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EMBANKMENT DAMS: ITS TYPES AND ESTIMATION OF SEEPAGE

Sonam Kaur[1] Parveen Chahal[2,]

[1]Assistant Professor, Department of Civil Engineering, Swami Vivekanand Institute of Engineering & Technology, Banur, Punjab-140601

[2]Assistant Professor, Department of Civil Engineering, Swami Vivekanand Institute of Engineering & Technology, Banur, Punjab-140601

Abstract:

Approximately half of all embankment dam failures are attributed to internal erosion. Internal erosion is a broad term that describes various mechanisms in which the erosive forces of moving water erode soil from within or beneath an embankment. While there are different categories of internal erosion, assessing the likelihood of internal erosion in general requires intricate knowledge of a structure's history, design, and the physics of seepage through an embankment. Often times, the documentation regarding a structure's history and original design is in a state of disarray, or altogether lost, making it difficult for today's engineers to adequately assess a structure. However, knowledge of the historical evolution of the profession understands of seepage and embankment design combined with the date a structure was constructed is often times enough information to make inferences regarding how an embankment was designed and what elements may not have been considered as part of the original design. This paper is intended to provide the reader with this information through a historical review of embankment seepage design. An overview of seepage design is provided beginning with the empirical designs constructed prior to 1900 through the modern designs of today. In particular, the evolution of analytical techniques (creep ratio, flow net, electric analogy, and finite element analysis) is discussed as a parallel to the evolution of the profession's understanding of failure mechanisms (piping, concentrated leak erosion, suffusion, structural uplift).

Keywords: Embankment, Dams, Earth dams, Seepage, Breach, Temperature

Introduction:

In general, embankment dams or fill-type dams are used to describe dams made of soil and rock components. Compared to concrete dams, embankment dam construction has a significantly longer history. It is obvious that certain earth dams were built in the eastern countries, which were the cradles of ancient cultures, roughly 3,000 years ago. Dams that are taller than 15 meters are referred regarded as "high dams" in the standard manual provided by the International Commission on Large Dams (ICOLD), which has roughly 63 member countries as of this writing. More than 70% of the approximately 14,000 high dams that have been registered so far are embankment dams. A recent assessment on the building of high dams also indicated that only roughly 20% of the 1,000 high dams built in the last two years were concrete dams, with the remaining 80% being embankment dams. Thus, it is clear that building embankment dams rather than concrete dams has been increasingly popular recently. When building embankment dams, two key advantages and traits stand out. 1. Concrete dams need a solid rock foundation, whereas the dam foundation does not need to be subjected to strict conditions. Even on the alluvial deposit and pervious foundations, embankment dams can be built. 2. Building embankment dams has a financial benefit; that is, the project can be designed outside of a city area because of the benefit indicated above, and building supplies are mostly to be supplied close to the dam site. [1]

Embankment Dams

Dams along embankments are typically composed of organic materials. They can produce relatively wide and shallow reservoirs on sites with wide valleys and shallow slopes. They can be built on soils that are generally weaker and less uniform. Due to the vulnerability of embankment dams to erosion brought on by water overflow, a spillway that will release water from the reservoir when the water level climbs too high must be built. Earth fill embankment dams and rock fill embankment dams are the two basic forms of these dams. Typically, local quarries or excavations are used to obtain the materials. When viewed in cross-section, this type of dam resembles a hill or bank.

Types of Embankment Dams

Earth fill Dams

Compacted earth makes up the majority of earth fill dams. The majority of embankment dams have a zone in the center, referred to as the core, made of low permeability material; a permeable portion extending gradually outward on the two sides covering the core is referred to as a filter; and the shell on the upstream and downstream heels is referred to as the shell. In order to prevent water from getting through the dam, the core is typically built of clayey soil. [2]

Rock Fill Dams

Construction of rock fill dams is appropriate where adequate rock can be quarried on the dam site or nearby and where the foundations won't be exposed to significant settlement from loads or erosion from seepage through or beneath the dam. A watertight membrane must be included in the design, and it is typically placed either in the center of the dam or as an upstream facing. [3]

