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Study on SCB Cut-off Walls to Control the Seepage in Earthen Dams

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Abstract: Slurry trench cutoff walls have been used since the 1970s and have come into widespread usage since the 1980s as a component in overall remedial systems to control groundwater flow, particularly for seepage mitigation in earthen dams. Different types of slurry trench cutoff walls, such as Soil-Bentonite (SB), Cement-Bentonite (CB) and Soil-Cement-Bentonite (SCB) are used to control seepage. Although numerous methods have been adopted, there is still a question about the most effective method to control seepage. As such, this research study reviews the possibility of using Soil-Cement-Bentonite (SCB) cutoff walls for seepage control in earthen dams. This paper discusses the available construction procedures and required engineering characteristics of SCB backfill such as gradation, unconfined compressive strength, permeability and durability. SCB backfill is composed of soil, cement, and bentonite. Most literature indicates that cement and bentonite contents directly affect the strength and permeability characteristics of SCB cutoff walls. SCB cutoff walls become more economical as trench excavated soil is used as the backfill material. It was noted that in order to get the maximum benefit of SCB, fines content of backfill material should be 10%-30%. The addition of cement and bentonite to the SCB mix delivers moderate strength and lower permeability in the cutoff wall. Cement enhances strength, while bentonite reduces permeability. The basic design strength of SCB cutoff walls is 100 kPa, which can be increased up to 1000 kPa by varying the cement and bentonite content. In terms of permeability, values of less than 1×10^{-6} cm/s can be achieved in SCB cutoff walls. However, there are many incompatibilities between the cement and bentonite ratio suggested after conducting laboratory experiments and those applied in the field. Therefore, it is necessary to investigate the optimum cement and bentonite contents to deliver the most economical and best-performing SCB cutoff wall. Additionally, it is essential to study the influence of alternative wetting-drying condition on the performance of SCB cutoff walls.

Keywords: Unconfined compressive strength, Hydraulic conductivity, Soi-Cement-Bentonite cutoff wall

1. Introduction

Slurry trench installation methods are widely used to establish vertical groundwater cutoff systems, mitigating groundwater seepage from earth dams and reducing the leakage of contaminants through the subsoil profile [1-4]. Cutoff walls installed using the slurry trench method are typically classified based on the material composition of the final wall. The three most common types of slurry trench cutoff walls are Soil-Bentonite (SB), Cement-Bentonite (CB), and Soil-Cement-Bentonite (SCB). The first use of SB backfill was reported in the mid-1940s at the Mississippi River by the U.S. Army Corps of Engineers to control seepage [5]. Later, SB walls were developed and used as anti-seepage barriers in dam construction projects from the 1970s onward. The earliest record of CB walls dates back to the 1960s in France, with the first CB cutoff walls constructed in 1965 [5].

Typically, SB cutoff walls have a compressive strength of 5-15 kPa, while CB cutoff walls can achieve up to 1 MPa due to the cementitious properties of the CB slurry [6]. The permeability coefficient of SB cutoff walls is generally $1x10^{-7}$ cm/s, which is significantly lower than that of CB cutoff walls (1×10^{-6} cm/s) [6]. Unlike CB cutoff walls, SB walls can utilize on-site soil for backfill preparation, making them more economical [6]. However, SB walls have relatively low mechanical

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strength and cannot withstand large loads. Additionally, in contaminated environments, the expansion of bentonite will be reduced which significantly degrade the anti-seepage performance of SB walls [5]. On the other hand, CB cutoff walls are more suitable for locations with poor soil quality or where high mechanical strength is required. However, due to their higher permeability coefficient, CB walls are not ideal for applications requiring very low permeability [5]. This implies that cutoff wall materials must balance low permeability with sufficient compressive strength to ensure long-term performance [4, 6]. In this regard, many researchers have focused on modifying bentonite slurries to improve their compatibility with surrounding environments and to achieve a balance of moderate strength and low permeability, addressing the limitations of both CB and SB walls [5].

