Finite element analysis of seepage for Kongele earth dam
Using Geo-Studio software

M Th Al-Hadidi, S H Hashim
1 University of Baghdad, College of Engineering, Water Resources Engineering Department
E-mail: s.hashim1310@coeng.uobaghdad.edu.iq

Abstract. Seepage occurs under or inside structures or in the place, where they come into contact with the sides under the influence of pressure caused by the difference in water level in the structure U / S and D / S. This paper is designed to model seepage analysis for Kongele (an earth dam) due to its importance in providing water for agricultural projects and supporting Tourism sector. For this purpose, analysis was carried out to study seepage through the dam under various conditions. Using the finite element method by computer program (Geo-Studio) the dam was analysed in its actual design using the SEEP / W 2018 program. Several analyses were performed to study the seepage across Kongele dam in several cases, including when the reservoir was empty, and at the normal and maximum water level. The final results of the analysis show that the dam is safe.

Keywords: Kongele. Earth dams, Seepage analysis, Geo-Studio, SEEP/W.

1. Introduction
Dams were mainly constructed of rocks and earth filling materials, with simple shapes and appropriate slopes. Earth dams depend on their own weight to protect against slip and tipping failure. Types of failure in earth dams. The following: structural failure, seepage failure, hydraulic failure, and piping through the dam body [1]. Seepage causes corrosion on the inside of the dam body in places with a high hydraulic gradient. If erosion occurs inside the dam, voids are created at the site of erosion. The voids take the form of channels and tubes, which weaken the stability of the dam [2]. The accurate calculations for quantities of seepage from the dam body and foundation are very important for technical and economic considerations. Water seepage from the bodies and foundations of dams and earths leads to acceptable water losses in arid climates. Therefore, control of the crisis. Control of seepage through dams is located on foundations of high permeability, one of the most important problems. The effects on the stability of the dam are acceptable in water management [3]. The chairman of the board of directors, the chairman of the board of directors, and accordingly, and based on his share, and accordingly, the engineer in charge of the dam must be highly aware of and solve the problems of seepage, monitor and prevent them [4]. Noori and Ismaeel used the finite element method during the Geos-studio program and the 2012 SEEP2D sub program to find the free seepage theoretical line, pore water pressure distribution, the amount of seepage through the dam body and overall head measurements as well as finding the effect of differential properties. The basic materials of the Dohuk dam were tested for the effect of the penetration ratio in both the horizontal and vertical directions (Kx / Ky) for the seepage. The results showed that the amount of seepage is directly proportional to the change in this ratio. The stability of the earth dam in Dohuk was analyzed using the geostudio program and the subsystem STABIL 2.3. The results of the analysis were that the safety factor was inversely proportional to the increase in the permeability ratio in both directions and that the earth dam was safe against leakage failure [5]. Fattah and colleagues used the finite element method [6] to solve seepage equations across earth embankments using Geo-Studio computer program and its SEEP / W subprogram [7]. An earth dam is a design on previous and investigative studies, special knowledge, experience and the individual designer’s preferences. In a particular location, we can typically construct a range of dams that are both secure and economical, and we have a lot of examples in that skillful engineers suggest various designs on a large scale for the same basin.
Moreover, the characteristics of the designated location have a bigger effect on an earth dam design [9]. The basic earth dam design should take into account four matters, as the following:

A: Selection appropriate materials: by choosing appropriate materials for the earth dams’ core, there are two factors to be taken into account the quantitative and qualitative factors, in addition to the elimination of materials.

B: Determining of the core thickness: in general, the core material includes a great amount of fine particles of silt and clay will, consequently, get lesser shear strength than the shell substance.

C: The core geometry may be built as the vertical and slope in the earth dam section.

D: the comparative core permeability: whatever core.

Permeability is lesser than downstream permeability of the shell, in the shell leakage line is in the lower place and vice versa. Therefore, the location of the leakage line in the downstream shell is efficiently pulled off, it is necessary that at least permeability has some hundred equivalent permeability [10].

The soil of downstream side hydraulic structures get lift up under effect of piping phenomena, that’s due to excess water pressure exert from the soil as a result of seepage water. Interaction between soil and percolating water many valuable affecting in the following actions:

1- Design foundations and earth slope.

2- Volume of water loss from a dam by percolation, or fail of sub soil foundation due to piping which are quite common. In case of slope stability.

