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# Role of the Single Sheet Pile Beneath the Dams on Seepage Parameters Maintenance: Review

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## Abstract:

Seepage is a significant issue that contributed to the dam's failure. Different water levels on the U/S and D/S sides produce seepage and uplift pressure. This process displaces particles under the dam foundation, creating a seepage pathway and ultimately weakening the structure. This review paper focuses on identifying the optimal single-sheet pile technique for reducing seepage flow, uplift pressure head and controlling the exit gradient beneath the dams. Sheet pile walls are flexible, interlocking structures embedded in soil to resist horizontal pressure and accommodate significant deformations. Seepage in some Iraqi earth dams was concluded. The optimal situation for single sheet pile penetration, as one of the economic techniques, has been identified. The review results indicated that the best location for penetration of a single sheet pile is at the toe point, at an angle of 125° toward the upstream to mitigate seepage and 90˚ to 120˚ to provide the best exit gradient. However, the upstream heel sheet pile has been recommended to provide the lowest uplift pressure at an angle of 90° to 150° towards U/S.

## Keywords:

Seepage; Single sheet pile; Dam failure; Iraqi dam issues; Economic techniques.

## Highlights:

- Discuss various problems with Iraqi dams related to karstification and seepage phenomena.
- Summarizing the previous studies based on the single sheet pile penetration in different techniques to mitigate the seepage characteristics and detect the optimum situation.

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# 1.INTRODUCTION

Dams are complex engineering projects and may become hazardous if poorly constructed. One major risk is seepage. The difference in water level between the U/S and D/S creates the uplift pressure. Infiltration can lead to underground erosion (piping), forming seepage channels and transporting fine particles downstream, which may compromise the dam's structural stability [1, 2]. Seepage failure is a significant issue for embankment dams, as they account for around 80% of all dams in the United States [3]. More than 70% of dams worldwide are embankments; half of piping failures occur in embankment dams during initial filling, with 64% occurring within the first five years of operation. For foundation piping, about 25% of failures take place during initial filling, while 75% occur within the first five years [4]. The seepage phenomenon modifies the properties of the soil materials, resulting in increased permeability, reduced cohesion and stress, weakened shear strength, and, ultimately, piping surges as the critical level is attained. Seepage is affected by three main factors: the soil medium, the flow type, and the boundary conditions [5]. One of the significant factors affecting water pressure and seepage is the position of the groundwater table and its fluctuations around the dam [6]. Various methods, including compaction, filters, and sheet piles, are used to address seepage. Sheet piles extend the flow path and reduce the exit gradient [7]. Sheet pile walls are metal or low-permeable material, or concrete walls. Metal sheet piles consist of a series of sheet piles that penetrate side to side into the ground. Location, length, number of sheet piles, penetration angles and interval spaces affect the seepage characterizes [8-10]. Several Iraqi dams pose a challenge to the seepage issue. Mosul Dam is the largest among them and is affected by karstification. Several mitigation techniques have been suggested. Penetration sheet piles have been recognized as an economical and effective solution [11]. The primary object of this review paper is to review the previous studies on the seepage and sheet pile utilization to detect the optimum situation for single sheet pile usage and to conclude some Iraqi dam issues.

# 2.SEEPAGE PROBLEMS IN SOME IRAQI DAMS

This country is famous for its water resources. More than 30 great dams have been built on the Tigris and Euphrates rivers. To ensure dam safety, an assessment of the site's geology and ground engineering characteristics is necessary. Geological investigation is important for the Dam Foundation and the Dam-occupied area with respect to slope stability [12]. The Arabian Plate underlies about 95% of Iraq's territory, or even earlier. This Arabian Platform consists of progressive sedimentary layers built back to the Tertiary. The sedimentary cover thickens as it extends northward and northeastward toward the former passive margin of the Arabian Plate, which is closer to the Zagros Fold-Thrust Belt [13]. The outer Arabian platform includes the Mesopotamia Foredeep and the Western Zagros Fold-Thrust Belt. Also, a very limited portion extends within the Eurasian (Iranian) plate. The low folded zones are sedimentary layers, and the oldest exposed rocks are Late Cretaceous in age and belong to the Shirish Formation, including the Kirkuk, Erbil, and Mosul zones [14]. This layer causes karstification in some Iraqi dams and degrades dam quality [12].

## *2.1.Mosul Dam and Karstification Phenomenon*

The general understanding of karst has changed over the last 30-40 years [15]. Karstification is a serious problem in the gypsum and limestone beds of the Fatha Formation, affecting not only the Mosul Dam site but also many other exposed areas. Karstification occurs due to the dissolving of the gypsum layer and erosion of the sediment layer. Karstification creates the great holes. Chalky limestone, gypsum, anhydrite, marls, and limestone are among the rock strata that make up the dam's foundation geology. The sinkhole extends below 100 m from the dam foundation. Solubility intensity for the Mosul Dam ranged from 42 to 80 tons per day for limestone, marl, and dolomite [16, 17]. The Mosul dam with central clay is the largest earthfill dam in Iraq [11]. The grouting method was used to address these issues during dam construction, as it became evident that the gypsum breccia layers were highly resistant to grouting within the deep grout curtain zones, resulting in a positive outcome. A recent study for the last few years indicated that the grouting technique has temporary results, and cannot solve gypsum dissolution permanently; still, sinkholes are created [18].

### *2.1.1.Mosul Dam and Cutoff Utilization*

Seepage and hydraulic pressure can cause structural damage if not protected. The penetration of the sheet pile causes an extended seepage path. Sheet pile configuration utilization affects the seepage characterizes [19]. Configuration includes the number of sheet piles, the interval distance, the depth, and the penetration angle [20]. Cutoff walls, as one of the economical ways, may be produced in fine clay soil, mortar, or metal. The cutoff technique can be used with other techniques, such as filter blankets, to enhance their roles [21]. The cutoff was used at the Mosul dam foundation at a depth of 75m below the grouting gallery, and grouting was performed continuously to mitigate seepage and karstification. It has been installed in the dam center. Even an upstream blanket is also used. It has positive consequences, but they are also temporary. Despite significant maintenance efforts, gypsum dissolution continues, and the gypsum breccia layers exhibited strong resistance to grouting in the deeper sections of the grout curtain [22]. Gypsum or anhydrite surfaces can be protected from dissolution by sealing them, which involves maintaining a saturated or supersaturated SO4 solution in contact with the rock. This approach requires a continuous supply of the solution to seepage water, potentially sourced from an upstream gypsum blanket.