Soil-Cement-Bentonite (SCB) cutoff walls have emerged as a promising alternative to CB and SB walls, offering several advantages that address the limitations of conventional cutoff walls. SCB walls are constructed using a self-hardening slurry that combines soil, bentonite, and cement to form an impermeable barrier with enhanced strength and durability. Typically, SCB walls have sufficient strength to bear surface loads [7]. In engineering design practice, SCB cutoff walls are usually designed with a basic strength of 100 kPa [6]. Additionally, they can achieve hydraulic conductivity levels of less than $1 \times 10^{-6}\ cm/s$, offering an economic advantage by utilizing on-site excavated soils [7]. Despite their potential, there are still knowledge gaps regarding the long-term performance, optimal material composition, and behaviour of SCB walls under various environmental conditions. For example, further research is needed to determine the optimum soil-cement-bentonite ratios for different soil types and applications, as well as how these ratios affect permeability, strength, and durability. There is also a need to investigate the long-term performance of SCB walls under different loading and environmental conditions, including the effects of chemical exposure, wet-dry cycles, and mechanical stresses. Furthermore, previous reviews on self-hardening slurries are outdated and incomplete [5].

Thus, this review paper discusses the available construction procedures for SCB cutoff walls and their engineering characteristics, including backfill soil gradation, unconfined compressive strength, permeability and durability, based on the available literature. The reviewed details about construction procedures and engineering characteristics, along with their statistical analysis, will contribute to a better understanding of the general and specific performance of SCB cutoff walls. Identifying general and specific deficiencies will open new research areas for future studies. These efforts will promote innovation and development of SCB cutoff wall technology in the construction industry.

2. Construction Procedure

Conventional slurry trenching is a proven technology and is the most common method for installing cutoff walls [8]. SCB wall is constructed in much the same manner as a conventional SB wall [9, 10]. After conducting a site survey and demarcating the layout of the wall, a narrow trench is excavated under bentonite slurry using excavation equipment such as excavators, clamshells, long-arm excavators, or drilling machines. During the excavation process, bentonite slurry is used to maintain trench stability. Typically, 6-7% bentonite by weight of water is used to stabilize the trench [11, 12] as shown in Figure 1. The trench is excavated to the required depth, with the bentonite-water slurry preventing the collapse of the trench walls. Excavation can proceed to depths of up to 40 meters using bentonite-water slurry [12].

Figure 1 - Trenching under bentonite slurry in Miller pump station in Naples [11]

Once trench excavation is completed, the construction phase progresses to the preparation and placement of the backfill. The integrity of an SCB wall relies heavily on the proper proportioning and mixing of soil, cement and bentonite. Achieving the correct mix ratio is critical for the wall's permeability, strength and structural integrity. The mixture is typically prepared in a batch plant or open area near the trench, where soil, cement and bentonite are combined and homogenized. At the backfill mixing location, excavated soil, bentonite and cement are mixed until all required properties are achieved. In order to prepare the SCB mix, hydrated bentonite is used, in which bentonite power is mixed and soaked in water for 24 hours. Then, bentonite slurry is spread over the excavated material and thoroughly mixed using a bulldozer. After soil and bentonite have been sufficiently mixed, cement slurry is added and mixed together to form SCB slurry [11]. Then, the backfill material (SCB) is transported to the site and placed at the top of the trench, allowing it to slump or slide into the trench in a manner that minimizes the entrapment of slurry and soil within the wall. As backfilling proceeds, the slope of the backfill is maintained at a ratio of 4:1 or 5:1 (horizontal to vertical) and pushed forward towards the excavation heading [12]. When backfilling is placed at different times over previously placed layers, construction joints are formed. However, to the authors' knowledge, no studies have been conducted on the performance of these construction joints.The SCB wall requires time to cure, during which the cement component hydrates, gaining strength and reducing permeability. The curing period may vary depending on weather conditions and project specifications, typically spanning several days. To protect the wall during curing, measures are taken to shield it from erosion or damage due to environmental exposure. Covering the trench or applying protective layers can prevent issues such as desiccation or cracking, which might compromise the wall's impermeability.