TYPES OF EARTH DAMS

Homogeneous Embankment Type

The simplest kind of earthen embankment, it is made entirely of one material and is uniform throughout (Fig. 2). When only one type of material is economically or locally feasible, a purely homogenous section is employed. For modest to moderately high dams and levees, this section is employed. Large dams are rarely built with uniform embankments. Purely homogenous sections are typically susceptible to seepage issues, and large sections are needed to make them stable and piping-proof. In practically all types of embankments, internal drainage systems are always present. Low dams are always built as uniform dams because creating zones will result in more expensive building.

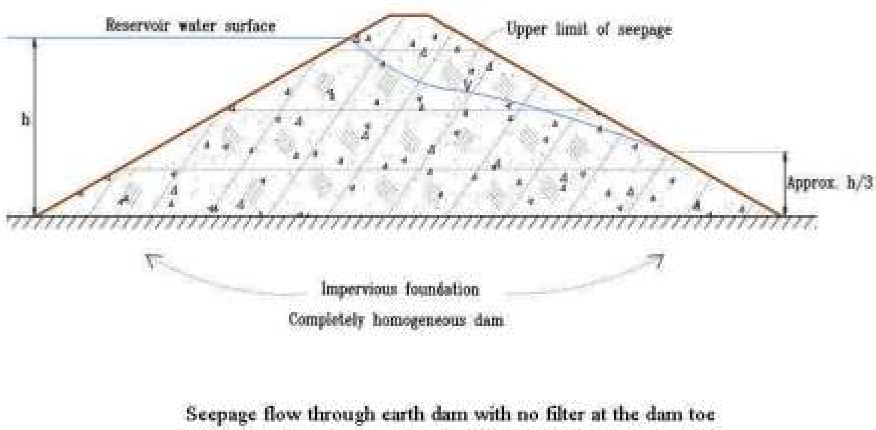

Fig 2: Homogeneous embankment type

Zoned Embankment Type

Zone embankments typically consist of an impervious core in the center, a transition zone that is somewhat permeable, and an outer zone that is significantly more permeable (Fig. 3).In zonal dams, the clay soil is typically placed in the center while well-drained materials like coarse sands and gravels are deposited in the surrounding shells. As a result, the dam's water tightness will be improved. The dam embankment's primary source of strength is the shells. This style of embankment has been built extensively, and the materials for the zones were chosen based on their availability.

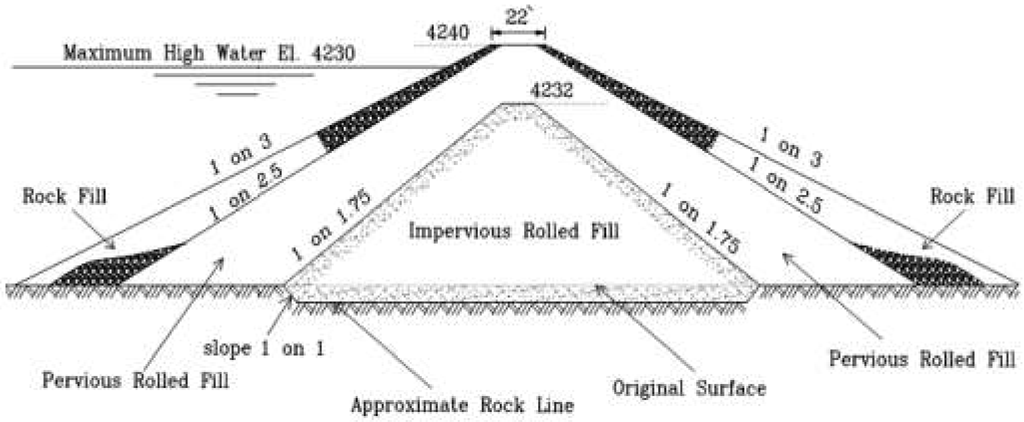

Fig 3: Zoned embankment type

Diaphragm Embankment Type

A diaphragm-type embankment has an impermeable core that is narrow and surrounded by fill materials made of dirt or rocks (Fig. 4). Concrete, steel, wood, impervious soils, or any other material could be used to create the impervious core, also known as the diaphragm. In order to stop seepage through the dam, it serves as a water barrier. Depending on the thickness of the core, the diaphragm type of embankment was distinguished from zonal embankment. The dam embankment is referred to as "Diaphragm Type" if the thickness of the diaphragm at any elevation is less than the height of the embankment. However, it is regarded as a zoned embankment type if the thickness is equal to or greater than this limit. [5]

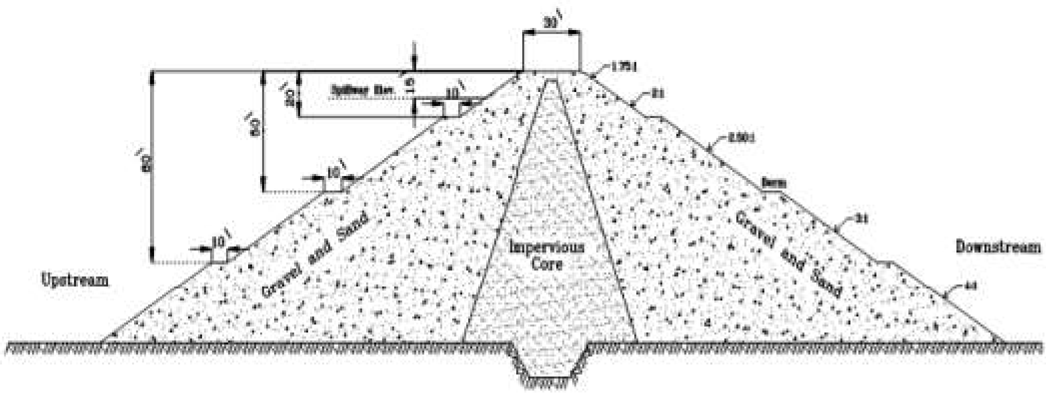

Fig 4: Diaphragm embankment type

EMBANKMENT FAILURE MODELING APPROACHES

Embankment failure modeling is a difficult task. The trans-disciplinary processes involved, including hydraulics, soil mechanics, and sediment transport, are primarily responsible for this. The complexity includes not just each of these independent features but also how they interact with one another. Three main approaches were followed in modeling dam breaching: (1) physical modeling, (2) statistical parameter estimation, and (3) numerical modeling.

The overtopping failure of non-cohesive embankments was tested in several ways. A regular progression of surface erosion down the downstream face of the embankment with a gradually flattening gradient that eventually reaches the lower end of the downstream slope is indicative of the collapse of non-cohesive soil embankments. A few research focused on the overtopping failure of cohesive embankments. The emergence of several head cuts (steps or overalls) with virtually vertical slopes along the downstream face of the embankment is indicative of the failure of cohesive soil embankments. These head cuts eventually deteriorate and completely breach as they go upstream near the embankment's crest.

Analysis of historical data on dam failures is used to estimate statistical parameters. To estimate some of the parameters describing the breach process in embankments, regression equations are developed. The qualities of the embankment are used to compute these parameters. Fig. 1 summarizes the embankment attributes and the breach parameters and shows the dimensions of the embankment. A dataset of 182 earth and rock fill dams was used to categorize them based on their erodibility, likelihood of failure (overtopping and piping), and other characteristics (such as whether they had core walls). They provided prediction equations based on this study for the breach height, average breach width, top breach width, time of failure, and peak outflow discharge.

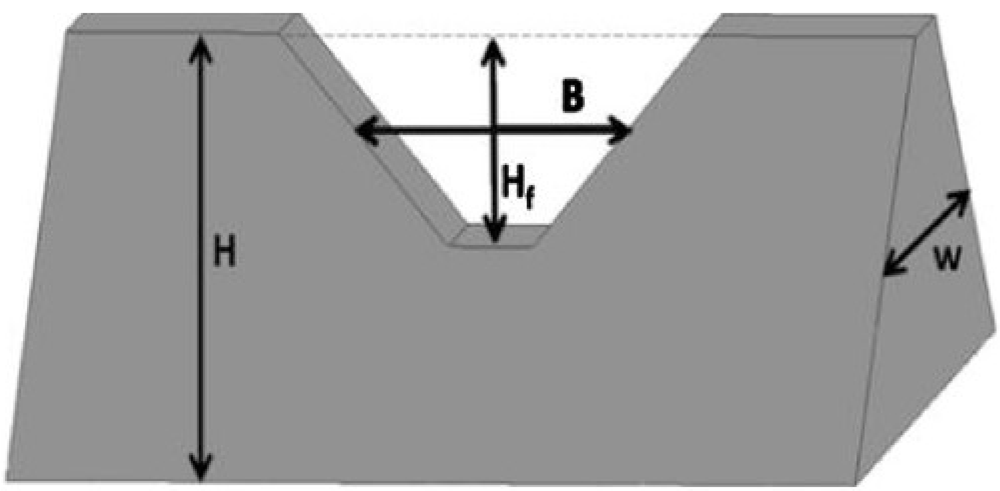

Fig 1: Breach Opening Parameters and Embankment Dimensions.

1. B=48.644 V0.275 W-0.086B=48.644 V0.275 W-0.086

2. Hf = 1.093 H0.894 V0.027Hf = 1.093 H0.894 V0.027

3. Tf = 0.15 + 1.865 H-0.675 V0.408

The advantage of these equations is that the height of the breach opening was one of the predicted parameters while it was an input for calculating the other parameters. The equations for average breach width and Time of formation produced coefficients of determination with values of 0.67 and 0.864 respectively.

To simulate embankment breaching, numerous numerical models were created. Numerical models were mainly focused with simulating collapse of non-cohesive soil embankments due to the complex three-dimensional character of flow accompanying breaching of cohesive soil embankments. The lateral erosion is described in numerical models for non-cohesive soil embankments as a continuous process, although in fact slope failures are abrupt and serious. [4]

Estimation of Seepage

Dam construction is regarded as the most efficient method for managing and utilizing the water supply, and as a result, has greatly aided in human development. However, reality showed that numerous dams suffered damage or collapsed during operation, which frequently results in significant human casualties as well as environmental and property harm. The bulk of the dam failure statistics consistently showed that embankment dams failed. Seepage and erosion accounted for a substantial share of the causes of embankment dam failure as well. The majority of dam failures related to seepage issues were either caused by a lack of monitoring systems or by monitoring systems that were malfunctioning. All of the aforementioned issues clearly demonstrated the need of seepage inspection for embankment dams as a duty that enhances project efficiency and safety throughout operations.

One practical solution that has been suggested for providing real-time information on seepage situation is the evaluation of seepage from temperature data. The temperature of seepage flow in 1953 is next. This technique, which was used to pinpoint leakage in an embankment dam and played the part of a nature tracer, had been shown to be an effective way to identify and monitor in situ. Nowadays, a number of methods have been presented to examine the seepage status within the dam due to improvements in evaluating methodology and monitoring technology.

The two areas of method development that are frequently taken into consideration are analytical methods and temperature monitoring technology. Based on the length of the monitoring, two categories of seepage evaluation from temperature data can be made for the former. Long-term surveillances can be used to determine seepage velocity, while short-term observations are typically employed to locate leakage regions. The latter, temperature monitoring technology, is divided into groups based on the equipment or measurement techniques used. [6]

Analysis of Seepage When Maximum Water Level

The analysis of seepage during the maximum water level (M.w.l.) will be drawn as shown in Figure (5) which illustrates the path of the phreatic line through the dam. In addition, Figure (6) shows the distribution of the pore water pressure and the value of water flux through the flux section.

