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Seepage Analysis of An Earthen Dam: A Case Study of Tamta Dam

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Abstract: The Construction of embankment dams is most common and popular due to the easy availability of material. The important point during the construction and after completion of an earthen embankment is the control of seepage through the dam body and foundation. Seepage control is necessary to prevent the downstream slope from sloughing, uplift pressures, piping phenomena, and loss of materials from the dam body to the outside of the dam body. The present study has been carried out on the Tamta earthen embankment which is located in Pathalgaon, Chhattisgarh. The existing dam has been selected for a case study because it has been recently approved for renovation work by Chhattisgarh Government due to leakage through Masonry and the RCC barrel. Hence, it is required to ensure the safety of the dam against seepage. A 2-dimensional seepage analysis has been carried out using the computer-aided software SEEP/W to determine the seepage quantities. Results are presented for three conditions i.e., maximum pool level, normal pool level, and minimum pool level.

Keywords: Seepage Analysis, Tamta Earthen Dam, Seepage flux.

1 Introduction

Seepage is one of the major causes of dam failure. The statistics show that more than 30 percent of earthen dam failure is due to inadequate control of seepage. Seepage in earthen dams cannot be avoided but usually does not be devastating if it is under control. According to international humanitarian law [8], Dams are regarded as "installations containing dangerous forces" because of the significant impact that a disaster would have on people and property.

Seepage is one of the reasons for weakening the structure of the dam which may results in sudden failure [9] due to piping or sloughing of the downstream slope. The water flows in the dam body and foundation cause pore pressure, uplift pressure, and seepage forces and if it exceeds the tolerable limit then the dam stability [6] may be insecure and may collapse. So, seepage control is a cure before crises and it becomes a greater concern for the dam stability when the dam materials have higher permeability [5]. Hence, a dam engineer must be conversant with seepage problems, their management, and remedial measures. Various methods have been applied to effectively solve the problem of seepage. Henry Darcy (1856) was the first to work for finding out the amount of seepage taking place through homogenous soil.

A homogeneous dam is constructed of earth material throughout, except for the possible insertion of internal drains or drainage blankets. Rock fill dam has which more than 50 percent of the total volume is contained compacted or dumped pervious natural or crushed rock. A zoned embankment dam is composed of zones of selected materials having diverse degrees of porosity, permeability, and density. A diaphragm earth fill dam is a modification over the homogenous embankment type in which the bulk of the embankment is constructed of pervious material and a thin diaphragm [1] of impermeable material is used to control the seepage. The diaphragm may be of impervious soils, or cement concrete.

In this paper, a case study has been taken to analyze the actual seepage problems existing in an earthen dam. A cavity on the upstream face of the dam has been found due to which the capacity of the dam's reservoir is not being fully utilized, even there is a possibility of failure of the earthen dam due to seepage through the cavity. Long-term seepage through the cavity may lead to piping phenomena.

There are many softwares [**2**] that incorporates the seepage problems where appropriate input and data are given. SEEP/W is a finite element-based (FEM) based computer-aided software to solve the seepage and excessive pore water pressure dissipation problems within porous materials [9] such as soil. SEEP/W can be used in designing geotechnical, hydrological, mining, and civil engineering problems. This software can figure out the problem of steady-state issues to saturated/unsaturated time-dependent problems. The finite element approach is preferred because of the simplicity with which it can handle two-dimensional problems involving many materials and uneven boundary conditions.[**3**]. Sivakugan and Das [**7**] have validated this software for a number of seepage problems and advocate the use of the same for solving problems related to seepage analysis.

1.1 Problem Identification

The Tamta earthen dam with a maximum height of dam 20.9 m, maximum reservoir level 19.1 m, normal reservoir level 18.1 m and minimum reservoir level 9.6 m is situated near Pathalgaon, Chhattisgarh, India. The longitude and latitude are 22°39'15"N and 83º39'15"E respectively. The Catchment area is 35.74 sqkm and completed in the year 2005. The earth dam has been found with a cavity of the approximate diameter of 1-1.5 m at upstream face of the dam lying in between maximum reservoir level and minimum reservoir level, due to which the capacity of the dam is not being fully utilized. Figure 1 (a) shows the identification of the problem during site visit.

Fig. 1 (a) Problem identification by a site visit.

Fig 1(b). Cavity on the upstream face of the reservoir.