A comprehensive monitoring and quality assurance process is conducted throughout and after the construction of the SCB walls. Parameters such as permeability, strength and alignment are measured to ensure the wall meets design standards. During the placement of the SCB backfill in the excavated trench, samples are collected and sent to the laboratory to measure unconfined compressive strength and permeability [13]. This ensures that the placed SCB mix achieves the target final properties. During SCB cutoff wall installations, samples of the SCB backfill are typically collected at a minimum frequency of 1 per 25 linear meters or 1 per 875 m^3, whichever is more frequent [13]. Post-construction inspections may involve evaluating changes in hydraulic conductivity using piezometers and observing desiccation or cracks in the placed SCB wall.

3. Engineering Characteristics of SCB Backfill

3.1 Backfill Soil Gradation

SCB backfill is created by mixing soils with hydrated bentonite slurry and ordinary Portland cement grout [14]. Excavated soils (spoil) are typically used in SCB mix preparation if they meet the desired properties. When the excavated soil does not fulfil the requirements for SCB backfill, a borrowed source of soil material is required to prepare the backfill mix [7]. For example, if a cutoff wall is excavated through very coarse material, the excavated material mixed with bentonite slurry may not meet the required properties, as it could be too coarse or internally unstable. In such cases, the designer may select the most suitable soil type to create the backfill mix, following previous designs and published general guidelines [7]. General guidelines for selecting suitable backfill materials for SCB backfill are recommended in design standards by the U.S. Department of the Interior Bureau of Reclamation, as shown in Table 1.

Table 1 - Typical gradation limits for SCB backfill (Design Standards No: 13, Embankments Dams) [7]

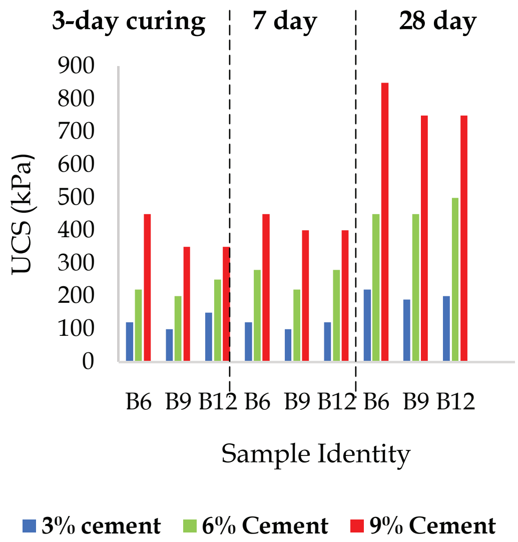
Screen Size (mm)	Europe and Australia	United States
	Percent passing by weight (%)	Percent passing by weight (%)
75	80-100	80-100
18.75	40-100	50-100
4.76	30-70	30-70
0.6	20-50	25-60
0.075	10-25	10-30

According to these guidelines, soils with the specified gradation have been successfully used in SCB cutoff wall construction in Australia, Europe and the USA. Furthermore, the guidelines mention that excavated soil containing pockets of organic materials or zones of plastic clay may not be suitable, as it would not produce a homogeneous SCB mix [6]. Based on the guidelines, soils with less than 10% fines are not recommended for backfill, nor are soils with over 25-30% fines. Filz [15] recommended 30-50% fines (by mix volume) for optimum SCB backfill to achieve lower permeability characteristics in the final wall. Evans and Cooley [10] proposed a coarse particle content of 50-70% (by volume) to contribute to the wall's strength and prevent excessive shrinkage or cracking. Ryan and Day [4] suggested that a minimum of 10% plastic fines in the soil is recommended for a well-proportioned SCB mixture. The presence of fines in the backfill mix is beneficial for achieving optimal performance in SCB mixes [7]. However, excessive fines may increase the water requirement in the SCB mix, resulting in a less dense backfill [3]. Additionally, higher percentages of plastic fines may negatively impact the homogeneity of the mixture [6]. Non-homogeneity in the mixture can lead to problems in the constructed SCB wall, such as higher permeability windows, creating weak zones that may be more erodible than other portions of the wall [6]. Moreover, high clay content in the fines can cause shrinkage and cracking in SCB cutoff walls. Balancing the clay content with silt or other fines helps to reduce the risk of shrinkage and maintains wall continuity and durability [16]. Conversely, lack of fines can lead to higher permeability and reduced effectiveness in groundwater control. Therefore, fines must be carefully monitored to ensure they meet the minimum required threshold for hydraulic performance. Ultimately, soil gradation must be designed based on site conditions, considering local soils and environmental factors, with adjustments as necessary to meet permeability and strength requirements [15].

