Permeability change driving effect on embankment dams
Case Study: The Zonouz embankment dam

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Abstract: Seepage is one of the most important problems in Civil engineering especially in the field of damping particularly in Embankment dams. Existence of wide valleys in basins puts the execution of embankment dams in priority. In this study the seepage of the Zonouz embankment dam body is numerically modeled by finite element method (FEM). Seepage analysis is one of the matters that if doesn't care could lead to destroying factors such as seepage forces and creation of pore water pressure that threat the stability of the dam.

In this study the seepage of the Zonouz embankment dam body is numerically modeled by finite element method (FEM). This analysis is numerically modeled by observational head piezometric data and its comparing with the results. It was done in two different cross sections of Zonouz embankment dam and the modeling for each section was done after the calibration of permeability coefficients and verification by the numerical modeling.

Key words: Numerical Modeling, Seepage Phenomenon, Finite Element Method, Seepage in Embankment Dam, Zonouz Embankment Dam

1. Introduction

Seepage phenomenon should be control in embankment dams, because of it is one of the most destructive cases in earth embankment dam. Internal erosion of the embankment dams caused by seepage, for instance the reservoir water level continuous to drop, which also leads to upstream dam slope coating.

Seepage is the continuous movement of water from the upstream face of the dam toward its downstream face and filling the filter grains in toe part of dams, naturally many changes will be created by the core. here it can be to name previous researches about current study:Nourani.et.al.,2008,have investigated seepage phenomenon by a 3d Black box modeling in earth fill dam(Sattarkhan earth fill dam, Iran).Narsimhan.et.al.,1978,presented a numerical modeling for water movement analysis in nonhomogenous unsteady state system with multidimensional situation, Tayfur.et.al.,2005,have done an numerical modeling by FEM for seepage phenomenon analysis in transient state on two embankment dams in U.S.A. In this study seepage phenomenon has analyzed by numerical modeling via finite elements method (FEM).

The effect of permeability change in Zonouz embankment dam has calibrated so many times in different numerical models by finite element method, then verification of data to witness reduction (R.M.S.E) at comparing observational piezometric total head in location of the dam with finite element method piezometric head, any where the(R.M.S.E) never won’t be zero, the cause of it existence of calculation and executive deficiencies.[7].

The last model will be the best numerical model; because of there is the fewest gap between observational piezometric total and(FEM) piezometric head.

2. Basic Equations

In principle, the water level is behind of the dam is changeable in a month; it used transient state with time steps. The Richard's Eq. will show this case. That Equation results is equal with Darcy’s law, consequently the Richard’s Eq. and will be used for unsteady state.[1].

\[
\begin{align*}
\text{Arrival mass in x direction} & \Rightarrow \rho q x \Delta y \Delta z \\
\text{Balcony mass in x direction} & \Rightarrow (\rho q x + \frac{\partial \rho q x}{\partial x}) \Delta y \Delta z \\
\text{Net balcony mass} & \Rightarrow \left(\frac{\partial \rho q x}{\partial x}\right) \Delta x \Delta y \Delta z
\end{align*}
\] (1)
3. Zonouz Embankment Dam

The Zonouz embankment dam is made mainly from natural materials. The main type is rock fill dam with impermeability clay core. This dam has been built on hard rock, it doesn’t exert too much pressure on its foundation. That is made in East Azerbaijan province in Iran.

This dam is homogeneous system in core and 59 m height from bed rock and 60 m height from foundation, the elevation of the crest is 1892 m.

A cross-section through zonouz embankment dam as shown in fig.1.

![Cross-Section of the Dam](image1)

In body of the dam, there are 18 electrical piezometers totally, that in fig.2 and fig.3 have been showed.

