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Determination of Required Ion Exchange Solution for Stabilizing Clayey Soils with Various PI

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***Abstract*—**Soil stabilization has been widely used to improve soil strength and durability or to prevent erosion and dust generation. Generally to reduce problems of clayey soils in engineering work and to stabilize these soils additional materials are used. The most common materials are lime, fly ash and cement. Using this materials, although improve soil property , but in some cases due to financial problems and the need to use special equipment are limited .One of the best methods for stabilization clayey soils is neutralization the clay particles. For this purpose we can use ion exchange materials. Ion exchange solution like CBR plus can be used for soil stabilization. One of the most important things in using CBR plus is determination the amount of this solution for various soils with different properties. In this study a laboratory experiment is conduct to evaluate the ion exchange capacity of three soils with various plasticity index (PI) to determine amount or required CBR plus solution for soil stabilization.

***Keywords*—**CBR plus, clayey soils, ion exchange, soil stabilization

I. Introduction

CLAY soils are commonly stiff in dry state but lose their stiffness when saturated with water, soft clays are characterized by low bearing capacity and high compressibility, the reduction in strength and stiffness of soft clays cause bearing capacity failure and excessive settlement, leading to severe damage to building and foundations [1]. The use of traditional geotechnical engineering techniques for infrastructure, such as the replacement of unsuitable soils for stiff and resistant embankment, is often problematic, not only for their high costs, but even more for environmental reasons. In roads, for instance, the use of granular bases becomes unsuitable when the extraction site is at a significant distance from the construction site [2]. As respects clayey soils constitute a large part of soils and because of engineering specific characteristics, are important and to reduce problems of clayey soils in engineering work and to stabilize these soils additional materials are used.

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Application of stabilization agent on soils has a long history. Cement was first used as stabilizing agent at the beginning of the 20th century to mix with the soils and form road materials. Since then many other materials such as lime [3], fly ash [4], Organic polymers [5] and their mixture were used as stabilizing agent.

Lime stabilization is one of the methods of soil stabilization. Clay soil can be stabilized by the addition of small percentages, by weight of lime, thereby enhancing many of the engineering properties of the soil for producing an improved construction material. Lime in its various forms are widely used in stabilizing the soil for, improving the sub-base and sub grades of road rail track, runway of airports, embankment construction, soil exchanging in unstable slopes, canal lining, improving the soil beneath foundation etc.

When lime is added to a clayey soil it has an immediate effect on the properties of the soil as cation exchange begins to take place between the metallic ions associated with the surfaces of the clay particles and the calcium ions of the lime. Clay particles are surrounded by a diffuse hydrous double layer, which is modified by the ion exchange of calcium. This alters the density of the electrical charge around the clay particles, which leads them being attracted closer to each other to form flocs, the process being termed flocculation. It is this process which is primarily responsible for the modification of the engineering properties of clay soils when they are treated with lime [6].

Here CBR plus solution that have polymeric structure and yet was used in many countries for construction road, without asphalt with clayey soils are available in that place, reduction thickness of asphalt and dust control can be used for soil stabilization.

In this study our aim is to utilize CBR plus for soil stabilization and increase soil bearing. The amount of CBR plus solution is different for various soils and our aim is determination of the amount of this solution for soil stabilization. Our aim is determination of this solution for soils with various PI.

II. Material

A. CBR plus

CBR plus is a stabilizer for anionic soils that improves the load bearing performance of a variety of clays and silty soils. It has been used word wide over twenty years to control dust and improve compaction [7]. CBR plus allows engineer to utilize in situ materials. Materials normally are not suitable for road construction can now, after treatment with con-aid/CBR plus be used for base and sub base in roads foundations [8]. To better understand performance of the CBR plus first it is necessary to understand the characteristics of clay.

