*Proceedings of the 7th World Congress on Civil, Structural, and Environmental Engineering (CSEE'22)*
*~~Lisbon, Portugal~~ Virtual Conference – April 10 – 12, 2022*
*Paper No. ICGRE 175*
*DOI: 10.11159/icgre22.175*

# Sludge as an Alternative to Cement for Canal Lining

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***Abstract*** - Plain concrete is used for water canal lining due to its low permeability to reduce water losses due to seepage. However, cement manufacture has a negative environmental impact as it produces large amount of CO2 emissions in addition to high energy consumption. In this study, bio-sludge of sewage plants was used an alternative for cement, mixed with sand and crushed stone, and used as an alternative to plan concrete for canal lining. An experimental testing program was designed based on percentages of sludge and soil equal to 2.5%, 5%, and 10% by weight. For each sludge mix, properties were characterized such as particle size, density, and specific gravity. Also, shear strength properties were determined and California bearing ratio. The permeability of the sludge mix was also determined in laboratory. It was evident that mixing limited percentages of sludge with cohesionless soil significantly reduced the permeability. To assess the practicality of this approach for canal lining purposes, two trapezoidal in-situ trial pits were excavated in a sandy soil profile, one pit without lining and the other using sludge-mix lining. The seepage rate of water in each pit was monitored with respect to time after taking into consideration the water evaporation rate. Outcomes of the experimental program showed that sludge-soil mix can be used as an eco-friendly alternative in enhancing the properties of the canal lining soil.

***Keywords*****:** Sludge-Soil Mix, Strength, Permeability, Canal Lining.

## 1. Introduction

Significant water loss occurs in irrigation canals due to seepage from its sides and bed. This loss is overcome by lining the bed and the sides of canals by a resistant and impermeable layer [1]. Canal linings are very important as they enhance the flow characteristics, reduce the seepage rates, and increase the water usage efficiency. Different materials are used in canal lining such as: concrete, masonry, bitumen, and geomembrane. One of the most used materials for canal lining is concrete due to ease of manufacture and low cost [2]. However, the manufacturing process of concrete is not eco-friendly as it consists of cement which highly consumes energy and intensively emits carbon dioxide.

Several studies were conducted to reduce water seepage and the transfer of contaminants to the groundwater through using different materials in canal lining. Some studies have examined low permeability industrial materials such as geosynthetic clay liners. A study was presented by [3] to examine the impact of applying geomembrane in canal lining on the seepage. The findings showed that using geomembrane has reduced seepage by 90%. Another study was conducted by [4] to evaluate seepage of canals using four different anti-seepage materials. Those materials are concrete lining, pebble lining, compacted canal bed only, and clay lining with compacted canal bed. Results showed that clay lining with compacted canal bed delivers the best alternative as an anti-seepage material, followed by compacted canal bed only, then pebble and concrete lining. [5] performed a comparative study on three types of canal lining materials that were polyvinyl chloride (PVC), brick masonry and earth lining. Their main aim of the study was to observe the primary economical material suitable for canal lining. Results indicated that PVC is the most economical material compared to others. However, one of its drawbacks was its sensitivity to chemicals. Other studies examined lining based on compacted earth such as [5], who used a finite element to examine the compacted earth lining impact on seepage of a trapezoidal earth canal. They indicated that compact earth lining is an effective way that may save 99.8% of water lost by seepage.

The main objective of the previous studies was to reduce water seepage in canals by using cement or manufactured materials for lining. However, not enough studies were available about using bio-sludge as a canal lining material. Although, waste management and recycling into a sustainable construction material are proven to be a waste disposal alternative for environmental and economical pollution. Different waste types have been recently reused in developing the sustainable construction materials. Bio-sludge "or sludge" is considered as one of these materials that can be extracted from different water treatment plants [6]. Dry pulverized sludge was used in prefabricated bricks by [7], who used 2% of the pulverized sludge in bricks and measured its engineering properties. Results showed increase in the compressive strength, reduction in porosity and water absorption. [8] used dry sewage sludge in concrete instead of fine sand with ratios from 0-10%. Using sludge in concrete was effective as the volume of heavy leached ion was decreased compared with sludge reacting with cement. However, sludge content had a negative impact on the concrete compressive strength.

The main goal of this study was to use bio-sludge of sewage plants with sand and crushed stone as an alternative to cement for canal lining. The used sludge was biologically treated to eradicate possible hazards. Various mixing percentages of the sludge with soil were used, starting with 2.5%, 5% and 10% by weight. Physical properties such as particle size, density and specific gravity were characterized for all sludge mixes. In addition, direct shear and California Bearing Ratio were conducted to determine the shear strength parameters and CBR. Permeability of these sludge-soil mixes was measured in the laboratory. Then, the sludge-soil mix with optimum percentage was examined in the field. Two trapezoidal in-situ trial pits were excavated in a sandy soil profile and the sludge mix was used for lining. Soil in the first pit was compacted without lining, and the second pit included a layer of sludge-soil mix. The seepage rate was observed in each pit with respect to time after considering the water evaporation rate.

## 2. Sludge Mix Characterization

Treated sewage sludge from Al-Waraq water treatment plant was used in this study in all the laboratory tests with different percentages, which varied from 2.5%, 5%, to 10%. Five different mixes were used in this study. The first mix (A), which was the control specimen, contained only sand as it represented the actual sand in the field work. The second mix (B) was (sand + aggregate) with ratio 2:1 (sand: aggregate), this percentage was used in all the other mixes. Mixes (C, F, and E) were (sand + aggregate) in addition to sludge with different percentages ranging from 2.5%, 5%, and 10%, respectively. The maximum size of coarse aggregate used in this study was 9.5 mm.

### 2.1. Sludge Mix Gradation

Five sludge mixes were graded via sieve analysis in accordance with ASTM C33 (1999) standards [9]. The percent passing from each sieve was determined. The weights of the samples were 1365 and 1665 gm for A and B, respectively, and 3000 gm for C, D, and E. The particle size distribution curves of the five samples are plotted in Figure 1, in addition to lower and upper limits according to the ASTM C33.The particle sizes 1.81 mm and 600 μm respectively exceeded the upper limit for sample (A) which was only sand. Particle sizes 4.75 mm and 2.36 mm for samples (C, D, and E) respectively fell below the lower limit. Most of the other particle sizes were within limits, which is in accordance with ASTM C33 can therefore be used for construction purposes and canal lining.

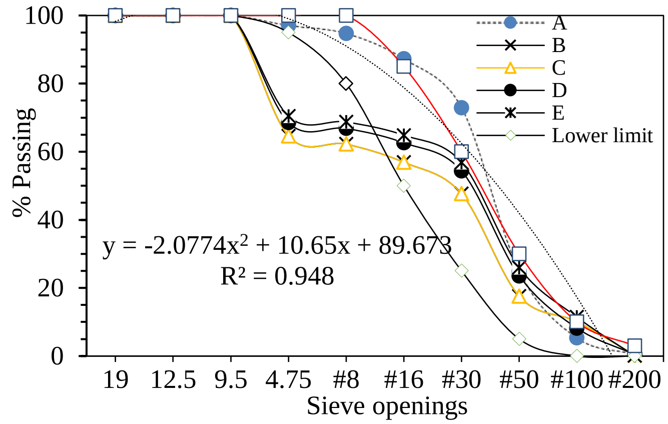


Fig. 1: Particle size distribution according to ASTM C33

### 2.2. Swelling Tendency of Sludge Mixes

Free swelling test was adopted according to ASTM D5890 [10] to stand on the degree of expansivity of the different sludge mixes used in this study. The free swelling index represents the volume expansion of the specimens when submerged in water without boundary restrictions. A total of five samples were used in this test where each sample was mixed with distilled water in a graduated cylinder leaving the samples to settle as shown in Figure 2. The initial height of each specimen was 30 cm while that of the water poured inside the flask was 100 cm. The readings were taken after 24 hours as shown in Table 1. The results showed that there is a slight decrease in the volume of the sand sample (A), which reflects the sedimentation of sand. On the other hand, there was no change in the volume of the (sand + aggregate) sample (B), and there was a slight increase in the free swelling index of samples (C, D, and E). This indicates that adding sludge with limited percentages should not have a significant influence on swelling and should not cause large cracks when used for canal lining.

