Effect of electrolyte concentrations on swelling behaviour of sand- and marble dust-bentonite mixes

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Abstract

The major concern of the impermeable landfill liner design is to retard the passage of pollutants to the ground water. So, for waste management purposes various environmental regulations are to be followed for the design of landfill liner. Sand-bentonite mixture generally used as a liner or barrier material in waste contaminates sites. Permeability, plasticity and swelling are the most important criteria’s of sand-bentonite mixture to design the liner of the waste contaminates sites. The electrolyte concentration in the pore fluid also affects the geotechnical properties of sand-bentonite mixture which ultimately impact on the regulation of the liner material. The present study attempts to investigate the effect of electrolyte concentration on swelling of sand-bentonite and marble dust bentonite mixtures.

Keywords: Bentonite, Contaminate, Liner, Regulation, Swelling

1. Introduction

A landfill liner must be constructed or designed to retard the migration of leachate [51] and landfill gases [6] on the waste contaminated site. Giridhar (2018) reported that landfill liners are accessible to different sorts of physical, synthetic and organic measures. In charge to avoid the contamination of ground water due to the leachate, a provision of proper and safe hydraulic barrier is an important aspect. For landfills and other contaminate sites the structure constructed must be of low permeable material. The materials used to construct these liners are bentonite, compacted clay, plastic geo-membrane and geo-textile [57]. Basically, to slowdown the movement of contaminant in landfills, clay are commonly used because of their higher water absorption capacity [17]. Currently, various types of modern landfill liners are developed such as geo-synthetic clay liner (GCLs), geo-membrane (GM), clay liner, sand-bentonite liner. These liners are designed in an appropriate way for the definite waste condition and the contaminate site [4]. Alther (1987) suggested some criteria’s for designing the liners: (i) Facility type, (ii) Waste type and its volume, (iii) Location of site and (iv) Long life of facility. To prevent the ground water by the leachate from the waste the HDPE (High density polyethylene) liner is a proper material due to its imperviousness, but these liners are prone to puncturing, so considering this an extra clay liner of low permeability is essential to ensure containment [51].

Various researchers have worked on the effective utilization of clays in landfill liner or hydraulic barrier, such as the use of shale of Oman in liners and the use of different deposition of turkey to determine the permeability of clay liners, the use of Nigeria shale in the development of clay liner [55]. Bentonite, forms an important material for the design of a liner because of its lower hydraulic conductivity, high swelling and contaminant adsorption capacity [14]. The bentonite particles are consisting with montmorillonite mineral of smectite group. The montmorillonite mineral is a sheet of alumina silicate with 2:1 unit layer structure. The thickness of each layer of montmorillonite layer or lamellae is 10Å [28; 51]. The unit particles of montmorillonite are piles of 1 to 16 lamellae whereas 2-3 lamellae is sodium montmorillonite.
It is suggested by Pusch (1999) that the cluster of bentonite consists of various unit particle approximately $10^7$ to $10^9$. Therefore, the element of structure exist at several scale are arranged in the following size order: Unit layers (Lamellae) < Unit particles < Particle clusters. The volume of bentonite consists of particles and voids which are arranged in the following size order: Interlayer pores < Interparticle pores (or micropores) < Intercluster pores (macropores). The attraction of water or water vapour on the surface of bentonite causes to the hydration on surface. The availability of bentonite is generally of two types: (i) Sodium bentonite (ii) Calcium bentonite. Generally, sodium bentonite is more used because of its high swelling and lower hydraulic conductivity [4; 56]. It is reported that the calcium based bentonite is approximately 1000 times more permeable than the sodium based bentonite [50]. The behaviour of bentonite material upon wetting has been investigated: in terms of wetting [19; 35; 36; 37; 38; 65]. Hydraulic conductivity in the saturated case [32; 33; 37] hydraulic conductivity in unsaturated state [41; 43; 45]. Besides of various advantageous properties of bentonite, high compressibility, low shear strength, low compaction density and high desiccation shrinkage are the matter of concern for the development of clay liner [20]. Hence, various researchers used a locally available soil like sand, as a mixture in bentonite to improve the maximum dry density [20], shrinkage, thermal conductivity [27] and shear strength. Hence, the addition of sand into bentonite provides mechanical stability to the mixture [53]. With the contact of water the bentonite particles swell and fills the void spaces present in the mixture, resulting decreases the hydraulic conductivity [34]. It is also reported that the mixture of sand-bentonite has less susceptible to frost damage with natural clays [20]. The mixture of sand-bentonite also possesses the low shrinkage in the terms of wetting or drying processes, therefore it provides better volume stability and higher strength. Sand-bentonite mixture are utilizing in various engineering applications such as cut off wall, Cores of earth-dam, buffer, backfill material, landfill liner and on hydraulic containment. Various studies have been conceded on the bentonite-sand mixture as a buffer material [14; 32]. Although, to develop the sand-bentonite liner, following criteria’s must be full fill by the mixture. Hence, as per Chapuis (1990), Gueddouda et al. (2008) that the requirement are as follows: (i) The thickness of sand-bentonite liner between 15 cm to 30 cm (ii) permeability range at saturated conduction between $10^{-6}$ to $10^{-8}$ cm/s (iii) good ability to swell (iv) hydraulic stability must be ensured through particle size distribution (v) prevention of pollutants through the exchange and adsorption capacity of the mixture (vi) stability of the mixture in wet condition. Some studies also have been done to examine the effect of particle size on the mixture of sand-bentonite mixture.