Most clay minerals are made up of stacks of silica and alumina sheets. The arrangement of these sheets results in different clay minerals such as kaolinite, montmorilloint and illite. Simply stated, these clay minerals inherently have a predominantly negative electrical or anionic charge, this cause the clay minerals to have strong attraction for any cautions that are present. The negative clay mineral, attract cations like iron filings to a magnet and will react with water when present (the electro static forces are greater in close proximity to the clay molecule or particle, resulting in very strong bonds).normal temperatures and compaction pressures will not remove then. This layer of water is known as the electrostatic diffused double layer of *adsorbed* water [7]. Clay particles like montmorillonite are like sheets of book have space between the plates or layers that can absorb water causing them to expand. These are known as expansive or swelling clays and are the cause of many failures in foundations or read layers [7]. The obvious solution is to reduce the adsorbed layer of water surrounding the soil particle if powerful positive molecules (such as 4^{+} charge in CBR plus) can be supplied, the negative charge of the clay minerals can be satisfied or balanced out. At the same time any weaker cautions, such as water can easily be disassociated and replaced, and/or occupation of the vacant ionic sites on the clay surface can take place [7].

In general terms it can be said that Con-aid/ CBR plus forms an extremely thin oily layer on the surface of soil particles and especially on clay particles. This facilitates the compaction of soil and allows water, which is normally chemically bound with the soil particles, to be driven out of the soil matrix. In this process the soil can be compacted to a higher density. Since con-aid CBR plus neutralizes the natural electrical charges that occur on the soil particle surface, the soil particles can be compacted to a much closer degree (especially by traffic forces). This result in increase internal friction between the soil particles, which in turn result in a higher bearing capacity for the soil [8].

CBR plus reduces ion mobility and ion exchange and simultaneously make the material hydrophobic by eliminating the adsorption of water. The result is a soil material that is much less sensitive to moisture, more workable and can be compacted to a better particle- interlock state by equipment and traffic forces [7]. CBR plus will treat materials ranging from clays to silty sands and some gravels. Non-cohesive materials such as sand can be treated only after they have been modified by mixing them with a suitable clayey material [7]. CBR plus expulsion adsorbed water in clay particles, to achieve maximum density, with less mechanical effort and to prevent the re-adsorption of water [Fig. 1,2 &3]. This result in a permanently stabilized construction materials[7].

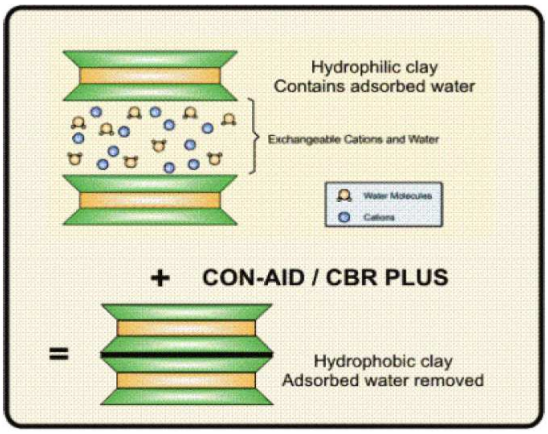

Fig. 1 Adding CBR plus increase the volume of clay particles [9]

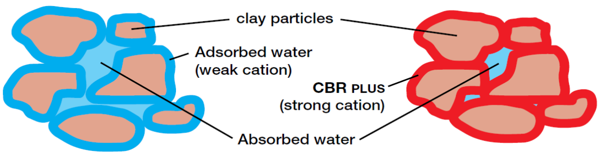

Fig. 2 CBR plus remove adsorbed water [7]

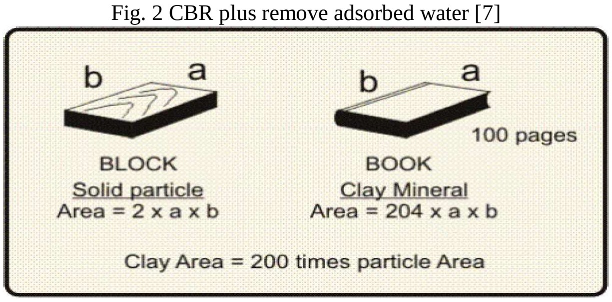

Fig. 3 Reduce particles area after adding CBR plus [9]

Con-aid/CBR plus has the following physic-chemical properties:

- Totally water soluble with no solid residue.
- Non-flammable
- Non-corrosive
- Non-toxic and safe
- Environment and user friendly [10].

Physical and Chemical Properties of CBR plus is shown in Table I.