Figure 1(b) shows the cavity existing in between the minimum reservoir level and maximum reservoir level on the upstream face of the dam with approximate diameter of 1.2 m. The cavity exists at a height of 12.8 m from the base of a dam hence, it can be inferred that there is a loss of 5.3 m head storage in a dam's reservoir, due to which some parts of the village are not getting water for irrigation.

As the appropriate measures have been taken by the Chhattisgarh water resource department to fill the cavity of an earth dam. The cavity formation on the upstream face of the dam was due to leakage in the sluice barrel (which is used to pass canal discharge) made of stone masonry. The earthwork surrounding the sluice barrel, erroring continuously which ultimately leads to cavity formation. Tamta Earthen dam model with cavity formation using SEEP/W has been shown in the Fig. 2

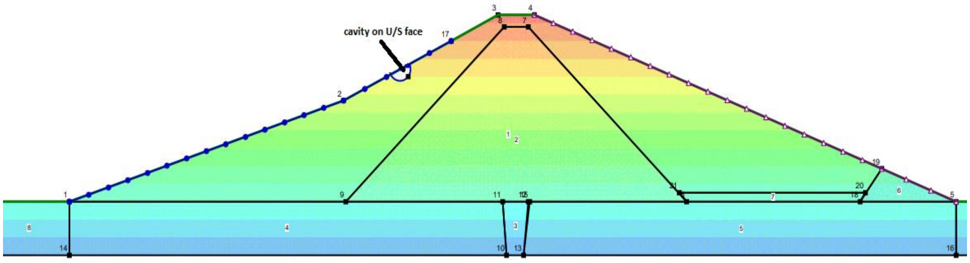

Fig. 2. Model of the dam with cavity formation

1.2 Problem solution

In order to make the dam safe against seepage, the present study is done to model the 2 -dimensional seepage analysis of Tamta earthen dam using SEEP/W software after filling the cavity of earth dam, so that its full capacity can be utilized and also seepage should not affect the performance of the earth dam

2 Methodology

The seepage analysis has been carried out to know the pore pressure distributions, seepage velocity, discharge, and flow through the dam body under the maximum water level, normal water level, and minimum water level under steady-state Seepage conditions.

2.1 Seepage Analysis

According to Darcy's law, the discharge through saturated soil medium is given by-

$$q=k*i \tag{1}$$

Where q= discharge per unit area through the soil medium, k= the hydraulic conductivity of soil material, i= hydraulic gradient.

Darcy's law was initially applied to measure the specific discharge through a saturated soil medium. The overdue time was also applied to an unsaturated soil medium. The general equation of the two-dimensional differential equation (Laplace equation) to estimate seepage is expressed as-

$$\frac{d}{dx}\left(k_x \frac{dH}{dx}\right) + \frac{d}{dy}\left(k_y \frac{dH}{dy}\right) + Q = \frac{d\emptyset_w}{dt} \tag{2}$$

There are two basic equations for seepage analysis, steady-state seepage and transient steady-state condition for sudden drawdown, can be represented by eq. (2) and (3) respectively.

$$\frac{d}{dx}\left(\boldsymbol{k_x}\frac{dH}{dx}\right)+\frac{d}{dy}\left(\boldsymbol{k_y}\frac{dH}{dy}\right)+\boldsymbol{Q}=\mathbf{0} \quad (3)$$

H= total hydraulic head difference, $k_{x=}$ hydraulic conductivity in a horizontal direction, $\emptyset_w$ =volumetric water content, t = time, Q = flux(discharge), $k_{y=}$ hydraulic conductivity in the vertical direction, $m_{w=}$slope of the storage slope, $\gamma_{w=}$unit weight of water.

2.2 Modelling

The discretization, definition of material attributes, and boundary conditions are the core components of finite element modeling. Selecting an adequate geometry, segmenting the model into suitable regions, and producing the discretized mesh are all stages in the development of the finite element model. Fig 3 shows the mesh generation for seepage analysis using SEEP/W software of Tamta earthen embankment with an approximate element size of 1 m, 2187 Nodes, and 2064 elements as it is considered a global element size. In general, it is said that if it would be zoomed in 100% then all the element sizes should be visible, too much finer element size results in too much data and it is difficult to analyze the results view. There is a phreatic zone along the toe drain hence considered the finer element size of 0.5m along the toe drain. The mesh is composed of triangular, square, rectangular and trapezoidal type of elements.