Seepage force is a very important, shear strengths of soils reduced with respect to increase of neutral stress (pore pressures). Therefore, well understanding of hydraulic conditions is essential for structure design. The computation of seepage loss via a dam includes uplift pressures caused by the water on the base of dam and effect of .seepage on the stability of earth slopes, which can study constructing flow nets [11]. In addition, study hydraulic gradient gives general ideas about the potential piping. Seepage becomes problem if it loads material of dams along with it. Seepage must be control to prevent the erosion in dam body or foundation [12]. Mahmood” the program SEEP/ W is used to compute seepage value through the homogenous or non-homogeneous earth dams and they are known dimensions. Later the results from the program are show the relationship between the seepage and water height in U/S dam for saturated soil was nonlinear if the dam is homogenous [13].

![Cross section of Kongele dam (the scale 1/400)](image)

2. Kongele earth dam

It's located between the villages of Shorjah and Haftajshemeh / Qarat Hasan area on the Kongele valley, and is no more than a kilometer away from the main road leading to Kirkuk (in Figure 1). It is one of the important small dams proposed to be implemented by the Ministry of Water Resources in Kirkuk Governorate, due to its importance in providing water for agricultural projects and supporting the tourism sector. The capacity of the treasury is (2,234,000) m3 and 20.2m height.
2.1. The design of Kongele dam

It was designed as an earth dam with a length of 407 m and a height of 8 m which is sufficient to be a two-lane road, the slope of the upper side is 3:1 and the slope of the back of the dam is 2.5:1. The dam with a cutter extending to a depth of 6 m until it reaches the solid clay layer. The width of the cutter base is 4 m. Its end is slanted upward until it meets the ends of the clay core and the sides of the mud core are surrounded by a layer of filter of 2.5 m. Floor of the head of the dam shall be coated with a layer of clay with a thickness of 3 m, topped by a layer of filter with a thickness of 2 m, connected to the filter layer sloping from the front side of the mud pulp. As for the filter layer at the back of the mud pulp, it extends to the end of the back end of the dam with a thickness of 2 m and a layer of filter extends 2 m thick for the purpose of protecting the trench at the back of the dam. The front surface of the dam is covered with a stone material (Rip Rap) with a thickness of 1 m with a minimum size of 0.4 m and a layer of filter is placed under it 30 cm thick. The back slope was covered with a layer also of solid stone, with a thickness of 0.5 m and a size of not less than 30 cm, for the purpose of protecting it from rainfall and erosion factors. The upper and back sides of the dam were filled with a material with a certain gradient of silt, sand and gravel. The front and back slopes are both covered by a surface 5 m wide at a level of 512 above sea level.

2.2. General features for Kongele dam

It's important to know the details information about the dam to seepage analysis by SEEP/W. Table 1. And 2 below show some information about the design and properties of Kongele dam.
Table 1. General features for Kongele dam

| Name                      | Value       |
|---------------------------|-------------|
| Length of dam             | 407 m       |
| Catchments Area           | 68.27 Km    |
| Crest level               | 520 m a. s. l |
| Maximum storage           | 3,454,151 m³ |
| Bed Level                 | 499.8 m a. s. l |
| Dead Storage              | 30600 m³    |

Table 2. Material properties Kongele dam.

| Material     | Property          | Value      |
|--------------|-------------------|------------|
| Core         | Gravel            | Nil        |
|              | Sand              | 20%        |
|              | Silt              | 62%        |
|              | Clay              | 20%        |
|              | Dry density       | 1.52 gm/cm³ |
|              | Hydraulic conductivity | 1.9x10⁻⁴ m/day |
| Shell        | Dry density       | 2.09 gm/cm³ |
|              | Hydraulic conductivity | 0.072 m/day |
| Coarse filter| Hydraulic conductivity | 43180 m/day |
| Foundation   | Hydraulic conductivity | 1.9x10⁻⁵ m/day |

2.3. Safety criteria of Kongele earth dam
Kongele earth dam checked against mechanism failure through comparing the cross section with (BDS, 1994), [14] as shown in Table 3

Table 3. Mechanism safety for Kongele dam according to BDS safety limits.

| Parameter                  | Value   | BOS limits          | Safety status |
|----------------------------|---------|---------------------|---------------|
| Crest width                | 8       | Not less than 2m    | acceptable    |
| Upstream slope             | 3:1     | 2.5:1               | acceptable    |
| Downstream slope           | 2.5:1   | 2:1                 | acceptable    |
| Free board                 | 3.0     | Minimum=1.5 m       | acceptable    |
| Bed width of core          | 44 m    | H/3=24.6/3=8.2      | acceptable    |
| Core slope                 | 1:1     | 1:12                | acceptable    |

It can notice from table 3 that the proposed geometric design of Kongele earth dam is acceptable.
3. **Seepage analysis of Kongele earth dam**

In the following sections, the dam section will be analyzed for different conditions normal water level and maximum water level. Seepage through Kongele dam was study according to the defined specifications for nonhomogeneous earth dam with help of SEEP/W software (2018).

