The parameters for a retaining wall interaction mathematical model with a reservoir in the ground conditions determination in the krasnodar territory

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Abstract. The main parameters affecting the interaction of the retaining wall with the reservoir foundation on the slope are considered. A reservoir park sites geomorphological structure classification in the Krasnodar Territory is proposed. The separation is made on the plain, coastal and mountainous areas, depending on the relief incidence angles. It was also found that, in most cases, the large reservoirs’ natural foundations base in the Krasnodar Territory is loam and clay consistency from solid to refractory. The obtained data were used to assess the staging impact of work on the “retaining wall - tank” system construction in the territory of the Afipsky refinery tank farm. The evaluation was carried out on a mathematical model using the finite element method in the Midas GTS 2012 software package. To model the base foundation, the program the Mohr – Coulomb model was used. The components in the construction sequence “slope trimming - retaining wall device - reservoir foundation building” have alternately changed in the model. In this case, the device structures sequence almost does not affect the tank bottom deflection.

Introduction
The Krasnodar Territory plays a leading role in the transportation and processing of petroleum and petroleum products today. The large federal projects of international importance, such as South Stream, Blue Stream, Caspian Pipeline Consortium, etc. have already been implemented and are at the design and construction stages on the region territory. For example, with the completion of the construction of the “Tengiz- Astrakhan-Novorossiysk” pipeline complex in 2001, the volume of oil transported increased from 28.2 million tons to 35 million tons per year and a project is currently being implemented to expand the pipeline with an increase in throughput to 67 million tons per year [1]. The increase in production volumes will require the three new reservoir parks construction and the modernization of the existing ones with the construction of a large number of tanks with a capacity of more than 10 thousand m³. There are currently a lot of tank farms and facilities for the storage and processing of petroleum products in the territory of the Krasnodar Territory and the Republic of Adygea. 15 large ones of these can be identified (Figure 1).

Taking into account the special conditions of the large tanks foundations interaction with the base, when calculating the tanks foundations, it is necessary to take into account such parameters as the load transfer rate to the base, a large number of tanks filling-emptying cycles, the base non-linear deformation [2]. All these parameters can be taken into account in the mathematical model in the
calculation by the finite element method (FEM). The mathematical model formation is also influenced by the geological and geomorphological features of the reservoir parks territory relief.

**Figure 1.** The large objects layout of the oil industry and tank farms in the Krasnodar Territory and the Republic of Adygea

1 - Krasnodar CHP; 2 – transfer tank farm “Tikhoretskaya”; 3 - Afipsky Oli Refinery; 4 - Ilsky Oil Refinery; 5 - Krasnodar Oil Refinery; 6 - Oil depot “Lukoil”; 7 - Gazpromneft Oil Depot; 8 - Tuapse oil depot; 9 - OJSC “Tolyattiazot”; 10 - Tamanneftegas CJSC; 11 - transfer tank farm Sheskharis; 12 – line operation dispatcher station “Krymskaya”; 13 - transfer tank farm “District”; 14 - transfer tank farm “Grushovaya”; 15 - Tuapse Oil Refinery

**Main text**

The reservoir parks territories geological and geomorphological composition features in the Krasnodar Territory

The largest reservoir parks territory has a diverse topography. Using the example of the Tuapse tank farm, let us follow the method for calculating the maximum (αmax) and average (αср) relief incidence angles. In the Google Earth program, the calculated sections along the relief were made for each object. The maximum (αmax) and average (αср) relief incidence angles were measured at each calculation point.
Figure 2. The Tuapse oil depot scheme
Figure 3. Calculated sections: a) I-I; b) II-II; c) III-III

All the results were summarized in Table 1. Based on the geographical location (in accordance with Table 1), all the objects can be divided into three groups:
I - objects located in the flat terrain;
II - objects located in the seaside area;
III - objects located in mountainous areas.