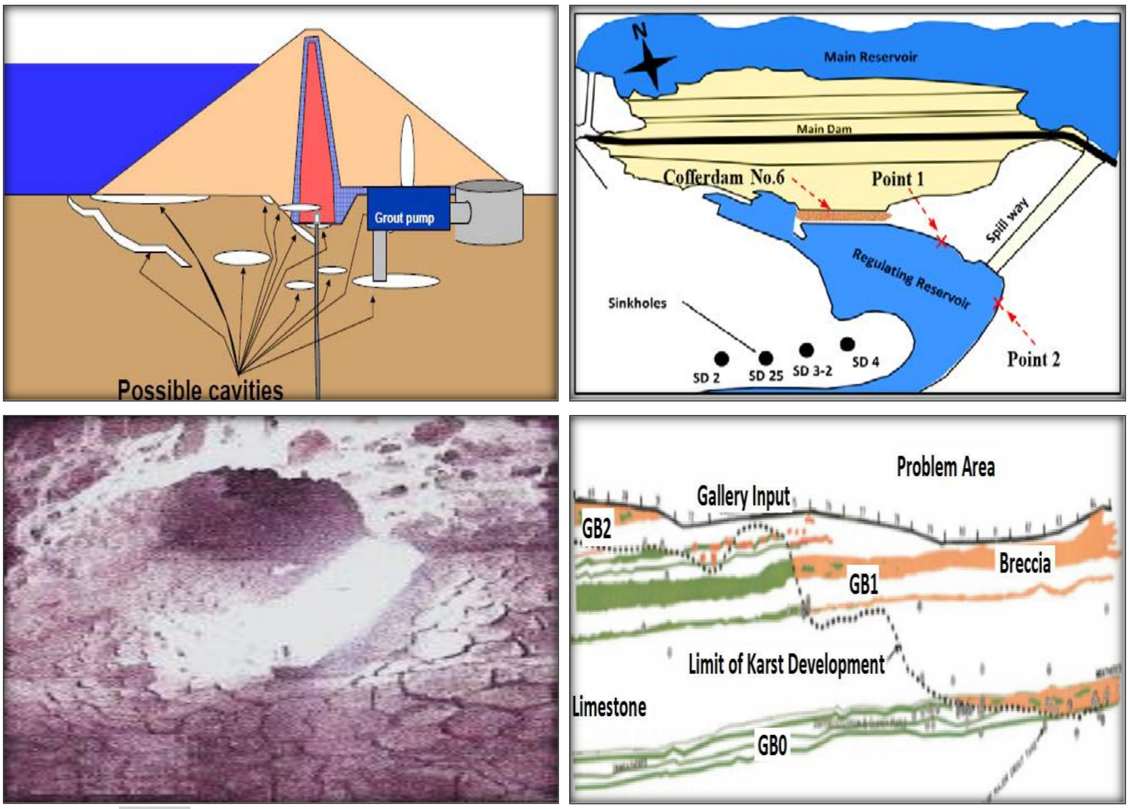

**Fig. 1** Detail of Mosul Dam, Sinkholes and Cutoff Utilization with Grouting.

### *2.1.2.Al-Hindiya Dam and Cutoff Utilization*

It is one of the important projects on the Euphrates River. The dam is 115m long and features (6) radial gates and is used for multipurpose, including a hydropower plant. 36 piezometers were used to detect the seepage. The result was examined by the Seep/w program for a non-homogeneous soil foundation. Sheet pile utilization reduced the total head and seepage flux (96.89 kPa to 96.42kPa) and (0.16 m$^3$/s/m to 0.05 m$^3$/s/m) from the dam hill to the dam toe [23]. The study analysis confirms that the cutoff wall structure significantly reduces the hydraulic gradient, thereby enhancing resistance to uplift pressure. This improves the safety factor by about 5. Concrete dam body in a safe situation [24].

### *2.1.3.Haditha Dam and Seepage Issue*

This dam was built on the Euphrates River in latitude 34° 11' 30" - 34°13' 30" north, and longitudes 42°20' 00" - 42°23'30”, and it is an earth fill dam. Dolomite and limestone from the Euphrates Formation (Lower Miocene) make up the dam's geology. In this layer, karstification, cracks, and seepage are produced. The geological formation underlying the dam site's structure is composed of sedimentary rock layers that formed over millions of years, from the Triassic period (approximately 250 million years ago) to the more recent Quaternary period, the last 2.6 million years [25-27]. The piezometric and Seep/W programs were used to estimate the seepage ratio beneath the foundation. This equation below was used:

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

Where $T$ is the domain time and $\theta$ is water content volume (%), $H$ is a hydraulic head, $kx$, $ky$ is hydraulic conductivity in the $x$ and $y$ direction, and $Q$ is the boundary flux. Dolomite rock was used as a low-permeable rock [27]. The asphaltic concrete cutoff was installed under the dam core at 65 m deep beneath the dam foundation (K = 1 × 10$^{-9}$ m/s). It has been penetrated perpendicularly at the upstream crest point beneath the dam with a grout curtain. It was followed by mealy detrital dolomites (1.15 × 10$^{-8}$ m/s). These techniques lowered the phreatic line and the exit gradient near the toe, keeping the dam in a safe condition against seepage failures [28]. However, karstification affects both the Hadith dam and the Mosul dam. Haditha Dam's karstified rocks are a collapse type that occurs in limestone strata of the Euphrates Formation. There are 54 circular sinkholes observed around the dam site, with diameters ranging from a few to around 110 meters and depths ranging from a few to 55 meters. The Euphrates layer is roughly fifty meters deep. However, the Mosul Dam's sinkholes are more active [29].

