Potential application of cement amended marine clay as liner material

V Veena¹, S Reghunath, S Cyrus and B M Abraham
Division of Civil Engineering, School of Engineering, Cochin University of Science & Technology, Kochi, Kerala, India
¹Email: veenasubramony@gmail.com

Abstract. One of the major problems being faced today in the society is solid waste disposal. Compacted clay soils are commonly used as liner materials in waste containment systems. As marine clay is abundant in the coastal belt of Kochi, this locally available soil was used in the study. Desiccation cracking of clay mass can lead to development of shrinkage cracks and also provide pathways for moisture migration into the landfill. In order to minimize the adverse effect of cracks, the behaviour of sun-dried marine clay amended with cement in different percentages of 1%, 2%, and 4% were studied. To stimulate the field conditions, the samples were subjected to alternate wetting and drying cycles. For different cement content, three cycles of alternate wetting and drying were performed. The study indicates that the extent of crack formation decreases with increase in cement content and the optimum percentage of cement amendment is 4%.

1. Introduction
Rapid development and immense growth in global population has led to the generation of enormous amount of solid waste every year. Landfills are one of the popular methods adopted to address the problem of solid waste disposal. Compacted clay soils are commonly used as liner materials in waste containment systems. Desiccation cracking is a major factor affecting the performance of clay liner landfills. This is encountered when they are subjected to alternate wetting and drying, which are due to seasonal variations. The alternate wetting and drying of the liner soil result in the development of tensile stresses and consequent formation of tensile cracks [1]. Development of shrinkage cracks creates pathways for moisture migration into the landfill and this increase the generation of waste leachate. This ultimately increases the potential for soil and ground water contamination [2]. As such reduction of desiccation cracks is of paramount importance.

The compacted clay liner material should satisfy norms for coefficient of permeability, plasticity index, minimum fine content and maximum gravel content as per the standards prescribed by Environmental Protection Agency (EPA) [3]. As marine clay is abundant in the coastal belt of Kochi, this locally available soil was used in the study. Soil improvement with cement addition is an economic common practice for modifying the engineering properties of soil. Addition of cement is small quantities can increase strength, reduce hydraulic conductivity, shrinkage, swell potential and possibility of crack formation in soils [4-7].

A review of literature indicates that very limited work has been done on the use of cement amendment in containing desiccation cracks in Cochin marine clay liner soils. Here an attempt is made to study the effect of cement amendment on the compaction, strength and desiccation characteristics of marine clay liner soil.
2. Materials

2.1 Marine Clay

Marine clay collected from a local site at Kochi, Kerala was sundried by spreading the representative samples of moist clay to constant weight. After pulverising the dried samples using a heavy hammer, the same was passed through 425 micron sieve and stored in airtight polythene bags. Table 1 show the properties of moist and sundried marine clay (SMC) used in the study. The particle size distribution of moist and sundried marine clay was conducted by hydrometer analysis as per IS 2720 (Part 4) and the grain size distribution curve is presented in Figure 1.

| Particulars                        | Moist marine clay | Sundried marine clay |
|-----------------------------------|-------------------|----------------------|
| Natural moisture content (%)      | 101               | -                    |
| Liquid limit (%)                  | 120               | 67                   |
| Plastic limit (%)                 | 54                | 46                   |
| Plasticity Index (%)              | 66                | 21                   |
| Shrinkage limit (%)               | 25                | 22                   |
| Grain Size Distribution           |                   |                      |
| Sand (4.75-0.075mm) (%)           | 14                | 24                   |
| Silt size (0.002-0.075mm) (%)     | 39                | 51                   |
| Clay size (<0.002mm) (%)          | 47                | 25                   |

Table 1. Properties of Marine Clay used in the study

![Figure 1. Grain size distribution curve of marine clay used in the study](image-url)
Results indicate that sun drying of moist marine clay significantly reduces the Atterberg limits. The variations in Atterberg limits are due to the aggregation of finer particles to coarser ones. During drying the clay content reduces which in turn brings down the Atterberg limits [8]. The results also indicate that sundried marine clay satisfied the norms of percentage fines, plasticity index and % of gravel size particles specified by EPA and was found suitable for use as a liner material. Hence further study was conducted using this material.

