Influence of Calcium Chloride and Sodium Silicate on Index and Engineering Properties of Bentonite

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Abstract—Bentonite is well known for its suitability as molding material in pottery and utensils, drilling mud to support the vertical sides of bore holes. Despite several favorable properties of bentonite for the above applications, such deposits exhibit large volume changes upon wetting and drying due presence of montmorillonite clay mineral with expandable lattice structure. In view of huge cyclic volumetric changes, these deposits are discouraged for construction activity. However, when it is inevitable to construct structures or run a high way, a canal or a pipe line in their deposits, suitable remedial techniques to combat the damages caused by them are to be adopted. In the present study an attempt has been made to study the influence of CaCl₂ and Na₂SiO₃ on Atterberg limits, swell, strength and consolidation properties of bentonite and the effect of individual and combined influence of chemical additives on the above properties of Bentonite is investigated.

Keywords— Bentonite, Calcium Chloride, consolidation, Sodium Silicate, strength, swell.

I. INTRODUCTION

BENTONITE is formed by weathering of volcanic ash, rich in montmorillonite mineral[1]. Such soils are widely spread in arid regions like Rajasthan and Kashmir of India, Africa, several states in U.S.A, Mexico and other parts of the world [2]. Bentonite is highly plastic and thixotropic which enabled its wide use as drilling mud to stabilize boreholes and the sides of trenches [3]. It is also used to reduce the side friction in pile driving and to reduce the negative skin friction, for the construction of diaphragm walls, in grouting, as impermeable liner, molding in metallurgy and in the filtration and clarification of wines [4]. Sodium saturated bentonites are prepared and used for most of the above applications due to its superior plasticity and gelling properties. Despite several industrial and engineering applications of bentonite, such deposits exhibit large magnitudes of swelling and shrinkage upon moisture fluctuations. Moreover, the properties of bentonite are sensitive to the changes in chemical environment. Influence of NaCl and kcl of compaction and permeability characteristics of bentonite is used as liner for waste disposal facilities [5]. Several attempts have been made to study the influence of the addition of granular fraction to dilute the mineralogy or chemical additives on the index and engineering properties so as to assess its behavior under varying environment.

II. MATERIALS AND METHODS

A. Materials

The CaCl₂ and Na₂SiO₃ Commercial grade Na₂SiO₃ is used in the present work. The index and engineering properties of bentonite are determined as per I.S code of practice and are presented below.

The grain size distribution Sand 3%, silt 29%, clay 68%, Atterberg limit (Liquid limit 280, plastic limit 50.shrinkage limit14.5 and plasticity index 230 percentages. The soil is classified as highly compressible soil (CH).The specific gravity is 2.81. The compaction characteristics are MDD 1.33 and OMC 35 percentage. The UCC strength(kpa) at OMC and MDD 355. Finally the swell characteristics i.e. differential free swell index 450, swell potential 21 percentages and swell pressure 620 kpa.

B. Variables

The study was carried out on bentonite - CaCl₂ - Na₂SiO₃ mixes. Calcium chloride and sodium silicate were varied in the following percentages. i.e Calcium chloride - 0.5%, 1.0% and 2.0% by weight of bentonite. Sodium silicate - 0.5% and 1.0% by weight of bentonite.

C. Methods

Laboratory Study

The various laboratory studies such as Atterberg limits, unconfined compressive strength test and Swell Properties, Differential free swell index, Swell potential and swelling pressure and Consolidation Test were carried out on the samples of bentonite, bentonite -CaCl₂ and bentonite - Na₂SiO₃ mixtures to as per standard procedures specified in the code of practices.

III. DISCUSSION

It can be observed from Fig.1 that the liquid limit of bentonite is decreased from its original value of 280% to 100% at 1% CaCl₂. At 0.5% Na₂SiO₃ also the liquid limit of
bentonite is decreased from its 280% to 100% and with further addition of Na₂SiO₃, a slight increase in liquid limit is observed.

