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Seepage in Existing Earthen Dams in Sri Lanka

A. I. Liyanage, N. H. Priyankara and L. S. Sooriyabandara

Abstract: In Sri Lanka, most of the irrigation reservoirs were constructed by ancient Kings and these were made using earthen dams. The main purpose of constructing these reservoirs was to supply water to the irrigation fields. It can be noted that most of the earthen dams are situated in the dry zone, especially North central, North and East of Sri Lanka. Even though, Sri Lanka has a very popular history of construction of earthen dams, condition assessments of earthen dams were not been properly addressed as Sri Lanka was conquered and controlled by Europeans for about 400 years, as well as 30 years of civil war in the North and East. Hence, at present, most of the existing earthen dams show signs of seepage and piping. In the global scenario, seepage of earthen dams is considered as the second driven factor which makes dams fail. As such, many research studies have been conducted to study the behaviour of earthen dams and their associated failures and mitigation methods, etc. However, in Sri Lanka, only very limited research studies have been conducted to study the seepage behaviour of earthen dams. Therefore, in this research study, the existing seepage conditions of some of the earthen dams in Sri Lanka were evaluated. Based on this research study, it was revealed that, at present, there is huge seepage in Tissa Wewa and Minneriya reservoir, which indicates the importance of utilization of proper seepage controlling techniques in Sri Lanka.

Keywords: Earthen dam, Mitigation technique, Seepage, Tissa Wewa

1. Introduction

Dams are engineering structures constructed to retain water for different purposes [1]. In ancient history, dams were mainly built to supply water for irrigation works [2]. But, with the development of civilization, dams were built to cater for flood controlling, navigation, generating hydroelectricity and maintaining water quality, etc. According to history, the first known dam has been constructed somewhere around 2950 -2750 BC in Egypt [3]. Tarbela Dam on the Indus River in Pakistan is the largest earth filled dam and second largest dam in the world by structural volume [3-6]. Height of the dam is 153 m and volume is $153\ x\ 10^6\ m^3$[4].

According to ICOLD (International Commission on Large Dams), dams are mainly categorized into single-purpose and multi-purpose dams [7]. Figure 1 illustrates the distribution of single purpose dams in the world. It can be seen that 48% of the single purpose dams are used for irrigation purposes, 17% for hydroelectricity, 13% for water supply, 10% for flood control, 5% for recreation, and 1% for navigation and fish farming [7]. According to ICOLD, dams which are built using concrete, stones and other masonry are called gravity dams, arch dams or buttress dams. Dams built using earth or rock materials are called embankments or earthen dams. According to ICOLD, earthen or embankment dams represent 75% of all dams in the world [7]. This is because the earthen dams are the oldest type of dams, and most of the ancient dams are still in existence.

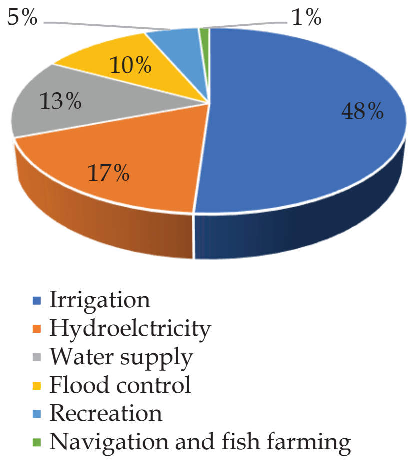

Figure 1 - Distribution of Single-Purpose Dams in the World [7]

Eng. A.I. Liyanage, AMIE(SL), B.Tec. Eng. (OUSL), MSc. (Ruhuna), MBA (Cardiff), Irrigation Engineer, Irrigation Department, Sri Lanka.
Email: liyanageamal@ymail.com
ORCID ID: http://orcid.org/0009-0000-6407-8892
Eng. (Prof.) N.H. Priyankara, C. Eng, MIE (SL), B.Sc. Eng. (Hons) (Moratuwa), M.Eng. (AIT), PhD. (Tohoku), MSLGS, Department of Civil and Environmental Engineering, University of Ruhuna
Email: nadeej@cee.ruh.ac.lk
ORCID ID: http://orcid.org/0000-0002-8775-7246
Eng. L.S. Sooriyabandara, C. Eng, MIE (SL), B.Sc. Eng. (Hons) (Moratuwa), Director of Irrigation (Hydraulics), Irrigation Department, Sri Lanka
Email: lsooriyabandara@yahoo.com

In this aspect, dam failures can occur in different formats, such as overtopping due to flooding, foundation defects including settlement and slope stability, piping due to internal erosion, cracks, vegetation and seepage inside the dam body, and structural failures induced by inadequate material use and poor maintenance. Dam failures can make huge damage to humans and their assets. The world's deadliest dam failure in the 20th century took place in Banqiao Reservoir Dam, Zhumadian city, China, in the year 1974. Due to this dam failure, 171,000 people died [8]. Figure 2 illustrates the most critical factors identified by Association of State Dam Safety Officials (ASDSO), USA for the dam failures [9].It can be seen that seepage and internal erosion is the second largest driving factor which creates dam failures. Therefore, seepage is a critical factor in the aspect of dam failures. As such, special consideration is required to identify and mitigate the seepage in earthen dams.

The Kantale Dam disaster on the 20th April 1986 is considered as the worst dam disaster in Sri Lanka's recent history [10]. After this major disaster, Irrigation Department of Sri Lanka established a new division called "Dam Safety" to monitor the stability of the earthen dams[10].

After the civilwar in the Northeast, the country was driven towards multipurpose development programs. Under these development programs, the Government of Sri Lanka has given attention to improve the existing irrigation network to enhance the agricultural facilities for farmers. The rehabilitation of existing reservoirs was a primary focus of these upgrading efforts [11]. Many such projects were implemented by local and foreign funding agencies. The primary focus of these rehabilitation efforts was to manage seepage in numerous existing irrigation tanks [11].

Based on the Dam inspection report: Dam safety division of Irrigation Department [12], it was noted that there is still considerable seepage in earthen dams in Sri Lanka. Even the major earthen dams such as Parakrama Samudra, Tissa Wewa and Girithale reservoir, etc. have considerable seepage. As such, the authorities have taken many steps to identify, monitor and mitigate the seepage in these earthen dams. Initially, actions have been taken to monitor and identify the seepage locations and measure the rate of seepage. Precautions are taken to control the seepage intensity by maintaining the reservoir water level followed by monitoring.

In Sri Lanka, the most common approach to control seepage is the use of a grout curtain using clay or a mixture of clay and cement. In addition to a grout curtain, upstream and downstream loading berms and clay cutoff walls are in practice. As such, provisions of sustainable solutions to control the seepage in earthen dams are required for catering the irrigation requirements of the people, especially in the dry zone of Sri Lanka. The capacity of reservoirs isa more critical factor in the aspect of supplying water for irrigation purposes. When seepage is exhibited in reservoirs, shortage of water is a major concern. Researchers from different nations have taken notice of the problems caused by seepage [13].

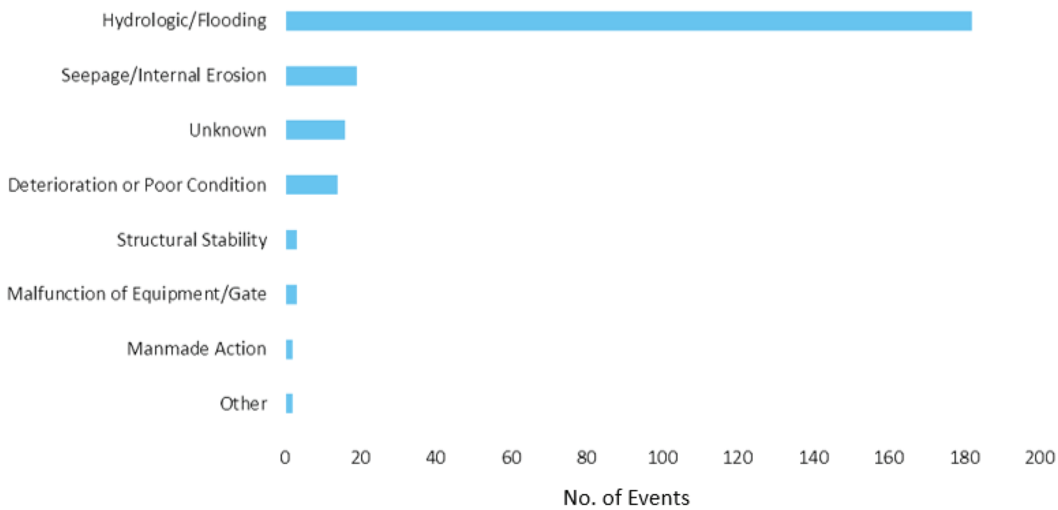

Figure 2 – Dam Incidents Data Base (Association of State Dam Safety Officials, USA) [9]

However, only very limited research studies have been conducted in Sri Lanka related to control of seepage in earthen dams[13-16]. Hence, in this research paper, the impact of seepage in earthen dams on irrigation activities and existing practices on mitigation of seepage in earthen dams in Sri Lanka are presented with respect to case studies.

2. Case Study -Tissa Wewa

2.1 Historical Background

Tissa Wewa is one of the largest ancient tanks in Southern Sri Lanka, which was constructed in the 3rd Century BC by King Yatala Tissa or regional King Maha Naga (250-210 BC) [17]. The tank was mainly built to address the scarcity of irrigation water in the area. According to a report written in 1858 by Harrison [18], the bund was built of large roughly-hewn blocks of stone, few of which are less than a ton in weight [17]. According to Parker [17], the earthen dam that was constructed across the KirindiOya to build Tissa Wewa is the world's first oblique dam. The dam has been constructed across the shortest trace with a 45^0angle to receive the maximum discharge of water from KirindiOya to Tissa Tank [17]. The ancient Sri Lankan irrigation engineers' vast practical expertise of handling water was interpreted by this oblique dam. When building dams across rivers, ancient humans could have thought that oblique dams would be more stable than squareones. As well, they might have believed that the dam may follow more stability against the impact loads that can be induced by larger trunks and debris rather than a square-shaped dam [17].

2.2 Technical Details

The Irrigation Department of Sri Lanka currently oversees Tissa Wewa, and Figure 3 depicts the area as it is today. Approximately 2750 acres of paddy fields are irrigated by tank water. The surface area of the tank at FSL (Full Supply Level) is 285.40 hectares and the storage capacity is 4.32 MCM (Million Cubic Meter). The tank's depth from its FSL is approximately 4.75 m. The minimum operation level is 1.53 m and the dead storage of the tank is 0.006 MCM. The type of the bund is earthen and the extended length is 1,493.52 m. The bund width is varying from 6 to 10 m and the maximum height of the bund is 4.88 m. The side slope of the bund in upstream (U/S) is 1:2 (1 vertical: 2 horizontal), whereas in downstream (D/S) it is 1:3. Tank supplies water for irrigation lands through a 70.271 km lengthy canal network [19][20].

Figure 3 - Present View of Tissa Wewa

2.3 Seepage in Tissa Wewa

The Irrigation Department of Sri Lanka (IDSL) is managing the sustainable use of water resources across the country. By implementing modern irrigation practices and promoting efficient water management techniques, IDSL aims to enhance agricultural productivity while preserving vital ecosystems. It is reported that 72 major reservoirs and 160 minor reservoirs are managed by IDSL [21]. Under the operational and maintenance activities on irrigation tanks, IDSL follows routine inspection of their major and minor dams through divisional irrigation offices.