![Section 1 of the Dam](image2)

![Section 2 of the Dam](image3)

4. Results and Discussion

In this paper, seepage phenomenon in the Zonouz embankment dam has been analyzed by finite elements method. To attention the permeability coefficient to be reported by executor Co. [10], that is \( k = 1.2 \times 10^{-5} \text{m/s} \) and equal deal permeability coefficient in direction \( x \) (\( k_x \)) and permeability coefficient in direction \( y \) (\( k_y \)).

\[
\begin{align*}
\text{Arrival mass in y direction} & \Rightarrow \rho q_x \Delta x \Delta z \\
\text{Balcony mass in y direction} & \Rightarrow (\rho q_y + \frac{\partial \rho q_y}{\partial y}) \Delta x \Delta z \\
\text{Net balcony mass} & \Rightarrow -\frac{\partial \rho q_y}{\partial y} \Delta x \Delta y \Delta z \\
\text{Arrival mass in z direction} & \Rightarrow \rho q_z \Delta x \Delta y \\
\text{Balcony mass in z direction} & \Rightarrow (\rho q_z + \frac{\partial \rho q_z}{\partial z}) \Delta x \Delta y \\
\text{Net balcony mass} & \Rightarrow -\frac{\partial \rho q_z}{\partial z} \Delta x \Delta y \Delta z
\end{align*}
\]

as:

\[
\frac{dM}{dt} = \left[ \frac{\partial (\rho q_x)}{\partial x} + \frac{\partial (\rho q_y)}{\partial y} + \frac{\partial (\rho q_z)}{\partial z} \right] \Delta x \Delta y \Delta z
\]

The above formula (4) has been showed total balcony of mass from element’s area.

as:

\[
\frac{dM}{dt} = \frac{\partial (pc)}{\partial t} \Delta x \Delta y \Delta z
\]

Where:

C: Water volume
\( \rho \): Specific mass of water
\( t \): time

To attention Darcy’s Equation:

\[
\begin{align*}
q_x & = -k_x \frac{\partial \phi}{\partial x} \\
q_y & = -k_y \frac{\partial \phi}{\partial y} \\
q_z & = -k_z \frac{\partial \phi}{\partial z}
\end{align*}
\]

And \( \rho \) should be constant assume set is given as

\[
\frac{\partial}{\partial x} (\rho k_x \frac{\partial \phi}{\partial x}) + \frac{\partial}{\partial y} (\rho k_y \frac{\partial \phi}{\partial y}) + \frac{\partial}{\partial z} (\rho k_z \frac{\partial \phi}{\partial z}) = \frac{\partial (pc)}{\partial t}
\]

\[
\nabla (\rho k \nabla \phi) = \frac{\partial (pc)}{\partial t}
\]

Where: (\( \rho \)) is specific mass of water and (\( t \)) is time, (\( c \)) is water volume.

The relationship (6) shows that Richard’s Eq. is in transient state for flow formulas.[8]
The variation of water level in behind the Zonouz dam, has been caused to accomplish transient state of modeling, with time steps and initial conditions, initial condition can be water level on upstream of the dam.

4.1. First Model: (Steady state Homogeneous Core)
This modeling to accomplished with the permeability coefficient reported by executor Co.[10]. \( K = 1.2 \times 10^{-5} \text{ m/s} \).
At first steady state has been assumed without time steps and water contents parameters. In fig.4 the changes of permeability coefficients and matric suction has been showed.

![Fig.4.permeability coefficients and matric suction changes of the core](image)

The result of steady state modeling and flow net graph is in fig.5.

![Fig.5.pheratic line and flow net in steady state](image)

4.2. Second Model: (Transient state, Triangular Nonhomogeneous Core)
The main reason of this geometric shape is existence moment of inversion in toe of the dam and erosion of clay grain inside of filter and drainage system.
On the other hand the changes of permeability coefficients and matric suction that relevant to upstream part of the core is in fig.7 by \( 2.5 \times 10^{-8} \text{ m/s} \) and downstream part of the core (triangular zone) has been showed in graph fig.8 by \( 8.4 \times 10^{-9} \text{ m/s} \).
After calibration of permeability coefficients, the root- mean- square- error in order of for section 1 is 34.4% and section 2 is 14.11% shows reduction as compared with homogeneous state. Triangular section in the core is good section after verification of data; these regions have been showed in fig.6.

