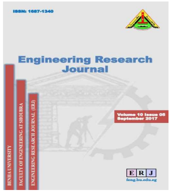
ENGINEERING RESEARCH JOURNAL (ERJ)

Vol. 1, No. 49 Jul. 2021, pp 113-121

Journal Homepage: http://erj.bu.edu.eg



A Review of Dams and the Ring of Calculating the Water Seepage in the Earthfill Dams

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Abstract. Earth dams' failure may occur due to different reasons such as structural instability conditions, hydraulic conditions, seepage through dam body, and/or rapid drawdown. The determination of factor of safety for the dam slope stability under different cases of operations is vital to ascertain the dam overall safety. In this study, Finite Element modelling is used to simulate seepage and slope stability analysis of earth dam problems using GeoStudio software. The model is verified by the practical implementation of the dam. Then, it is used to analyse seepage and stability of Prototype earth fill dam in Banha University. The Bishop analytical method is used to assess the stability of the dam side slopes. The results of the analysis presented in this thesis confirm the safety of earthfill dam against combined seepage and slope stability under all the normal and failure cases during the operation. Seepage analysis and Stability Investigation are very important issues, which should be considered in designing.

Keywords: Seepage,

1.INTRODUCTION

A dam is a hydraulic structure of fairly impervious material built across a river to create a reservoir on its upstream side for impounding water for various purposes. Dams are constructed especially for water supply, flood control, energy production, irrigation, recreation, and fishing. They are mainly divided into two parts based on their structure types: concrete dams and embankment dams. Embankment dams are two types; Earth-fill and rock-fill dams.

Dams must be designed and maintained to safely control seepage. Nevertheless, most dams experience at least some seepage and many suffer from excessive seepage. Excessive seepage may lead to a problem with the safety of a dam if not treated properly. The basic problem is trying to discern how seepage is affecting a particular dam and what measures, if any, must be taken to ensure that the seepage does not adversely affect the safety of the dam.

You may be called upon to make a visual inspection of a dam and its appurtenant structures and inspect a project's document files for clues to the likelihood of failure due to seepage problems. You may need to review background information on geologic characteristics, construction specifications and records, and safety and inspection records to discern critical information pertaining to seepage. If a seepage problem has already been identified, you may be asked to determine the probable cause of the seepage and the remedial action needed. In addition, you should understand seepage and identify whether your dam and its appurtenant structures are safe with regard to seepage. It is also important to monitor seepage and maintain seepage control measures that are already in place. Detention dams are constructed to retard flood runoff and minimize the effect of sudden floods. Detention dams consist of two main types. In the first type, the water is temporarily stored and released through an outlet structure at a rate that does not exceed the carrying capacity of the channel downstream. In the other type, the water is held as long as possible and allowed to seep into pervious banks or into the foundation. The latter type is sometimes called a water-spreading dam or dike because its main purpose is to recharge the underground water supply. Some detention dams are constructed to trap sediments and they are often called debris dams. Although it is less common on small projects than on large developments, dams are often constructed to serve more than one purpose. Where multiple purposes are involved, a reservoir allocation is usually made to each distinct use.

2.DAMS APPLICATIONS

Dams have been used since the early days of civilization to store water for irrigation. This is attested both by history and by the remnants of ancient structures. Some of the structures built in antiquity were very large. An earth-fill dam completed in Ceylon in 504 B.C. in [1],a 11 miles long, 21.34-meter-high, and contained about 13*106 m^3 of embankment. Today, as in the past, the earthfill dam continues to be the most common type of dam, principally because its construction involves using materials in their natural state with little processing.

One of the first authors who suggested that the slopes for earthfill dams should selected on that basis was Bassell in 1907[2]. However, little progress was made on the development of rational design procedures until the 1930's. The rapid advancement of the science of soil mechanics since that time has resulted in the development of greatly improved procedures for the design of earthfill dams. The procedures include:

1. Thorough preconstruction investigations of foundation conditions and of construction materials.
2. Application of engineering skills and techniques to design.
3. Carefully planned and controlled methods of construction.
4. Carefully planned and designed instrumentation and monitoring systems.

The dams can be classified according to the wide function they do such as storage, diversion, or detention. Refinements of these classifications can also be made by considering the specific purposes involved. Storage dams are built to seize water during periods of extra supply in order to be used during periods of lacking supply. These stages may be seasonal, annual, or longer. Many small dams impound the spring runoff for use in the dry summer season.