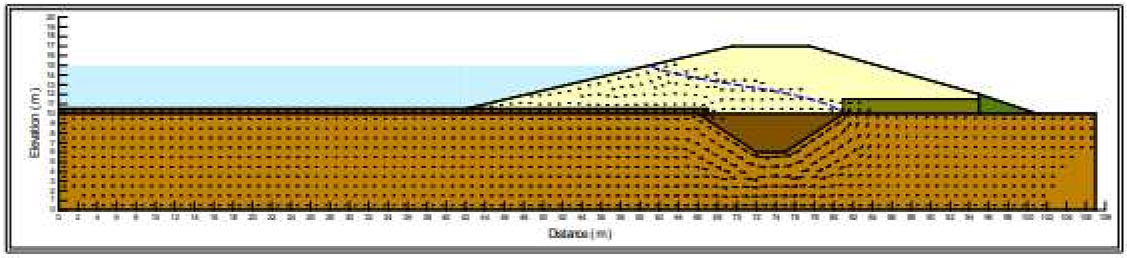

Fig 5: Phreatic line and velocity vectors

Figure (5) shows the phreatic surface of the dam at its highest water level as a blue dot line. For stability, it is preferable that the phreatic surface now starts at a higher water level, declines across the dam, and exits at the dam toe.

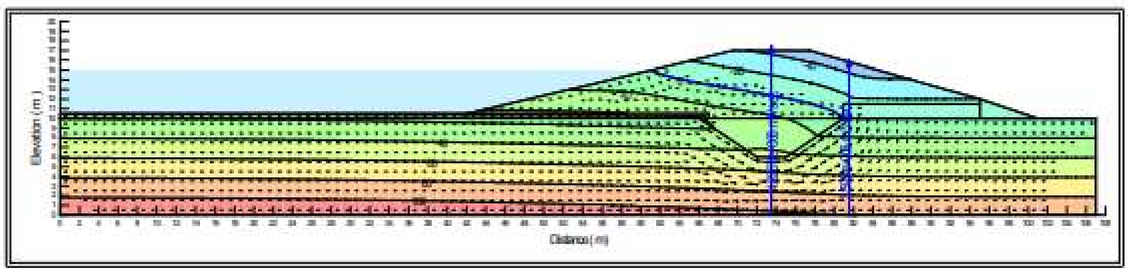

Fig 6: The distribution of the pore water pressure (Kpa) and the value of water flux through the flux section

The blue dot line, which is also the iso-line when the pore water pressure is zero, represents a phreatic surface. Below the phreatic surface, the pore water pressure is positive and negative, respectively. The blue vertical lines, commonly known as flow lines, were used to quantify the water flow across them.

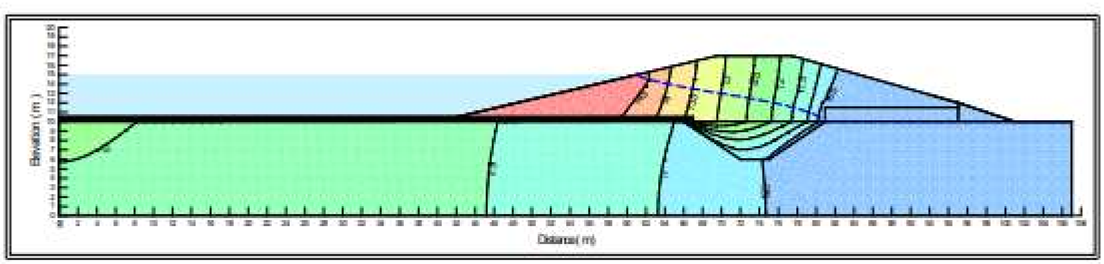

Fig 7: Contour lines of total head (m)

The total head on the left is greater than the total head on the right, as shown in Figure 7. Water flows from the left to the right as a result of the overall head differential.