Divisional irrigation engineers take the responsibility of continuous monitoring of dam status and they have to report the condition of dams to the ''Dam Safety'' division in the head office of IDSL, monthly. As a result of this monitoring system, seepage of the Tissa Wewa had been observed in the year 2019 [21]. Initially, seepage had been observed at one location as shown in Figure 4, and seepage was at its lowest level. Two further seepage spots were discovered in 2020[22].

According to the available recordings, it was found that peak seepage is observed when the tank water level reaches FSL, i.e. 4.75 m (15 feet) [22]. Table 1 presents the cumulative seepage values under different water levels [22]. According to the data presented, seepage appears when the tank water level reaches 3.96 m (13 feet). As a corrective measure to control the seepage, the tank water level must be maintained below 3.96 m (13 feet).

Figure 4 - A Seepage Location at Tissa Wewa

Table 1 – Cumulative Seepage under different Water Levels of the Tank

Water Level (m)	Seepage Amount (l/s)
3.96	1.41
4.00	6.47
4.10	9.65
4.15	12.32
4.20	14.05
4.25	15.89
4.30	17.73
4.35	19.30
4.43	22.49

Figure 5 depicts the variation of cumulative seepage over reservoir water level at different locations, which were identified at different stages. It can be seen that under the seepage of locations 1 and 2, maximum cumulative seepage is 3.0 ls^{-1} even under the reservoir water levelat FSL of 4.75 m. However, when the third seepage location was identified, cumulative seepage was increased to13.0 ls^{-1} under the water level at FSL. Further, it can be noted that, cumulative seepage has been significantly increased upto 22.49 ls^{-1}even under the low reservoir water level of 4.43 m when the fourth seepage location was identified.This clearly indicates the importance of immediate remedial actions once the seepage locations were recognized in the field.

2.4 Impact of Seepage on Agricultural Demand

Tissa tank is the major reservoir in the Hambantota zone which supplies irrigation water to paddy lands. Tank water is often used to cultivate 2750 acres of paddy land during the Yala and Maha seasons. In general, the Maha season lasts from October to March, while the Yala season lasts from April to September. However, the length of these seasons varies depending on the monsoon patterns that are accessible. Climate change has recently changed these monsoon seasons, as well as the start and finish times of the agricultural seasons of Yala and Maha. Apart from these two major cropping seasons, an intermediate cropping season is cultivated by the farmers [23]. As stated in section 2.3, even during the rainy seasons, the tank water level is kept below 3.96 m (13 feet) because of seepage. As such, full capacity of the tank cannot be utilized for the irrigation purposes due to huge seepage. Table 2 shows the tank capacity under different water levels [22].

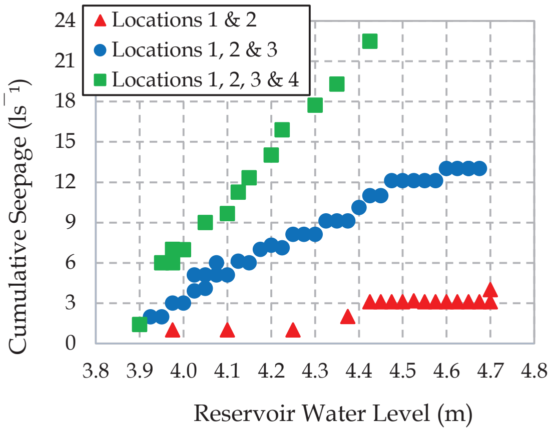

Figure 5 – Variation of Cumulative Seepage Versus Reservoir Water Level

Table 2 - Tank Capacity under different Water Levels [22]

Water Level(Feet)	Tank Capacity (Acre-Feet)
10.0	835
11.0	1150
12.0	1575
13.0	2025
14.0	2565
15.0	3175
15.8	3510

According to the tabulated values, when the tank water level is around 13 feet, storage of the tank is 2025 acre-feet while the water level is in its FSL of 15.8 feet (4.75 m), capacity is 3510 acre-feet. This clearly implies that, when the water level is increased by 2.8 feet (from 13 feet to 15.8 feet), storage of the tank can be increased by 73 % (storage increase from

2025acre-feet to 3510 acre-feet). Therefore, it is very important to control the seepage within the earthen dams.