![Fig.6.two difference regions of the core](image)
The results of finite elements method for section 1 and 2 have been brought in table 1 and table 2.

**Table 1. Non homogeneous core- section1- (+1840)**

<table>
<thead>
<tr>
<th>No</th>
<th>Piezometric No</th>
<th>Situation</th>
<th>Water level (m)</th>
<th>Finite element head (m)</th>
<th>Observational head (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>108</td>
<td>US</td>
<td>27.35</td>
<td>1867.35</td>
<td>1866.8</td>
</tr>
<tr>
<td>2</td>
<td>109</td>
<td>DS unsaturation</td>
<td>33.3</td>
<td>1873.3</td>
<td>1873.9</td>
</tr>
<tr>
<td>3</td>
<td>105</td>
<td>US</td>
<td>18.9</td>
<td>1858.9</td>
<td>1858.6</td>
</tr>
<tr>
<td>4</td>
<td>107</td>
<td>DS</td>
<td>19.5</td>
<td>1859.5</td>
<td>1858.87</td>
</tr>
<tr>
<td>5</td>
<td>106</td>
<td>CL</td>
<td>9.84</td>
<td>1849.5</td>
<td>1848.7</td>
</tr>
</tbody>
</table>

Observation piezometric head comparison with finite elements method (FEM) results in specified time steps for sections 1 and 2 can be considered in figures 9 till 11.

**Table 2. Non homogeneous core- section2- (+1834)**

<table>
<thead>
<tr>
<th>No</th>
<th>Piezometric No</th>
<th>Situation</th>
<th>Water level (m)</th>
<th>Finite element head (m)</th>
<th>Observational head (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>212</td>
<td>US</td>
<td>36.79</td>
<td>1870.79</td>
<td>1871.1</td>
</tr>
<tr>
<td>2</td>
<td>213</td>
<td>DS unsaturation</td>
<td>38.27</td>
<td>1872.27</td>
<td>1873.15</td>
</tr>
<tr>
<td>3</td>
<td>209</td>
<td>US</td>
<td>23.12</td>
<td>1857.12</td>
<td>1856.42</td>
</tr>
<tr>
<td>4</td>
<td>210</td>
<td>CL</td>
<td>25.45</td>
<td>1859.45</td>
<td>1858.79</td>
</tr>
<tr>
<td>5</td>
<td>211</td>
<td>DS unsaturation</td>
<td>19.1</td>
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<td>1852.31</td>
</tr>
<tr>
<td>6</td>
<td>205</td>
<td>US</td>
<td>11.9</td>
<td>1845.9</td>
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</tr>
<tr>
<td>7</td>
<td>206</td>
<td>US</td>
<td>24.14</td>
<td>1858.14</td>
<td>1857.50</td>
</tr>
<tr>
<td>8</td>
<td>207</td>
<td>DS</td>
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<td>1855.87</td>
</tr>
<tr>
<td>9</td>
<td>208</td>
<td>DS unsaturation</td>
<td>8.7</td>
<td>1842.7</td>
<td>1856.42</td>
</tr>
</tbody>
</table>

**Fig.7. permeability coefficients and matric suction changes of the upstream part of core**

**Fig.8. permeability coefficients and matric suction changes of the downstream part of core**

The results of finite elements method for section 1 and 2 have been brought in table 1 and table 2.