3.2 Unconfined Compressive Strength

The strength of a cutoff wall is not only linked to bearing surface loads but also to handling durability and deformations [17]. However, cutoff walls should be compatible with the stiffness of the surrounding embankment soil to mitigate uneven deformations [17]. Therefore, the required strength of a cutoff wall should be determined by considering these factors. According to Ryan and Day [4], the minimumstrength properties of SCB walls typically range from 100 to 700 kPa after 28-day curing period. However, in field applications, SCB walls even have reached strengths of up to 1000 kPa [4, 5].

Several laboratory studies [6, 18, 19] have explored the interactions between different cement and bentonite content ratios on the Unconfined Compressive Strength (UCS) of SCB walls. Zhou et al. [6] conducted a comprehensive laboratory experiment with cement content varying from 3% to 9% and bentonite content ranging from 6% to 12%. Figure 2 illustrates the UCS values under different curing periods. The study revealed that the strength of the samples increases with higher cement content. For example, samples with 9% cement showed peak strength values, even with varying bentonite content. Similar to conventional concrete, SCB also achieved its highest strength after 28-days curing period. Another study by Hui et al. [18] used 30% cement content with 5-15% bentonite and achieved UCS values of 850-1120 kPa after 28-days. De Silva and Wijewardhana [19] used a minimum of 3% cement content and achieved a compressive strength of 98 kPa. Wu et al. [20] reported a UCS of 520 kPa for a sample containing 5% cement and 5% bentonite and 600 kPa for a mix with 10% cement and 10% bentonite. Additionally, Andromalos and Fisher [21] proposed 2-3% bentonite content and 4-10% cement content for SCB to achieve a compressive strength of 350 kPa. However, excessive cement content may create joints in the backfill or reduce the wall's flexibility under loads, potentially leading to cracks caused by crushing or shear-type loadings [4]. In a field application in California, USA, 9% cement content was used to achieve a UCS of 1000 kPa after 28-days, while 12% cement content achieved 1345 kPa under 9% bentonite content. In two field applications in Nepal and Canada, 100 kPa UCS was achieved using 3.5% and 6-8% cement content, respectively, with bentonite content maintained at 1-3% in both cases. Ruffing and Evans [14] designed an SCB cutoff wall in Kentucky, USA, recommending 5% cement and 6% bentonite content. After 28-day curing period, the SCB cutoff wall achieved a UCS of 300 kPa.



(Note: Bx – B stands for Bentonite, where x represents the bentonite content (x = 6, 9, 12))

Figure 2 - Unconfined compressive strength values [6]

Although the amount of bentonite in SCB slurry is relatively low, it has a notable effect on strength, with research revealing opposing trends [15]. Some studies indicate that increasing bentonite content leads to a decrease in the compressive strength of SCB slurry [6, 18]. Hence, a comparison of Zhou et al. [6] and Hui et al. [18] is illustrated in Figure 3 to study the impact of bentonite content on strength.