2.2 Cement
Portland Pozzolana cement procured from local manufacturer is used in this study. As per the guidelines in IS 1489 part I, the various tests on cement were conducted and their results are shown in Table 2.

| Particulars                 | Cement  |
|-----------------------------|---------|
| Fineness (%)                | 2.6     |
| Standard consistency        | 31      |
| Initial setting time (min)  | 204     |
| Final setting time (min)    | 332     |
| Compressive strength        |         |
| 7 day                       | 26      |
| 28 day                      | 35      |

3. Methods

3.1 Preparation of samples
In this study, the specimens to be tested were compacted in Standard Proctor mould at their respective optimum moisture content, and 95% dry unit weight. Compaction is an important variable controlling the hydraulic properties of liner material. A typical construction specification requires that the soil compacted over a range of water content not to exceed the optimum moisture content by 4%, and a minimum dry unit weight of 95% of the maximum dry unit weight from standard compaction [9].

For preparing the specimens, the sundried clay was mixed with an amount of water depending on the optimum moisture content of the soil. All mixing was done manually with proper care at each stage of mixing to prepare a homogenous mixture. Then the soil samples were sealed in plastic bags and allowed to hydrate for 24 hours prior to compaction.

3.2 Desiccation test
Desiccation tests were carried out in samples prepared in Proctor moulds to study the effect of alternate wetting and drying. The soil mixtures were compacted at their respective optimum moisture content and at 95% dry unit weight. For drying, the test specimens prepared were insulated on sides using a thermal insulating material and was placed in specially designed drier which simulated the slow rate of drying that occur in the field. The photograph of the drier used in the study is presented in Figure 2. Drying test was conducted till no significant decrease in weight of the specimen occurred. Considering the local climatic condition, a drying temperature of 40°C was selected. Then the samples were saturated by keeping them in a tank of potable water.

Tests were conducted to determine the duration of drying and wetting periods. The compacted soil specimens were kept in drier and the weight of the specimen became stable after 9 days of drying. In
order to determine the duration of wetting period, dried samples were saturated by ponding with water. Every two days, soil specimens were taken from different samples for determination of water content from top, middle and base of sample and the duration of wetting period were obtained as 15 days. The experiment was repeated for three wet and dry cycles. The duration of wetting and drying cycles are as tabulated in Table 3.

| Soil          | Cycle No. | No. of days |      |      |
|---------------|-----------|-------------|------|------|
|               |           | Drying      | Wetting |
| Sundried      | I         | 9           | 15   |
| Marine Clay   | II        | 10          | 14   |
| (SMC)         | III       | 10          | 12   |

Figure 2. Drier used in the study

The investigation of wet–dry cycle was done in the following sequence: drying of compacted soil, then wetting to saturation, followed by drying and so on. This sequence can be expected to stimulate better field conditions.

4. Results and Discussions

4.1 Compaction characteristics

Compaction tests were carried out to assess the optimum moisture content and maximum dry unit weight of unamended and cement amended SMC by standard proctor test as per IS: 2720 (Part 7). The
compaction characteristics of unamended and cement amended SMC are presented in Table 4 and the compaction curves in Figure 3.

Table 4. Compaction characteristics of unamended and cement amended SMC

| Cement content (%) | Max dry unit weight (kN/m³) | OMC (%) |
|--------------------|----------------------------|---------|
| 0                  | 12                         | 33.1    |
| 1                  | 12.1                       | 33.2    |
| 2                  | 12.2                       | 33.1    |
| 4                  | 12.4                       | 33      |

Figure 3. Compaction curves of SMC amended with different percentages of cement

4.2 Unconfined compressive strength (UCS)

As per the guidelines of IS 2720 part 10, unconfined compressive strength of the sample were carried out. The tests were conducted on both unamended and cement amended specimens compacted at their optimum moisture content and maximum dry unit weight.

Results indicate that the UCS increases with increase in percentage cement amendment. The UCS of unamended SMC was obtained as 257kN/m². With 1% cement amendment the UCS increased to 325kN/m². The maximum UCS of 455kN/m² was obtained for 4% cement amended SMC.

The variation in strength with ageing of cement amended SMC at 1 day, 7 day, 28 day and 60 days are presented in Figure 4. From the graphs it is clear that, with ageing, unconfined compressive strength increases for all percentage of cement inclusion. The percentage increase in strength for 1%, 2% and 4% cement amended SMC with ageing of 60 days were 48%, 42% and 58% respectively.
4.3 Effect of cement on desiccation characteristics

The samples of both amended and unamended SMC were subjected to three wet/dry cycles and the photographs were taken at the end of each wet/dry cycles. A close visual examination of the photographs of desiccated samples indicated that the extent and depth of crack propagation decreased with increase in cement amendment. With addition of cement the volumetric shrinkage decreases thereby containing desiccation cracks. The photographs of desiccated samples of unamended, 1%, 2% and 4% cement amended samples are presented in Figure 5 to Figure 8. The depth of crack measured is presented in Table 5.

