A REVIEW ON ANALYSIS OF SEEPAGE IN ZONED EARTH DAMS

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ABSTRACT

In the conditions of severe climatic changes that are sweeping the world now, causing many problems, of which high surface water levels, torrential rains and floods are among the most dangerous phenomena. Since dams are the most engineering and structural protection means that engineers resort to, to protect against these dangers in such circumstances, not to mention the other important uses of dams such as storing water for irrigation purposes, generating electricity, feeding the underground reservoir, or diverting flow paths for any engineering purpose. Dams are usually classified on the basis of several considerations, including solid dams of different types, and flexible dams. Flexible dams, which are sometimes called earth dams, are of a special nature as they consist mainly of loose materials of a special porous nature and different ratios of interspaces that allow water to pass through them and penetrate the dam body in different proportions, which, if not prevented or avoided, may lead to the collapse of the dam body. In the present study a numerical analysis of seepage through zoned earthen dams is introduced, as they are the most popular type of flexible dams, to clarify the behavior of the streamlines of the seepage water through the body of such type of dams with different types of used soil of filling materials. Decreasing the relative permeability coefficient between the inner and transition zones up to 0.001 caused a significant decrease in the different seepage properties, after that, the effect was minor.

Keywords: Zoned earth dam, Seepage control, Phreatic line behavior.

1. INTRODUCTION

Earth dams are popular water structures which widely constructed across rivers and water streams, for different purposes, such as storing water for irrigation, human uses, flood control, and electric hydropower generation, or as an embankment in waterways. Earth dams consist of soil particles attached to each other in compacted layers. They usually have a typical trapezoidal shape with a broad base, and designed as a non-overflow section with a separate spillway for escaping any excess water. One of the serious stability concerns is the seepage through the earth embankment. Seepage is a very important parameter for earth dams' design, as it affects significantly the overall stability and safety. About 30% of dams' failure is due to uncontrolled seepage [1]. Seepage measurement through dams is necessary as excessive seepage, scouring and piping may lead to dam failure. Seepage may occur due to poor soil compaction, poor foundation and abutment preparation. The control of seepage through earthen dams has been given a great attention and care of scientists, as many precautions were studied to control seepage and avoid or prevent such failure. Using horizontal, inclined, trapezoidal, or pipe filters and constructing cores or cut offs are the main protection methods studied to minimize the seeped quantities of water, directed towards the downstream side of the dam.

There are three types of earth dams: homogeneous, zoned and diaphragm earth dams. Homogeneous earth dam is the simplest type of earth dams which consists of homogeneous single material, diaphragm type earth dam which has a thin impervious core, and surrounded by earth fill. Zoned earth dam is an earth dam which consists of an impervious core, and covered by a comparatively pervious transition zone, which finally surrounded by a much pervious outer zone which forms the whole dam body. Earth dams with different zones are constructed when adequate quantities of impervious materials are not available, so zoned earth dam is a practical type can be constructed to overcome the seepage phenomena. The permeability of the different zones is the main parameter which decreases the seepage from the upstream outer zone to the core. Dam zones are the significant defenders against failure because the weight of the heavy outer zones provides the needed stability of the dam. As it was mentioned that the seepage through earth dams can be controlled with different protection methods such as filters and cores, the seepage through zoned earth dams is mainly affected by the different zones' characteristics.

2. LITERATURE REVIEW

2.1 Analysis of Seepage Problem through Earth Dams

The problem of seepage through earth dams has attracted the attention of many authors all over the world. Hnang [2] analyzed the stability of an earth dam under steady state seepage in Taiwan, the factor of safety against stability failure for the dam was adequate. Elshemy [3] studied the soil blockage effect on the seepage through earth dams, the block gave a slight effect if it was closed to the exit face, that effect was vanished when that was located at the upstream side. Mohammed et al. [4] investigated the seepage through two earth dams in Malaysia, the introduced numerical model, successfully predicted the seepage and phreatic surfaces of the studied dams. Soleimanbeigi and Jafarzadeh [5] analysed the seepage through rock-fill dams in narrow valleys, the 2D seepage analysis was far from reality, while 3D modelling of such sites was vital. Flores and Lopez [6] presented several recommendations for preventing damages due to soil erosion in earth embankments. Jamel [7] investigated the seepage through homogenous earth dam without filter, her suggested equation when compared using artificial neural network showed an error less than 3%, and with numerical results showed an error less than 2%, it was noticed that, Dupuit's solution showed an error more than 20%, while with Casagrande's solution gave an error more than 15%. Vaezinejad et al. [8] introduced a new method for leakage modelling of Baft dam in Iran, the results showed the possibility of using the introduced method in locating leakage in such problems. Zeidan et al. [9] simulated seepage of Mandali Dam in Iraq, the model results confirmed the safety of the dam against seepage. Sazzad and Islam [10] observed that, the performance of inclined rock toe was better than vertical rock toe, the trapezoidal shape of internal core was better than other shapes. Ghazaleh and Gholamreza [11] indicated that the cut off wall under the clay core produced the most seepage reduction, while increasing horizontal drain length decreased the uplift pressure. Sazzad and Alam [12] studied the seepage characteristics of different types of earth dams and proved that the seepage was high in case of zoned type dam compared to other types.