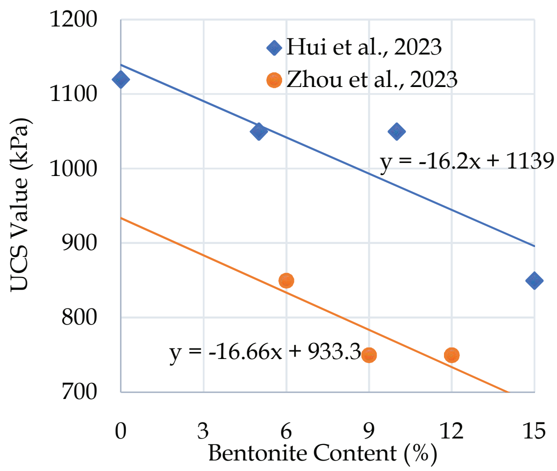


Figure 3 – Comparison between UCS value and bentonite content [6, 18]

Zhou et al. [6] (using results for 9% cement content) showed a downward trend in UCS values as bentonite content increased from 6% to 12%. The maximum UCS of 850 kPa was observed for 6% bentonite, while samples with 9% and 12% bentonite achieved a maximum of 750 kPa. Based on these observations, it can be inferred that UCS values decrease as bentonite content increases up to 12% [6]. The linear model in Figure 3 shows a negative correlation between bentonite content and UCS. However, further research with additional bentonite contents is needed to confirm this trend and understand the behaviour of UCS under varying bentonite contents. In Hui et al. [18], increasing bentonite content from 0% to 15% resulted in a strength reduction. However, when bentonite content increased from 5% to 10%, UCS values ranged from 1100 to 1050 kPa. A further increase to 10%-15% bentonite content caused a significant drop in UCS (1050 to 850 kPa). The linear models in both Zhou et al. [6] and Hui et al. [18] show similar gradients, indicating compatible results regarding the influence of bentonite content on UCS. However, both studies showed that increase of bentonite affected to reduce the strength of SCB under the specified conditions. Furthermore, these observations highlighted the importance of understanding the optimum values of bentonite and cement contents in SCB cutoff wall construction to deliver best performed and cost-effective SCB walls.

3.3 Permeability

The permeability of the SCB cutoff wall is the result of a complex interaction between the various components of the backfill mix [4]. Rayan and Day [4] stated that the minimum permeability value required for SCB cutoff wall is $1\, x\, 10^{-6}\, cm/s$. Furthermore, it has been reported that the addition of Ordinary Portland cement negatively affects the permeability as it affects the ability of bentonite to swell and retain water, as well as requires adding more water to achieve the required slump. However, adding more water leads to a decrease in the density and increases porosity. Thus, it increases the permeability coefficient. Moreover, it was reported that bentonite does not make any significant influence in the SCB mix concerning permeability coefficient. However, there are limited research studies about SCB cutoff walls related to permeability [4, 6, 18, 22].

Zhou et al.[6] studied the effects of cement content and bentonite content on the permeability of SCB slurry and coefficent of pereabilityof samples were determined using falling head peremeameter [6]. It was reported that the permeability coefficient dropped significantly with an increase in cement content (up to a certain content) for fixed bentonite content. The laboratory test results reported by Zhou et al. [6] as illustrated in Figure 4 is used for further discussion.

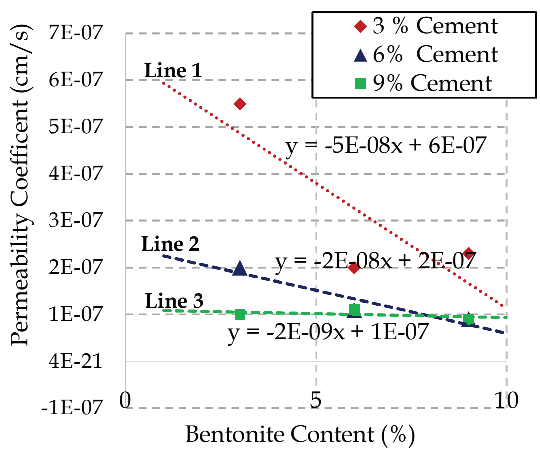


Figure 4 - Variation of permeability coefficient vs bentonite content for different cement contents [6]

Comparing line 1 and line 2 in Figure 4, it can be noted that the permeability coefficient significantly dropped with respect to bentonite content when the cement content from 3% to 6%. However, a slight decrease in permeability coefficient can be observed when the cement content varies from 6% to 9% (lines 2 and 3). Thus, it can be concluded that an increase in cement content imposes a reduction in the permeability coefficient of a given bentonite content. Also according to Figure 4, the lowest permeability coefficient was obtained for the samples which contained 9% cement. However, all the samples showed a permeability coefficient less than $1\,x\,10^{-6} cm/s$. Furthermore, lines 1, 2 and 3 showed a negative combination between bentonite content and permeability coefficient. Based on this observation, it can be concluded that, when bentonite content increased permeability coefficient decreased and become constant after a certain level. Hence, all these observations pointed out that the permeability coefficient decreases when increasing cement and bentonite content up to a certain limit.

Hui et al. [18] have studied the variation of permeability coefficient under different bentonite contents (5%, 10% and 15%) for a fixed cement content of 30%. The study presented that the permeability coefficient decreases when the bentonite content increases. Figure 5 shows the variation of the coefficient of permeability under different bentonite content based on the research study of Hui et al. [18] for further discussion.

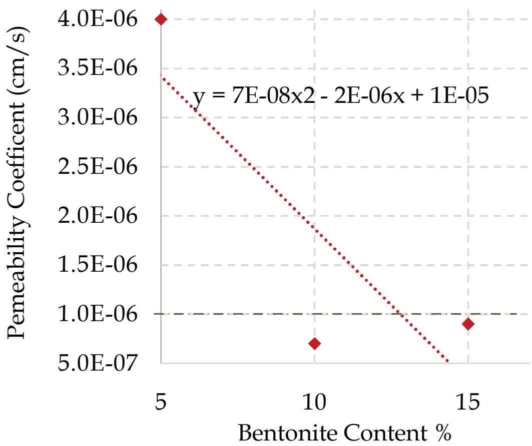


Figure 5 - Variation of permeability coefficient Vs bentonite content for 30% cement content [18]

Based on Figure 5, statistically, the negative combination between the permeability coefficient and bentonite content is presented. Thus, it states that the permeability coefficient reduces when increasing the bentonite content on a given cement content. According to the illustration of points in the graph, the sample which contained 30% cement and 5% bentonite does not achieve the minimum permeability requirement ($1\,x\,10^{-6} cm/s$) anticipated in the SCB cutoff walls. It was achieved only by the samples which contain 10% and 15% bentonite content. However, the permeability coefficient decreased significantly between 5% and 10% bentonite content. It can be seen that there is no significant variation in permeability when bentonite content increases from 10% to 15%. Thus, it is clear that a higher content of cement with a lower content of bentonite does not satisfy the minimum permeability requirement; similarly, increasing bentonite content also does not proportionally decrease the permeability. Hence, this research gap emphasizes the requirement for further studies in this field to optimize SCB performance. However, few studies have recommended some values for cement and bentonite content in permeability performance in SCB walls. Ata et al. [23] studied the effect of bentonite and cement bypass dust content on permeability of Soil-Bentonite-Cement mixture for cutoff walls. The study revealed that increasing the cement bypass dust content from 5%-15%, permeability coefficient can be significantly reduced. However, when cement bypass dust content increases from 15% to 25%, the effect of cement bypass duston the permeability coefficient is slightly reduced. Further, this study clearly stated that increasing bentonite content up to 15%, the permeability coefficient can be effectively reduced in the SCB mixture by keeping the cement bypass dust content at 10%.

Furthermore, De Silva and Wijewardhana [19] studied the performance of SCB mixture which consists of 1% bentonite and 3% cement to achieve a lower hydraulic conductivity of $1.5\,x\,10^{-10} m/s$. Andomalos and Fisher [21] proposed 2-3% bentonite content and 4-10% cement content are required to obtain a $5\,x\,10^{-7} cm/s$ permeability coefficient value for SCB backfill mixture. Based on an actual SCB cutoff wall construction in Smithland, KY (a City in Livingston County, Kentucky, United States of America), Ruffing and Evans [14] have proposed 5% cement and 6% bentonite are required to achive the 28-day average permeability coefficient of $2.2\,x\,10^{-7} cm/s$ in a SCB cutoff wall. Apart from the amount of bentonite content, Zhang et al. [17] studied the effect of the specific gravity of bentonite on the performance of permeability in SCB. In this study, the specific gravity of bentonite slurry was varied from 1.20 to 1.35 in the interval of 0.05 and it was reported that lower specific gravity of bentonite significantly increases the hydraulic conductivity of SCB slurry. Furthermore, the specific gravity value of 1.30-1.35 was recommended for the bentonite slurry to obtain the minimum peremeability value of $2.6\,x\,10^{-5} cm/s$ after after a curing period of 28-days.

The hydration period of bentonite slurry is also a major factor in the reduction of permeability [5]. However, relevant to the cement-bentonite mixture (CB backfill mix), Jefferies et al. [24] studied the characteristics of cement-bentonite slurry prepared with unhydrated and adequately hydrated bentonite. A study revealed that hydrated bentonite show ''two orders'' magnitude lower values as permeability coefficient than that of permeability coefficient of unhaydrated bentonite mixture. As such, this study clearly implies the importance of adequate hydration of bentonite slurry before use for SCB mixpreparartion.

Based on above studies, it is clear that the permeability coefficient is subject to decrease when increasing the bentonite and cement content up to a certain value. Similarly, specific gravity and hydration period of bentonite also affect permeability coefficient. Thus, the amount of cement and bentonite content and other factors such as density of bentonite and hydration period should be well defined by further research studies to deliver optimum performance of SCB cutoff walls.

3.4 Durability

In engineering practice, durability is defined as the ability of a physical product to remain functional, without requiring excessive maintenance or repair, when faced with the challenges of normal operation over its design lifetime [25]. In cutoff wall design, the planned lifetime typically ranges from 50 to 100 years for seepage control applications [26]. Based on the available literature, durability has been assessed for Cement-Bentonite (CB) and Soil-Bentonite (SB) cutoff walls based on their ability to withstand chemical compatibility, as most cutoff walls are installed below ground level and surrounded by subsoil, which may expose them to various chemical environments. Furthermore, long-term and short-term effects are analyzed through strength and permeability parameters [5, 27, 28, 29, 30]. Other factors, such as the water/cement ratio, also significantly affect durability [6]. However, limited research has been conducted to assess the impact of water/cement ratios on the durability of Soil-Cement-Bentonite (SCB) cutoff walls. A higher water/cement ratio indicates higher water content in the mix, which leads to increased porosity. Higher porosity is associated with reduction in durability [6]. Conversely, lower water content can result in local defects in cutoff walls, which may also compromise durability [6]. Therefore, an optimum water/cement ratio must be selected to achieve the desired water content and to ensure durability in cutoff walls. For CB slurry cutoff walls, Mikkelsen [31] published appropriate water/cement ratios that vary with strength. Table 2 summarizes the recommended mix proportions by Mikkelsen [31] for different soiltypes.

Table 2 - Cement-Bentonite grout mixes [31]

Application	**Grout for Medium to Hard Soils**	**Grout for Soft Soils**
Materials	Ratio By Weight	Ratio By Weight
Water	2.5	6.6
Portland Cement	1	1
Bentonite	0.3	0.4
Note	The-28 day compressive strength of the mix is about 340 kPa, similar to very stiff to hard clay	The-28 day compressive strength of the mix is about 27 kPa, similar to very soft clay

According to Table 2, a water/cement ratio of 2.5:1 is recommended for medium to hard soils, while a ratio of 6.6:0.4 (16.5:1) is recommended for soft soils. However, the optimum water/cement ratio for SCB cutoff walls needs to be determined through rigorous laboratory investigations and validated through field applications.