![Figure 4. Variation in Unconfined Compressive strength with ageing](chart)

**Figure 4.** Variation in Unconfined Compressive strength with ageing

**Figure 5.** Desiccated samples of unamended SMC for different cycles

(a) Cycle 1  
(b) Cycle 2  
(c) Cycle 3

**Figure 6.** Desiccated samples of 1% cement amended SMC for different cycles

(a) Cycle 1  
(b) Cycle 2  
(c) Cycle 3
Figure 7. Desiccated samples of 2% cement amended SMC for different cycles

(a) Cycle 1                     (b) Cycle 2                     (c) Cycle 3

Figure 8. Desiccated samples of 4% cement amended SMC for different cycles

(a) Cycle 1                     (b) Cycle 2                     (c) Cycle 3

Table 5. Maximum crack depth details of cement amended SMC

| Cycle | Maximum depth of crack (cm) |
|-------|-----------------------------|
|       | Cement content (%)          |
|       | 0.0 | 1 | 2 | 4 |
| 1     | 0.3 | 0.1 | 0.1 | 0.1 |
| 2     | 0.8 | 0.2 | 0.3 | 0.1 |
| 3     | 0.9 | 0.1 | 0.1 | 0.1 |

It can be observed that in unamended SMC, the extent of cracking increases in cycle 2 and thereafter it decreases. It was observed that the extent and depth of crack formation reduced significantly with addition of 4% cement. The cement amendment of 4% was found to be effective in containing desiccation cracks and as such can be taken as the optimum value.

5. Conclusions

The effects of cement amendments on the strength and desiccation characteristics of compacted sun dried marine clay was studied. Thus of SMC improved with amendment of cement in various percentages of 1%, 2% and 4%. The maximum UCS of 455 kN/m² was observed for 4% cement amendment SMC. The percentage increase in strength for 1%, 2% and 4% cement amended SMC with ageing of 60 days were 48%, 42% and 58% respectively. To study the desiccation characteristics, the samples of both amended and unamended SMC were subjected to three wet/dry cycles. A close visual examination of the photographs of desiccated samples indicated that the extent and depth of crack propagation decreased with increase in cement amendment. It was observed that the extent and depth
of crack formation reduced significantly with addition of 4% cement. The optimum percentage of cement amendment considering strength and desiccation characteristics is 4%.

References

[1] Costa S, Kodikara J, and Thusyanthan N I 2008 Modelling of Desiccation Crack Development in Clay Soils 12th International Conference of International Association for Computer Methods and Advances in Geomechanics (IACMAG) pp 1099-1107.

[2] Carol J Miller, Hong Mi, and Nazli Yesiller 1998 Experimental Analysis of Desiccation Crack Propagation in Clay Liners J Am Water Resour Assoc 34 (3) 677-686.

[3] EPA (1985) Draft minimum technology guidance on double liner systems for landfills and surface impoundments, EPA/530-SW-85-014

[4] Consoli N, de Moraes R and Festugato L 2013 Parameters Controlling Tensile and Compressive Strength of Fiber-Reinforced Cemented Soil J. Mater. Civ. Eng. 25 (10) 1568–1573

[5] Kvennas M., Sparrevik M and Grim R S 2009 Effects of Amendment Materials on Cement-Solidified Contaminated Marine Sediments, Mechanical Stability and Leaching of Heavy Metals Journal of ASTM International 6(4).

[6] Omidi G H, Prasad T V, Thomas J C & Brown K W 1996 The influence of amendments on the volumetric shrinkage and integrity of compacted clay soils used in landfill liners Water Air Soil Pollut 86 263–274.

[7] Abbey S J, Eyo E U & Ng’ambi S 2020 Swell and microstructural characteristics of high-plasticity clay blended with cement Bull Eng Geol Environ 79 (3) 2119–2130.

[8] Rao S M, Sridharan A and Chandrakaran S 1989 Influence of Drying on the Liquid Limit Behaviour of Marine Clay Geotechnique 39 (4) 715-719.

[9] Bagchi A 1996 Design construction and monitoring of landfills (New York: John Wiley and Sons)