![Fig 1. Influence of CaCl₂ and Na₂SiO₃ on liquid limit of bentonite](image1)

The reduction in liquid limit of bentonite with CaCl₂ could be attributed to cation exchange by calcium ions and increased electrolyte concentration in the pore-fluid thereby decreasing the thickness of double layer. In case of Na₂SiO₃, the reduction on liquid limit could be attributed to increased electrolyte concentration with sodium ions in the pore-fluid that result in depressed double layer. Further, it is observed that the addition of Na₂SiO₃ made the bentonite slurry flowable, similar to that with a plasticizer in concrete. The combined influence of CaCl₂ and Na₂SiO₃ on liquid limit of bentonite is shown in Fig. 2. The liquid limit of bentonite is decreased from its 280% to 105% either 0.5% Na₂SiO₃ + CaCl₂ or 1.0% Na₂SiO₃+1.0% CaCl₂.

![Fig 2. Influence of Na₂SiO₃ on liquid limit of bentonite stabilized with 1% CaCl₂](image2)

Form figure 2 a slight increase in liquid limit of bentonite due to the combined influence of CaCl₂ and Na₂SiO₃ compared to their individual effects could be supported by the formatting of gel, which is likely to offer resistance by increasing the viscosity of pore-fluid.

The above figure 3 shows the variation of plastic limit with CaCl₂ and Na₂SiO₃ contents. The plastic limit of bentonite is reduced from its original value of 50% to 38% and 33% for 1% CaCl₂ and 2% CaCl₂ respectively. Similarly the plastic limit is decreased to 37% and 38% for 0.5% Na₂SiO₃ and 1% Na₂SiO₃ contents respectively. Similarly the plastic limit is decreased to 37% and 38% for 0.5% Na₂SiO₃ and 1% Na₂SiO₃ respectively. The reduction in plastic limit could be attributed to a multifold reduction in plasticity compared the possible degree of flocculation that lead to decreased plastic limit as against the conventional increase with lime or cement stabilization.

![Fig 2. Influence of Na₂SiO₃ on plastic limit of bentonite stabilized with 1% CaCl₂](image3)

The combined influence of CaCl₂ and Na₂SiO₃ on plastic limit is shown in Fig 4. The plastic limit of 1% CaCl₂ treated bentonite is reduced from its original value of 38% to 37% and 32% for 0.5% Na₂SiO₃ and 1% Na₂SiO₃ contents respectively. A marginal additional reduction in plastic limit of bentonite upon the addition of CaCl₂ and Na₂SiO₃ in combination could be attributed to further reduction in plasticity due to gel formation.

![Fig 4. Influence of Na₂SiO₃ on plastic limit of bentonite stabilized with 1% CaCl₂](image4)

The combined influence of CaCl₂ and Na₂SiO₃ on shrinkage limit of bentonite is shown in Fig 5. The shrinkage limit of 1% CaCl₂ treated bentonite is reduced from its original value of 25% to 20% and 15% for 0.5% Na₂SiO₃ and 1% Na₂SiO₃ contents respectively. Similarly the shrinkage limit is decreased to 20% and 15% for 0.5% Na₂SiO₃ and 1% Na₂SiO₃ respectively. The reduction in shrinkage limit could be attributed to a similar mechanism as in the reduction of plastic limit due to gel formation.

![Fig 5. Influence of CaCl₂ and Na₂SiO₃ on shrinkage limit of bentonite](image5)
The individual influence of CaCl$_2$ and Na$_2$SiO$_3$ on shrinkage limit of bentonite is shown in Fig. 5. It can be seen from this figure that the shrinkage limit of bentonite is increased from its original value of 14.5% to 18.10% for 1% CaCl$_2$ and 2% CaCl$_2$ respectively. Similarly the shrinkage limit is increase to 22.10% and 23.14% for 0.5% Na$_2$SiO$_3$ and 1% Na$_2$SiO$_3$ respectively. The increase in shrinkage limit of bentonite upon the addition of CaCl$_2$ and Na$_2$SiO$_3$ could be supported by the fact that the plasticity is decreased by cation exchange and flocculation that lead to increased shear resistance which enables the clay to stop shrinking at a higher void ratio.

Fig. 6. Influence of Na$_2$SiO$_3$ on shrinkage limit of bentonite stabilized with 1% CaCl$_2$.