Storage dams can be further classified according to the purpose of storage such as water supply, recreation, fish and wildlife, hydroelectric power generation, irrigation, etc. The specific purpose or purposes to be served by a storage dam often influence the design of the structure and may establish criteria such as the amount of reservoir fluctuation expected, the amount of reservoir seepage permitted, or concrete gravity structure serving both diversion and storage purposes.

Diversion dams are ordinarily constructed to provide head for carrying water into ditches, canals, or other conveyance systems. They are used for irrigation developments, diversion from a live stream to an off-channel-location storage reservoir, = municipal and industrial uses, or any combination of the above.

A common multipurpose project combines storage, flood control, and recreational uses. Dams can also be classified as overflow or non-overflow dams. Overflow dams are designed to carry discharge over their crests or through spillways along the crest. Concrete is the most common material used for this type of dams.

Non-overflow dams are those designed not to be overtopped. This type of design extends the choice of materials to include earthfill and rockfill dams. Often the two types are combined to form a composite structure consisting of, for example, an overflow concrete gravity dam with earthfill dikes.

The most common classification used for the discussion of design procedures is based on the materials used to build the structure. This classification usually recognizes the basic type of design, for example, the "concrete gravity" dam or the "concrete arch dam. This study is limited in its scope to the consideration of the more common types of dams constructed today namely; earthfill, rockfill, and concrete gravity dams. There are other types of dams including concrete arch, concrete buttress, and timber dams .Earthfill dams are the most common type of dam as shown in figure1, particularly because their construction involves the use of materials from the required excavations and the use of locally available natural materials requiring a minimum of processing.

FIGURE 1. Earth fill dam

Earthfill dams require appurtenant structures to serve as spillways and outlet works. The principal disadvantage of an earth fill dam is that it will be damaged or may even be destroyed under the erosive action of overflowing water if the sufficient spillway capacity is not provided.

Rockfill dams use rock of all sizes to provide stability and an impervious membrane to provide water tightness. The membrane may be an upstream facing of impervious soil, a concrete slab, asphaltic-concrete paving, steel plates, other impervious elements, or an interior thin core of impervious soil.

Like the earth embankments, rockfill dams are subject to damage or destruction by the overflow of water and so must have a spillway of adequate capacity to prevent overtopping. An exception is the extremely low diversion dam where the rockfill facing is designed specifically to withstand overflows. Rockfill dams require foundations that will not be subject to settlements large enough to rupture the watertight membrane. Therefore, The only suitable foundations are rock or compact sand and gravel.

Rockfill dams are popular in tropical climates because their construction is suitable for long periods of high rainfall.

Concrete gravity dams are suitable for sites where there is a reasonably sound rock foundation, although low structures may be founded on alluvial foundations if adequate cut offs are provided.

Gravity dams may be either straight or curved in plan. The curved dam may offer some advantage in both cost and safety. Occasionally, the dam curvature allows part of the dam to be located on a stronger foundation, which requires less excavation. The concept of constructing concrete dams using RCC (roller-compacted concrete) has been developed and implemented. Several RCC dams have been constructed in the United States and in other countries.

Concrete arch dams are suitable for sites where the ratio of width between abutments to the height is not great and the foundation at the abutments is solid rock which is capable of resisting arch thrust.

Buttress dams are comprised of flat deck and multiple arch structures. They require about 60 percent less concrete than solid gravity dams, however the increased formwork and reinforcement steel required usually offset the savings in concrete. A number of buttress dams were built in the 1930s when the ratio of labor costs to material costs was comparatively low. The cost of this type of construction is usually not competitive with that of other types of dams when labor costs are high.

Dams of types other than those mentioned above have been built, but in most cases they meet some unusual local requirement or are of an experimental nature. In few instances, structural steel has been used both for the deck and the supporting framework of the dam. Before 1920s, a number of timber dams were constructed, particularly in the Northwest. The amount of labor involved in the timber dam, coupled with the short life of the structure, makes this type of structure uneconomical for modern construction.

A purely homogeneous type of dam is composed entirely of a single type of material. Since the action of seepage is not favorable in such a purely homogeneous section, the upstream slope should be relatively flat for safety in rapid draw down when embankment is relatively impervious, and the downstream slope must also be flat to provide a sufficiently stable slope to resist the forces resulting from a high saturation level. For a completely homogeneous section, it is inevitable that seepage emergence will occur in the downstream slope.

When the dam embankment is homogeneous or when the downstream zone is of questionable permeability, a horizontal drainage filter is provided to keep the phreatic line well within the dam body so as to allow the adequate embankment and foundation drainage and eliminate piping from the foundation and the embankment as in figure2.