TABLE I
PHYSICAL AND CHEMICAL PROPERTIES OF CBR PLUS [11]

Appearance:	Chocolate Brown viscous fluid
Odour:	Sulphurous Odour
Physical State:	Viscous Fluid
Freezing Point(°C):	<-10° C
Boiling Pint (°C)	100°C
pH:	0,9
Specific Gravity:	0.94
Coeff Water/Oil:	100% water soluble

B. Soil

Fine-grained clayey soil was used in this experimental study. Soil is from Iran-Ghazvin –Abyek. Particle size analysis of soil is done. The soil lies above the A-line (Fiq.4). The soil is classified as low plasticity soil according to the unified soil classification system (ASTM D422-87) and its name according to USCS is CL (clayey soil with low plasticity).

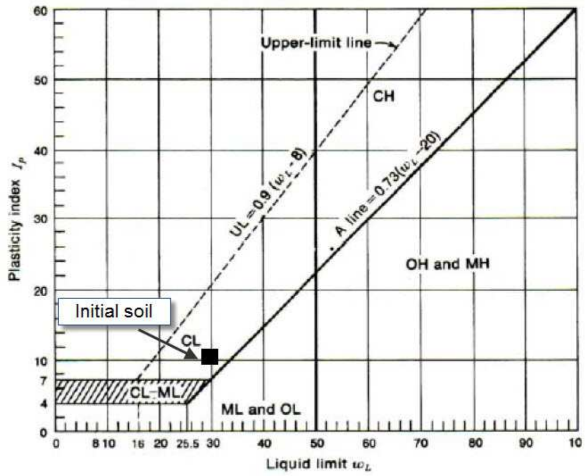

Fig. 4 Location of initial soil in plasticity chart

For determination maximum dry unit weight and optimum water content modified proctor test is done according to ASTM D-1557 and this result is used for preparation CBR samples.

After doing this test, CBR test is done according to ASTM D-1883. We did CBR tests on samples with optimum moisture and saturated moisture. For doing CBR test with optimum moisture we did CBR test immediately after preparation the samples and for doing CBR test on saturated samples we first soaked the samples in water for 96 hour and then did CBR test. A result of CBR tests on saturated sample is shown in Fig. 5. CBR values for saturated sample are shown in Table II.

According to CBR tests results, specially saturated CBR test it is understand that this clayey soil has low bearing capacity and for using in base or sub base of roads, stabilization is required.

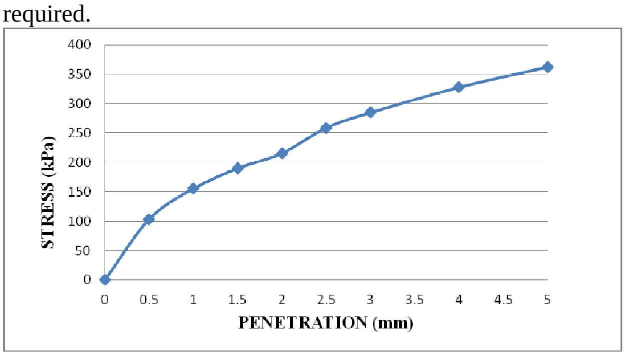

Fig. 5 A result of CBR tests on saturated sample

TABLE II
CBR VALUES FOR SATURATED SAMPLE

At 2.5 mm penetration	5.4
At 5 mm penetration	5.1

Determination amount of required ion exchange solution is done through cation exchange capacities test.

To achieve an overall relationship between ion exchange solutions required and soil characteristics like grading, and especially Atterberg limits, we need a wide range of soils for this study. For this purpose and to achieve soils with different grading and Atterberg limits (LL and PL) we used bentonite.

We added various percentages of bentonite; 10% and 20% of the soils weight is bentonite. After adding 10% and 20% bentonite, we have three different soils, initial soil and soil with 10% bantonite and soil with 20% bentonite with various grading and plasticity index it is in accordance with B. Naderi nia [13].

III. CATION EXCHANGE CAPACITIES

Phyllosilicate clay minerals have particular properties and reactions related to, and controlled by, their small size and net electrical charge. The sheet-like crystallographic structure along with the small size gives these soil clays a very high surface area in relation to their mass. The excess negative charge on many of these clay surfaces results in the attraction of water and ions (charges atoms and molecules) to the clay minerals.

