Three-dimensional engineering-geological model of the soil massif: the case study of the base of a hydrotechnical building

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Abstract: In the process of engineering and geological surveys, three-dimensional engineering-geological modeling makes it possible to perform a comprehensive assessment of the state of the territory for making sound-design decisions on the placement of construction sites and their structures. Secondly, a logical conclusion of a detailed study of engineering-geological and geotechnical conditions, which is implemented to use three-dimensional modeling, is a well-grounded design with a reasonable margin of safety, which causes a reduction in the total cost of the erected or reconstructed structure. Thirdly, in comparison with traditional engineering-geological two-dimensional models (cuts, maps, etc.), three-dimensional models give more information. This is especially important, when we think about the scale of the hydraulic structures. According to archival materials, it can be noted that there are many spatial geological heterogeneities in this territory, and the engineering-geological conditions turned out to be complex. Taking into account the advantages of three-dimensional modeling, the creation of a three-dimensional model of a dispersed soil massif is an actual task for solving complex engineering-geological problems. The article analyzes a three-dimensional engineering-geological model of the soil massif under a hydrotechnical building in the Moscow region, and then calculates its stress-strain state and the coefficient of stability of the sides of the ditch.
Keywords: three-dimensional engineering-geological modeling; soil massif; stress-strain state; vertical stress; shearing stress; coefficient of stability.

1. Introduction

Today, an unstable situation has developed in engineering-geological surveys. On the one hand, chronic underfunding, obvious difficulties with the actualization of Soviet regulatory documentation, the emergence of foreign companies that carry different norms and approaches. On the other hand, the increasingly urgent need to switch to digital transmission of information, in particular engineering survey data [1], the use of modern software systems, allowing to solve problems in three-dimensional formulation [4] for the design of increasingly complex buildings and structures, the emergence of new research methods engineering and geological conditions [2, 3, 5, 6] (and cheaper, and faster) and soil behavior models. In such conditions, the established approach to modeling engineering-geological conditions, based on a table with calculated and normative indices and two-dimensional sections with digits denoting the numbers of engineering-geological elements, often gives rise to failures. The design decisions, which are made on the basis of such models, are sinister with errors, with mistakes, which are made at the earliest stages and, as a consequence, are extremely difficult to correct.

The way out of the situation is the application of three-dimensional engineering-geological models - digital systems in a spatial setting, the study of which serves as a means for obtaining information on engineering-geological conditions in general and (or) their components in particular, while ensuring the needs of economic activity. Of course, we are not talking about a complete replacement of the existing approach and it takes a rather long transition period, and three-dimensional modeling itself is not always required, but only when building complex and unique objects where we have a sufficient amount of engineering-geological information [6].

At present, much attention to three-dimensional engineering and geological modeling will been taken into the following problems:

1) Analysis of the stress-strain state of the soil massif;
2) Assess the stability of the slope, taking into account various factors;
3) Calculation of plastic deformation of the soil massif.

2. Physic-geographical and engineering-geological conditions of the study object

The object of the study is pumped storage power plants (HPPPs), which is located in the north-eastern part of the Moscow region. Its aerial photograph is reflected in Fig. 1.

Fig. 1. Aerial photograph of the simulated territory, taken in Google Earth

General features of the geological structure of the territory are determined by the presence of two structural stratigraphic stages. The root base of the geological section for the studied depth (250 m) is formed by Mesozoic (mostly Cretaceous) rocks. They lie almost horizontally and represent rhythmically alternating layers and packs, mainly of sandy and clayey composition. The surface of the Cenozoic (mainly Quaternary) sediments is developed from the surface. They formed a modern relief and fill deep buried erosion cuts. Thus, the site is completely composed of non-scree rocks. Rock rocks - limestones of the Carboniferous - are at a depth of 150-300 m.

With respect to the relief, the area is confined to the northern slope of the Klin-Dmitrovsky ridge, which is one of the orographic elements of the Smolensk-Moscow Upland. The absolute mark is 150-220 m.

Groundwater is contained in bedrock and overlapping thickness of Quaternary sediments.