The combined influence of CaCl$_2$ and Na$_2$SiO$_3$ on shrinking limit of bentonite is shown in Fig. 6. It can be seen from this figure that the shrinkage limit of 1% CaCl$_2$ treated bentonite is increased from its original value of 18% to 24.10% and 26.02% respectively for 0.5% Na$_2$SiO$_3$ and 1% Na$_2$SiO$_3$ respectively. The nominal further increase in shrinking limit due combined effect of additives could be supported by the gel formation, which further increases the shear resistance of bentonite.

UNCONFINED COMPRESSIVE STRENGTH OF BENTONITE ADDITIVE MIXES

Fig. 7(a). Influence of curing period on UCS of bentonite additive mixes.

The variation of unconfined compressive strength of CaCl$_2$ stabilized bentonite with curing period is shown in Fig. 7(a). It can be observed from this figure that the UCS of bentonite + CaCl$_2$ mix is marginally increased up to 7 days curing period and thereafter a decrease is observed. In case of bentonite + CaCl$_2$, the UCS is marginally increased up to 3 days curing period and thereafter a considerable reduction in strength is observed at 14 days curing period. However, for bentonite +2% CaCl$_2$ there is a slight increase in its UCS with curing period. From these observations, it is understood that the variation of UCS with curing period for bentonite + CaCl$_2$ mix is random. Such behavior is attributed to variation in the formation and loss of cementations bonds with curing period (Sivanna et al., 1976). Despite these variations, the addition of CaCl$_2$ to bentonite cause an overall reduction in UCS, this could be attributed to reduce cohesion due to a multifold reduction in plasticity.

Fig. 7(b). Influence of curing period on UCS of bentonite additive mixes.

Figure 7(b) shows the variation of unconfined compressive strength of bentonite- Na$_2$SiO$_3$ mixes. It can be observed from this figure that the UCS of bentonite + Na$_2$SiO$_3$ increases up to 7 days curing period and thereafter a considerable reduction in strength is observed at 14 days curing period. Similarly for bentonite + Na$_2$SiO$_3$, an increase in strength is observed up to 3 days curing period and thereafter a considerable reduction in strength is observed at 14 days curing period. The gain in strength up to certain curing period could be attributed to formation of initial cementitious bonds and subsequent reduction in strength could be due to loss of such bonds. Similarly trends are observed even with bentonite + CaCl$_2$ + Na$_2$SiO$_3$ mix also.

Fig. 7(c). Influence of curing period on UCS of bentonite additive mixes.

Fig. 8 (a)
Fig. 8 (a&b): Relative influence of CaCl2 and Na2SiO3 on UCS of bentonite at different curing periods.

The variation of DFS with CaCl2 and Na2SiO3 is shown in Figure 9(a). It can be observed from this figure that the DFS of bentonite is decreased from its original value of 450% to 140% and 130% for 1% and 2% CaCl2 respectively. Similarly, it is decreased to 300% with either 0.5% or 15 Na2SiO3. The reduction in DFS of bentonite upon the addition of CaCl2 and Na2SiO3 could be attributed to depressed double layer thickness due to cation exchange electrolyte concentration, which results in the reduction of repulsive forces between clay particles.

The combined influence of CaCl2 and Na2SiO3 on DFS is shown in Figure 9(b). The DFS of bentonite is decreased from its actual value of 450% to 150% for both 0.5% Na2SiO3+1% CaCl2 and 1% Na2SiO3 + CaCl2 combinations. No additional improvement is observed with Na2SiO3 when used along with CaCl2 in the reduction of DFS.

The swell potential and swell pressure of different bentonite-additive mixes are determined in Oedometer. The Fig. 10 (a, b, and c) show the variation of swell potential of bentonite with CaCl2 content as presented above. The swell potential of bentonite is decreased to 16.9% and 12.68% for 1% CaCl2 and 2% CaCl2 respectively from the original value of 21%. However, the addition of Na2SiO3 increased the swell potential by more than two folds (Fig. 10(c)). When CaCl2 and Na2SiO3 are used in combination, the swell potential is close to that of untreated bentonite. The reduction in swell potential with CaCl2 treatment could be due to cation exchange by calcium ions and increased electrolyte concentration thus reducing the repulsive forces between particles. The
substantial increase in swell potential with Na$_2$SiO$_3$ could be attributed increased sodium concentration and improved permeability whereby the rate of water ingress is affected, upon which the well potential depends. Also, sodium ions hold large number of water molecules by cation hydration. The gel formation due to the addition of CaCl$_2$ and Na$_2$SiO$_3$ changes the clay fabric thus changing the pattern of water ingress.