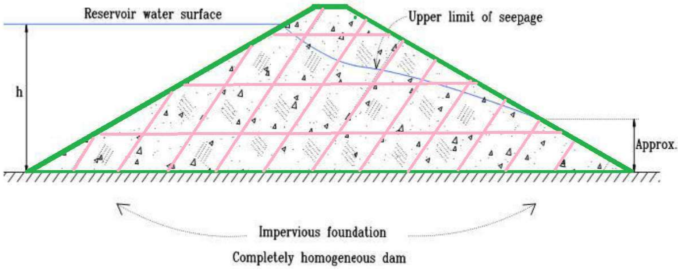

FIGURE 2. Homogeneous embankment.

3. CURRENT PRACTICES AND FAILURE MODES

Earth fill dams contain a variety of advantages both technically and economically as stated in [3]-[4] as follows:

1. Construction materials are readily available.
2. Design criteria are simple.

3. Less foundation preparation is required when compared with other dams.
4. They are quiet flexible than other rigid dam structures and suitable for seismic sensitive regions.

On the other hand, they have some disadvantages when compared with other dam types as follows:

1. Higher possibility to damage or slide than other dam types.
2. The lack of compaction of material leads to increased seepage.
3. Continuous monitoring and assessment is needed to prevent slope erosion, abnormal seepage, and growing plants.

The complete failure modes are shown in Figure3.

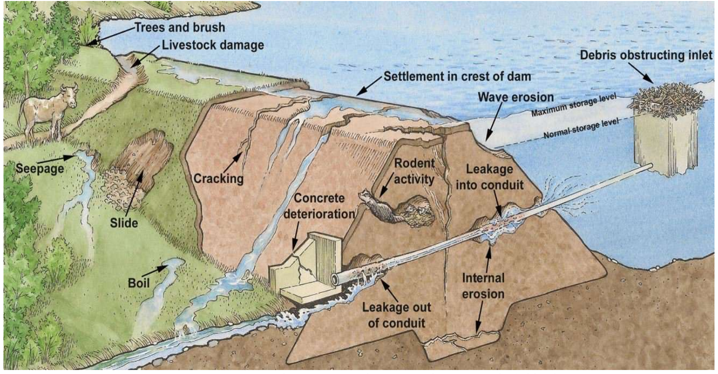

FIGURE 3. Failure modes in the earthfill dams

Science and mathematics have become more important in the design and construction of dams and seepage control measures in dams built after the 1920s. However, empirical methods continue to play an important role. In spite of these advancements, failures still occur as a result of the following:

1. Unrecognized foundation conditions.
2. Poor design.
3. Inadequate construction quality control/quality assurance.
4. Lack of necessary maintenance.
5. Lack of monitoring systems.

4. SEEPAGE

Seepage depends on several factors including permeability of the soil and the pressure gradient, essentially the combination of forces acting on water through gravity and other factors. Permeability can vary over a wide range depending on soil structure and composition making it possible to establish the safe design of such structures as earthen dams and reservoirs with negligible leakage loss and other structures such as roadbeds and filtration beds in which rapid drainage is desirable. In order to draw flow net to find quantity of seepage through the body of the homogenous earth dam, it is essential to locate the phreatic surface of seepage. This upper boundary is a free water surface and will be referred to as the line of seepage or phreatic line.

The two dimensional flow of fluid through porous media for steady state can be expressed by Laplace's Equation

$$\frac{\partial^2 \phi}{\partial X^2} + \frac{\partial^2 \phi}{\partial Z^2} = 0 \tag{1}$$

Graphically, the equation can be represented by two sets of curves that intersect at right angles. The combined representation of two sets of lines is called a flow net. With the help of a flow net, the seepage problems can be analyzed at any point within the section of the embankment. The phreatic surface is defined as the line within a dam section which separates the saturated zone and dry zone. Below this line, there are positive hydrostatic pressures in the dam; on the line itself, the hydrostatic pressure is zero; above the line, there will be a zone of capillary situation.

The location of the phreatic line is necessary in order to draw complete the flow net accurately. It is also useful in analyzing stability of the dam. It may be noted that the location of this seepage line is dependent only on the cross-section of the dam, filter length, and the upstream reservoir head [5].

In 1856, a French engineer named "Darcy" proposed that what flows through soils is laminar and the discharge velocity (v) is proportional to the hydraulic gradient (i). Darcy's law is thus:

$$v = ki \tag{2}$$

Where: k is the coefficient of permeability or simply permeability. It is also called hydraulic conductivity and it has the unit of velocity (L/T), and i is dimensionless and hydraulic gradient (head loss/length over which head loss occurs).

$$Q = vA \tag{3}$$

$$Q = kiA \tag{4}$$

Q is quantity of discharge (L^3/T), A is the cross-sectional area of flow (L^2).
Where:

$$A = yB \tag{5}$$

B is the width of earth dam (L), q is the rate of discharge per unit width ($L^3/T/L$).

$$q = kiy \tag{6}$$

The solutions of steady-state laminar flow of seepage problems need to solve Laplace's equation.

5.MODELLING NUMERICAL METHODS

5.1 The Finite Difference Method

This method solves the Laplace equations by approximating them with a set of linear algebraic equations. The flow region is divided into a discrete rectangular grid with nodal points which are assigned values of head (known head values along fixed head boundaries or points, estimated heads for nodal points that do not have initially known head values). Using Darcy's law and the assumption that the head at a given node is the average of the surrounding nodes, a set of (N) linear algebraic equations with (N) unknown values of head are developed (N equals number of nodes).

5.2 The Finite Element Method

This is a second way of numerical solution. This method is also based on grid pattern (not necessarily rectangular) which divides the flow region into discrete elements and provides (N) equations with (N) being unknown. Material properties, such as permeability, are specified for each element and boundary conditions (heads and flow rates) are set.

5.3 Finite-Volume Method

The finite volume method was originally developed as a special finite difference formulation. Finite volume method is a numerical approach for solving partial differential equations instead of using an analytical method.

The finite volume approach is especially useful for problems where interfaces exist between regions having different physical properties.

5.4 The Boundary Element Method

There are a number of engineering and physical problems such as the steady state heat conduction, the torsion of prismatic bars, and the potential flow problems which are governed by an elliptic, quasi-harmonic, and partial differential equation generally expressed as follows[6]:

$$\frac{\partial}{\partial x}\left(kx\,\frac{\partial u}{\partial x}\right) + \frac{\partial}{\partial y}\left(ky\,\frac{\partial u}{\partial y}\right) + \frac{\partial}{\partial z}\left(kz\,\frac{\partial u}{\partial z}\right) + \int(x.y.z) = 0 \tag{7}$$

Where:
(kx, ky and kz) are the given material properties, u(x, y, z) is the unknown field function, *f*(x, y, z) is a given function ,(x, y and z) are the Cartesian coordinates.

6.GRAPHICAL METHODS

6.1 Casagrande Method

The phreatic line can be considered as in the shape of a parabola with assuming that hydraulic gradient is equal to the slope of the free surface. In some sections, a little divergence from a regular parabola is required practically at the surface of entry and discharge of the line seepage.

The equation used to determine the coordinate of the phreatic surface is as follows:

$$Y = \sqrt{2XS + S^2} \tag{8}$$

Where

$$S = \sqrt{D^2 + h^2} - D \tag{9}$$

$$D = B - \text{filter length} - 0.7\, l \tag{10}$$

The earth dam section for the Casagrande solution is shown in figure4 [7]:

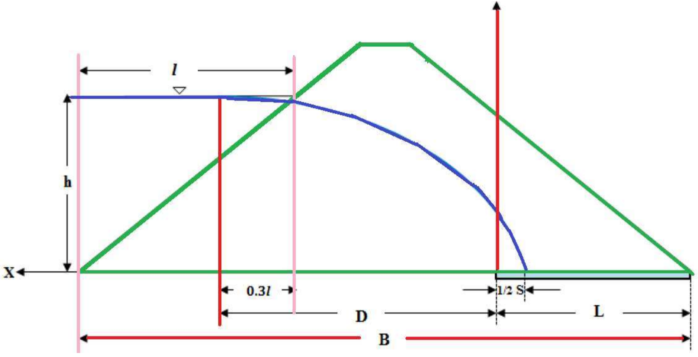

FIGURE 4. Earth dam section for Casagrande solution

6.2 Numerov Method

The configuration of the phreatic surface was determined by the following equations after Numerov in 1942[8].

$$x = k\,\frac{h^2 - y^2}{2q} + h(\cot \bar{\alpha}\pi - F1(u.\bar{\alpha}) + \tan \bar{\alpha}\pi F2(u.\bar{\alpha}) \tag{11}$$

Where

x is the distance between heel of earth dam and the point on the base (L); y is the head of the liquid in the upstream reservoir (L); q is the rate discharge per unit width ($L^3/T/L$), and k is the hydraulic conductivity (L/T). The functions of F1($u.\bar{\propto}$) and F2($u.\bar{\propto}$) were tabulated by shanking. Hence, all the required information to affect the solution has been reduced to simple graphical form; that is, (q/k) can be determine from the following equation:

$$\frac{q}{k} = \frac{h^2}{L + \sqrt{L^2 + \dfrac{h^2}{3}}} \tag{12}$$

6.3 Dupuit Solution

It is a simplifying assumption for the solution of phreatic surface. It is based on the water table or free surface is only slightly inclined, streamlines may be considered horizontal and equipotential lines are vertical and slopes of the free surface and hydraulic gradient are equal as in the figure5.