Upward down 4 aquifers:

1) intra-moraine aquifer;
2) submerged aquifer
3) the Dnieper-Moscow aquifer (fgl,lglQ_{II}dn-ms)
4) apt-Albian (sub-Paramon) aquifer (K_1ap+al).

3. The method of three-dimensional engineering-geological modeling

In this paper, three-dimensional modeling is performed in the software complexes Surfer, AutoCAD Civil 3D and Midas GTS NX. Midas GTS NX is a program, which is specially designed for modeling interactions between structures and their bases on the basis of the finite element method.

By writer, the whole process of modeling is divided into 7 stages.

Stage 1: collect all the necessary field archival materials to create a three-dimensional engineering-geological model and draw up a map of the actual materials of the territory.

Stage 2: develop all the collected materials and prepare for the creation of a three-dimensional model.

At this stage, the following tasks have been performed:

1) performing the schematization of the basis for geomechanical modeling on the basis of a comprehensive analysis of archival materials;

2) analyzing the drilling data and design a database to create the roof surfaces or the soles of geological bodies and underground aquifers;

3) making files for creating surfaces;

4) digitizing the map of topographic surveys.

After completing the schematization, 12 computational-geological elements were identified, which is shown in tab. 1.

Table 1. Table of selected computational-geological elements

CGE	EGE	Geological indices	Description
1	1, 2	tQ_{IV}	Technogenic deposits
2	3	$dprQ_{III-IV}$	Covering deposits
3	5, 6	$glms_{II}$	Moscow moraine
4	7	$dp(glms_{II})$	Moscow moraine in a mixed occurrence
5	8, 9	$fglms_{II}$ / N2bg	Sandy deposits of fluvioglacial Moscow horizon and Neogene rocks of Bogorodskaya suite
6	10	fgl,lgldn-ms	Fluvioglacial deposits of paleolines
7	11, 12	K_2st	Deposits of the santonian stage
8	13	K_2cm	Sand deposits of the Cenomanian stage
9	14, 15	K_1al_3	Deposits of the Paramonov Formation
10	16	$dp(K_1al_3)$	Deposits of the Paramonov Formation in the mixed occurrence
11	17, 18	K_1al+ap	Sand deposits of the Aptian-Albian deposits
12	19	J_3	Upper-urassic deposits

After the selection of the elements, a database was created for three-dimensional modeling, which contains:

1) coordinates of boreholes;

2) dates of drilling wells;

3) absolute marks of groundwater levels;

4) absolute marks and depth of occurrence of each calculation-geological element except $dp(K_1al_3)$, taking into account its volume.

Stage 3: create isolines of relief surfaces, roof or soles of geological bodies in Surfer and export them to AutoCAD Civil 3D in .DXF format.

Stage 4: create a set of surfaces, including the two relief surfaces before and after construction, the roof surface or the base of the computational-geological elements in the Midas GTS NX through the built isoclines in stages 2 and 3 (Fig. 2).