2.2 Controlling Seepage through Earth Dams

Many authors tried to control the seepage through earth dams and minimize this seepage by different protection methods such as cores, cut offs, grout curtains, and filters as shown in fig. 1.

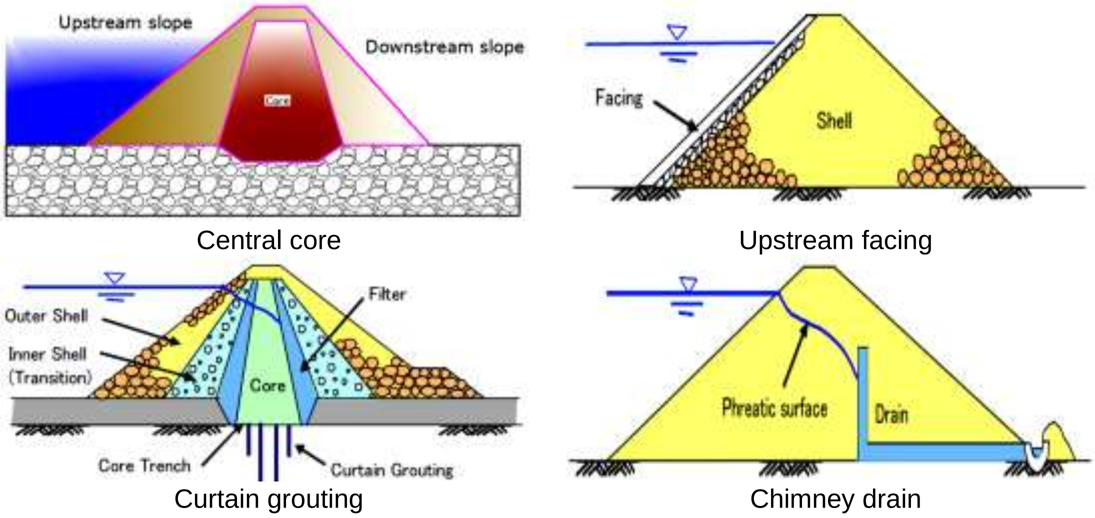

Fig. 1: Some methods of seepage control in earth dams [13]

2.2.1 Using DS filters or drains

Elmasry and Saafan [14] concluded that, the optimum pipe drain location was at 0.3 to 0.48 of the base width from the downstream side. Elmasry [15] stated that, the seepage increased by decreasing the distance between the chimney filter and the upstream face. Abdel-Gawad and Safin Shamaa [16] analyzed the seepage with horizontal filters, the numerical results had a good agreement with the analytical results. Abdel-Gawad [17] constructed some equations to solve the seepage problem through earth dams depending on a previous work (Abdel-Gawad and Shamaa [16]). Djehiche et al. [18] obtained some relations were to control the flow rate in the chimney drain. Giglou and Zeraatparvar [19] presented some factors of earth dam such as permeability, upstream and downstream slope of the dam, and predicted the seepage flow through the dam. Giglou et al. [20] introduced a simplified method to calculate the seepage through earth dam with vertical drainage. Aboelela [21] stated that, the toe drainage systems showed a great effect on the properties of seepage through earth dams based. Irzooki [22] concluded that, seepage increased with increasing upstream, or downstream slope, upstream water depth and horizontal drain length. Alam [23] observed that, the phreatic line was linearly decreased for the chimney filter, but when rock toe and horizontal filters were used, the phreatic line dropped at the starting point of filter. Alam et al. [24] showed that, the dam failure could be controlled by providing different filters. Kumar et al. [25] stated that, increasing the dam height, filter length, and downstream slope, increased the seepage and vice versa with upstream slope, clay core thickness. Refaiy et al. [26] indicated that, the downstream drain length was the most effective parameter on the seepage, while the height and angle had a negligible effect.