In comparison to FSL, about 1500 acre-feet of water volume was lost in the tank as a result of the immediate remedial action of keeping the water level below 13 feet to stop the seepage. An extra 500 acres of paddy land can be grown in a single season with 1500 acre-feet of water volume if the 3 acre-feet of water duty (water requirement per 1 acre of paddy land per season) is assumed [24]. About 2050 kg of yield per acre is produced in the Hambantota district [25]. Therefore, in a single season, 500 acres of rice lands can yield 1,025,000 kg of paddy production. According to this argument, the country's economic progress is aided by the earthen dams' ability to prevent seepage.

In the year 2022, the Engineering Material Branch in IDSL, introduced a thin clay cutoff wall at upstream (parallel to the seepage locations) to control the seepage. After introduction of the clay cutoff wall, seepage has been controlled and now it is maintained around 4.5 l/s. Even if the seepage is controlled at this level, Table 3 shows the possible irrigable area to be cultivated using seepage water. Based on the calculations presented in Table 3, it can be noted that about 210 acres of cultivated lands can be irrigated per year using the seepage water. These results indicate that, even now, if the seepage is maintained in existing intensity, it looses a considerable amount of water which is sufficient to commence the cultivation of around 210 acres.

The above calculations are based on the technical guidelines provided by the Irrigation Department [23] [24]. For harvesting months, there is no irrigation requirement. However, at present, even during the harvesting months (ex. March, August and September), there is a trend for intermediate cultivation. As such, the water requirement in the adjoining months was used to estimate the irrigation requirements in those months. For example, the water requirement in the month of March was assumed as that of February. Similarly, water requirements of months of August and September were assumed as those of July and October, respectively.

Typical calculations related to possible cultivation area using seepage for the month of October is as follows:

Estimated rate of Seepage is = 4.5 l/s

(1 cusec = 1 ft^3/s = 28.32l/s)

$$=\frac{1}{28.32} \times 4.5 \text{ cusec}$$

$$= 0.159 \text{ cusec}$$

Irrigation duty or water requirement per month October (Table 3) = 0.28 acre-feet

Therefore, water requirement per acre per month October =43560 × 0.28

(1 Acre =43,560 ft^2)

=12,196.8 $ft^3/acre$

Rate of water requirement per month October

$$= \frac{12196.8\ ft^3/acre}{30\times24\times3600\ sec}$$

$$= 0.0047\ ft^3/s/\text{acre}$$

Number of acres that can be cultivated using seepage in the month October

$$= \frac{0.159\ ft^3/S}{0.0047\ ft^3/S/acre}$$

= 33.77 acres

Table 3 - Possible Cultivation Area based on Existing Seepage

Month	Irrigation Requirement (Acre-Feet)	Possible Cultivation Area (Acres)
October	0.28	33.77
November	0.46	20.56
December	0.63	15.00
January	0.84	11.26
February	0.40	23.64
March	0.40*	23.64
April	0.45	21.01
May	1.10	8.57
June	1.40	6.75
July	1.34	7.05
August	1.34*	7.05
September	0.28*	33.77
Total		**210**

*Assumed values based on adjoining month

This study revealed that due to the seepage, a considerable amount of water losses occur, which can be used to irrigate large irrigable lands. Hence, it is clear that seepage issues should be treated immediately when they occur and it is a timely needed requirement of Sri Lanka.

2.5 Seepage Issues in Other Reservoirs

As Sri Lanka is an agricultural based country, there are large numbers of major and minor reservoirs throughout the country. Most of these tanks were built by ancient Kings

1000-2000 years ago [11] [17]. With time, at present, these reservoirs have developed seepage issues through the earthen dams. For instance, seepage problems are also present in Parakrama Samudra. In addition, there are seepage problems in major reservoirs like Girithale and Minneriya tanks. Table 4 shows few reservoirs that exhibited considerable seepage losses [26][27]. The seepage points at the Parakrama Samudra and Girithale tank are depicted in Figure 6 and Figure 7, respectively.