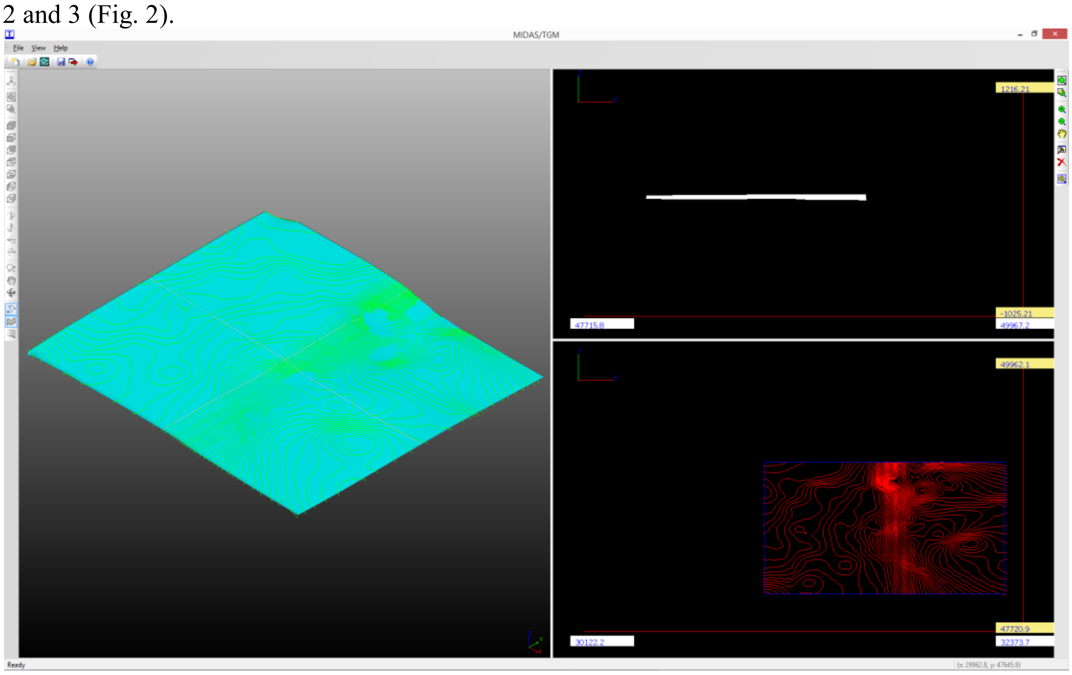

Fig. 2. Building the surface of the sole of the Santonian stage K_2st through isolines in the Midas GTS NX

Stage 5: construct a geomechanical model through the surfaces constructed in stages 3 and 4.

Stage 6: build the surface of the sole of the Santonian stage K2st through isolines in the Midas GTS NX.

Stage 7: determine the type of materials and set the physical and mechanical properties for each calculation-geological element during the construction of grids, set groundwater levels and boundary conditions, depending on the calculated cases.

In this paper, all CGEs are determined by model Isotropic-Modified Mohr-Coulomb. Their physic-mechanical properties are shown in tab. 2.

Tab. 2. Physicomechanical properties of computed-geological elements, which are taken in the program Midas GTS NX

CGE	Geological indices	Unit weight (Gamma) γ kN/m³	Unit weight (Saturated) γ_{sat} kN/m³	Porosity **e**	Poisson's Ratio **ν**	Secant Elastic modulus in shear Hardening) $\mathbf{E_{gp}}$ kN/m²	Tangential stiffness Primary Oedometer test $\mathbf{E_{oedref}}$ kN/m²	(Elastic Modulus at Unloading)) $\mathbf{E_{urref}}$ kN/m²	Friction Angle at shear **φ** degree	Cohesion **C** kN/m²	Ultimate Dilatancy angle, Ψ degree
1	**tQ_{IV}**	21.9	22.5	0.420	0.3	26000	30000	138400	15.5	42	0
2	**$dprQ_{III\text{-}IV}$**	20.0	20.5	0.600	0.35	24600	31000	213000	8	40	0
3	**$glms_{II}$**	22.6	22.8	0.327	0.31	24600	31000	213000	30.2	26.9	0
4	**$dp(glms_{II})$**	22.7	22.8	0.340	0.3	24600	31000	213000	30.0	27.1	0
5	**$fglms_{II}$ / N2bg**	17.8	20.2	0.642	0.27	44700	56300	230000	33.2	22.4	3
6	**fgl,lgldn-ms**	19.9	20.6	0.663	0.28	30500	35900	221700	34	14	4
7	**K_2st**	19.1	20.3	0.893	0.34	23000	34000	223000	19	23	0
8	**K_2cm**	18.2	20.4	0.642	0.27	44700	56300	230000	33.2	22.4	3
9	**K_1al_3**	18.7	19.0	0.986	0.38	27700	25000	163000	22.1	110.5	0
10	**$dp(K_1al_3)$**	19.0	19.2	0.820	0.38	19000	32400	242000	19.8	83	0
11	**K_1al+ap**	16.6	17.5	0.555	0.27	35200	57600	237500	32.8	21	3
12	**J_3**	18.9	20.1	0.831	0.34	25000	36000	240000	9	280	0

4. Results and discussion

As a result of three-dimensional engineering-geological modeling, 2 engineering-geological models have been created: models before and after construction (fig. 3 and 4).