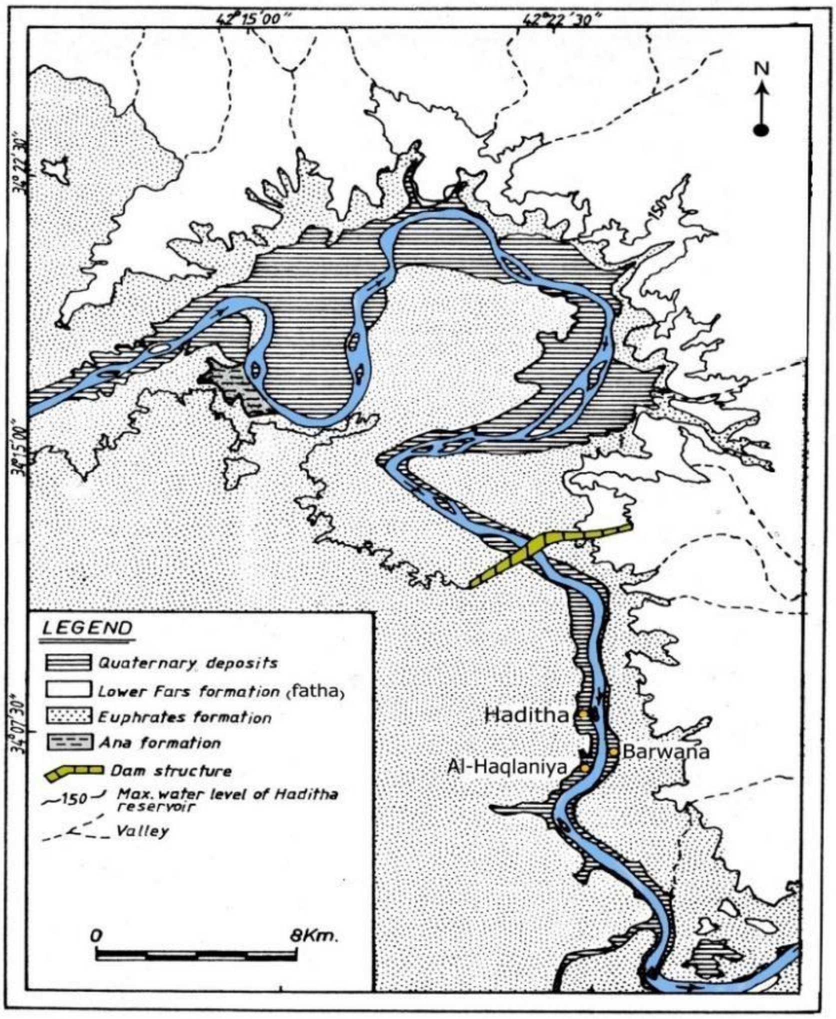

**Fig. 2** Geological Map of Haditha Dam.

## ***2.2.Cavity and Sheet Pile Utilization***

When gypsum dissolves in soil, large holes called cavities form. Cavities weaken the soil layers and can damage the foundation. Seepage quantity depends on the cave diameter. The influence of cave depth depends on the sheet-pile region, the dam load, and the soil type. The presence of a cavity depends on bearing capacity. Sinkholes may form horizontally, as seen in the major collapse of 2017, which resulted in an elliptical crater measuring 35 by 26 meters with a depth of 17 meters. The study area was located in Neogene sediments composed of clayey, silty, and sandy materials, approximately 2 km south of El Welja, the capital of Setif Province in northeastern Algeria. [30, 31]. When horizontal cavities are located upstream, they exert a greater influence on seepage than when they are located downstream. If the diameter of the cave increases, the flow rate increases as well [32]. Increasing the dam's shear strength does not affect the cavity's stability. The study was conducted at the cave location to assess dam stability. The result shows that as the horizontal distance from the dam's centerline to that cave increases, the safety factor increases, as shown in a model dam. The study has been done on the location of a horizontal cave under the model dam at a depth of 1m on both upstream and downstream sides with distances (0,8,18,20,24,28,35,45) m at the dam center line. The optimum situation is in the cave on the downstream side away from the centerline [33]. A cavity within or beneath the dam disrupts stress distribution and decreases its resistance to external forces. If the cavity is located on the upstream side, rapid drawdown conditions can further reduce upstream water pressure, which normally provides stability, thereby compromising the dam's overall stability. The rapid upstream drawdown reduces water pressure and creates a counterbalancing force on the dam, ultimately degrading the dam's stability [34]. The figs. below show the details of different types of sinkholes:

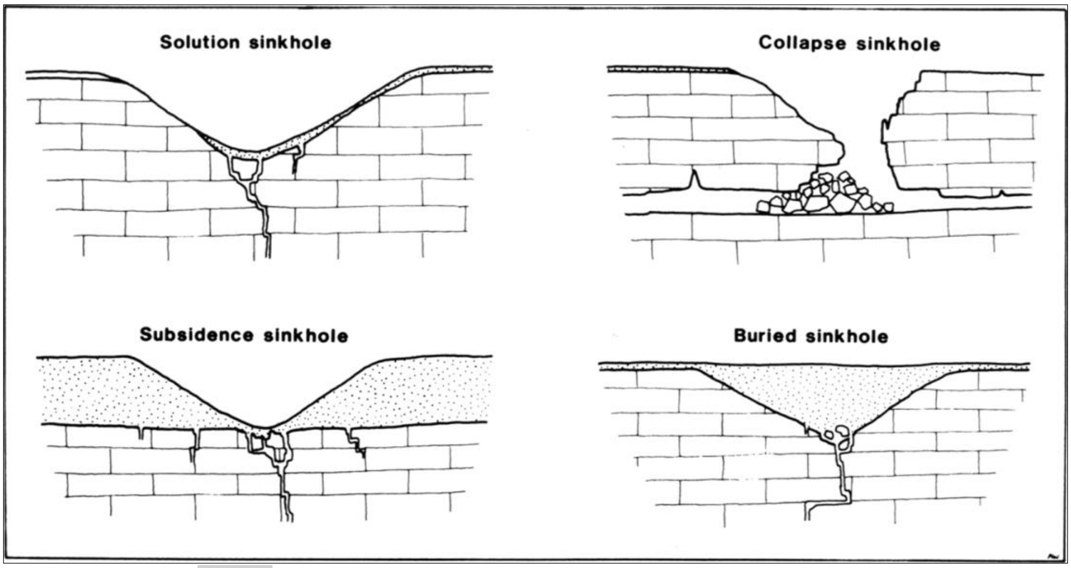

**Fig. 3** Cross-Section of Different Types of Sinkholes [35].

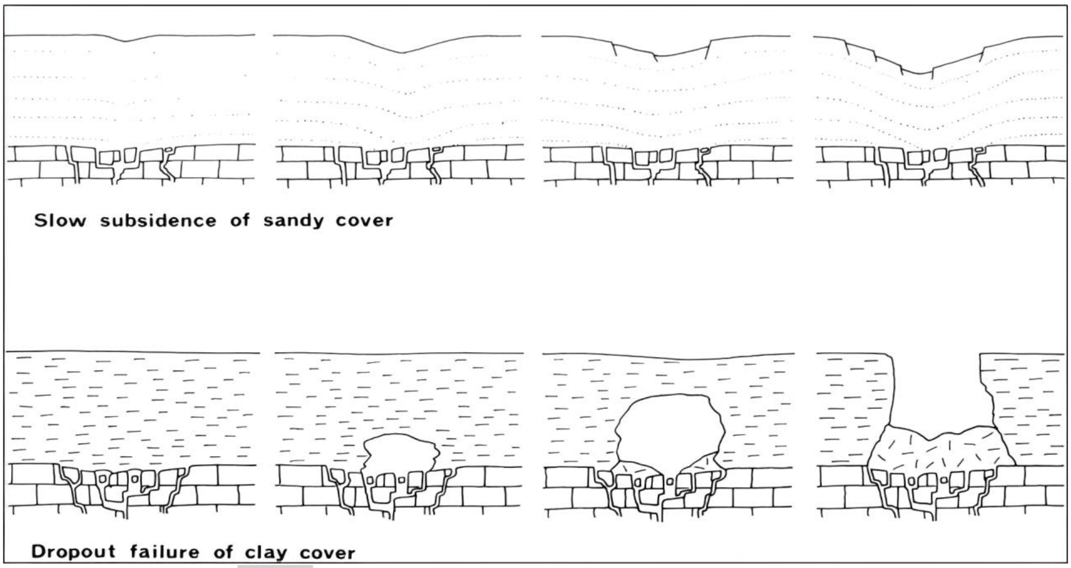

**Fig. 4** Progressive Development of Sinkholes [35].

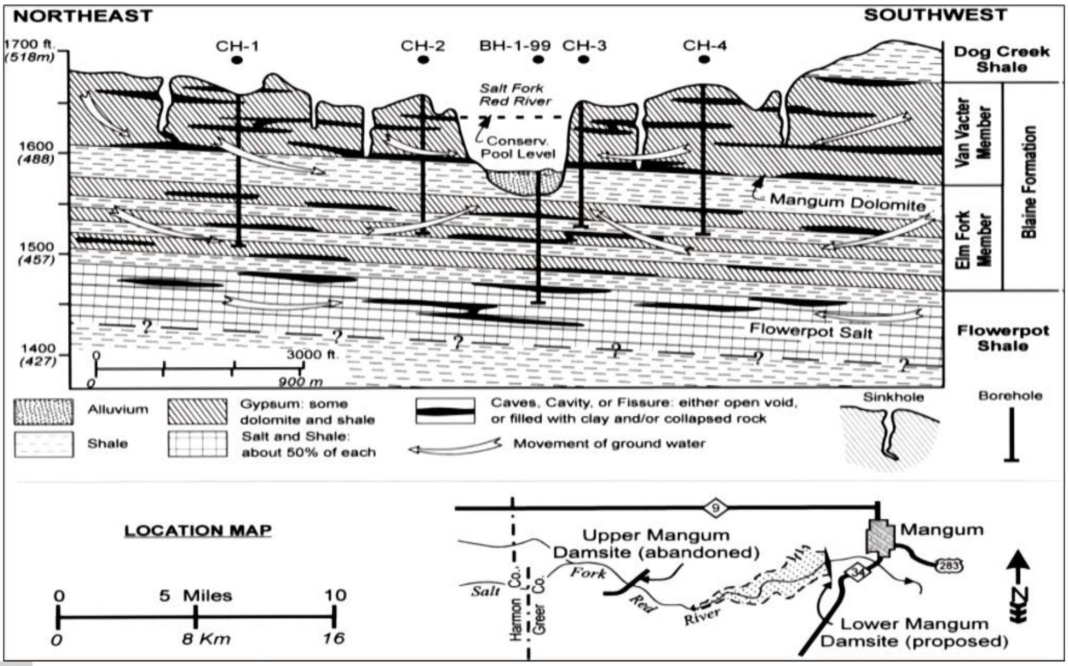

**Fig. 5** Cross-Section of Geological Layer under Mangum Damsite, Shows the Karstification and in Gypsum, Dolomite and Salt [36].