Table 1. The dependence of the angles of incidence of the relief on the nature of the terrain of the object

| №  | The objects location | Name                                            | α_{max}, ° | α_{ср}, ° |
|----|----------------------|-------------------------------------------------|------------|-----------|
| 1  | Plain                | Krasnodar thermoelectric plant                  | 0.30       | 0.10      |
| 2  |                      | transfer tank farm “Tikhoretskaya”              | 1.70       | 0.70      |
| 3  |                      | Afipsky Oil Refinery                            | 1.90       | 0.65      |
| 4  |                      | Ilsky Oil Refinery                              | 2.30       | 0.85      |
| 5  |                      | Krasnodar Oil Refinery                          | 2.30       | 0.90      |
| 6  |                      | Oil depot “Lukoil”                              | 3.15       | 0.10      |
| 7  |                      | Gazpromneft Oil Depot                           | 3.25       | 2.20      |
| 8  | Maritime             | Tuapse Oil Depot                                | 5.0        | 1.40      |
| 9  |                      | OJSC “Tolyattiazot”                             | 7.76       | 3.10      |
| 10 |                      | Tamanneftegas CJSC                              | 10.75      | 6.85      |
| 11 |                      | transfer tank farm Sheskhari                    | 17.75      | 8.55      |
| 12 | Highland             | line operation dispatcher station “Krymskaya”  | 9.65       | 6.85      |
| 13 |                      | transfer tank farm “District”                   | 17.30      | 8.25      |
| 14 |                      | transfer tank farm “Grushovaya”                 | 19.30      | 5.70      |
| 15 |                      | Tuapse Oil Refinery                             | 26.60      | 8.50      |

The “retaining wall - tank” system construction staging consideration during the model preparation

The main problem of building tanks in mountainous areas is the roll formation as a result of the sliding surfaces formation. Currently, the maximum permissible values of tank rolls in different sources are interpreted differently. So, in the joint venture “Foundations of buildings and structures” [4], the tanks belong to rigid structures (Section 6, Table D1), for which the maximum inclination is 0.004. At the same time, according to section 6.1 of the Joint Venture “Constructions of Industrial Enterprises” [5], the limit roll for tanks with a pontoon roof is 0.002, for all others - 0.003. Analyzing the foreign sources [6, 7], it should be noted that the maximum allowable roll of tanks in them depends on the base plate thickness and the tank design, and is 0.0012-0.0048. As a result of the natural hydraulic testing data by I.L. Dimov and L.A. Dimov analysis [8] the criterion given in source [5] is most appropriate. Separately, it should be noted that in addition to the roll size during the hydrotesting simulation, it is also necessary to take into account its increment during the reservoir operation, during which it is significantly increased and may even lead to the building failure [9, 10].
The roll magnitude is influenced by the construction site geological, geomorphological features, as well as the “retaining wall - reservoir” system construction staging.

The “retaining wall - tank” system construction staging effect assessment was carried out using the example of a tank with a capacity of 10,000 m$^3$ in the territory of the Tupse oil refinery.

For modeling, a topographical survey of the territory the Tuapse refinery was used, taking into account the design solutions for the holding structure and the reservoir foundation construction [11]. The foundation structure is made in the form of a circular slab with a diameter of 27 m and a thickness of 1 m. The holding structure is a pile retaining wall, pile length L 15 m, and diameter D 630 mm. A flat finite element model was performed in Midas GTS2012 (Figure 6).

![Figure 4. Finite element model:](image)

1 - EGE – 1 - semi-solid loam, water-saturated, refractory, crushed, with interbedded crushed soil; 2 — EGE – 2 — hard loams (clay, argillite-like, calcareous mudstones); 3 - pillow made of GSM; 4 - reservoir base plate; 5 - pile holding structure

To simulate the SSS of soils and crushed stone pillow, a model of the ideally elastic plastic material with the Mohr-Coulomb strength criterion was used.