2.2.2 Constructing cores and cut offs

Rezk and Senoon [27] studied the seepage through earth dam with an internal core, the suggested mathematical solution was compared with previous experimental work [28], and close agreement was noticed. Krikar [29] stated that, the cut off wall depth exceeded 75% of the foundation depth gave the lowest values of exit gradients and permitted the lowest seepage values. Fattah et al. [30] found that, the exit gradient may increase about 300% if the clay core didn’t not exist for a zoned earth dam. Sazzad et al. [31] made a comparison between numerical and analytical analysis of seepage through earth dams, the numerical results were consistent to that calculated analytically by Fakhari and Ghanbari [32]. Sazzad et al. [33] concluded that, the core shape had a significant effect on seepage, the trapezoidal shape gave least discharge both for pervious and impervious base. Khassaf and Madhloom [34] studied the effect of impervious core on seepage through Khassa Chai dam in Iraq, the core was very necessary in the dam to lower the phreatic surface and decrease seepage through the dam. Elmolla [35] found that, increasing the sheet pile’s height decreased the seepage by about 34.4% of its value without sheet pile. Salem et al. [36] observed a noticeable drop of seepage line was with decreasing core permeability, increasing core thickness, and the quantity of seepage and exit gradient decreased. Issam et al. [37] stated that, the cut-off wall reduced the water pressure through the dam body. Sazzad and Alam [38] found that, the grout curtain was an effective measure to control the seepage, especially for an earth dam with impervious base .Abdel-Kawy et al. [39] concluded that, the wedge-shaped core was the most effective to reduce seepage discharge and the phreatic line, the vertical core came second. Attia et al. [40] investigated the seepage through earth dams with internal cut off, the optimum position of cut off was at the middle length of the dam base width. Razek et al. [41] carried out a study for the seepage with internal cut off, a good agreement was obtained between phreatic surface drawn numerically and that measured experimentally.

3. ZONED EARTH DAM

Zoned embankment is an earth dam which usually provided with an internal impervious core, covered by a pervious transition zone, and finally surrounded by a more pervious outer zone as shown in fig. 2. For zoned earth dams, materials such as sand and gravel should be placed in the outer zones and clay soils are placed in the inner zone. The zoned earth dam is widely used and the materials of the zones are selected depending on the availability of such materials.

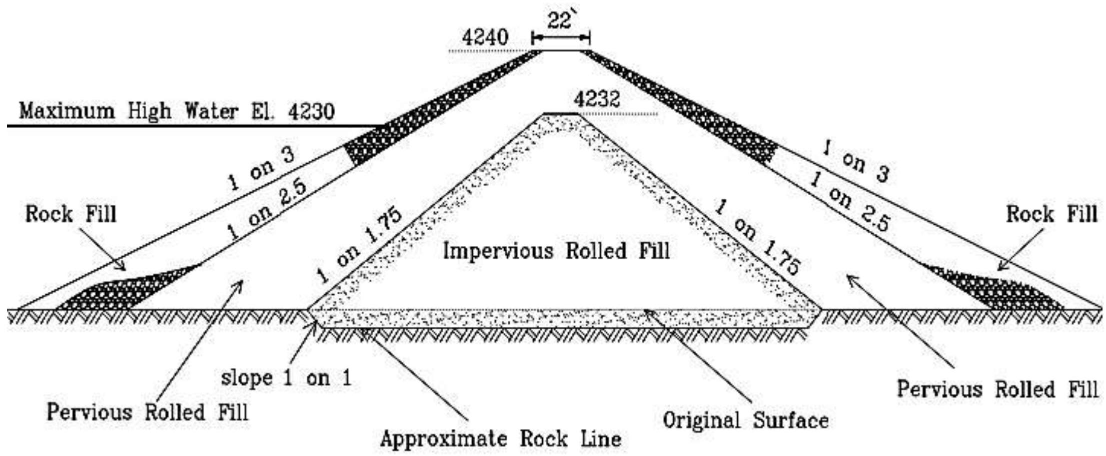

Fig. 2: Zoned embankment dam type [42]

4. METHODOLOGY

Considering a zoned earth dam as shown in fig. 3, and by using the SEEP/W program (which is a sub-program of Geo-Studio [43]), the study aims to investigate the effect of the different zones' coefficient of permeability (k), thickness (t), and upstream and downstream slopes (S) on the seepage through the earth dam body with different dam dimensions and different US water levels.

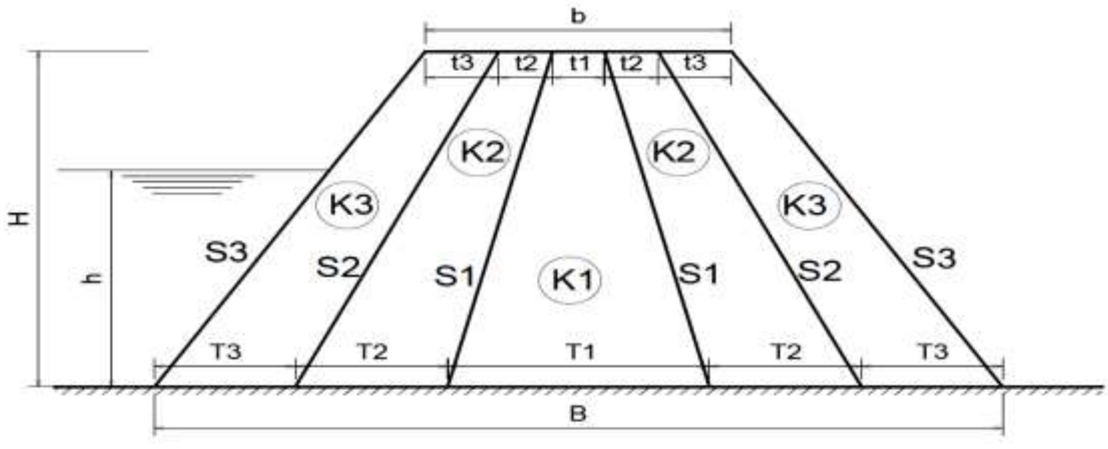

Fig. 3: Properties of different zones of the introduced model

SEEP/W is a finite element model and a sub-program of Geo-Studio that analyzes the seepage flow through earth embankment. It is based on the flow of water through saturated and unsaturated soils following Darcy's Law. The first step with SEEP/W is to define the units and scale, and sketch the cross-section. The regions of soils are defined with different material properties, then the boundary conditions can then be assigned. In earth dams' analyses, a zero-pressure boundary condition should be assigned to the downstream dam toe, a potential seepage face boundary condition selected for the downstream face, and the reservoir total head boundary condition applied to the upstream face. The saturated/unsaturated material model was used for the zone' material in this study. The sample functions method was used for the outer zone (sand), transition zone (silt), and inner zone (clay) for the volumetric water content data point function.

The permeability coefficients of the control model were chosen to be 10^{-8}, 10^{-6}, and 10^{-4} m/s for the inner, transition, and outer zones respectively. The top thickness of each zone was constant and equal 0.2 of the top width of the dam. The upstream and downstream side slopes (H:V) were 1:3, 1:1, 3:1 for the inner, transition, and outer zones respectively. Fig. 4 shows the dimensions of the introduced zoned earth dam.

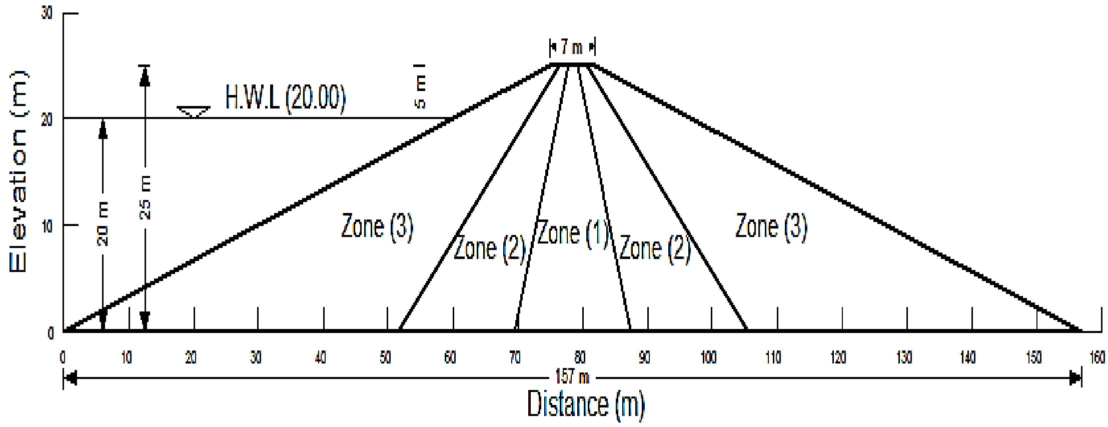

Fig. 4: Dimensions of the introduced zoned earth dam

5. RESULTS AND ANALYSIS

Effect of the Permeability Coefficient of the Inner Zone (Core)

In order to determine the effect of the hydraulic conductivity of the inner zone on the seepage through the zoned earth dam as shown in fig. 5, five models were tested with relative permeability coefficient between the inner and transition zones (k_1/k_2) ranging from 0.01 to 0.0001.

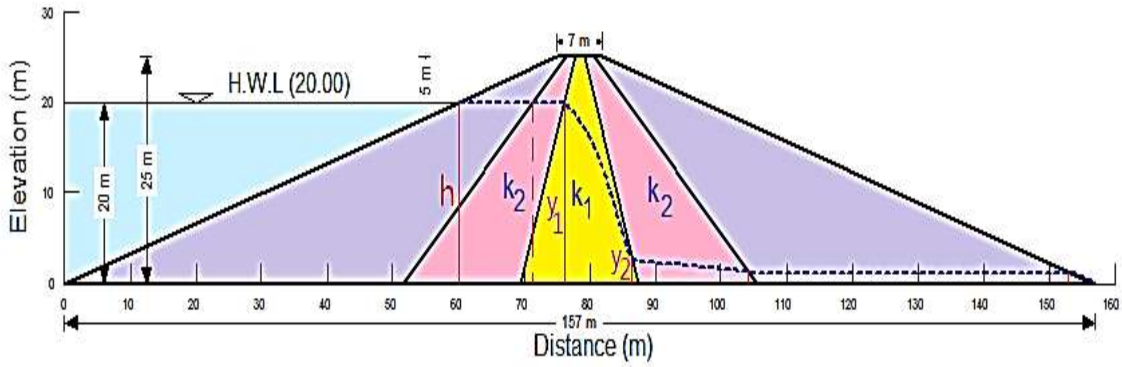

Fig. 5: Phreatic line through the zoned earth dam

Fig. 6 shows the relation between the relative permeability coefficient (k_1/k_2) and the phreatic line level at the upstream side of the inner zone (y_1/h). The figure shows that, with value of the relative permeability coefficient (k_1/k_2) less than 1%, decreasing the permeability coefficient of the inner zone caused a slight increase in the phreatic line level at the upstream side of the inner zone (With less than 1%).

Fig. 7 illustrates the relation between the relative permeability coefficient (k_1/k_2) and the phreatic line level at downstream side of the inner zone (y_2/h), from which it is clear that, decreasing the permeability coefficient of the inner zone decreased the phreatic line level at the downstream side of the inner zone (By about 43% at k_1/k_2 = 0.001 and 54% at k_1/k_2 = 0.0001).

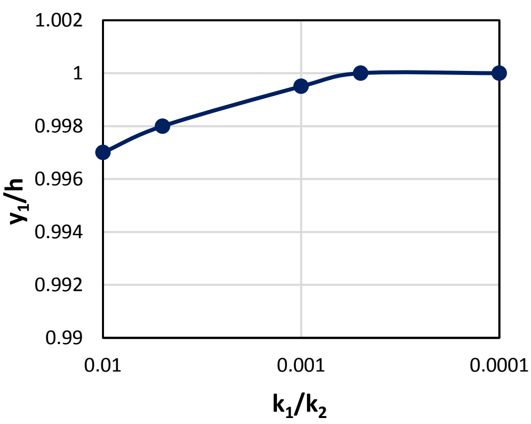

Fig. 6: Relation between the relative permeability coefficient (k_1/k_2) and the phreatic line level at the upstream side of the inner zone (y_1/h)