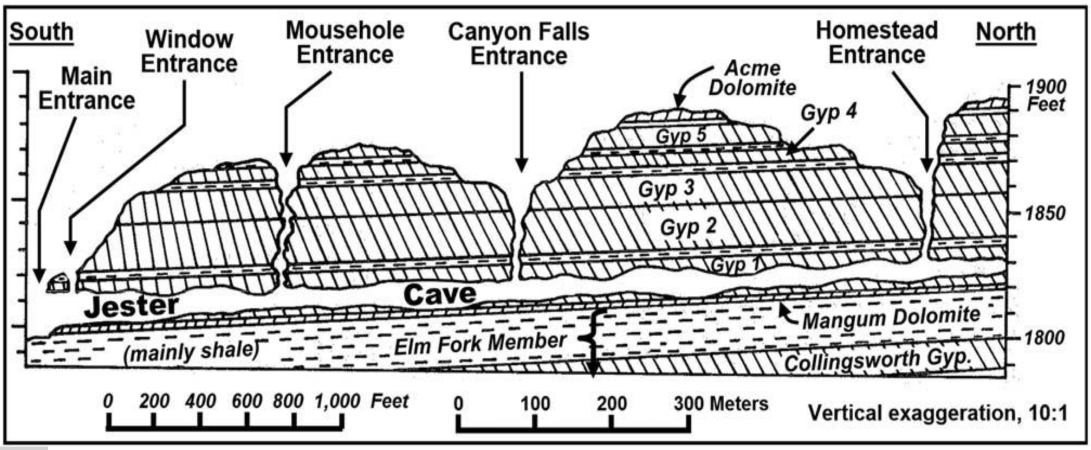

**Fig. 6** Schematic Cross-Section Shows that a Cave is Developed in Gypsum in the Karstic Layer of Southwest Oklahoma and North-Central [37].

The breakthrough time for draw down water level due to a sinkhole in the gypsum layer can be driven as:

$$\mathbf{T} = \left(\frac{1}{a_0}\right)^{\frac{2n+1}{n-1}} . \left(\frac{L^2.\eta}{h\ ceq}\right)^{\frac{n}{n-1}} . (kn)^{\frac{1}{n-1}} . \mathbf{Const} \qquad (2)$$

Where *T* is the breakthrough time, *L* is the distance between the upstream and downstream head. *The* equilibrium concentration (ceq) is $15.4\times10^{-6}$ mol cm$^{-3}$. *T*he rate constant for the constant moles is $3.10^{-3}$ mol s$^{-1}$ cm$^{-2}$. $\eta$ is water dynamic viscosity and $n = 4.5$ [38]. The depth of sheet piles is critical in influencing soil cavity formation by modifying the exit gradient and prolonging the seepage flow path. Factors such as cavity position, size, soil-layer thickness, and cutoff depth play a crucial role in determining their influence on the dams' hydraulic and structural stability. Culshaw and Waltham [35] examined the relationship between the sheet pile and the cave position in homogeneous sandy soil in Al Najaf. The result indicates that when the cave moves downstream, the relationship between uplift pressure (*P/Po*) under the dam decreases, becoming minimal when the cave is located at (*X/B*) = 1. Where *B* = is the base and *X* is the distance from the cave center to the dam heel point. The position of the cave within the dam base centre creates the most serious situation due to water accumulation and increased pressure. The best position is penetrating the cutoff at the midpoint. The Uplift force is lower for deeper caves. The presence of the cave increases the uplift force by about 40 to 80% when it is located near the ground. The result shows the uplift force for the mid-point sheet pile is (0.8) as compared to the heel and toe point sheet piles, which were (1.3) and (1.2) respectively. The correlation between the soil cavity and the position of sheet pile penetration was identified for Al Najaf soil. The gypsum dissolution under the dam was observed. The soil type is calcium carbonate, which reacts with calcium to form calcium bicarbonate, and it is 30 times more soluble in water than calcium carbonate. This equation was used to estimate seepage.

$$\mathbf{Q} = \frac{2\pi k H^{o}}{\ln\left(\frac{2Z}{r}\right)} \times \frac{1}{8} \qquad (3)$$

Where *k* is hydraulic conductivity, *Z* is tunnel depth, *Q* is seepage water flow, $H^{o}$ is hydraulic head, and *r* is radius of flow.

The test result indicates the uplift force is greater in the cavity case compared to the non-cavity. The quantity of seepage for a shallow cave (*Yc/T = 0.25*), where *Yc* is the depth of the cave under the ground, and T is the depth of the soil layer, is greater than that of a deeper cave. The seepage flow increases when the cutoff moves toward the center line of the dam. The seepage quantity (*q/qo*) rapidly increases when sheet piles move to the dam heel. It has been confirmed that the best situation for the non-sheet-pile case is the existing cave downstream. The value (*q/qo*) decreases when the sheet pile moves to the dam toe for cases (*Yc/T=0 and 0.5*) [39].

## 3.SHEET PILE

It is a seepage control method applied beneath the barrier foundation, offering a cost-effective, easy-to-install, and quick solution. Zhao et al. [40] investigated enclosed sheet piles using interlocked and sealed steel sheet piles. The study confirmed that steel sheet piles are usually produced in high-strength material. The U-shaped sheet pile is usually very durable, especially in joints, with excellent flexural resistance and very high leakage-tightness. The number of sheet piles employed, their spacing, inclination, and the difference in elevation between the upstream and downstream sheet piles affect seepage and the associated risk of contamination [41]. Sheet piles can be constructed from a variety of materials, such as steel, concrete, plastic, aluminum, or any other material characterized by low permeability. These durable retaining structures are composed of interconnected pile segments buried in the ground and are designed to withstand large deformations and soil horizontal pressures. Metal sheet piles are driven into the soil and interlocked, whereas concrete sheet piles are constructed by jetting fresh concrete into a specially excavated hole. Steel sheet piles are the easiest ones for initialization and have a long-life service with high resistance to high stress. Traditional sheet pile shapes are “Z” type and “U” type. The Hat-Type sheet pile 900 significantly reduces both construction costs and durations [42]. Das [43] discussed that the interlocks between sheet pile sections are designed in a thumb-and-finger or ball-and-socket configuration to ensure watertight connections. The designated permissible flexural stress for steel sheet piles is specified as follows:

**Table 1** Allowable different Stress Values for Various Types of Sheet Piles.

| Type of Steel | Allowable Stress |
|---|---|
| ASTM A-328 | 170 MN/m$^2$ (25000Ib/in$^2$) |
| ASTM A-572 | 210 MN/m$^2$ (30 000Ib/in$^2$) |
| ASTM A-690 | 210 MN/m$^2$ (30 000Ib/in$^2$) |