The following steps were adopted to model the seepage through the dam:

1. Define the type of analysis to be steady state,
2. Set the work sheet, scales, axes and grids,
3. Drawing Kongele dam according to cross section,
4. Definition hydraulic conductivity for different parts of dam and locations for dam materials,
5. Assign material properties defined for different areas of the dam,
6. Define boundary condition,
7. Select the mesh barrier with combination elements of square, rectangular and triangular.

3.1. **Analysis of seepage when empty reservoir (no water level)**

Seepage analysis for steady state through and under the ground dam is done using the SEEP / W 2018 program. Finite element mesh is used for analysis when the reservoir checks in several states, including when it is empty, as shown in (Figure 3).

Number of elements for all boundaries is 2275 and nodes numbers 2154 approximate global element size 1m.

![Figure 3. Mesh for Kongele earth dam](image)

3.2. **Analysis of seepage (normal water level)**

Seepage analysis during the normal water level (n. w. l) at 20.6 m can draw as shown below which illustrates the path. (Phreatic line through the dam).

- a- Water total head
- b- Pore water pressure.
- c- Pressure head.
- d- Velocity vectors.
- e- Hydraulic gradients.
Figure 4. Water total head for normal water level

In Figure 4. The blue dotted line represents the line of seepage through the dam, through the core and exiting the end of the filter, which is required to achieve stability.

Figure 5. Distribution of the pore water pressure normal water level

Figure 6. Distribution of the pressure head for normal elevation
In Figures 5 and 6. The pressure value of the seepage line is always zero and the value that is positive from the pressures below the seepage line area is completely saturated and the upper area of the line is negative pressure and it is unsaturated.

3.3. Analysis of seepage when maximum water level
Seepage analysis during maximum case (m. w. l) at 21.6 m can draw as shown below.
   a- Water total head
   b- Pour water pressure.
   c- Pressure head.
   d- Velocity vectors.
   e- Hydraulic gradients.
Figure 9. Water total head for Kongele dam at maximum water level

Figure 10. Distribution of the pore water pressure for maximum water level

Figure 11. Distribution of the pressure head for maximum water level
Figure 12. Water flux for maximum water level

Figure 13. Water XY gradient for maximum water level

From Figures 8 and 13, it was found that the maximum exit hydraulic gradient ($i_e$) is (0.3) so the factor of safety against uplift equal to $(i_c/i_e) = (1/0.3) = 3.33$

Also the factor of safety against heave = $(1/(24.6/119)) = 4.84$

The results of hydraulic safety criteria is illustrated in Table 4

| Safety factor | value | (USBR,2014) limits | Safety status |
|---------------|-------|--------------------|---------------|
| Against heave | 4.84  | Not less than 4    | acceptable    |
| Against uplift| 3.33  | Not less than 2    | acceptable    |

It can notice from table 4 that the Kongele earth dam is safe against failure in seepage at steady state according to hydraulic safety criteria of (USBR, 2014) [15].

The seepage velocity analyzed as shown in figures 8 and 12 for normal and maximum water level and the results of the maximum seepage velocity in core zone is shown in Table 5
Table 5. Maximum seepage velocity in core zone

| case                      | Velocity (m/day) | Safety of dam status |
|---------------------------|------------------|----------------------|
| Normal water level        | 1.50 \times 10^{-4} | Acceptable           |
| Maximum water level       | 1.47 \times 10^{-4} | Acceptable           |

4. Results discussion

- In the normal water level: seepage line passes through the filter. Figure (4), Figure (5) and Figure (6) show that, Hydraulic conductivity 1.9 \times 10^{-4} m/day from Table 2. More than the seepage velocity 1.5 \times 10^{-4} m/day from Figure 9. That is meaning the core can pass the water, which is safe against piping failure.

- Maximum water level: seepage line passes through the filter. Figure (9), Figure (10) and Figure (11) show that. Hydraulic conductivity 1.9 \times 10^{-4} m/day from Table 2. More than the seepage velocity 1.47 \times 10^{-4} m/day from Figure 14. That is meaning the core can pass the water, which is safe against piping failure.

5. Conclusions

When we made seepage analysis for Kongele dam and the results shown in the drawings above, we conclude that the dam is safe against seepage (piping) failure, uplift and against heave in the two cases of the normal level and the maximum level.

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