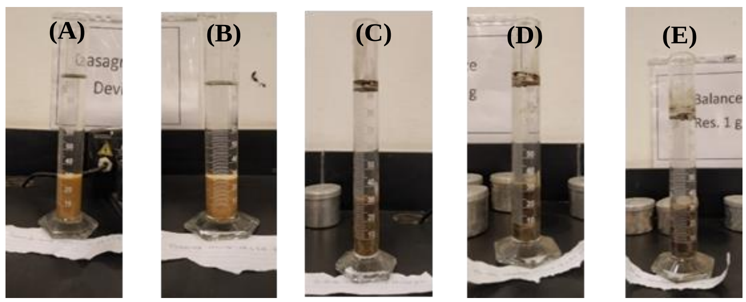

Fig. 2: Free swelling test on all samples

Table 1: Results from free swelling test for all samples

| Test Specimens | Swelling Values (cm) | Free swell index (%) |
|---|---|---|
| A | 28 | -6.7 |
| B | 30 | 0.0 |
| C | 31 | 3.3 |
| D | 32 | 6.7 |
| E | 32 | 6.7 |

### 2.3. Shear Strength Parameters

Following the ASTM D3080 (1997) [11], the direct shear test was carried out to identify the shear failure envelope of the sludge mixes and thus calculate cohesion (c) and internal friction angle ($\phi$). The direct shear was performed on the five samples (A, B, C, D, and E). Three normal stresses ($\sigma n$) equivalent to 19.6, 39.2 and 78.5 kPa were adopted. The rate of shear displacement for all samples was 0.05 mm/min. The maximum displacement reached was equal to 95.42 mm in sample (A) at shear stress equal to 52.9 kPa. On the other hand, due to the presence of the aggregate, the equipment could not reach the shear failure stress.

Figure 3 shows shear stress–displacement curves at various normal stress ranges. To determine the actual impact of adding sludge at different percentages on sludge-soil shear strength, the failure envelops of the five samples were plotted in Figure 4. The figure shows that by adding aggregate to sand, $\phi$ significantly increased and started to gradually increase by adding sludge. As a result of using the same water content of 6% with all samples, increasing the percentage of sludge caused a slight decrease in the friction angle. Also increasing sludge caused a slight increase in cohesion, where the highest value was recorded when using 5% sludge then it declined by using 10% sludge.

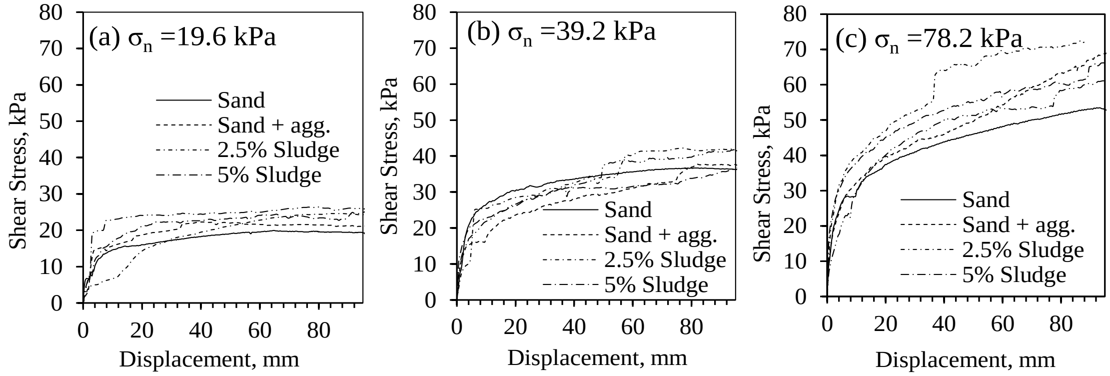


Fig. 3: Shear-displacement at normal stresses: (a) 19.6; (b) 39.2; and (c) 78.2 kPa

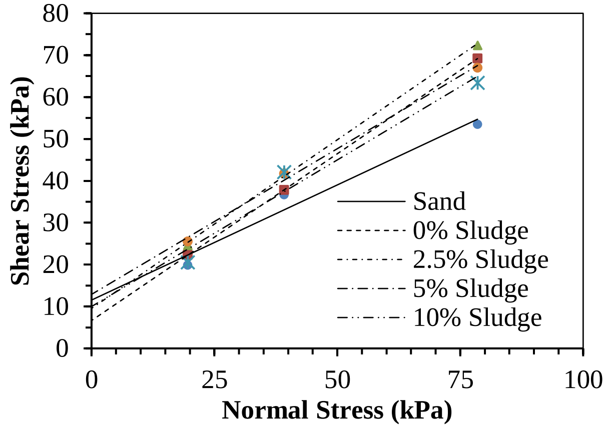


Fig. 4: Shear failure envelopes for the five test samples

Figure 5 represents a correlation between the percentage of sludge in the soil mix and changes that occur in friction angle and cohesion. It can be seen from the figure that ϕ was not significantly affected by adding a small percentage of sludge equal to 2.5%. However, by increasing sludge to 5% the value of ϕ was slightly affected and declined from 38.8o to 34o. This means that the effect of sludge is not significant on the internal friction. For the cohesion, c increased significantly by 42.7% when adding 5% sludge and started to decrease by 21% when increasing the ratio from 5% to 10% sludge. Accordingly, the sludge mainly increases the soil cohesion till a certain extent (optimum value of about 5% sludge) then this effect is switched, which is quite similar to the soil compaction curve.

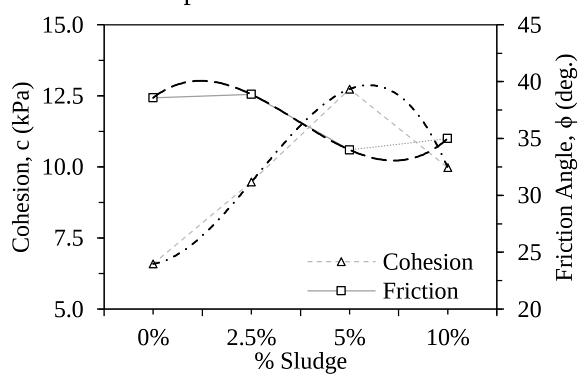


Fig. 5: Change of shear strength vs. percentage of sludge in the mix

## 2.4. California Bearing Ratio

In order to validate the results of the direct shear test, the California Bearing Ratio (CBR) test was carried out on samples samples A, B, C, D and E. Test was performed following the ASTM D 1883 (2016)[12]. The test is mainly a penetration test test which used to assess the subgrade strength of roads and pavements. A standard 50 mm diameter piston was used in the the test to penetrate a compacted sample inside proctor mould at a penetration rate of 1.25 mm/min. Sample preparation, loading machine and testing are shown in Figure 6.

Fig. 6: CBR samples preparations and load test machine

During compaction of each sample in preparation for the CBR test, the density was measured. Records for the measured density are presented in Figure 7(a). It was noticed that the change in the mix density with respect to percentage of sludge followed the same behavior that was previously detected with cohesion. The density increases by increasing sludge up to an optimum value of 2.08 gm/cm2 that corresponded to a sludge percentage of about 5%, then density declined. In Figure 7(b), the CBR% are presented with various percentages of sludge. It was noticed that the CBR significantly increased from 21% to 51.6% with increasing sludge from 0% to 10%.

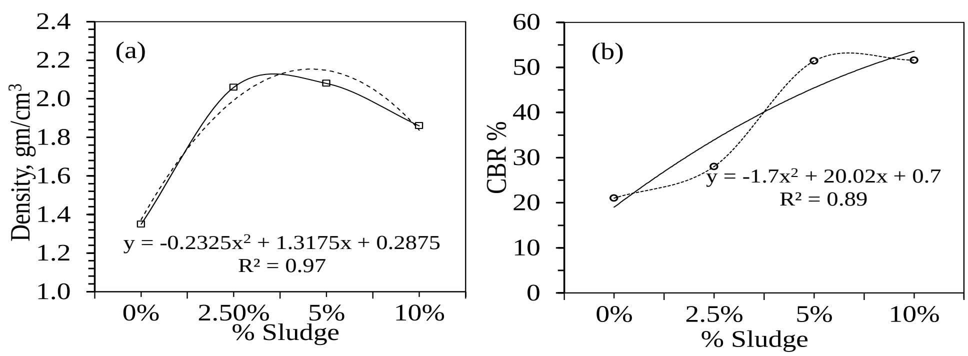


Fig. 7: Change in % sludge versus: (a) density; and (b) CBR%

## 2.5. Pressure Membrane Testing

Using sludge for the purpose of canal lining means that it should reduce the permeability of the cohesionless soil mix used in this study. Therefore, permeability was considered as the most important parameter as it governs the seepage rate of water through the lining. Hence, the pressure membrane test as per BS EN ISO 22282-2 (2012) [13] was conducted in the laboratory to measure the permeability coefficient (k) of the five samples. The pressure membrane test device and components are shown in Figure 8. The constant head method was followed during testing where samples are placed in cylinders with length equals to 15 cm. A column of water H, which represents the amount of water used for testing, was left above the sample. The permeability coefficient of the samples was calculated as shown in Equ. (1) below.

$$k = \frac{QL}{A.\Delta h.\Delta t} \quad (1)$$

where Q is the volume of passing water, ΔT is a time interval, A is the cross-section of the sample, L is the sample column height, and Δh is the constant pressure difference.


Fig. 8: Pressure membrane test device and components

Table 2 shows the values of the permeability coefficient (k) for the five tested samples A to E. The value of k for sample A (i.e., sand only) was equal to 8.33 cm/hr, which increased by adding up aggregate to sand where sample B provided k = 12.5 cm/hr. Mixing sludge to the sand-aggregate samples by various percentages reduced the permeability from 12.5 cm/hr to 6.85 cm/hr at sludge equal to 10% of sample weight. This means that the permeability of the mix drooped by about 45.6%. Accordingly, adding sludge can significantly reduce soil permeability.

Table 2: Permeability coefficient of the five samples

| Samples | Permeability Coefficient (cm/hr) |
|---|---|
| A (sand) | 8.33 |
| B (0% sludge) | 12.5 |
| C (2.5% sludge) | 10.5 |
| D (5% sludge) | 7.92 |
| E (10% sludge) | 6.85 |

## 3. Field Experimental Work

To use the sludge-soil mix with the known properties detected from the laboratory stage, two in-situ trapezoidal pits were excavated in a sandy soil profile as shown in Figure 9(a) and 9(b). The top and bottom width of each pit was 1.5 and 0.5 m, respectively. To have stable sides a slope of 1:1 was used, and the depth of each pit was 0.5 m. The first pit was based on in-place compacted soil without lining, and the second pit was using the sludge-sand-aggregate lining. The used thickness of the sludge-soil lining in this study was limited 0.5 cm, where the 5% sludge mix was selected since it provided optimum results in terms of cohesion, CBR, density, and permeability. For the preparation of the lining, 16% water content was used in with the sludge mix for ease of mixing, and the ratio used in the sand and aggregate were 2:1. The two pits were filed with water at the same time, with the same water level that was equal to 21 cm at the beginning of the test. Figure 9(c) and 9(d) show test at the beginning for sand pit and pit with sludge lining, respectively.

