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Antiseepage Measures and Disturbances on Earth Dam

Mesures et Perturbations de l’Anti-Percolation dans le Barrage en Terre

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SYNOPSIS

The effectiveness of four different antiseepage measures /that of the horizontal blanket, that of the blanket and a cut off wall, that of a cut off wall connected with clay core, and that of a cut off wall with grout curtain/ is analysed from the point of view of groundwater hydraulics, and of the danger of disturbances as well.

INTRODUCTION

In the engineering practice the hydraulic effectiveness of antiseepage measures is evaluated most frequently. The deformations and damages possibility, caused by hydrodynamic loading is not respected despite of the fact that this danger menaces the structure as it will be shown in the paper.

DIFFERENT EARTH DAM AND SUBSOIL SEALINGS

There were built four small dams with inclined core on permeable foundations in the Váh Valley /in Czechoslovakia/ with different antiseepage measures in subsoil /Fig.1/. The geological structure of the territory is nearly the same: the heterogeneous flysch layers /sand and clay stones/ covered by alluvial deposits which enabled to use following sealing elements:

FIG. 1 TERRITORY GEOLOGICAL COMPOSITION AND DAM CROSS-SECTION
An upstream blanket connected with the inclined core.  
A short blanket and slurry cut off wall on its end.  
A slurry cut off wall connected with the core.  
A cut off wall with grout curtain - as a double sealing.

The values of basic characteristics of soils and other materials used in dam construction and in its subsoil are given in the Table I, containing the deformation characteristics and the values of permeability coefficients used in the calculations made by finite elements methods /FEM/, too. To have the possibility of comparison - the same geological profile and the same cross-section of the dam with inclined earth core /on the right side of the drawing - /Fig.1/ was taken into consideration. The following permeability coefficients /k/ of the layers have been considered:

1/ $k = 5 \times 10^{-4} \text{ms}^{-1}$; 2/ $2 \times 10^{-3}$; 3/ $4 \times 10^{-5}$; 4/ $6 \times 10^{-4}$ and 5/ $2 \times 10^{-5} \text{ms}^{-1}$, for the sealing elements /11 till 15/ $k = 1 \times 10^{-6} \text{ms}^{-1}$.

The ground water movement characteristics for the sealing element plant, in the area of connection of two sealing elements - this of the dam and that of the subsoil /profile B/ and in the dam axis /profile C/ were investigated.

The potential function $\psi$ and velocity $v_x$ relation, such that

$$\frac{\partial \psi}{\partial x} = -k \frac{\partial h}{\partial x} \quad \text{and} \quad \frac{\partial \psi}{\partial y} = -k \frac{\partial h}{\partial y}$$

and flow function in the form:

$$\frac{\partial v}{\partial x} = -k \frac{\partial h}{\partial x}$$

was introduced.

The solution of the Laplace equation:

$$\frac{\partial^2 \phi}{\partial x^2} + \frac{\partial^2 \phi}{\partial y^2} = 0$$

was investigated by FEM - satisfying the Dirichlet and Neuman border condition.

The results of velocity vectors $\vec{v}$, velocity directions and equipotentials $\psi$ are given in the Fig.2 and in the Table II. This investigation gives the potential maximal values in the vertical sealing elements alternatives which shows the maximal values of gradients /1/ too. The minimal values of gradients /$\partial\psi/0.1$ was reached at horizontal blanket. The minimum of rate discharge $q = 3.3 \times 10^{-5} \text{ms}^{-1}$ was obtained in the alternative /14/ - as it was expected. The elevated values of $q$ at the alternative /11/ can be explicated by an inappropriate application of cut off wall sealing element by designer who ignored the geological conditions.
The wall was binded with the binding in the weathering zone of the flysch with \( k = 2 \times 10^{-3} \text{ m}^{-1} \) which lowered the effectiveness of this element. By the correct application of the wall, the rate of discharge \( q \approx 5 \times 10^{-5} \text{ m}^3 \text{ s}^{-1} \) could be reached.

**TABLE I**

Values of soil characteristics

<table>
<thead>
<tr>
<th>Soil in the layer</th>
<th>Shear Strength ( \varphi_u /^\circ / )</th>
<th>Deformation ( E/\text{MPa}/ )</th>
<th>Seepage ( k /\text{m/s}/ )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-5</td>
<td>38-42</td>
<td>20-100</td>
<td>2,10^{-5} - 2,10^{-3}</td>
</tr>
<tr>
<td>6</td>
<td>25-30</td>
<td>6-9</td>
<td>10^{-4} - 2,10^{-7}</td>
</tr>
<tr>
<td>8</td>
<td>36-42</td>
<td>5-20</td>
<td>5,10^{-4}</td>
</tr>
<tr>
<td>10</td>
<td>36-42</td>
<td>5-20</td>
<td>3,10^{-5} - 4,10^{-3}</td>
</tr>
</tbody>
</table>

