# Investigation and Comparison of Saturated and Unsaturated Flow in the Gilan-Gharb Embankment Dam

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**Abstract**
The purpose of this study is to investigate the characteristics of seepage flow in the *Gilan-Gharb* embankment dam in two saturated and unsaturated flow states using numerical simulation. The results of the numerical model for saturated flow and unsaturated flow indicated that the seepage flow rate in the unsaturated flow state is higher than the saturated flow state due to the addition of the amount of flow in the areas with capillary fringe flow. The comparison of the first flow line (phreatic line) in these two investigated states indicates that the phreatic line is in a lower location in the saturated flow compared to the unsaturated flow. The factor that has caused such conditions is the presence of suction in the areas above the phreatic line in an unsaturated state, which has provided the ability for the water flow to rise to a higher level. Also, the exit hydraulic gradient in downstream of dam was also evaluated in both cases and the results of this study revealed that the highest values of the exit hydraulic gradient occur nearly after the toe of the dam, so that the exit hydraulic gradient in the unsaturated state is 1.8 times of the saturated state. Since the exit hydraulic gradient is less than one for both saturated and unsaturated states, sand boiling phenomenon does not occur in the investigated earthen dam. It should be noted that the hydraulic gradient in the dam body was also investigated for two saturated and unsaturated states and the results showed that the hydraulic gradient in both states are not meaningfully different from each other and the hydraulic gradient values decrease significantly when exiting the dam core so that the value of this reduction in the state of unsaturated flow is more than that of saturated flow. The comparison of the results of the numerical model in both simulation modes indicates that the slope of the phreatic line in the central core is 0.947 for the unsaturated state and 0.905 for the saturated state, so the value of the phreatic line slope in the unsaturated state is 1.047 times of the saturated state.
**Keywords:** Embankment dam, saturated and unsaturated flow, phreatic line, uplift force, hydraulic gradient

## 1. Introduction

Water flow through soil is a fundamental issue in soil mechanics. In this investigation, the most significant problem is pore-water pressure [1]. Both negative and positive pore-water pressure have a direct relationship with the shear strength and soil deformation properties. Much study has been prepared in this field and the results confirm that even water flow in an unsaturated soil and the earth surface has a direct relationship with soil matric suction (or negative pore-water pressure). Consequently, if seepage is important, the pore-water pressure in the vertical soil profile should be carefully investigated [2]. Investigations related to flow in porous media are mainly limited to saturated soils. The water surface is considered an upper boundary and the flows that may occur in the capillary region (above the water surface) are ignored. This simplification is not acceptable for unsaturated conditions and thus an important component in the water flow of soil is ignored [3]. Seepage in earthen dams is a significant design consideration and if it exceeds a specified value, the dam may experience failure. There are numerous methods available for predicting seepage however these methods produce varied findings with respect to the soil-water medium behavior, the complexity of layered soils, and the hydraulic conductivity of soil in earthen dams ([4];[5]).

## 2. Material and methods

The differential equation governing the flow in porous media for saturated and unsteady flow [6]:

$$\frac{\partial}{\partial x}\left(k_x \frac{\partial H}{\partial x}\right)+\frac{\partial}{\partial y}\left(k_y \frac{\partial H}{\partial y}\right)+Q=\frac{\partial \theta}{\partial t} \qquad (1)$$

where, $H$ is the water total head ($m$), $Q$ is the flow rate ($m^3/s/m^3$), $\theta$ is the volumetric water content ($m^3/m^3$), $k_x$ is the hydraulic conductivity in the $x$-direction ($m/s$), $k_y$ is the hydraulic conductivity in $y$-direction ($m/s$), and $t$ is time ($s$).

The properties of the materials entered into the numerical model in Gilan-Gharb earthen dam are listed in Table 1. The numerical model of the Gilan-Gharb earthen dam is presented in Fig. 1.