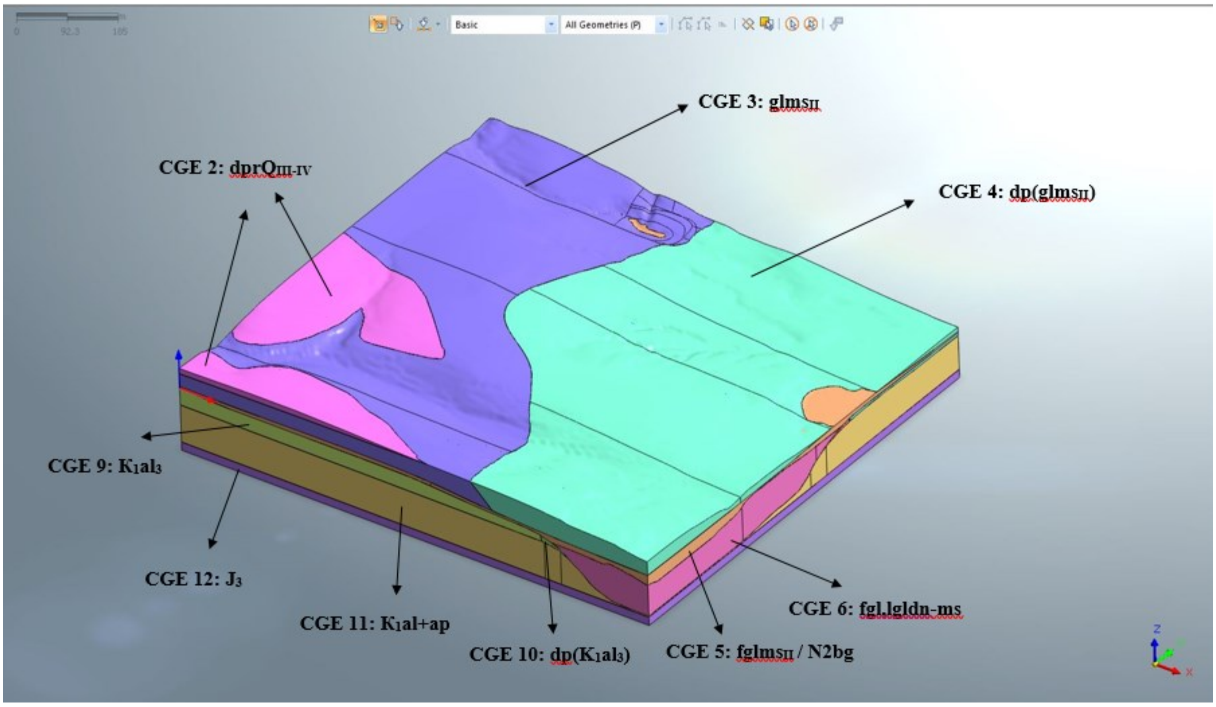

Fig. 3. Geomechanical model before construction

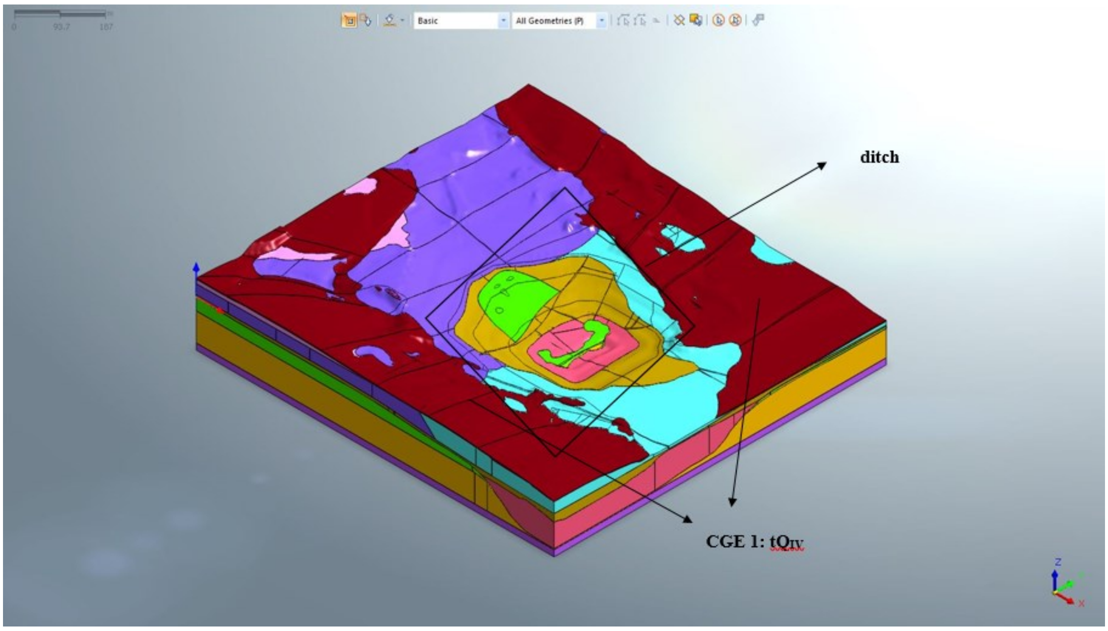

Fig. 4. Geomechanical model before construction with a ditch

Before construction of the hydrotechical building the stress-strain state of soil massif has been analyzed. It fidgeted in a natural state, so stress-strain state is typical.

By the method of reduction, the stability coefficient of the soil massif was obtained - Ky = 2.25, which is greater than unity. Therefore, it can be judged that a dispersed soil massif before construction (in the natural state) is stable for given physico-mechanical properties of computational-geological elements and the natural configuration of the slope.