Adsorption: The negative electrostatic charge of clays attracts cations from the surrounding soil solution, which can be retained, or adsorbed, at the mineral surface. Other cations can compete with and replace adsorbed cations. This results in the property known as the *cation exchange property* (CEC). Exchange reactions result in a) retention of certain plant nutrients in a plant available form in soils; b) control and buffering of soil pH (acidity); c) modification of the chemical composition of water as it passes through soil. CEC can also result in the adsorption of organic compounds if they are charged. Exchange reactions are usually rapid, reversible and stoichiometric.

Cation Exchange Capacity: The cation exchange capacity is defined as the sum of exchangeable cation *charge* that a soil can adsorb. The ability to exchange cations is an important property of clay minerals; however, this phenomenon is not exclusive to phyllosilicate clay minerals. Other components of soil, such as organic matter and soil oxides have cation exchange properties as well.

Adsorption of Organic Substances: Clays that exhibit a net negative charge due to isomorphic substitution (such as montmorillonite) will attract water and cations. Small, nonpolar molecules such as benzene, unable to displace either water or a cation, will not adsorb. Organic cations, such as some herbicides, will be adsorbed through cation exchange. Large molecules, even if uncharged, can be adsorbed on to some clay due to a hydrophobic effect (they would rather be

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on the clay than in the water). Negatively charged molecules may either bridge to the clay via a multivalent cation, or adsorb to broken edges of the clay particles. Association with clay surfaces is believed to protect organic molecules from biodegradation.

Cations are not rigidly held on the colloidal surface, but because of their thermal energies have some degree of motion on and away from the surface, such that a hemisphere of motion is defined for each particular combination of ion and colloidal surface. Consider two cases, the first case, a tightly held and hence, nonexchangeable or fixed cation and the second case, a less tightly held exchangeable cation (Fig. 6).

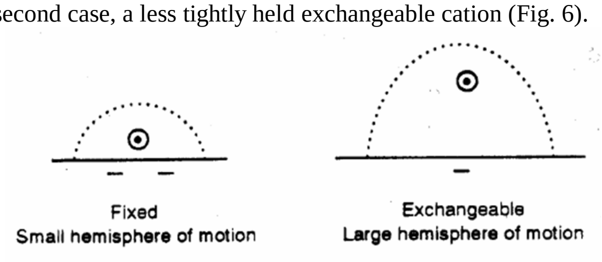

Fig. 6 Fixed & Exchangeable cations [12]

Cation exchange occurs (Fig. 7) when ions (⊗) in the bulk solution move into the hemisphere of motion of a cation on the surface at a point in time when the exchangeable cation (⦿) is far from the surface. The ion initially in solution becomes trapped on the surface by the negative charge, and the ion initially on the surface moves into the soil solution. If the surface ion is close to the charged colloidal surface when the solution ion randomly moves into the hemisphere of motion, ion exchange does not occur , and the ion returns to the solution. The motion of the ions in the bulk solution is due to their thermal energies.

Cation Exchange Capacity of three various soils with laboratory tests are determined.

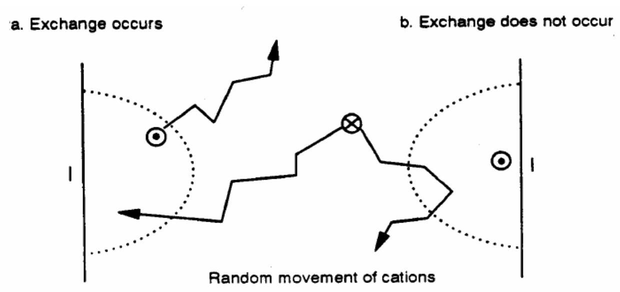

Fig.7 Example of cation exchange [12]

IV. Result And Discussion

A. Effects of bentonite on soil characteristics

Determination of the distribution of particle size in soils is done according to ASTM D-422, (Fig.8). The names of these three soils are A, B and C; A is initial soils, B is soil with 10% bentonite and C is soil with 20% bentonite.

In addition to grain size distribution test of three soils, other tests were done for these three soils; Specific gravity test according to ASTM C-128, Atterberg limits test according to ASTM D-4318, compaction test according to ASTM D-1557. The names of three soils are determined according to USCS. Soils locations in plasticity chart are shown in Fig. 9. Results of these analyses are shown in Table 3; these results are in accordance with B. Naderi nia et al. [14].