Table 1 Characteristics of soil materials used in this study

| Dam component | Core | Filters | Foundation | Shells |
|---|---|---|---|---|
| Soil texture | Clay | Silty sand | Sand | Silt |
| Saturated volumetric water content ($m^3/m^3$) | 0.525 | 0.4 | 0.35 | 0.45 |
| Saturated hydraulic conductivity (m/s) | $10^{-6}$ | 0.01 | $10^{-8}$ | $10^{-5}$ |
| Residual volumetric water content ($m^3/m^3$) | 0.1 | 0.06 | 0.01 | 0.05 |

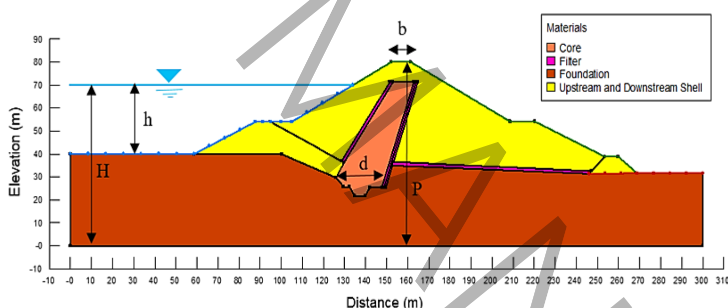


Fig. 1 Simulated dam model

## 3. Results and discussion

Figures 2 and 3 show the location of the phreatic line in the body of the dam for $H$ = 70 m, in a saturated and an unsaturated flow, respectively. As can be seen, in the unsaturated flow, the phreatic line reaches the upstream face of the clay core at a higher point than in the saturated state. The reason for this is capillarity flow which increases the water level for the unsaturated flow in that zone by the rise of the water inside the small pores inside the dam core. Also, the phreatic line slope inside the clay core is different in saturated and unsaturated states. The slope of the phreatic line inside the clay core is 0.947 for unsaturated case and 0.905 for saturated flow, so the slope of the phreatic line inside the clay core in the unsaturated flow is 1.047 times that of the saturated flow.

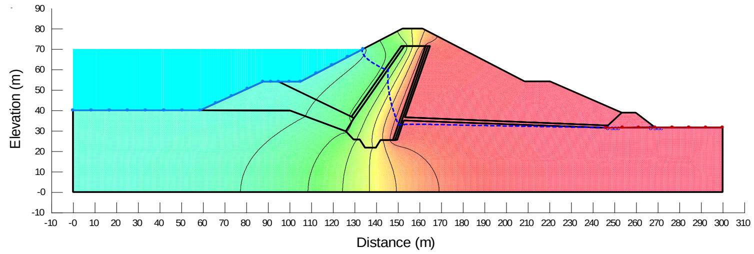


Fig. 2 Location of phreatic lines in the dam body for saturated flows

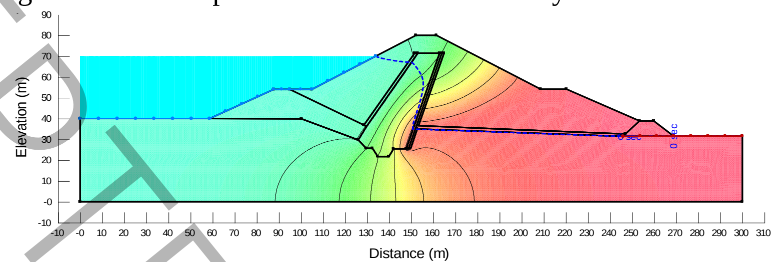


Fig. 3 Location of phreatic lines in a dam body for unsaturated flows

## Conclusions

The most important results related to this study are presented below.

- The results obtained from the numerical simulation using SEEP/W software for saturated and unsaturated flows showed that soil matric suction (negative pore-water pressure) above the phreatic line means the existence of a capillary fringe flow.
- Considering the height and the capillary fringe flow, the seepage from the body in the unsaturated flow was higher than for the saturated flow. The discharge in the unsaturated state increases by reaching the core points of the dam and the seepage of water from the dam body accounts for a larger percentage of the discharge. Also, the density of flow lines at the end points of the dam downstream and above the phreatic line shows the greater effect of the capillary flow on the flow passing through the dam body.
- The effect of unsaturated soil on the phreatic line inside the earthen dam has been investigated and the higher density is evident in the core in the phreatic line area and above it in the center of the core compared to the shell. This indicates a greater flow resistance of clay grains for water and the increase in the volume water content in the clay core. Compared to the shell, it can be concluded that the capillary flow is more significant in the clay core than in the shell.
- Installing one or more horizontal drains in the upstream shell of the dam can have a positive effect in reducing the pore water pressure. The decrease in pore-water pressure and the phreatic line loss will increase the dry zones in the dam shell, and with the increase in the shear strength of the soil, it will increase the stability of the slope of the dam body. At the same time, checking the stability of the upstream and downstream slopes and calculating their factor of safety against stability can be the subject of further study.

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