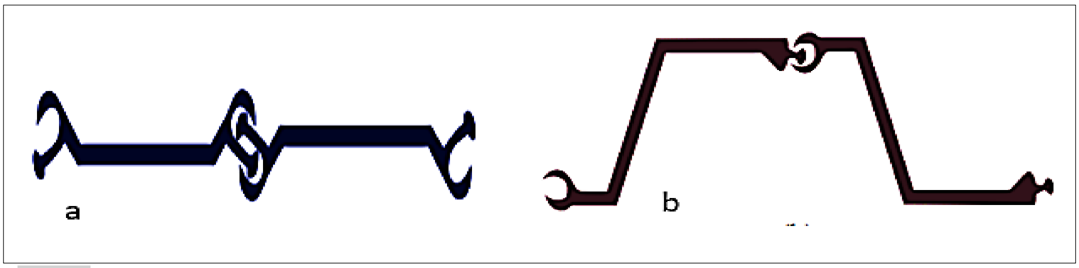

**Fig. 7** Types of Sheet Pile Connections: (a) Thumb and Finger (b) Ball and Socket n [43].

The required penetration depth and maximum bending moment are important. Many factors, including water quality, sheet pile depth, service life, supporting loads, and soil properties, affect the design of all steel sheet piles. During the design phase, various options can be considered, such as the use of corrosion-resistant steel, zinc coatings, paint layers, and "duplex" [44]. The maximum thickness reduction for the steel sheet pile is shown in Table 2.

**Table 2** Reduction in the Thickness of Steel Profiles, Measured in Millimeters Acc.

| Design Time of Structure Usage (year) | 5 | 25 | 70 | 50 | 100 |
|---|---|---|---|---|---|
| | Thickness reduction in steel profiles(mm) | | | | |
| Undisturbed natural soils (sands, clays) | 0 | 0.3 | 0.6 | 0.9 | 1.2 |
| Normal fresh water: water table line | 0.15 | 0.55 | 0.9 | 1.15 | 1.4 |
| Sea water: full submersion & rippling zone | 0.25 | 0.9 | 1.75 | 2.6 | 3.5 |
| Sea water: splashing and low water level zone | 0.55 | 1.9 | 3.75 | 5.6 | 7.5 |

Ahmed et al. [45] found that when a leak in the sheet pile wall penetrates the central point under the floor of the hydraulic structure, it has minimal effect on seepage loss, hydraulic gradients, and uplift force. However, if a sheet pile is located at the downstream end of the pile and is present in the leak wall, its effects become important. The area and position of the seepage have a significant impact. A sheet pile with perforations was utilized, where the hole areas accounted for approximately 2.5% and 10% of the total wall area for a single 4-meter-long sheet pile. The most critical scenario occurred when seepage was concentrated in the upper central section of the barrier wall. In this case, the reduced flow path beneath the structure led to increased seepage rates. The barrier's flow efficiency under these conditions is illustrated below.

$$\mathbf{E_Q = \frac{(Q_0 - Q)}{Q_0}} \qquad \textbf{(4)}$$

Where $E_Q$ is the efficiency of water flow, $Q$ is the leakage flow in sheet pile $Q_o$ is the flow without sheet pile. Arafat et al. [46] concluded that the slot plays a significant role in groundwater pollution. The flow of water through the slot depends on the slot depth and position. The slot increases contamination discharge. In addition, the seepage discharge and its characteristics depend on the presence of the sheet pile.

### *3.1.Position of the Single Sheet Pile Utilization*

Hamad et al. [47] studied the influence of different sheet pile configurations on seepage. The SEEP/W code in GeoStudio 2018 was used to evaluate water seepage flow through a homogeneous, isotropic soil foundation and steady-state flow for a gravity-model dam, based on the Laplace differential equation. Also, two empirical equations were derived to predict the seepage quantity:

$$\mathbf{\frac{q}{Kh} = 0.512 - 0.258\left(\frac{d}{B}\right) - 0.092\left(\frac{d}{B}\right)^2 + 0.208\left(\frac{X}{B}\right) - 0.278\left(\frac{X}{B}\right)^2} \qquad \textbf{(5)}$$

$$\mathbf{\frac{q}{Kh} = 0.369 - 0.054\left(\frac{d}{B}\right) - 0.271\left(\frac{d}{B}\right)^2 + 0.217\left(\frac{X}{B}\right) - 0.289\left(\frac{X}{B}\right)^2} \qquad \textbf{(6)}$$

The study results indicated that the position of the sheet pile significantly influences seepage characteristics. The best position to drop the seepage and exit gradient is to install it at the toe point at 90° penetrations, but the pressure head increases when the sheet pile moves downstream. Shayan and Amiri-Tokaldany [48] confirmed that a right-angle penetration cutoff at the downstream end yields the best seepage reduction, and at the upstream end, penetration yields the maximum reduction in pressure head. This empirical equation was used to evaluate the seepage per unit width:

$$\mathbf{qo} = \frac{\mathbf{kh}}{\mathbf{1.05\frac{b}{D}+0.806}} \tag{7}$$

$$\frac{\mathbf{q}}{\mathbf{qo}} = -\mathbf{0.47}\left(\frac{\mathbf{x}}{\mathbf{b}}\right)^{2} + \mathbf{0.413}\left(\frac{\mathbf{x}}{\mathbf{b}}\right) - \mathbf{0.456}\frac{\mathbf{d}}{\mathbf{D}} + \mathbf{1} \tag{8}$$