Table 4 - Seepage in Major Reservoirs[26][27]

Name of Reservoir	Seepage (l/s)
Parakrama Samudra	8.45
Minneriya	24.8
Kawdulla	4.4
Girithale	14.3
Ethimale	2.5
Kakandura	2.0

Figure 6 - Seepage in Parakrama Samudra

3. Control of Seepage - Case Studies

This section presents the current methods used to control the seepage in earthen dams.

Figure 7 - Seepage Induced Boiling point in Girithale Tank

3.1 Case Study –Vendarasankulam Reservoir

Vendarasankulam reservoir is a twin reservoir located in Kanatale in the Eastern province. This is an ancient earthen reservoir which has been built close to the Kanthale tank. Once severe seepage was identified in the reservoir, the governing agency, IDSL, has taken different methods to rectify this issue [13]. In this case study, reasons for the seepage and methods adopted by IDSL to rectify the seepage problem in Vendarasankulam reservoir are discussed.

IDSL conducted a sub-surface exploration and closely monitored the platform to identify the root causes for the seepage in the Vendarasankulam reservoir. Based on sub-surface explorations and monitoring data, following factors were identified as the key reasons to induce seepage in the reservoir [13].

1. Tank bund is mainly composed of Silty Gravel material (GM). According to Ponrajah[23] Clayey Sand (SC) is recommended as the bund filling material. Since Silty Gravel (GM) is highly permeable material, water in the reservoir easily seeps through the earthen dam.
2. It was reported that material in the bund is heterogeneous [13]. In addition to the silty gravel, the bund consists of decomposed rock, which may enhance the seepage through the earthen dam.
3. Very low CR (Core Recovery) and RQD (Rock Quality Designation) values indicated that rock underneath bund is highly fractured, which may further enhance the seepage.

4. The Lugeon value results show a quite high permeability value indicating that rock is highly previous.

3.1.1 Seepage Control using Loading Berm in Downstream

The seepage of Vendrasankulam reservoir has existed for more than 20 years and IDSL introduced a loading berm to minimize the seepage in 1989 [13]. According to available data, IDSL constructed a loading berm as shown in Figure 8. The components in loading berm are stabilization fill, a sand blanket, a network of sand drains and a toe drain. During the construction, a strip of sand blanket was merged with sand drains and placed along the downstream toe of the dam. Sand drains had been constructed underlying the sand blanket to channel the water from the sand drains to the sand blanket. A rubble-pitched toe drain had been constructed to drain out all the drain water channels from the sand drain network. About 3m high stabilization fill had been placed on top of the sand blanket to create a surcharge effect (Figure 8). After construction of the loading berm, the following observations were made through the dam body [13].

1. Sand was washed away from the sand blanket in the toe drain. As a result, existing pot holes lead to failure of the bund.
2. Seepage is continuing along the entire length of the dam.
3. A new boggy area was founded downstream of the dam.
4. Reservoir storage was limited to 10m level. This is 60% of the reservoir's full capacity.
5. In the year 2002, reservoir bund shows piping at some locations.

These observations show that loading berm technology used to control the seepage in Vendarasankulam reservoir was not successful. Hence IDSL tried a new method to control this severe seepage issue.

3.1.2 Seepage Control using Grouting

After the loading berm failed to minimize the seepage issues in Vendarasankulam reservoir, IDSL moved to the use of grouting method to control the seepage. Before commencement of the grouting works, drilling had been carried out to explore the subsurface conditions. Grouting work had been carried out in two stages. Stage 1 was addressed for overburden and stage 2 was addressed for treatment of rocky foundation [13].

At stage 1, 37 holes were drilled in the overburden in two rows in parallel arrangement with a 3.0m distance from the centre line of the bund top as shown in Figure 9. The grout used had the composition of water:clay:cement ratio of 20:10:1 by volume.