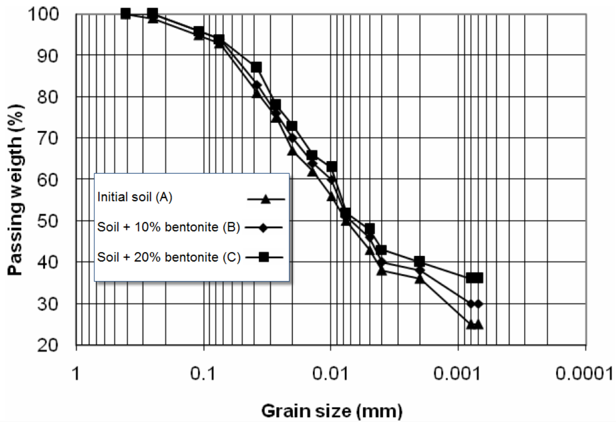

Fig. 8 Grain size distribution of three soils

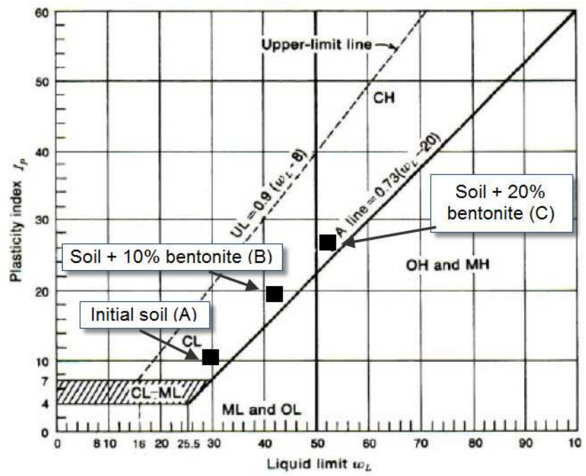

Fig. 9 Locations of three soils in plasticity chart

TABLE III
ENGINEERING PROPERTIES OF THREE SOILS

Property		Soil A	Soil B	Soil C
Specific gravity		2.75	2.73	2.71
	Liquid Limit	32	40	51
Atterberg limits	Plastic Limit	19	21	26
	Plasticity Index	13	19	25
Compaction parameters	Optimum moisture content (%)	12	13.2	14.3
	Maximum dry unit weight(kN/m^3)	19.1	18.7	18.3
Soil classification (USCS)		CL	CL	CH

B. Effect of bentonite on cation exchange capacity test results

Table 4 shows relationship between plasticity index (PI) and cation exchange capacity of soils. This shows that the increase in PI is because of increased area in clayey soils with adding bentonite and this increases the amount of ions in soils and thereby increase the amount of ion-exchange solution is required to stabilize the soils.

TABLE IV
AMOUNT OF CBR PLUS FOR STABILIZE 1 M^2 SOIL WITH 15 CM THICHNESS

Soil	Amount of CBR plus (Litre)	Plasticity Index of soils
Initial soil (A)	0.006	13
Soil + 10% bentonite (B)	0.0062	19
Soil + 20% bentonite (C)	0.0064	25

V. CONCLUSION

1) Ion exchange solution permanently can stabilize clayey soils. It is important that the soils must have clay particles to be appropriate for stabilization with ion exchange solution; this process has been observed in this study.
2) Adding bentonite to soils can change soils characteristics like plasticity limit and liquid limit. In this study it is observed that adding bentonite increase plasticity limit, liquid limit and plasticity index.
3) The presented soil has low CBR so stabilization is needed for increasing bearing capacity.
4) The negative electrostatic charge of clays attracts cations from the surrounding soil solution, which can be retained, or adsorbed, at the mineral surface. Other cations can compete with and replace adsorbed cations. This result in the property known as the *cation exchange property* (CEC), this is the process that occurs when CBR plus is added to anionic soil.
5) Increase in PI is because of increase area in clayey soils with adding bentonite and this increases the amount of ion exchange in soils and thereby increases the amount of required ion exchange solution for stabilizing the soils.

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