The landfill liner at waste contaminated sites are highly exposed to various chemical, biological and physical actions, and the resulting leachate will affect the liners [7]. So, it is essential to investigate the chemical compatibility of the liner material with different electrolyte concentrations to examine the durability of liner [16]. Various studies have been done on bentonite with the effect of salt concentration at different concentration [8; 50; 59; 30]. Winterkorn and Moorman (1941) investigate the effect of ionic water on the liquid and plastic limit of clay soil. Type of solution and its concentration, dielectric constant effects on the diffuse double layer thickness of the clay particle surface [8], due to change in the DDL various geochemical properties also changed of the soil. Mitchell (1976) reported that with the increment of the salinity in the pore fluid it would cause to reduce the diffuse double layer. Similar observation also reported by Bolt (1956), Maio (1994). Few researchers described the mechanism of osmotic and chemical consolidation phenomena which attribute the change in the diffuse double layer thickness. Gleeson et al., (1997) investigated the effect of CaCl2 at different concentration on the hydraulic conductivity of bentonite. Jo et al., (2001) reported the effect of NaCl, KCl, MgCl2, ZnCl, LiCl, CaCl2 salt solution on the hydraulic conductivity of geosynthetic clay liner. Shackelford et al. (2000) studied the effect of NaCl, ZnCl2, and CaCl2 on the hydraulic conductivity of geo-synthesis clay liner. Arasan&Yetimoglu, (2008) investigate the effect of NH4Cl, KCl, CuSO4 and FeSO4 on the consistency limit of clay. The pore fluid coming out in the form of leachate can alter the geotechnical properties of landfill liner. Very few attempts have been made by the effect of electrolyte concentration on the sand-bentonite mixture. It is also important to justify the validation of marble dust-bentonite mixture with the effect of electrolyte concentration.

The aim of the present study is to investigate the effect of electrolyte concentration on compaction characteristics, and swelling of sand-bentonite and marble dust-bentonite mixtures. So in this paper the key highlights are to quantify the influence of electrolyte concentration on sand-bentonite and marble dust-bentonite mixture as a geo-material for the development of secure landfill liner at waste contaminates sites.
2. Material and Methodology

The geotechnical properties of bentonite, sand and marble dust are presented in Table 1. The bentonite is collected from Bikaner district, Rajasthan, India. The collection of additive Marble dust is from the query site of Kishangarh, Ajmer, Rajasthan. The sand is collected from the Dahmikalam village, Bagru, Jaipur, Rajasthan. For all experimental purpose materials passing through IS 425 micron sieve are used. Sodium chloride (NaCl) and sodium hydroxide (NaOH) in the concentration of 0.1 N, 0.5 N, 1 N and 1 N, 1.5 N, 2 N respectively used as an electrolyte solution in the mixtures.

Table 1: Geotechnical properties of materials (Sand, Marble Dust & Bentonite)

| Description                              | Sand (4.75-0.075 mm), % | Silt (0.075-0.002 mm), % | Clay (< 0.002 mm), % | IS-CODE |
|------------------------------------------|-------------------------|--------------------------|----------------------|---------|
|                                          | 98.50                   | 1.50                     | -                    | (IS) [2720 (Part 4) (1985)] |
| Soil Classification as ISC and USCS      | SP (Poorly graded sand) | Poorly graded Clay with high plasticity |
| Specific Gravity                         | 2.63                    | 2.74                     | 2.65                 | (IS-2720-PART-3-1980) |
| Liquid Limit, %                          | 30.76                   | 17.60                    | 185.00               | IS 2720 (Part 5) (1985) |
| Plastic Limit, %                         | -                       | -                        | 67.33                | IS 2720 (Part 5) (1985) |
| Shrinkage Limit, %                       | -                       | -                        | 8.05                 | IS 2720 (Part 6) (1972) |
| Plasticity Index, %                      | -                       | -                        | 117.67               | IS 2720 (Part 6) (1972) |
| Max. Dry Density (MDD), gm/cc            | 1.58                    | 1.87                     | 1.12                 | Sridharan and Sivapullaiah (2005). |
| Optimum Water Content (OWC), %           | 14.44                   | 15.03                    | 45.76                | IS 2720 (Part-11) (1993) |
| CBR, % (Un-soaked)                       | 20.04                   | 14.12                    | 1.74                 | IS 2720 (Part-11) (1993) |
| CBR, % (Soaked)                          | 12.14                   | 6.67                     | 0.31                 | IS 2720 (Part-11) (1993) |
| UCS, kPa                                 | -                       | -                        | 242.83               | IS 2720 (Part 10) (1973) |
| Free Swell Index (%)                     | -                       | -                        | 490.00               | IS 2720 (Part 3) 1980 |
| MFSI (ml/gm)                             | -                       | -                        | 13.04                | Sivapullaiah et al., 1987 |
| pH value                                 | 8.31                    | 8.18                     | 7.97                 | IS 2720 (Part 26) (1987) |
| EC value (ms/cm)                         | 0.13                    | 0.11                     | 0.28                 | IS 2720 (Part 13):1986 (Reaffirmed in 2016) |
| Cohesion (kPa) (at OWC)                  | 19.00                   | 18.00                    | 40.50                | IS 2720 (Part 13):1986 (Reaffirmed in 2016) |
| Angle of internal friction (in degree) (at OWC) | 22.54              | 25.01                   | 3.76                 | IS 2720 (Part 17):1986 |

The mini compaction test procedure i.e. developed by Sridharan and Sivapullaiah (2005) is used to determine the compaction characteristics (Optimum Water Content and Maximum Dry Density) of parent materials and mixes. It is observed that optimum water content (OWC) of marble dust (i.e. 15.03%) is less than soil (i.e. 20.80%) whereas maximum dry density of marble dust (1.87 gm/cm3) is higher than soil (i.e.1.62 gm/cm3).

3. Results and Discussion

3.1 Effect of electrolyte concentration on marble dust on compaction characteristics of sand-bentonite and marble dust-bentonite mixture
The compaction characteristic of sand-bentonite and marble dust bentonite mixture with effect of NaCl and NaOH is presented in Fig. 1 and 2 respectively.

Fig. 1 Effect of NaCl on compaction characteristic of sand-bentonite and marble dust-bentonite mixes

Fig. 2 Effect of NaOH on compaction characteristic of sand-bentonite and marble dust-bentonite mixes
The maximum dry density of sand-bentonite mixture is increased and optimum moisture content is decreased with the increase in the concentration of NaCl. Similar result is also observed by Alainachi and Alobaidy, (2010); Anandhanarayanan et al., (2014); Emamiazadi, (2008); Mansour et al., (2008); Mahasneh, (2004). The changes observed in compaction characteristics are due to reduction in the diffuse double layer thickness and increment in the attractive force between particles with increment in the salinity of water [1]. This decrement in the diffuse double layer forced to pack the particles in the better way with the same amount of compaction energy, hence increases in the dry density. Furthermore, the net electrical forces between clay mineral layers were affected by the concentration and valence of cations. They indicated that increasing cation concentration or cation valence would result in a decrease in net repulsive forces, hence causing clay particles to flocculate. The maximum dry density increases and OWC decreased till 1.5 N concentration of NaOH, further increment in concentration of NaOH increases the OWC.

3.2 Effect of electrolyte concentration on marble dust on swelling of sand-bentonite and marble dust-bentonite mixture

The one dimensional consolidation swelling of sand-bentonite and marble dust bentonite mixture with effect of NaCl and NaOH is presented in Fig. 3 and 4, respectively.

The maximum swelling rate of sand-bentonite and marble dust-bentonite mixture gradually decreases with the increasing in the salinity of fluid. Similar results are reported by Castellanos et al. (2008); Karland et al., (2005); Komine et al., (2009). The reduction in swelling pressure with the effect of salt fluid is due to (i) Decrement in inter-particle repulsion in montmorillonite, and it becomes easy to move particles at lower inter-particle distance, (ii) Charge screening effect of cations leads to face-to-face aggregation and (iii) Decreases in the thickness of diffuse double layer. It is also suggested that the swelling potential can be decrease with time due to rearrangement of the particles of clay with time [18; 19; 54]. However, the maximum strain (%) of sand-bentonite and marble dust-bentonite mixture increases till 1 N NaOH concentration, further increment in the concentration of NaOH reduces the swelling of the mixtures.

![Graph of NaCl solution vs Swell Percentage](image-url)
4. Conclusion

Following conclusions are drawn out from the present study:

1. The maximum dry density of sand-bentonite and marble dust-bentonite mixture increases with effect of NaCl and NaOH concentration.
2. The optimum water content of sand-bentonite and marble dust bentonite mixture decreases with the effect of NaCl solution, while the optimum water content of sand-bentonite and marble dust bentonite mixture decreases till the 1.5 N NaOH, further addition of NaOH concentration increases the optimum water content.
3. The maximum swell percentage of sand-bentonite and marble dust bentonite mixture decreases with the effect of NaCl solution, while the swell percentage of sand-bentonite and marble dust bentonite mixture increase till the 1 N NaOH, further addition of NaOH concentration increases the strain.
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