Stage 2 had been started 2 months after completion of stage 1 in the year 2007. Thirty-six (36) holes were drilled in two parallel axeslines, 1.5m away from the centre line of the bund top. In overburden layers, stage 1 mix ratios were adopted while rock layer was treated by cement grout only. Initially, 7:1 water:cement ratio was used. However, based on the site observations, mix ratios had been modified to 5:1 and later 3:1.

After the completion of grouting process, it was observed that seepage reduced considerably. However, with time, seepage issues again arose in Vendarasankulam reservoir (Figure 10) and IDSLgave attention to apply a new method or technology to control the seepage.

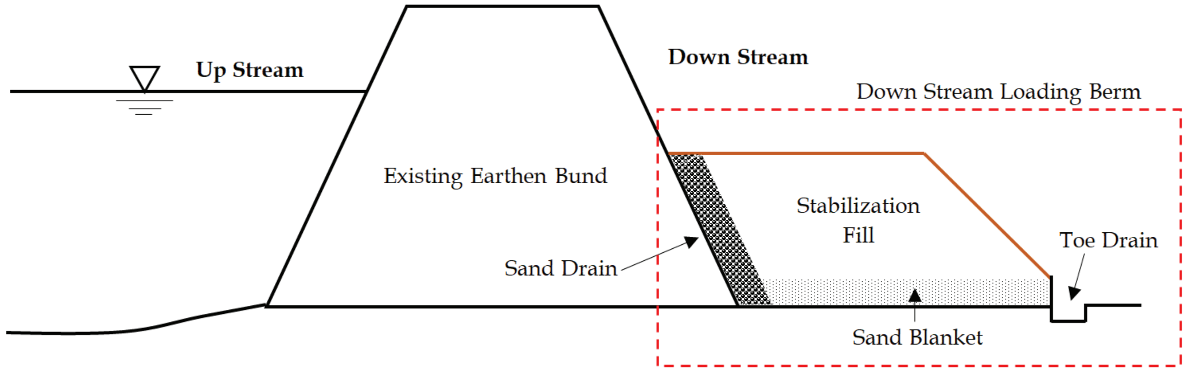

Figure 8 - Schematic View of the Loading Berm

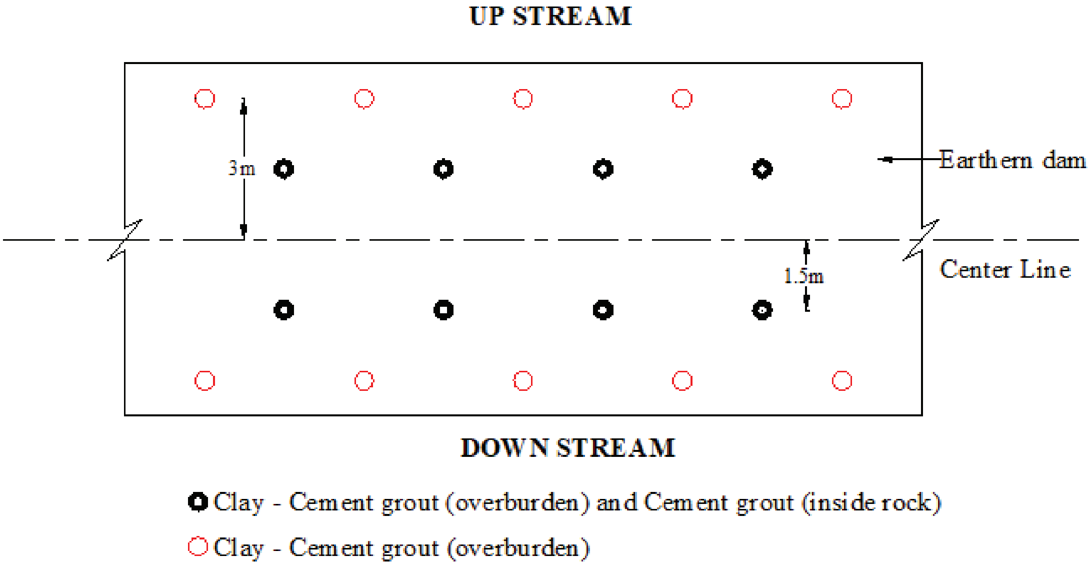

Figure 9 – Grouting Arrangement in Vendarasankulam Reservoir

At present, seepage is controlled by limiting the storage capacity of the tank. The tank capacity on its FSL is around 22,000 acre-feet. However, due to high seepage, tank storage was limited to 16,000 acre-feet as the controlling action. Based on the above analysis, it can be clearly seen that the conventional methods adopted to control the seepage were not successful. Hence, this case study highlighted the requirement for new construction method/s for successful seepage mitigation.

Figure 10 - Present Day Seepage at Vendarasankulam Reservoir

3.2 Case Study - Clay Core Trench at Debarawewa Reservoir

Debarawewa Reservoir is a 2500 acre-feet reservoir situated in Hambantota district. The tank has exhibited seepage issues in the year 2019 [20]. Many large trees were on the upstream and as a result of that, root systems have extended to inside the dam body. With time, one of the huge trees died and after a couple of months, seepage was observed in the downstream exactly opposite the location where the above tree was. As per site inspections and the Engineer's advice, IDSL constructed a clay cut-off wall along the existing dam body around a 50m stretch which covers the seepage locations. Clayey Sand (SC) was used as the filling material. Photo of the excavation of trench to construct the clay cutoff wall is illustrated in Figure 11 whereas clay core placement and compaction is depicted in Figure 12. It was reported that seepage has disappeared after this rectification technique [28].

Figure 11 – Clay Core Trench Excavation in Debarawewa Reservoir

Figure 12 - Clay Core Placement and Compaction

3.3 Case Study - Upstream Loading at Handapanagala Reservoir