Additionally, the impact of the water/cement ratio on the long-term performance of SCB cutoff walls requires further research. In field applications, SCB cutoff walls are subjected to alternative wetting and drying processes due to variations in groundwater levels. These cycles can lead to a reduction in compressive strength and an increase in permeability [18]. Changes in hydraulic conductivity and unconfined compressive strength due to wet-dry cycles can significantly impact the long-term performance of SCB walls, thereby affecting their durability. Wu et al. [20] studied the impact of wet-dry cycles on Ordinary Portland Cement (OPC) based and Ground Granulated Blast Furnace Slag (GGBS)-MgO-based backfill. For OPC based backfill, two mixtures were tested namely, Sample 1 (5% bentonite and cement) and Sample 2 (10% bentonite and cement). Both samples used clayey sand as the backfill soil. The mixtures were cast into cylindrical moulds (50 mm diameter × 100 mm height) and cured for 90 days under standard conditions (temperature = 20±2°C, relative humidity = 95%). After curing, the samples underwent 10 numbers of wet-dry cycles, with each cycle consisting of 48 hours in an oven at 30°C followed by 24 hours of soaking in distilled water at 20°C.

The results showed a 9% mass change in both mixtures after the 10th wet-dry cycle. In terms of dry density, Sample 1 and Sample 2 initially showed densities of 1.44 g/cm^3 and 1.42 g/cm^3, respectively. After the 10th cycle, the densities decreased to 1.39 g/cm^3 and 1.35 g/cm^3, respectively. This corresponds to a 3.5% dry density loss in Sample 1 and a 5% loss in Sample 2. These findings highlight that the percentage of cement and bentonite is related to both mass and density losses during wet-dry cycles. Before the wet-dry cycles, Sample 1 and Sample 2 had unconfined compressive strength values of 520 kPa and 600 kPa, respectively. After the 10th cycle, these values were reduced to 400 kPa and 500 kPa, representing strength losses of 23% and 16%, respectively. This implies that strength decreases as the number of wet-dry cycles increases, directly affecting durability. Therefore, it is crucial to study the long-term performance of SCB cutoff walls, particularly their durability under wet-dry cycles.

4. Conclusion

Soil-Cement-Bentonite (SCB) cutoff walls have emerged as a technically viable and economically efficient solution in seepage mitigation, offering a balanced combination of moderate unconfined compressive strength (UCS) and low hydraulic conductivity over traditional Soil-Bentonite (SB) and Cement-Bentonite (CB) cutoff walls. The construction of SCB walls involves the excavation of trenches stabilized with bentonite slurry (typically 6-8% by weight of water), followed by the placement of a backfill mixture comprising excavated soil, cement, and bentonite. The integrity and performance of the wall are highly dependent on the homogeneity and proper proportioning of these materials. The engineering properties of SCB walls are governed by the interactions between soil gradation, cement content, and bentonite content. Laboratory studies have shown that increasing cement content enhances UCS-yielding strengths exceeding 1000 kPa. Conversely, higher bentonite content tends to reduce strength while improving impermeability. 5% - 10% cement and less than 5% bentonite can deliver the desired strength and permeability values for SCB cutoff walls. Furthermore, proposed soil gradation, particularly the fines content (10-30%), plays a critical role in achieving a homogeneous and stable backfill. Excessive fines can lead to shrinkage and cracking, while insufficient fines may result in higher permeability and reduced effectiveness. Durability remains a significant concern for SCB walls, particularly under long-term exposure to environmental stresses such as wet-dry cycles, chemical interactions, and varying groundwater conditions. Studies indicate that the water/cement ratio, bentonite hydration time, and curing conditions significantly influence the long-term performance of SCB walls. Despite the proven effectiveness of SCB walls, several knowledge gaps remain. These include the need for standardized mix proportions, a deeper understanding of the long-term performance under environmental stresses and the development of guidelines for optimizing soil gradation and material composition. Addressing these gaps through further research will enable the development of more reliable and cost-effective SCB cutoff walls, ensuring their widespread adoption in geotechnical and environmental engineering projects.

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