After the construction of the foundation ditch, the building of the PSPP was built in it. Therefore, it is necessary to set the load from this building to the bottom of the excavation. The stresses acting on the soil massif are 1200 kPa.

The distribution of tangential stresses in the plane ZX τ_{ZX} is shown in Fig. 6. Voltages vary from 0.5 to -0.6 MPa. It can be seen from Fig. 5 that on the east side of the excavation (yellow color) the stress value is increased by a load of up to 0.2 MPa. It is possible to distinguish zones of stress concentrations at two sections in a soil massif under a foundation pit. Other zones of exceeding the concentration values also exist on three sections.

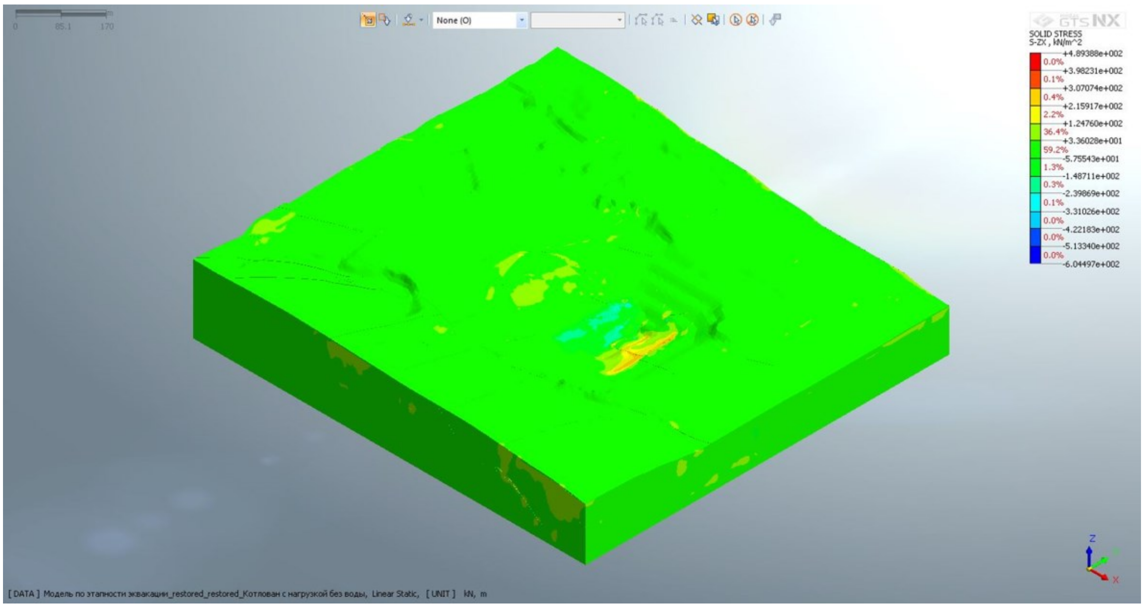

Fig. 5. Distribution of tangential stresses τ_{ZX} on the ZX plane of the soil massif after construction

The calculation of the stability of the four sides of the excavation was carried out by the reduction method. The resulting coefficient of stability is Ky = 1.45. The proposed sliding surface with a coefficient of stability of 1.45 is reflected in Fig. 6, the length of which is 490 m, and its grasping depth is 64 m. The value of the maximum deposition movement (red color) is 80 mm.

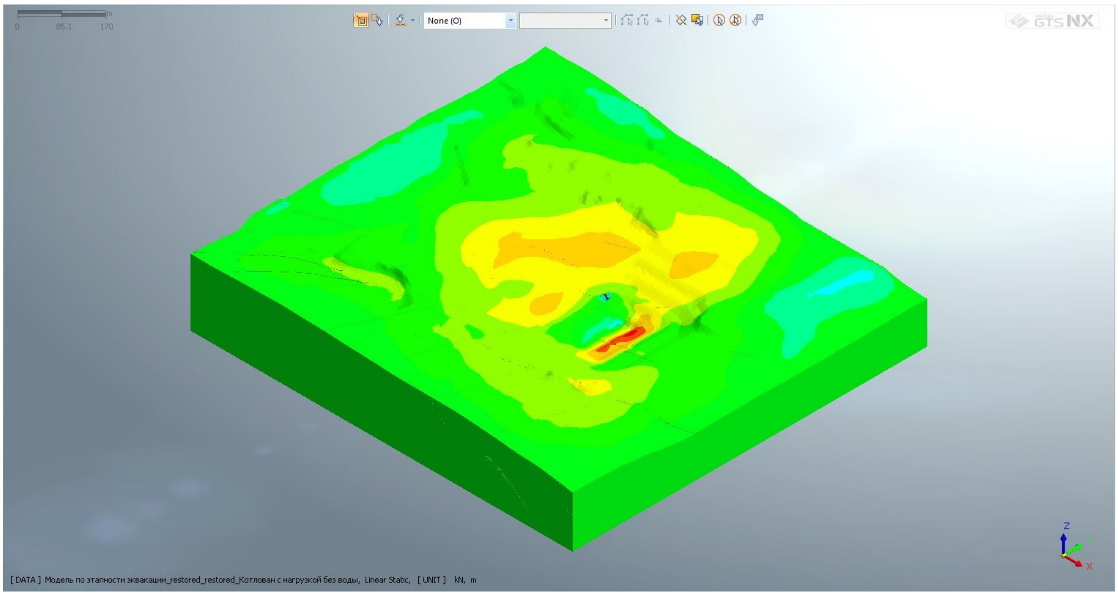

Fig. 6. The proposed sliding surface in assessing the stability of the sides of the ditch

5. Conclusion

East side of the ditch, on which the maximum displacement occurs, the most unstable. On the western and northern sides (yellow), the value of the movements is 20-30 mm. And the southern side of the pit is the most stable, the value of displacement is less than 7 mm.

During the erection of the foundation ditch, the distribution of vertical stresses σ_Z, horizontal stresses σ_X and σ_Y has changed greatly in comparison with it in the ground mass before construction. The isoclines of these stresses are bent within the excavation, and those zones of concentration confined to different geological bodies in the natural ground mass have disappeared. This is explained by the fact that among the factors affecting the distribution of stresses in the soil massif, the relief has a stronger effect on the stress-strain state than the geological structure. In the soil massif, after construction, the load acting on the bottom of the foundation pit increases the vertical stresses σ_Z, horizontal stresses σ_X and σ_Y. The coefficient of stability of the investigated soil massif with the constructed foundation ditch is Ku = 1.45, that is, it is in a stable state.

6. References

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