A successful implementation of upstream loading technique to control the seepage is reported in Handapanagala reservoir. Hadapanagala reservoir is a 15,590 acre-feet reservoir situated in the Monaragala district. It was built in the ancient period and caters for more than 3500 acres of paddy and other crops. Initially, the reservoir was 5 m high and its capacity was 5000 acre–feet of water. Under the Uma Oya downstream development project, reservoir was developed to store 15,590 acre-feet. Subjected to reservoir development, the bund was raised to 15 m from the existing 5 m height. After completion of the reservoir bund, it had been identified that a 3.8 $l/s$of seepage occurred.

Figure 13 - Upstream Loading in Hadapanagala Reservoir

Hence, as per the engineer's advice, upstream was loaded by large boulders around 10 m distance inside the tank bed along the suspected seepage origin places as shown in Figure 13. This loading was implemented in the year 2018 and seepage disappeared after completion of this upstream loading [29].

4. Conclusions

The study revealed that most of the existing earthen dams in Sri Lanka which were built by ancient Kings have developed considerable seepage of different intensities. By taking TissaWewa as a case study, it was demonstrated that the seepage of4.5 l/s through dam is sufficient to cultivate 210 acres of paddy lands. It was observed that lowering the reservoir's water level is the most widely used and straightforward strategy to reduce seepage in the short term. However, in order to control the seepage, long-term measures must be addressed. IDSL uses grouting, clay core, upstream loading, downstream loading, and other methods to control the seepage. The field records indicate that there is no assurance on the use of the aforementioned approaches to control seepage. In certain places, certain methods worked well, but in others, they broke down. For instance, loading berm technology worked well in the Handapanagala reservoir project but failed in the Vendarasankulam reservoir project. Similar to this, the use of clay core to reduce seepage in Tissa Wewa did not work out, but it was successfully used in the Debarawewa project. This demonstrates unequivocally how crucial it is to choose the best mitigation strategies depending on the subsurface situation. Additionally, since newly developed seepage mitigation techniques like soil-bentonite (SB) and soil-cement-bentonite (SCB) cutoff walls have been effectively implemented in other countries, more research is required to apply them in Sri Lanka.

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