Where *qo* is the discharge per unit weight, *x* is a horizontal space distance between sheet pile and upstream point, *D* is the depth of the permeable layer, *d* is sheet pile depth and *Kh* hydraulic conductivity. The hydraulic gradient downstream of the initial flow path is important. This is because it is the point where filtered water particles release the granular soil and flow into the free water of the downstream drain. Bakr et al. [49] concluded on the sheet pile location and degree of inclination of the exit gradient, and confirmed that the best place for penetration cutoff is the downstream end. Tung et al. [50] studied the influence of a single cutoff on the seepage under the rock fill dam. The dam base is 17m wide. The dam was made of homogeneous soil. The result indicated that the sheet pile bending moment increases when it moves toward the upstream. The following dam foundation parameters were (ϕ = 50, c = 18.7 kN/ m², k =1.45×10⁻⁸ m/s and E= 12000 kN/m²). The result indicated the maximum fluid victory was around the sheet pile, and the highest value referred to penetration cutoff from the toe point. The fluid vector is discharge per unit time. The fluid flow vector decreased with increased sheet pile depth at the upstream side due to the downward flow direction. Sheet pile positions help to reduce pore water pressure. The maximum pore-water pressure was on the upstream side; it gradually decreased, then decreased abruptly at the sheet pile position, and the minimum seepage rate and exit gradient were estimated when the cutoff was moved to the downstream side. As the sheet pile position shifts downstream, the average length of the flow path at the downstream end increases, reducing the exit gradient and thus improving the factor of safety against piping. Penetration of the downstream sheet pile is not recommended to reduce the uplift pressure head. In conclusion, the best position to penetrate the cutoff is upstream of the uplift head reduction point. The exit gradient is minimal when located at the toe point, 90° to the upstream world [51].

### 3.2.Inclination of the Single Sheet Pile Utilization

Esmat [52] confirmed that the inclined sheet pile plays a significant role in seepage control. The sheet pile was installed at angles from 0 ° to 180 ° and penetrated the upstream heel point. GeoStudio 2007 SEEP/W was used. The model dam was a gravity dam with soil permeability $2.5\times10^{-5}$ m/s. The result indicated that the sheet pile angle changes the flow net, and the minimum seepage flow occurs for the upstream sheet pile, with an angle of about 60 ° towards U/S, and the porewater pressure is minimum at about 125 °.

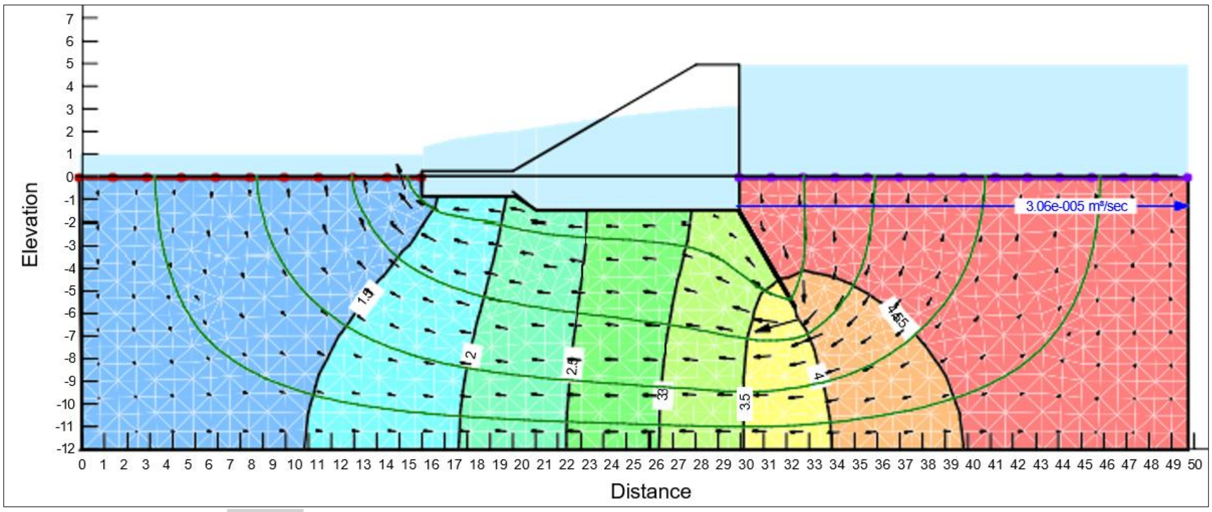

**Fig. 8** Single Sheet Pile Penetration at Upstream at 60° Degree.

Obead [51] used a FORTRAN 90 computer program to detect the impact of sheet pile angles on seepage. A model dam was a gravity dam. The foundation soil was homogeneous, isotropic and had saturated permeability. The sheet piles were penetrated in different positions, and the results showed that when the sheet pile is installed at the upstream heel with angles between 90° and 150° (toward the upstream), it provides the optimum condition for minimising head pressure. Different angles were tested between (30 ° and 150 °). The seepage value reached a minimum in the downstream area after a cutoff was installed at the D/S toe at an angle of around 120 °. Also, sheet pile inclination angles for homogeneous and isotropic soil were tested. The dam was a gravity dam. The (ANSYS V.11.0) program was used for analyzing. The result verified the previous studies. Dekhn et al. [53] confirmed that the upstream penetration sheet pile has a limited influence on seepage and on reducing the exit gradient. The exit gradient for structures and along the downstream side decreases when cutoff angles exceed 90 °, and the maximum reduction in exit gradient was observed when the angle was around 120 °, placed at the toe point. When the cutoff is placed at the midpoint of the hydraulic structure's base, high exit gradient and flow velocity reduction arise when the cutoff is inclined toward upstream ($\theta < 90°$). Muhammed et al. [54] investigated the sheet-pile effect beneath a concrete model dam in non-homogeneous, isotropic soil. The 2-D F.E. model ANYISIS Program has been used to detect the role of single sheet pile and inclination degree (30°, 45°, 60°, and 90°) on pressure head and velocity contour under the concrete dam. It has been confirmed that the best approach is to penetrate the sheet pile at the mid-point or upstream at 150° toward the upstream side. Alnealy [55] verified previous results; the best position for driving a single sheet pile in both single- and multiple-layer soils is at the downstream toe point, angled between 90° and 125° towards the upstream. This approach helps to reduce the exit gradient and seepage.