**Fig.9. Observational piezometric head and (FEM) as compared with time related to piezometer No, 105 in section 1**

**Fig.10. Observational piezometric head and (FEM) as compared with time related to piezometer No,205 in section 2**
4.3. Third Model: (Second state of Triangular Nonhomogeneous Core)

This model has been showed in Fig.12 via that, it has gotten the most reduction (R.M.S.E), in current model (R.M.S.E) the most reduction indicates, as for first section (R.M.S.E)₁=0.89m and for second section (R.M.S.E)₂=0.93m that 21.9% reduction in section 1 and 33.57% reduction in section 2 as compared with the second model and in order of 48.8% and 42.9% decrease as compared with the first model can be considered.

The result of finite elements method for the first and the second sections in current model have been brought in table 3 and table 4.

### Table 3. Non homogeneous core- section 1 (+1840)

<table>
<thead>
<tr>
<th>No</th>
<th>Piezometric No</th>
<th>Situation</th>
<th>Water level (m)</th>
<th>Finite element method head (m)</th>
<th>Observational head (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>108</td>
<td>US</td>
<td>27.3</td>
<td>1867.3</td>
<td>1866.8</td>
</tr>
<tr>
<td>2</td>
<td>109</td>
<td>DS unsaturation</td>
<td>33.57</td>
<td>1873.57</td>
<td>1873.9</td>
</tr>
<tr>
<td>3</td>
<td>105</td>
<td>US</td>
<td>18.91</td>
<td>1858.91</td>
<td>1858.6</td>
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<tr>
<td>4</td>
<td>107</td>
<td>DS</td>
<td>19.1</td>
<td>1859.1</td>
<td>1858.87</td>
</tr>
<tr>
<td>5</td>
<td>106</td>
<td>CL</td>
<td>9.45</td>
<td>1849.45</td>
<td>1848.7</td>
</tr>
</tbody>
</table>

### Table 4. Non homogeneous core- section 2 (+1834)

<table>
<thead>
<tr>
<th>No</th>
<th>Piezometric No</th>
<th>Situation</th>
<th>Water level (m)</th>
<th>Finite element method head (m)</th>
<th>Observational head (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>212</td>
<td>US</td>
<td>36.8</td>
<td>1870.8</td>
<td>1871.1</td>
</tr>
<tr>
<td>2</td>
<td>213</td>
<td>DS unsaturation</td>
<td>38.27</td>
<td>1872.27</td>
<td>1873.15</td>
</tr>
<tr>
<td>3</td>
<td>209</td>
<td>US</td>
<td>22.82</td>
<td>1856.82</td>
<td>1856.42</td>
</tr>
<tr>
<td>4</td>
<td>210</td>
<td>CL</td>
<td>25.42</td>
<td>1859.42</td>
<td>1858.79</td>
</tr>
<tr>
<td>5</td>
<td>211</td>
<td>DS unsaturation</td>
<td>19</td>
<td>1853</td>
<td>1852.31</td>
</tr>
<tr>
<td>6</td>
<td>205</td>
<td>US</td>
<td>10.83</td>
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<td>7</td>
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<tr>
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<td>DS</td>
<td>8.7</td>
<td>1842.7</td>
<td>1856.42</td>
</tr>
</tbody>
</table>
The most reduction distance between two diagrams has been considered in the current model, for the reason that suitable section choice for the core and suitable permeability coefficient calibration has been happened, especially in piezometer No.105 in section 1 by 0.3m decrease distance between two diagrams, and piezometers No.205 and 209 in section 2 by 0.4m.

5. Conclusion
A series of models were performed to investigate the 2D effect on seepage phenomenon of Zonouz embankment dam, with respect to some major factors, such as the geometrical characteristics of the core and permeability coefficients. The following conclusions can be drawn from the calculated results:
1. In the current models, which the transient state has been done, it has useful results as compared with steady state analysis, the existence of certain time steps (120days).
2. The most reduction distance between observational piezometric head and FEM is related to piezometer No, 105 amounting to 0.3m, for the reason that better section choice for the core.
3. According to the current numerical modeling, the importance of using Nonhomogeneous core by different permeability coefficients confirm whereas this model by it’s dynamic and transient state can be useful in forecast core of dams behavior.

References: