring the reaction pressure of the soil along the foot were compared with the values obtained by calculation from the condition of equilibrium of the tunnel block under the action of vertical pressure on the ceiling and of the structures' own weight. The divergences between the experimental and theoretical values amounted to 3-12%. 

Fig. 1. Distribution of contact pressures around the contour of tunnels at different stages of stress of the structures. a) For closed blocks in made ground; b) the same, in trench; c) for hinged structures in trench.