DEFORMATION OF SOILS AND DISPLACEMENTS OF STRUCTURES

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Time-settlement of a water supplying channel
Tassement dependant du temps du canal adducteur

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ABSTRACT: A geotechnical design of a water supplying channel for the "Kozloduy" Nuclear Power Station has been given. The channel region is characterized with complicated ground conditions. Stratifications are characterized with: high ground water level; soils are presented by: layers of organic clay and various consistency clay (at soft to stiff); fine loess silty sands and loess's sands (tending to liquefaction under dynamic loads); loess - collapsible and compacted by its natural weight; gravelly sands, gravels etc. A detailed investigation of the soil properties has been implemented in laboratory conditions and in situ. Standard and non-standard soil characteristics and properties have been determined. Values of settlement at the end of the construction and during exploitation have been calculated. A geotechnical structure: improving the ground base and accelerating the consolidation process has been suggested.

RESUME: Il est donne un project geotechnique du canal adducteur de la central atomique de "Kozlodouï". La region du canal est avec des conditions de terraine complexes. Les stratifications se caracterisent par: un haut niveau de l'eau scuteraine; les soils sont presentes par:des couches d'argile organique et d'argile de differentes consistances; des sables, fins silteux (d'une tendance de liquefaction sous les charges dynamiques) loess - donnant lieu à des effondrerrent et compacte par sans propre poid; des sable de grains moyens, graviers et d'outres. Il est effectur une investigation detaille des proprietes des sols au laboratoire et in-situ. Sont determines des caracteristiques et proprietes du sol standarts at non-standart. Sont calcules les valeurs du tassement en fin de construction et pendant l 'exploitation. Une structure geotechnique de renforcerrent de la base terrestre et d'acceleration de la consolidation est proposee.

1 INTRODUCTION

A basic problem for the accelerated putting into operation of reactor 6 in the "Kozloduy" Nuclear Power Station is to insure its safety. This is of significant importance for the energy crisis in Bulgaria to be overcome. Apart from the technical problems concerning the reactor's safe work it is necessary that additional technical water supply be constructed for a short period of time (Fig.1)

The existing problems made it necessary for this project to be taken into consideration first:

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1. The existing channels, connecting the other reactors to the Danube river, constructed by retaining earth dam walls were damaged in 1988 and this necessitated urgent repair works.

2. Soil conditions are extremely complicated. The new hydrotechnical channels permanent way is
directed South-North and passes through the Danube floodplain. The soil and hydraulic conditions are characterized with a number of phenomena and processes as:

- high groundwater level, partly confined groundwater;
- collapse due to wetting with or without additional load of loesses' layers which causes short time differential settlements;
- thixotropy of some silty and fine-grain clayey sands which under dynamic loads and great hydraulic gradients turn into liquefaction conditions;
- swampy regions under long-term and high groundwater head.

3. Earthquake intensity, according to the macro land register in Bulgaria is VII (Richter scale).

The variety in soil stratification can be seen on Fig. 2.

3.1 Standard tests

Using a number of boreholes, soil samples and standard penetration tests the soil properties of 37 cross sections to a depth of 18 m have been investigated. The total new channels longitude is 2.75km. Laboratory and in situ investigations have been done in order to determine the physical and mechanical properties of soils. Design soil characteristics are seen in Table 1.

Table 1. Soil characteristics

<table>
<thead>
<tr>
<th>stratum No.</th>
<th>type of soil</th>
<th>$\rho_g^{g/cm^3}$</th>
<th>$E_0$ MPa</th>
<th>$\phi'$°</th>
<th>$c'$ MPa</th>
<th>k m/d</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Soft silty clay</td>
<td>1.76</td>
<td>6.0</td>
<td>13</td>
<td>0.013</td>
<td>0.0104</td>
</tr>
<tr>
<td>2</td>
<td>Soft organic clay</td>
<td>1.89</td>
<td>5.2</td>
<td>18</td>
<td>0.03</td>
<td>0.0014</td>
</tr>
<tr>
<td>3</td>
<td>Fine sand</td>
<td>1.60</td>
<td>15.26</td>
<td>-</td>
<td>2 x10³</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Gravel</td>
<td>1.70</td>
<td>23.30</td>
<td>-</td>
<td>50x10³</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Stiff silty clay</td>
<td>2.0</td>
<td>24.20</td>
<td>-</td>
<td>0.0001</td>
<td></td>
</tr>
</tbody>
</table>

Modulus of linear deformations ($E_0$) is determined by trial loading in situ and shear strength parameters ($\phi'$ and $c'$) by unconsolidated undrained test. The other physical parameters density of soil ($\rho$), permeability coefficient (k) and consistency-using standard tests.