### ***3.3.Depth of the Single Sheet Pile Utilization***

Depth cutoff under is another economical technique with a great role. Sazzad [56] concluded that a silty clay foundation material may increase the risk of piping, as it allows water to pass through the layers more easily than a clay foundation. Using a cutoff at the downstream part has a greater role in elongating it toward the impermeable layer. Two different soils (silty clay and clay) were used in hydraulic permeability ($5 \times 10^{-7}$ m/s and $1.0 \times 10^{-9}$ m/s). Seepage velocity decreases if sheet pile length increases, because the longer the cutoff wall crosses, the more flow paths it covers, which causes the discharge and velocity to decrease as the wall length grows. Installing the downstream toe-point cutoff plays a greater role in reducing uplift head than other locations. In clay soils, the uplift pressure is more than that in silty clay due to the higher capillary rise in clay. Sabalan rock is an example of the role of cutoff depth in seepage maintenance. The dam located in Iran, on the Qara-Su River, with a clay core and a cutoff wall, was analysed using SEEP/W software; the soil foundation was heterogeneous and permeable. Heterogeneous refers to heterogeneity in the physical and chemical properties of soil as confirmed by [57]. The depth of the original cutoff was 50m beneath the dam, and the thickness of the clay core was 50 m. The result indicates that the cutoff position under the dam core does not affect seepage when the cutoff is varied in distances (0, 0.25, 0.50, 0.75, 1) at ratios of the cutoff position to the dam core base from the heel to the toe point. The hydraulic gradient was minimum at the dam shell. Hydraulic exit grain is reduced by transferring the cutoff from heel to toe, and is minimal at the toe, with a difference ratio of 34%. Transferring the cutoff does not obviously change seepage; only 0.2% differences were detected. The hydraulic gradient indirectly changes with the thickness of the clay core. Because the permeability of the clay core is lower than that of the shell, the uplift pressure under the dam decreases as the core thickness decreases. Approximately 39% difference in total uplift pressure as core thickness changes from 46 m to 28 m. With reduced soil permeability, the potential lines become so compressed that they produce greater potential drops over a shorter distance. Thus, the hydraulic gradient increases as permeability decreases. The effect of the clay core on the phreatic line is shown in Fig. 9, which causes a reduction in pressure head of about 20m.

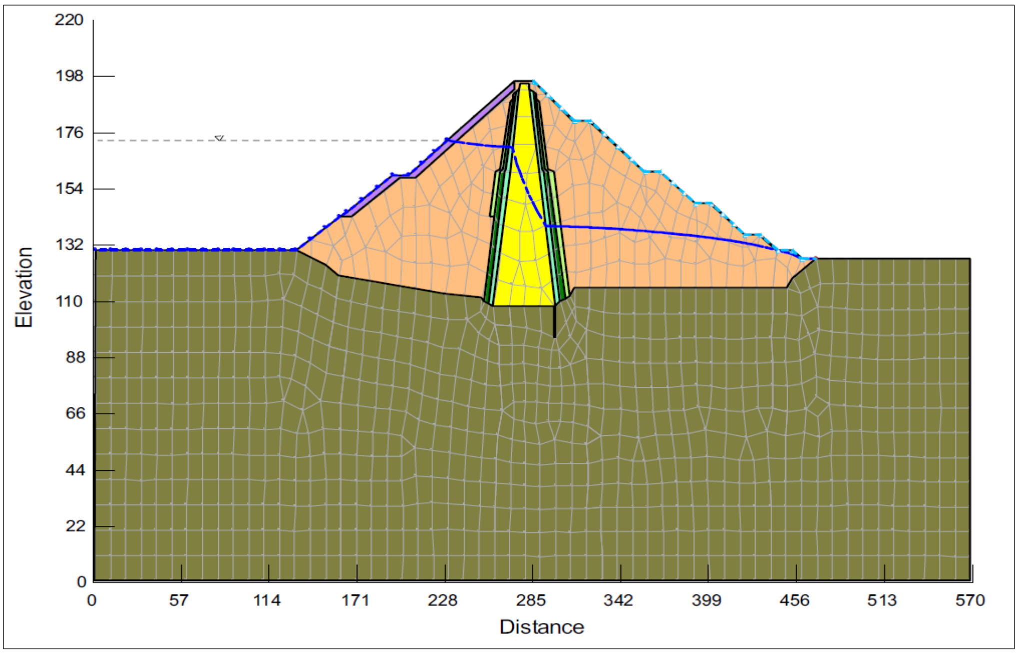

**Fig. 9** Iso-Pressure Curves of the Dam with a Cutoff 50 m Depth [58].

Uplift pressure under the Sabalan dam decreases with increasing cutoff depth, as confirmed by [59]. The foundation seepage decreases more significantly than the combined seepage from the dam body and foundation as the cutoff wall depth beneath the dam core increases. The percentage difference in seepage between the shortest and deepest cutoff walls is 4.33% for the dam body and foundation, and 49.31% for the foundation alone. Also, it is verified by [56, 60] for silty clay and clay foundations. Increasing the cutoff wall length leads to a decreasing hydraulic gradient. The optimum situation is to penetrate the sheet pile at the dam toe. In this case, the penetration cutoff under the clay core is better for penetrating the sheet pile in the centre, and the deeper cutoff is more effective in reducing seepage and uplift pressure. However, it requires greater financial investment.

## 4.CONCLUSION

The main conclusions of the present review paper could be summarized as follows:

- Karstification is a major problem in some Iraqi dams due to seepage and dissolving material beneath the dams. During the karstification, the great cave is created. The seepage characteristics depend on cave diameter, depth, and location.
- Sheet piling is an economical technique that can be used to maintain the seepage characteristics. The influence of the cavity phenomenon on dams can be mitigated by the sheet pile.
- Metal angle sheet pile penetration is the most economical and easiest way to maintain seepage. The best situation to mitigate seepage flow is to install a sheet pile at the downstream toe at an angle of 125° toward the upstream.
- The most effective situation to minimize the exit gradient is to penetrate the sheet pile at the downstream toe, angled between 90° and 125° toward the upstream direction.
- The optimum situation for minimum uplift pressure is the installation of a sheet pile at the upstream heel point, with an angle between 90° and 150° toward the upstream.
- In all cases, the deeper sheet pile utilization is better; the sheet pile depth should be elongated to intersect the impermeable layer.

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