When constructing a pumped-storage station (PSS) in the European sector of the USSR considerable difficulties arise when selecting the site, since areas suitable with respect to topographic conditions are composed mainly of saturated sands and clays with low physical and mechanical indices.

The need to create large heads of water for effective operation of a PSS compels siting them on bank slopes under complex engineering-geological conditions. One of the main problems of the design and construction of a PSS is the provision of stability of high natural slopes and pit slopes, especially in the region of the powerhouse, which includes the water intake, penstocks, and powerhouse proper of the PSS. The presently existing methods of estimating the stability of natural slopes and pit slopes based on mathematical methods of soil mechanics or on a natural historical analysis of the geological conditions do not guarantee the elimination of errors. We cannot use analogues of the design and construction of a PSS in foreign practice, since these structures are located on rocks under conditions of a mountain relief. There is no Soviet experience in evaluating the stability of high and long slopes, since so far argillaceous rocks have been studied only at the abutments of low dams or in slopes of comparatively shallow excavations of locks and canals [1].

During construction slopes whose coefficient of stability calculated from the data of soil tests is severalfold greater than unity often slide. This is related to the fact that there are a number of factors not amenable to consideration when performing static calculation. Thus, for example, a change in the natural stress state of the mass and unloading of argillaceous rocks by construction excavations causes the development of decompression of the natural structure of the rocks. As was noted in [1], the structure is disturbed as a result of the formation of release fractures, in which case zones of slipping form along the mass of rocks as a whole and along individual blocks of the rock. In saturated clays their further decompression occurs under the effect of the hydrodynamic pressure of subsurface waters. The process of decompression of the rock mass can last tens of years with an intensity varying in time and can reach depths commensurate with the height of the slope. Decompression considerably reduces the shear strength of rocks and increases their compressibility and permeability. It is not possible to estimate the degree of change in these parameters with an accuracy sufficient for calculations.

Variable wetting and drying of clays during the construction and operation of a PSS causes swelling and shrinkage, deformation of additional joint systems, and further development of zones of low shear resistance. In these zones the strength of clays can decrease by 1.5-2 times. The harmful effect of freezing of clays from the surface of the slopes is not precluded either. It causes transformation of the massive structure into a microlayered structure and its subsequent weakening. The presence of inflow of water leads to deepening of the effect of freezing, especially for jointed rocks being flooded along the joints.

Of decisive importance for sloped stability is the hydrogeological regime, a prediction of which upon filling the upper reservoir with water is quite difficult owing to the low accuracy of determining the seepage and piping characteristics of the rocks composing the slopes and their anisotropy. Seepage of water from the upper reservoir can lead not only to a change in the heads and physical, mechanical, and seepage properties of the soils but also to an additional change in the stress-strain state of the rock mass due to an increase of horizontal and tangential stresses. Wetting of the slope and a change in its stress state in turn promote the development of deformations and additional worsening of the soil properties.

In many cases disturbance of the stability of slopes occurs without the effect of additional forces and factors changing the shear resistance of soils. These phenomena are related to rheological processes causing long-time deformation of argillaceous rocks in connection with reorganization of the structure (creep). As a result of these processes the shear re-

sistance of clays decreases by more than 3 times [2]. It is very difficult to reveal beforehand zones and conditions of the possible occurrence of such deformations on the slopes of a PSS site.

The total effect of all indicated factors as well as the three-dimensional form of the relief cannot find complete reflection in an engineering-geological model or a mathematical model of the slope. The soil characteristics obtained by standard tests and the calculated factors of safety against sliding of natural slopes do not reflect their actual stability. Unlike the slopes of dams created from soils with controlled characteristics throughout the entire volume of the structures (and therefore having guaranteed stability factors), natural slopes formed in the presence of considerable differences of the relief during the geological life of the given region, as a rule, have a form corresponding to the ultimate stable state. It should be noted that the origin of certain slopes predetermines the slow "secular" movement of a thick soil stratum. Thus natural slopes are not ready to receive technogenic loads and changes in the established hydrogeological conditions. The reliability of laying the pressure pipes of a PSS can be guaranteed only with flattening of the natural slope and elimination of its undercutting, which would create the necessary stability factor. Formal calculations of stability and driving of piles into the surface of a natural slope do not give a guarantee of reliability against possible sliding. Unfortunately, the available examples of performing works when constructing a PSS do not meet the technical requirements. However, flattening of slopes and other engineering measures on their stabilization which would guarantee the operating reliability of a PSS are based only on a general analysis of the engineering-geological conditions, design considerations, and formal calculations of the stability of structures on natural and artificial slopes. Such calculations should be considered only estimates since the characteristics of the physical and mechanical properties of soils on surfaces of sliding being calculated, as a rule, are absent and are assumed on the basis of average values obtained in different zones. At the same time, stability calculations are made with respect to the two-dimensional problem, without consideration of completely real local anomalies of the characteristics of soils. As a consequence of this, the most accurate calculations by various methods (according to the theory of elasticity or theory of elastoplastic flow of soil) do not bring us to a sufficiently accurate assessment of the true state of the soil mass under conditions of technogenic loads and influence.

To eliminate possible errors it is necessary to incorporate considerable safety factors in the volumes of earthworks. An examination of the designs of the Kanev and Dnestr PSSs conducted in 1985 at the LL-Union Planning, Surveying, and Scientific-Research Institute (Gidroproekt) showed that there are considerable possibilities to reduce the volume of works and to increase the reliability of structures with the use of "nontraditional" designs, such as the use of open caissons and shaft types of PSS powerhouses. The designs were subjected to a very strict examination by experts. Numerous criticisms and revisions do not decrease but rather increase the quality of examined designs. Other designs of PSS, for example the Zagorsk or Leningrad for which there were fewer criticisms, look no better in comparison with them. In essence, dissatisfaction is being expressed concerning problems which cannot be solved by additional engineering-geological surveys being carried out in the usual volume and by the usual means. They concern problems still far from studied by geological science. This circumstance should be opposed not by unfounded doubts not accompanied by specific suggestions but by engineering solutions which would make it possible to construct reliable PSSs in the case of an insufficient study of a number of problems. It seems to us that such engineering solutions are available.

The considerable deepening of the units for operating in a pump regime requires the excavation of large deep pits. This leads to the construction of complicated groundwater-lowering systems and cofferdams and to undercutting of natural slopes and provoke the development of landslide phenomena. The negative experience of such kind at PSSs under construction compels searching for other layouts and designs which are more economical and reliable. The use along with the usual PSS schemes of open caissons and systems formed by diaphragm walls contain a number of interesting possibilities. But they, in our opinion, cannot radically solve problems when the pen-stocks are located on natural slopes. More promising are shaft layouts with underground delivery and discharge of water, which in Soviet practice refers primarily to the design of the Dnestr PSS [3]. In such layouts the exposed natural slopes remain untouched and an unconditional preservation of the natural conditions and relief is provided. The volumes of works on excavation, backfill, and concrete structures decrease markedly and capital expenditures are saved. The start-up complexes in these designs become substantially more flexible.