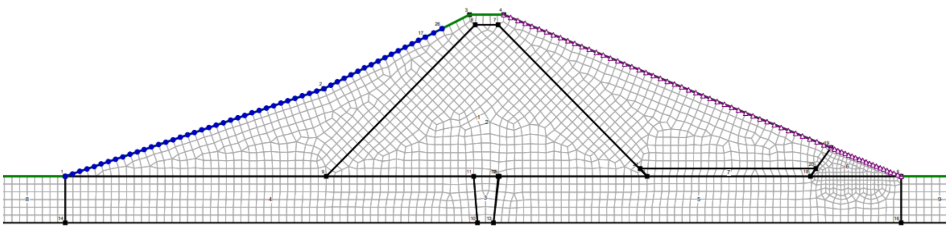

Fig. . Mesh generation for a selected section of the dam.

Volumetric water content reflects the soil's capacity to store water under variations in metric pressure (VWC). Degree of saturation of soil is equal to the VWC over the porosity of soil. VWC is equivalent to the soil's porosity in a saturated soil. Fig. 4 demonstrates typical VWC values and variation for sand and clay soil.

The hydraulic conductivity of a soil is the most significant soil characteristic utilized in seepage investigation. The hydraulic conductivities of the materials used in the model are shown in Table 1.

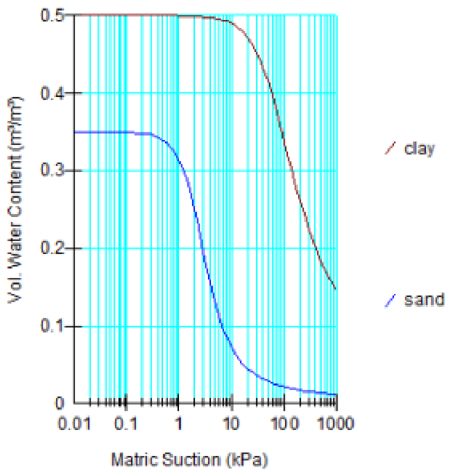

Fig. 4. Values and variation of VWC for clay and sand.

Table 1. Soil properties used in the analysis.

Materials	Horizontal permeability (m/s)	Vertical permeability (m/s)	Dry unit weight (kN/m^3)	Saturated unit weight (kN/m^3)
Core	1×10^{-10}	1×10^{-10}	15.5	17.82
Shell	7.06×10^{-06}	7.06×10^{-06}	16	18
Foundation	1×10^{-08}	1×10^{-08}	16	18
Puddle	1×10^{-12}	1×10^{-12}	18.92	18.92
Toe drain	1.02×10^{-05}	1.02×10^{-05}	18.62	18.92

3 Results and Discussion

The SEEP/W software generates flow net output, which includes total head contours, streamlines, and velocity vectors depicting seepage behaviors of earth dams. According to the results, the presence of a cutoff wall helps to reduce seepage and the gradient at the exit. The purposes of the cut-off wall are to regulate seepage flow and minimize internal pore water pressure, primarily in the subsurface area of the dam foundation. As a result, there are fewer and controlled risks of high-velocity flow vectors moving in the direction of the toe drain. Following cases were studied for the seepage of the dam.

3.1 Case 01-Normal Reservoir Level

The seepage flux through the earthen embankment is shown in Fig. 5 with a maximum flow rate of $2.2x10^{-07}m^3/sec$. The topmost flow inside the earthen embankment, with a red line, indicates the phreatic line, below which the seepage takes place where hydrostatic pressure acts and above which a negative pressure act.

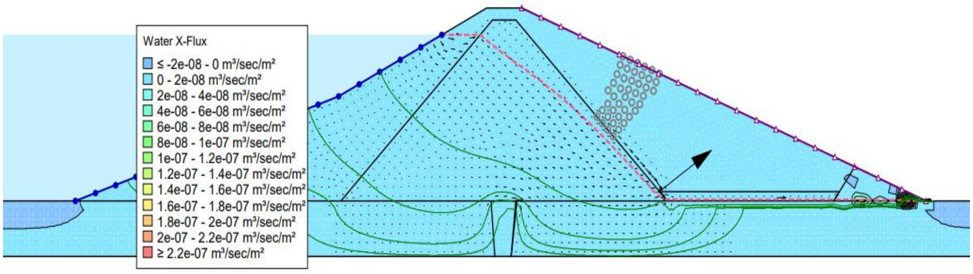

Fig. 5. Seepage flux through earthen dam's body at the normal reservoir level.