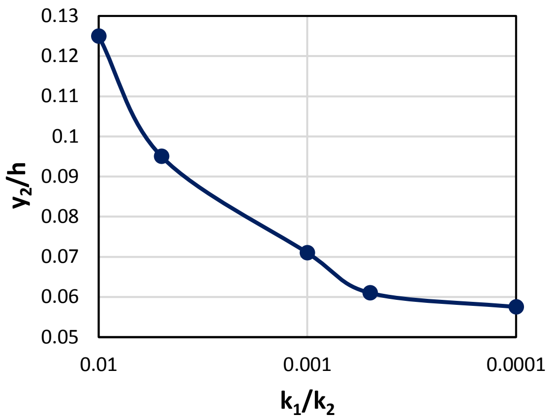

Fig. 7: Relation between the relative permeability coefficient (k_1/k_2) and the phreatic line level at downstream side of the inner zone (y_2/h)

Fig. 8 shows the relation between the relative permeability coefficient (k_1/k_2) and the seepage discharge ratio (q/k_1h), from which it is seen that the seepage discharge decreased with decreasing the permeability coefficient of the inner zone (By 89% at k_1/k_2 = 0.001 and 99% at k_1/k_2 = 0.0001).

Fig. 9 illustrates the relation between distance of the dam base and pore water pressure (PWP) at the downstream side of the inner zone. From the figure, it is clear that, decreasing the permeability coefficient of the inner zone caused a decrease in the pore water pressure at the downstream side of the inner zone (By about 46% at k_1/k_2 = 0.001 and 52% at k_1/k_2 = 0.0001).

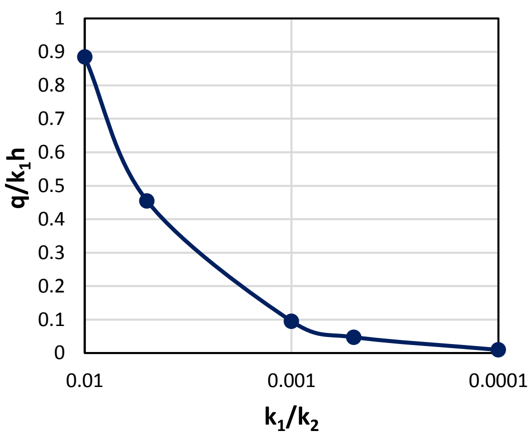

Fig. 8: Relation between the relative permeability coefficient (k_1/k_2) and the seepage discharge ratio (q/k_1h)

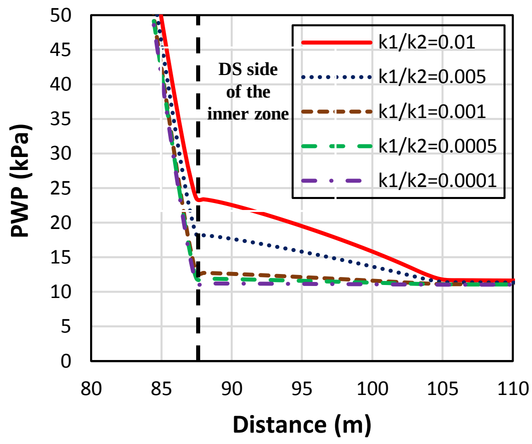

Fig. 9: Relation between distance of the dam base and the pore water pressure

Fig. 10 shows the relation between distance of the dam base and the velocity in the x-direction (v). The figure shows that, the velocity decreased with the decrease of the permeability coefficient of the inner zone at the downstream outer zone (By 89% at k_1/k_2 = 0.001 and 99% at k_1/k_2 = 0.0001).

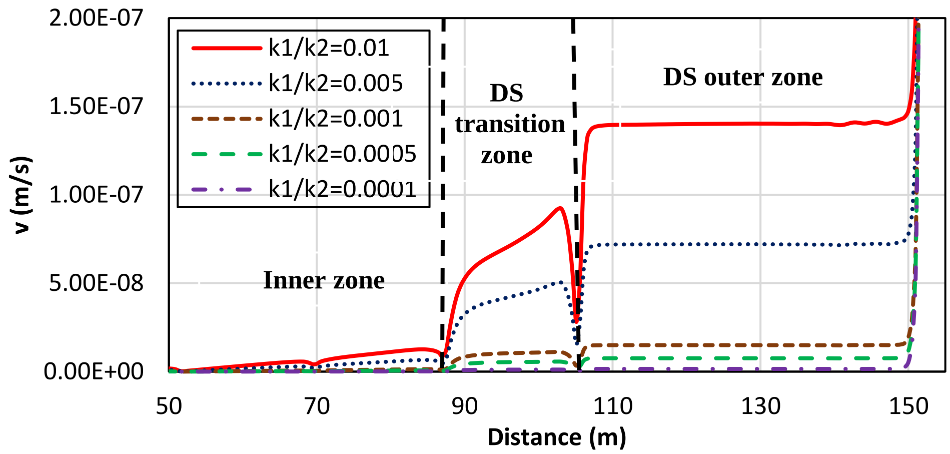

Fig. 10: Relation between distance of the dam base and the velocity in the x-direction