The phreatic surface define by:

$$y = \sqrt{h^2_1 - (h^2_1)\frac{x}{l}} \tag{13}$$

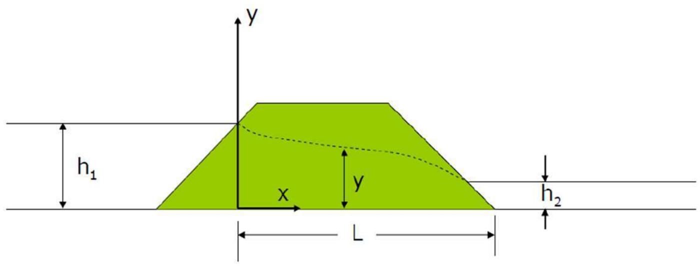

FIGURE 5. Dupuit Solution

7.EXPERIMENTAL METHODS

There are some different models which are used experimentally to simulate the flow of water in porous media. These models provide good feel for what is occurring during seepage and allow a physical feel for the reaction of the flow system to changes in head, design geometry, and other assumptions. In [9], the ability of the SEEP/W software to estimate the seepage from earthen watercourse has been studied. [10] studied the slope stability of earthen dams using GEOSTUDIO software[11]. In [12], a study to investigate the determination of the seepage-induced flow under and through an earth dam based on Group Method of Data Handling (GMDH) algorithm[13],[14] carried out. [15], analyzed the usage of various materials with different combinations to zone type earthen dams with central impervious vertical core to study the behavior of phreatic line at downstream phase by varying effective length of horizontal drainage filter. To determine the soil-water characteristic curve (SWCC), a model with a particular focus on its application to slope stability analysis under transient unsaturated seepage conditions was used. A series of laboratory experiments was conducted to determine the SWCC of different soils, ranging from high plasticity clay to silty sand, found across the Korean Peninsula. The experimental results were utilized to identify the suitable SWCC model for each soil type based on the fitting criterion [16]. Slope stability has been commonly analyzed by considering dry or saturated soils under two-dimensional (2D) plane-strain conditions. However, in practice, soils are often unsaturated and many slope failures exhibit a three-dimensional (3D) feature. In this study, the kinematic limit analysis method is adopted to estimate the stability of slopes subjected to vertical unsaturated steady flow in the context of a 3D rotational failure mechanism [17].

8. SLOPE STABILITY ANALYSIS METHODS

i. Limit equilibrium methods are important in slopes stability analyses. These methods calculate the factor of safety (F) by dividing a potential sliding mass into several vertical slices.

ii. The Ordinary or Fellenouis method: Fellenouis (1936) developed this method and it is sometimes referred to as “Fellenouis method”. The ordinary method satisfies the moment equilibrium for a circular slip surface but neglects both the inter slice normal and shear forces.

The advantage of this method is its simplicity in solving the (F).

iii. Bishop Simplified Method: advanced this method as a very common method in practice for circular shear surface (SS). This method considers the inter slice normal forces but neglects the inter slice shear forces [18].

iv. Janbu’s simplified method: This method is based on a composite shear surface (i.e. non-circular). As in (Bishop Simplified Method), this method does not satisfy moment equilibrium and considers inter slice normal forces but neglects the shear forces[19]

v. Morgenstern-Price method: This method satisfies both force and moment equilibriums and assumes the inter slice force function.

vi. Spencer's method: This method is the same (Morgenstern-Price) method except the assumption made for inter slice forces. A constant inclination is assumed for inter slice forces and the (F) is computed for both moment and force-equilibriums [20].

vii. Conventional methods: The finite element (FE) method that is available in software SEEP/W was employed to simulate 2-D steady state and transient seepage in the earth dam before and during the drawdown, respectively. In this study, the option (unsaturated-saturated seepage analyses) is used.

9.CONCLUSIONS

The main conclusions remarks are as follows:

The construction of the hydraulic structures such as earth dams are subjected to seepage. The soil permeability and the erosion are the most important effects of seepage on dams and levees. When the seepage has no limits the failure will be occure.in addition the piping and excessive pressure are another reasons of the seepage.

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