3.2 Non-standard tests

The solving of the mixed problem of the consolidation theory considering creeping of the soil skeleton has been used for the best time settlement forecast (Germanov 1988). This necessitated long-term tests for the determination of settlement parameters according to the theory of the linear creep of clay layers. The methodology given in Germanov (1988) has been used. Results are shown in table 2, where $m_0$ and $m_1$ are coefficients of instantaneous consolidation and of creep (secondary) volume deformation; $\eta$ - the parameter of creeping
The investigation proves that at earthquake intensity of VII (Richter-scale) liquefaction of saturated sand is hardly probable.

3 TIME-SETTLEMENT OF THE BASE

There are two layers of clays in the base which are of low-permeability, saturated and strongly deformable. During construction and exploitation great settlement is probable which necessitates an investigation of the base consolidation.

For the settlement at the end of construction and during exploitation to be determined Germanov's variants (1977 & 1979) have been used for which professional computer programs have been worked out.

Clays are examined as multy-phase soil medium consisting of soil skeleton with the creeping property filled with deformable fluid due to incomplete saturation. The construction works time-table is taken according to the scheme in Fig.4 at final term of construction load 24 months. Service load is taken according to Fig.4.

It is accepted in the algorithm that the full consolidation settlement of the layers of gravel and sands will come at the end of construction and time-dependent will come into the clay stratum. Cross deformations of the base for some specific profiles where clay layers are of greater thickness are shown on Fig.5.

The calculation results showed:

Maximum general settlements of the channel base are 4-8 cm which is acceptable for this kind of Structure. Relative deformations are up to the acceptable limits as well.

More than 50% (for some regions to 80%) settlement will come out during construction.

Table 2.

<table>
<thead>
<tr>
<th>stratum No.</th>
<th>type of soil</th>
<th>$m_0$ MPa$^{-1}$</th>
<th>$m_1$ MPa$^{-1}$</th>
<th>$\eta$ d$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Soft silty clay</td>
<td>0.000209</td>
<td>0.0032</td>
<td>0.0603</td>
</tr>
<tr>
<td>2</td>
<td>Soft organic clay</td>
<td>0.000334</td>
<td>0.0024</td>
<td>0.0792</td>
</tr>
</tbody>
</table>

In order to evaluate the possibilities for liquefaction of saturated sands some dynamic triaxial tests at various relative densities have been implemented (Kostov 1989). In accordance with the macro seismic land register in Bulgaria channels come into an area of VII intensity of earthquake (Richter-scale) equal to coefficient of seismicity $K_c=0.11$. Laboratory tests have been implemented based on the Seed and Idriss (1971) method where pore pressure increase is registered in the process of cyclic triaxial load.

The forecast of the liquefaction phenomena of saturated sands is implemented by determination of the liquefaction factor $FL_s$ as a ratio of the cyclic load coefficient (conforming to a certain number of cycles of given seismic intensity) to the cyclic load coefficient depending on the reaction specter.

The results of the laboratory investigation are given in table 3 where $FL_s(0.11)$ and $FL_s(0.29)$ are respectively liquefaction factors at coefficient of seismicity $K_c=0.11$ and $K_c=0.29$ - Id - density index.

The investigation proves that at earthquake intensity of VII (Richter-scale) liquefaction of saturated sand is hardly probable.

Table 3.

<table>
<thead>
<tr>
<th>Type of sand</th>
<th>Id (%)</th>
<th>$FL_s(0.11)$</th>
<th>$FL_s(0.29)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loess sand</td>
<td>50</td>
<td>1.51</td>
<td>0.571</td>
</tr>
<tr>
<td></td>
<td>77</td>
<td>1.95</td>
<td>0.740</td>
</tr>
<tr>
<td></td>
<td>36</td>
<td>2.08</td>
<td>0.790</td>
</tr>
<tr>
<td>Alluvial sand</td>
<td>72</td>
<td>2.62</td>
<td>0.990</td>
</tr>
</tbody>
</table>

Fig.3. Chart of construction period
Due to the small thickness of the clay layers and the presence of bidirectional filtration values of pore pressure are low (2.3 - 2.5 KPa) which shows that the influence on the bearing capacity of the base could be neglected.

Fig. 4 Service load:
   a. Structure of channel 1
   b. Load (MPa)

In this way an uniform load and decreasing of deformations is guaranteed, which is a precondition for faultless exploitation of the hydrotechnical equipment in the Nuclear Power Station.

In order to accelerate consolidation during construction period and to improve the base a gravel base of 1.75 thickness and gravel piles of 0.80 diameter situated in chess order at a distance of 4.0m and depth of up to 5.0m have been designed (Fig.6).

4 GEOTECHNICAL STRUCTURE FOR IMPROVEMENT OF THE BASE

Figure 5. Settlement curves:
   1. At the end of construction period
   2. 5 years after construction

REFERENCES