The flow vectors are lowered down due to the existence of a cut-off wall. Fig. 6 shows regular movement of pore water from the upstream to the downstream face of the dam at normal reservoir level condition. The movement of the velocity vectors was toward the filter drain, which is consonant with the seepage theory. Streamlines and equipotential lines were normal to one another.

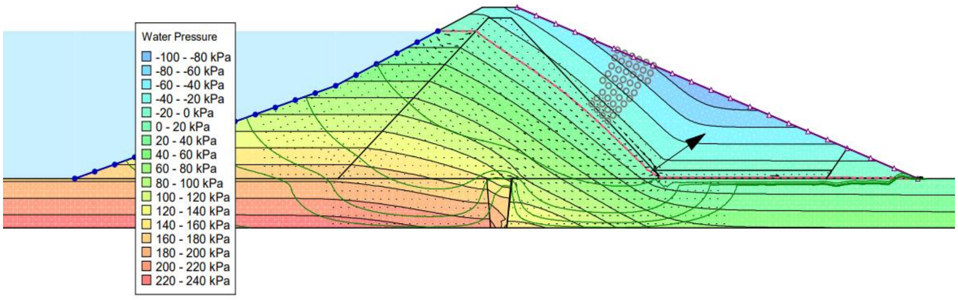

Fig. 6. Pore water distribution at normal reservoir condition

Case 2: Maximum Reservoir Level

Figure 7 shows the discharge passing through the dam's body at maximum reservoir level and Fig. 8 shows the pore water pressure distribution at maximum reservoir level.

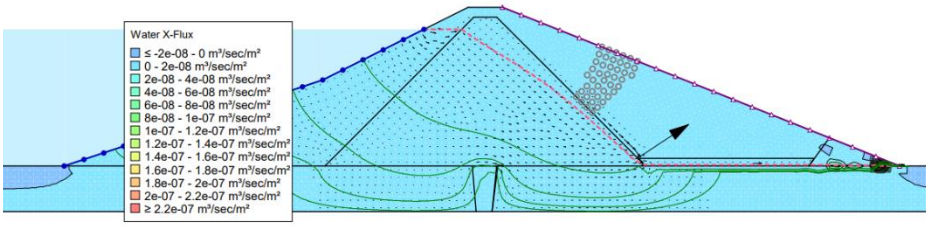

Fig. 7. Seepage flux through the earthen dam's body at maximum reservoir level.

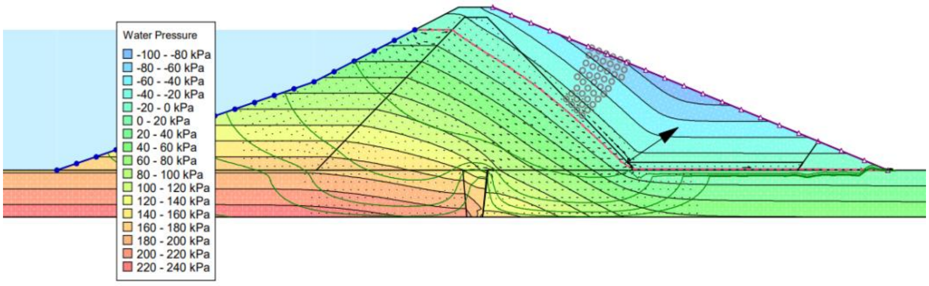

Fig. 8. pore water pressure distribution at maximum reservoir level

Case 3: Minimum Reservoir Level

Figure 9 makes it clear that the presence of a cut-off wall at the lowest pond level directly reduces seepage flux because it serves as a barrier and makes it possible to control the direction of flow vectors towards the toe drain. The seepage discharge passing through the dam's body i.e., $1.6x10^{-07}$ m^3/sec which is considerably low. Fig. 10 shows the pore water pressure distribution with contour level depicting pore pressure magnitudes.