To model the pile holding structure an elastic Hooke model was used. The isotropic elastic properties of concrete were assigned to the reservoir base plate. Characteristics of the materials used are summarized in Table 2.

**Table 2. The model materials physical and mechanical properties**

| No. EGE, name of material | Material model | Soil weight, $\gamma$, [kN/m$^3$] | Specific coupling c, [kPa] | Angle of internal friction, $\phi$, degree | Deformation modulus, E, [MPa] | Poisson’s ratio, $\nu$ |
|--------------------------|----------------|----------------------------------|--------------------------|------------------------------------------|----------------------------|-----------------------|
| 1                        | 2              | 3                                | 4                        | 5                                        | 6                          | 7                     |
The construction work stages were the reservoir foundation construction, the pile holding structure and the soil layer cutting. To identify the best sequence, three variants of the building structures construction were considered. For each option, the location of the stand-up reservoir foundation unit was decisive (Table 3).

The foundation plate sediment control measurements were performed at two diametrically opposite points (A and B) according to the 4th stage results for each option [12]. Moreover, calculations for hydraulic tests were carried out with a phased loading of the tank in three batches - 5 m, 10 m and 16 m. All obtained results were presented in tabular form (Table 4).

**Table 3.** The building structures construction stages

| Stage number | 1st variant | 2nd variant | 3rd variant |
|--------------|-------------|-------------|-------------|
| 1 | Stand-up reservoir device | Pile restraint device | Pile restraint device |
| 2 | Pile restraint device | Stand-up reservoir device | Soil trimming |
| 3 | Soil trimming | Soil trimming | Stand-up reservoir device |
| 4 | Stand-up reservoir hydraulic testing | | |

Table 4 shows that the relative precipitation at the 2nd and 3rd variants exceed the sediment results at the 1st variant by 2–6%, however, the smallest heel the reservoir receives in the third variant.

**Table 4.** The results of the sediment base plate calculation (3rd innage)

| Variant number | Final deformations, mm |
|----------------|------------------------|
|                | Checkpoint A | Checkpoint B | Bottom deflection | Roll    |
| Variant 1      | 195          | 213          | 246               | 0.00075 |
| Variant 2      | 197          | 214          | 247               | 0.00071 |
| Variant 3      | 207          | 213          | 251               | 0.00025 |
Checkpoints plots at hydraulic tests (Figure 5) show that with each innage the tank shrinks and gives a roll in the direction opposite to cutting the ground layer. This suggests the sliding surface formation, which occurs when the slope is loaded (Figure 6).

![Figure 5. The vertical sediment base soil total distribution](image)

**Figure 6.** Schedule sediment control points A and B during hydraulic testing a) option 1 b) option 3

**Experimental research**

As a part of the experimental studies, a mathematical model of the reservoir was prepared and the sequence of the device structures was analyzed. From the data obtained analysis it is clear that in the case of the holding structure advanced construction (option 3) it is possible to minimize the roll of the RVS. This is due to the fact that by the time of the beginning of the construction of the foundation, the construction of the foundation settlement due to the cutting of the soil below the wall has already been completed and does not affect the reservoir.

In the case of the primary construction of the stand-up reservoir foundation (option 1), at subsequent stages, the stand-up reservoir list is inclined, and by the hydraulic tests time, the precipitation increases and the inclination stabilizes.

The stand-up reservoir maximum final draft does not depend on the construction sequence and is almost the same in all cases.
Summary

The following main conclusions can be made from the work results:

1. According to geomorphological features, reservoir parks of the Krasnodar Territory can be divided into three groups: plain (slope up to 5°), seaside (slope up to 11°) and highland (slope up to 28°).

2. The reservoirs natural base on the Krasnodar Territory is loam and clay consistency from solid to refractory.

3. Analyzing the “retaining wall-tank” system device structure sequence, it can be concluded that the primary device of the retaining wall before the soil trimming the reservoir foundations device allows to reduce the foundation technological rolls during production.

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