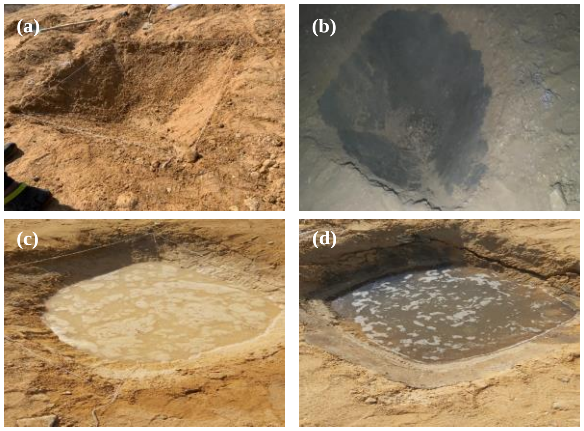

Fig. 9: (a) sand pit; (b) sludge pit; (c) sand pit with water; and (d) sludge pit with water

The level of the water in the two pits was observed and recorded every 10 minutes for one hour as shown in Table 3. After 10 minutes from filling the pits, the water level in the sand pit (1) was the same while that of the sludge pit (2) decreased by 1 cm. The water level in the two pits (1) and (2) continued to decrease gradually within the range of 1 and 0.5 cm, respectively, until the water level was constant in the two pits from t=30 min to t=60 min. The seepage for the two pits was calculated following [14] and [15] as presented in equation 2.

$$q_s = k\ y\ F \qquad (2)$$

where q is seepage discharge (cm2/s), k is permeability coefficient of the porous medium (cm/s), y is the water depth in the pit, and F is the channel geometry seepage function (dimensionless). For a trapezoidal section, the seepage function F is measured using equation 3 as follows:

$$F = [\pi(4-\pi)]^{1.3} + (2m)^{1.3}]^{(0.8+0.5m)/(1.3+0.6m)} + (\frac{b}{y})^{(1+0.6m)/(1.3+0.6m)})^{(1.3+0.6m)/(1+0.6m)} \qquad (3)$$

where m is the side slope, y is the water depth in the pit (cm), and b is the pit width (cm). The seepage results are shown in Table 3 where the seepage loss of the sludge pit (B) is less than that of the sand pit (A) by 6.6%. The reason for this is due to: (a) the sand pit already depends on in-place compacted sand which act as natural lining for the pit; (b) during the first 20 min, sludge particles in sludge pit started to absorbed water until full saturation, which led to some initial relative increase in seepage rate; and (c) after 20 min, the seepage rate in the sludge pit was reduced unlike the sand pit, which means that the pit with sludge lining succeeded to reduce the rate of seepage after 20 min compared with the compacted sand pit.

Table 3: Water levels and seepage rate in the test pits

| Time (min) | Water level in sand pit (cm) | Water level in sludge pit (cm) | $F_{sand}$ | $F_{sludge}$ | $q_{sand}$ | $q_{sludge}$ |
|---|---|---|---|---|---|---|
| t=0 | 21 | 21 | 7.490262 | 7.490262 | 0.362654 | 0.345176 |
| t=10 | 21 | 20 | 7.490262 | 7.684939 | 0.362654 | 0.337283 |
| t=20 | 20 | 19 | 7.684939 | 7.901018 | 0.354361 | 0.329428 |
| t=30 | 19.1 | 18.5 | 7.878348 | 8.018209 | 0.346932 | 0.325516 |
| t=40 | 19.1 | 18.5 | 7.878348 | 8.018209 | 0.346932 | 0.325516 |
| t=50 | 19.1 | 18.5 | 7.878348 | 8.018209 | 0.346932 | 0.325516 |
| t=60 | 19.1 | 18.5 | 7.878348 | 8.018209 | 0.346932 | 0.325516 |
| Average | | | | | 0.353411 | 0.331406 |

## 4. Conclusion

This study utilized bio-sludge as a replacement for cement in soil-aggregate mixes used for canal lining. Various percentages of sludge-soil mixes were prepared, characterized in the laboratory, and used as lining for a small-scale trial in the field. Out of the main outcomes, it was found that mixing 5% of sludge by weight has a significant effect on the properties, as cohesion increased by 42.7%, density increase to 2.08 gm/cm2, CBR increased from 21 to 51.6%, and permeability coefficient decreased by 46% to reach a value of 7.92 cm/hr. In addition, the sludge lining succeeded to reduce the seepage rate in field pit after an initial time required for saturation.

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