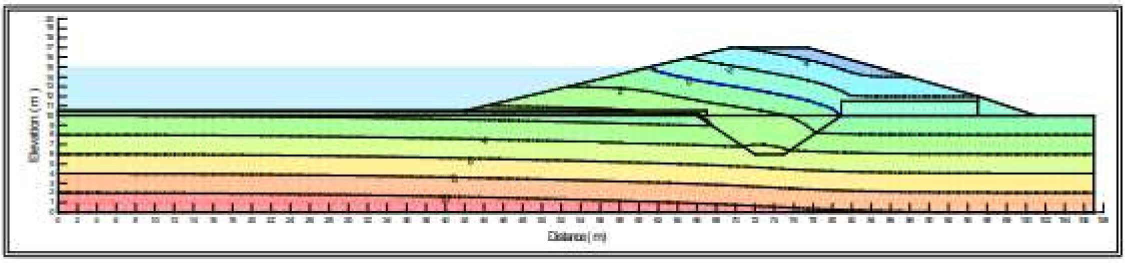

Fig 8: Contour lines of pressure head (m)

Figure (8) demonstrates how water flowing through the dam creates a positive pressure head below the phreatic surface and a negative pressure head above it.

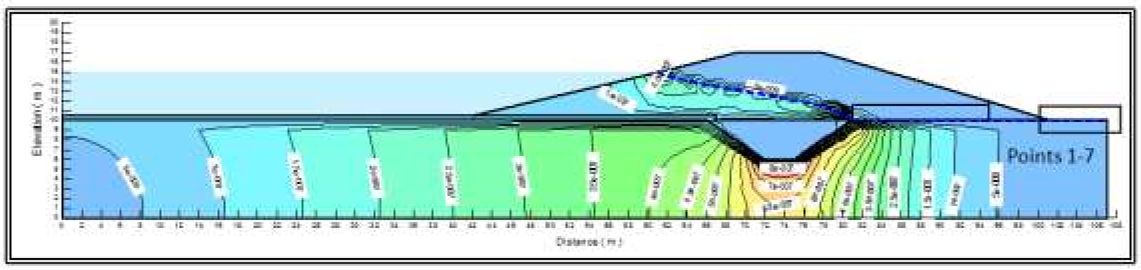

Fig 9: Contour line of XY-velocity (m/sec)

The greatest velocity is (8x10-7) m/sec, while the minimum velocity is (5x10-8) m/sec, as shown in Figure (9). The XY-exit gradient for important points at the last section of downstream is shown in Figure (10).

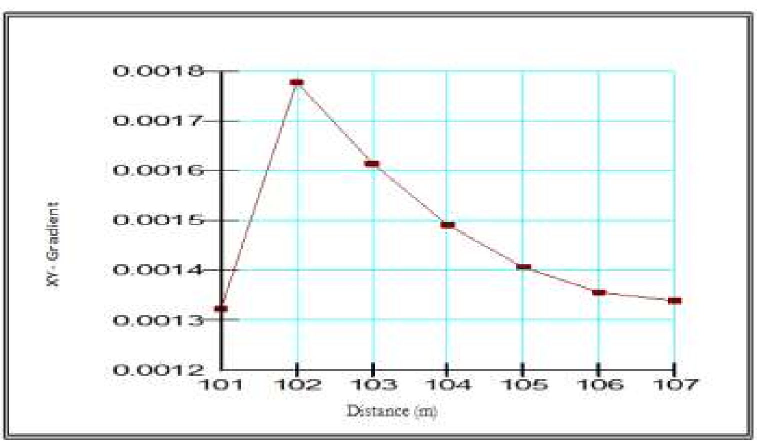

Fig 10: Values of XY- exit gradient at points (1-7)

Figure (10), which shows that the exit gradient increases with rising height of water level upstream of the dam, shows that the exit gradient is bigger during maximum water level than it is during normal water level. [7]

Conclusion

In this paper, we have discussed that Earth dam is a popular hydraulic structure, which widely used in rivers or canals for different technical purposes; seepage through earth dams is a very important parameter for safe design of the dam, due to its significant effect on the dam stability and safety. From the review study, different protection methods such as cut offs, cores, grout curtains, and filters were used to minimize and control seepage directed to the downstream face of the earth dam

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