**TABLE II**

Values determined by calculus

<table>
<thead>
<tr>
<th>Alternative</th>
<th>( \varphi_B /^\circ / )</th>
<th>Seepage ( \varphi_{max} /^\circ / )</th>
<th>Seepage ( \varphi_{max} /^\circ / )</th>
<th>Distance ( D_m /\text{m}/ )</th>
<th>Potential ( D_m /\text{m}/ )</th>
</tr>
</thead>
<tbody>
<tr>
<td>/i/</td>
<td>4,2</td>
<td>4,5</td>
<td>4,5</td>
<td>16,8</td>
<td>30,4-68,5</td>
</tr>
<tr>
<td>/ii/</td>
<td>2,8</td>
<td>4,0</td>
<td>9,9</td>
<td>23,0</td>
<td>11,8</td>
</tr>
<tr>
<td>/iii/</td>
<td>7,5</td>
<td>10,5</td>
<td>0,25</td>
<td>11,8</td>
<td>11,8</td>
</tr>
<tr>
<td>/iv/</td>
<td>8,0</td>
<td>0,25</td>
<td>15,0</td>
<td>11,8</td>
<td>11,8</td>
</tr>
</tbody>
</table>

**SEALING ELEMENTS DAMAGES IN ALTERNATIVE /iii/**

Subsoil deformations in the sealing elements vicinity provided deformations and ruptures of the clay core /Fig.4/. Supposing the flexure of the sealing element in a form of a parabola, a settlement of \( s = 0,2 \text{ m} \) causes the deflection of the value \( \varphi = 40^\circ 40' \) which gives the parabola parameter:

\[
p = 0,20 \sin 40^\circ 40' = 0,016 \text{ m}
\]

The core surface extension will be:

**FIG. 3 LOADING SETTLEMENTS AND DISLOCATION POTENTIALS**
al = 1 p lncot $\phi$ = 0,008 lncot 2°20' = 0,0255 m

This length difference was divided in 5 till 10 gaps of a width $d = 0,1 - 0,5$ /l/ mm /Fig. 4/. The rate of discharge of gap depends on the gap rate coefficient $C_g$ which was calculated by the formula

$$C_g = g \frac{d^2}{12

$$

for different values of $d$ under assumption of $g = 9,8$ m/s$^2$ and $\nu = 1,31 \times 10^{-6}$ m$^3$/s$^{-1}$. The value of $C_g = 5,10^{-4}$ till $C_g = 8,10^{-2}$ m/s$^{-1}$ was obtained by the calcul in the second case the pressure not far from hydrostatic pressure should dominate in the damaged area. Taking the water height $h = 3-10$ m into account, we state that there was acting a water pressure of the value $p = 29,4-98$ kN/m$^2$ in the dependence upon the depth of the damaged area.

There were used many methods of evaluation of the disturbance mentioned above. Using the classical seepage theory and FEM, for $k = 2,10^{-2}$ m/s$^{-1}$, the maximum velocity $v = 2,2 \times 10^{-3}$ m/s$^{-1}$ by a gradient $i = 0,65$ was calculated. The rate of discharge of the gap /in the beginning stadium/ was $q = 1,5 \times 10^{-2}$ m$^3$/s$^{-1}$ and in the toe drain $q = 1,31 \times 10^{-3}$ m$^3$/s$^{-1}$. The amount of the gap was 88,5% of the total rate. In the field the increase in seepage was neglected some weeks. In respect of the collector length /of 120 m/, the seepage quantity increased only some percent in the control well.

DISLOCATION POTENTIAL

In the engineering practice it is very important to know the damage phenomena /of the internal erosion, piping, hydraulic fracturing, etc./ and its places, and to have appropriate means for judging the danger of disturbance. All contacts of different materials and of soils of different permeability and the gaps of all kinds, represent a germ of such a danger. If we have /in our case/ a gap of a width $d = 0,5$ mm only, we get:

$$C_g = 7,85 \times 10^{-2} \text{m/s}^{-1}; \quad i = 0,865$$

and seepage force: $j = 9,8 \times 0,865 = 8,48 \text{kN/m}^2$,

respecting the permeability relation

$$/k_k/ \frac{7,85 \times 10^{-2}}{2,10^{-7}} = 392$$

with the concentration coefficient

$$\kappa = /i/ + \log 392/ = 3,593$$

Dislocation potential: $\phi_D = 8,48,1,0,3,593 = 30,4 \text{kN/m}^2$.

The clay core – having $c = 15 \text{kN/m}^2 /30,4/ should undergo progressive destruction. In the investigated case the dislocation and damages of an element were transferred from one to another sealing as it was shown in the field – in an examined trench – cut through both sealing elements. Theoretical analysis by means of dislocation potential gave us following values:

$\phi_D = 13,2 \text{kN/m}^2$ /in the upper part/, $\phi_D = 25,1 \text{kN/m}^2$ and $\phi_D = 68,5 \text{kN/m}^2$ near the wall toe /in the point B in the stadium of destruction – Fig. 5/

In the contrast of $\phi_D = 5,8,10,5$ and $25,3 \text{kN/m}^2$ before the destruction. The Table II shows that the values of dislocation potential are remarkably lower at the upstream blanket. There were observed no damages in the field at using this element.

SEALING DISTURBED

The evaluation of effectiveness and possibilities of damages occurrence of horizontal and vertical sealing elements showed that the cut off walls are menaced by the disturbances especially if there exists the presumption of an extent deformation – as it was in the case investigated in this paper where the origin and the influence of the failure was examined by means of the mathematical model – by FME and by use of the dislocation potentials; magnitude of which was equalized with the value of sealing cohesion.

CONCLUSION

The evaluation of effectiveness and possibilities of damages occurrence of horizontal and vertical sealing elements showed that the cut off walls are menaced by the disturbances especially if there exists the presumption of an extent deformation – as it was in the case investigated in this paper where the origin and the influence of the failure was examined by means of the mathematical model – by FME and by use of the dislocation potentials; magnitude of which was equalized with the value of sealing cohesion.

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