Fig. 11 illustrates the relation between distance of the dam base and the gradient in the x-direction (G). The figure shows that, decreasing the permeability coefficient of the inner zone increased the gradient in the x-direction in the inner zone (With about 9% at k_1/k_2 = 0.001 and 0.0001), while it decreased the gradient in the x-direction in the downstream transition zone (With about 94% at k_1/k_2 = 0.001 and 99% at k_1/k_2 = 0.0001).

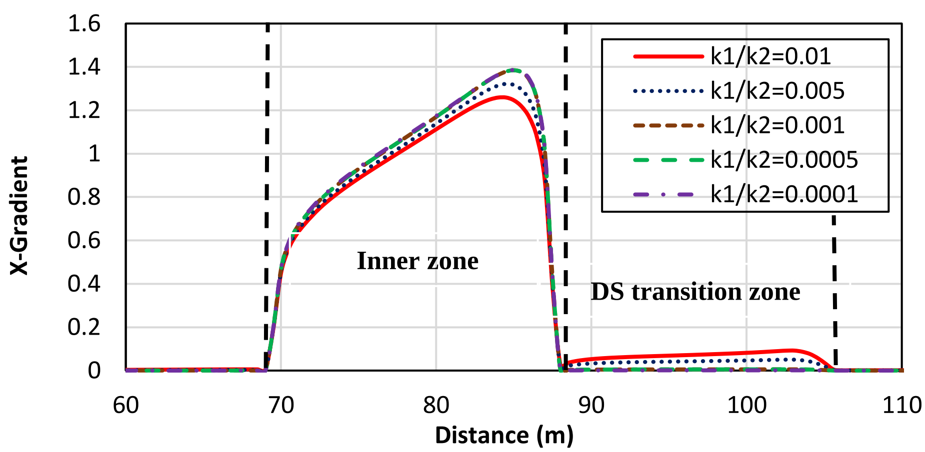

Fig. 11: Relation between distance of the dam base and the gradient in the x-direction

6. CONCLUSIONS

- 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:

a) The inclined rock toe was better than vertical rock toe in enhancing the dam performance to control the seepage.
b) The phreatic line was linearly decreased for the chimney filter, but when rock toe and horizontal filters were used, the phreatic line dropped at the starting point of filter.
c) The downstream drain length was the most effective parameter on the seepage, while the height and angle had a negligible effect.
d) A noticeable drop of seepage line occurred with decreasing core permeability, increasing core thickness, and the quantity of seepage and exit gradient decreased.
e) The trapezoidal core shape gave the least seepage discharge compared to other shapes.
f) The optimum position of cut off was at the middle length of the dam base width.

- Zoned earth dam is an earth dam which provided with an impervious core, and surrounded by more pervious outer zones, the most effective parameters on the seepage through zoned earth dams are the coefficient of permeability, thickness, and upstream and downstream slopes of the different zones.
- Decreasing the relative permeability coefficient between the inner and transition zones up to 0.001 caused a significant decrease in the phreatic level, pore water pressure, velocity and seepage discharge, after that, the effect was minor.

NOTATIONS

b: top width of the dam (m).
B: bottom width of the dam (m).
F: free board (m).
G: gradient in the x-direction (dimensionless).
h: upstream water head acting on the dam (m).
H: total hight of the dam (m).
k: hydraulic conductivity of the zone (m/s).
PWP: pore water pressure (kPa).
q: seepage discharge rate per unit length of the dam (m^2/s).
S: upstream or downstream slope of the zone H:V (dimensionless).
t: top thickness of the zone (m).
v: velocity in the x-direction (m/s).
y_1: phreatic level at the upstream side of the inner zone (taking the dam base as a datum) (m).
y_2: phreatic level at the downstream side of the inner zone (taking the dam base as a datum) (m).

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