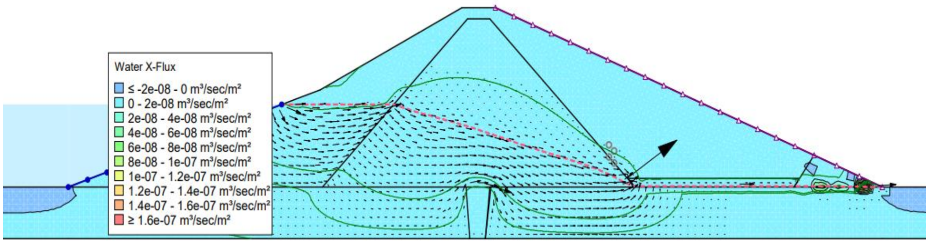

Fig. 9. Seepage flux inside the earthen dams' body at minimum reservoir level.

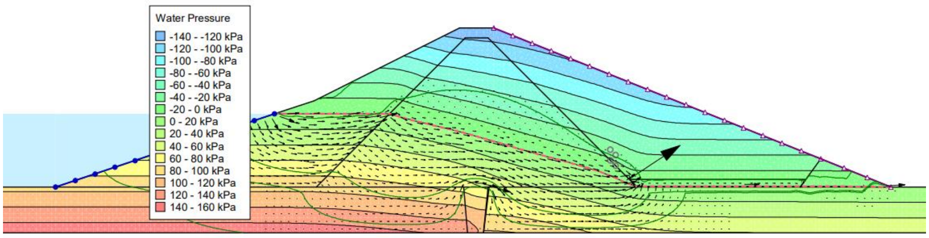

Fig. 10 Pore water pressure distribution at the minimum reservoir level.

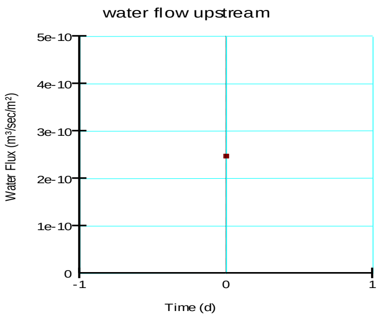

Fig. 11 (a) Water flux through upstream face

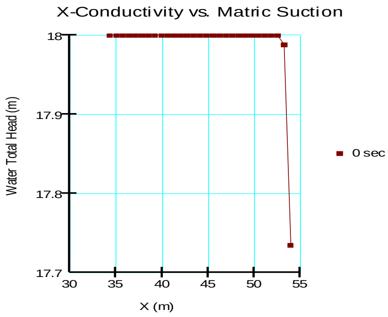

Fig. 11 (b) Conductivity vs matric suction

Figure 11 (a) shows the maximum discharge entering through the dam's body from the upstream face of the reservoir, which is 2.2×10^{-10} m^3/sec. Fig. 11 (b) shows that the matric suction (i.e., vacuum pressure) increases when the air starts entering into the voids of the soil, and due to this permeability of the soil decreases.

Seepage exit gradients states that the exit gradients should not be greater than 1.0, Fig. 12 shows graph of exit velocity gradient in the downstream of the dam which is less than 1.

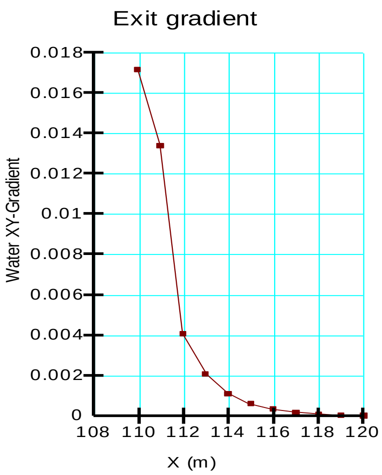

Fig. 12 Exit gradient velocity

4 Conclusions

In this paper, a case study analysis on Tamta earthen dam is presented for three scenarios i.e., maximum reservoir level, minimum reservoir level, and normal reservoir level and following conclusions have been drawn from seepage analysis.

(i) The quantity of seepage increases with an increase in the height of the water reservoir level, and it has been found that maximum seepage occurs at maximum reservoir level.

(ii) Maximum seepage flux obtained in the study is 2.2×10^{-07} m^3/sec where as in the minimum reservoir level seepage flux obtained as 1.6×10^{-07} m^3/sec, also exit gradient is within the permissible value.

(iii) The majority of the water total head is lost in the core and puddle of the dam section, ensuring the safety of the dam in seepage. As a result, an earthen dam must be constructed in a zoned manner.

(iv) After the analysis, it has been found that the main issue in the dam exists due to leakage from the sluice barrel due to which cavity has been formed and seepage is not affecting the performance of the dam significantly.

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