The variation of swell pressure with CaCl$_2$ contents shows in Fig 11(a,b,c). The swell pressure of bentonite is decreased from its original value of 620 kPa to 180 kPa at 1% CaCl$_2$. The swell pressure is increased by the addition of Na$_2$SiO$_3$. Even the combined addition of CaCl$_2$ and Na$_2$SiO$_3$ resulted in higher swell pressure compared to the addition of CaCl$_2$ alone.

The higher swell pressure values with the addition of Na$_2$SiO$_3$ or CaCl$_2$+ Na$_2$SiO$_3$ could be due to change in clay fabric by flocculation and cementation thus making the clay resistant to compression leading to the record of higher swell pressure values. The plasticity is significantly modified with Na$_2$SiO$_3$ and Na$_2$SiO$_3$+ CaCl$_2$ and hence, the corresponding increase in swell potential and swell pressure could not be attributed to any increased swelling behavior.

CONSOLIDATION PARAMETERS

Except for CaCl$_2$ and CaCl$_2$+ Na$_2$SiO$_3$ stabilized bentonite, the samples could not be consolidated below their initial void ratio due to large magnitude of swell pressure. However, the straight-line portions of e-log p plots are extended assuming similar pattern of compression even below original void ratios and Ce values are calculated. CV value is calculated for the pressure increment of 320 kPa in all cases. The Cv values are in the order of 10-$^{-5}$ cm$^2$/sec expect for bentonite with 2% CaCl$_2$ for which is in the order of 10-$^{-4}$cm$^2$/sec. this could be due to much reduced plasticity of bentonite at 2% CaCl$_2$. The following Cc and Cv values of different additive mixes i.e. Bentonite 0.53 9.814 x 10-$^{-5}$, Bentonite 0.5% CaCl$_2$ is 0.532,8.11 x 10-$^{-5}$, Bentonite + 1% CaCl$_2$ is 0.60 7.21 x 10-$^{-5}$, Bentonite + 2% CaCl$_2$, 0.53, 2.2 x 10-$^{-4}$, Bentonite + 0.5% Na$_2$SiO$_3$ 1.21, 7.64 x 10-$^{-5}$, Bentonite + 1% Na$_2$SiO$_3$ 1.17,7.21 x 10-$^{-5}$, Bentonite + 1% CaCl$_2$, + 0.5% Na$_2$SiO$_3$ 0.51 9, 815 x 10-$^{-5}$, Bentonite + 1% CaCl$_2$, + 1% Na$_2$SiO$_3$ 0.95 7 and 211 x 10-$^{-5}$ respectively.

IV. CONCLUSIONS

The following conclusions are drawn based on the laboratory investigations carried out in the present investigation.

- The plasticity properties of bentonite are significantly modified by the addition of CaCl$_2$ and Na$_2$SiO$_3$. The liquid limit of bentonite is decreased to one-third of its original value due to the addition of about 1% CaCl$_2$ or Na$_2$SiO$_3$.
- The shrinkage limit is increased by 45-80% with the addition of CaCl$_2$ and Na$_2$SiO$_3$ indicating the fabric changes and reduced potential for volume change.
- The swell potential of bentonite is reduced from its 21% to 16% at 1% CaCl$_2$. But with Na$_2$SiO$_3$, the swell potential is increased by more than twice its original value.
- The swell pressure of bentonite is decreased from its original value of 620 kPa to 180 kPa at 1% CaCl$_2$ whereas with Na$_2$SiO$_3$, the swell pressure is more than the original value.
- The addition of CaCl$_2$ and Na$_2$SiO$_3$ reduced the unconfined compressive strength with period for different bentonite-additive mixes.
A marginal variation is observed in consolidation parameters with CaCl₂ but the Cc of bentonite - Na₂SiO₃ mixes are about twice that for other mixes.

This study revealed that the plasticity and swell properties of bentonite can be substantially modified with CaCl₂ and the combined influence of CaCl₂ and Na₂SiO₃ is not impressive. However, micro-scale studies are required to understand the exact behavior changes with respect to strength, swell and consolidation properties.

REFERENCES