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Role of Silica in Additive Improvement of Engineering Characteristics of Expansive Soil

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Abstract: ***Expansive soils, on account of their typical swelling and shrinkage characteristics pose a lot of problems for construction engineers. These swelling and shrinkage characteristics are attributed to presence of certain minerals in expansive soils and they swell in presence of water and shrink otherwise. This alternate swelling and shrinkage endangers safety of the structures built over such soils and they need to be treated to improve upon such a behavior which can be done by addition to such soils, certain admixtures also containing silica. If any improvement is done by adding certain admixtures, such improvement is known as additive improvement. In this paper we will discuss about role of silica in achieving improvement.s***

Keywords: Expansive soil, Montemorillonite, Smecite, Quarry dust, Swelling, Shrinkage.

I. INTRODUCTION:

Expansive characteristics in soil is imparted owing to presence of certain clay minerals such as Montemorillonite . Every clay mineral has got a typical structural configuration. For example in Montemorillonite typical symbolic structural configuration is trapezoidal silica sheet followed by alumina sheet again silica sheet. This makes one part of the structural unit which is separated by a water film from a similar unit. This water film sandwiched between two parts is the root cause of the problem but is solution in disguise also. If the water film is replaced by certain particles/ ions the problem of expansion and shrinkage shall be solved up to a large extent, But such particles must be electrically charged which are going to replace water particles sandwiched in between the two units that is why term ion has been used here otherwise adhesion of such particles to soil particles shall not be possible which are already charged negatively.. In this study quarry waste/dust has been used as an admixture to improve swelling and shrinkage behavior. In a nutshell it can be said that expansive potential of a soil is decided by percentage of clay and amount of constituent mineral in clay in any soil. This shall not be out of place to mention here that water entrapped in the structural unit of the mineral mentioned above namely Montemorillonite is polar in nature and can be replaced by Cations offering one of the possible solutions. In the previous studies of the problem every researcher focused upon the improvement aspect of any of the admixtures but no research paper is available on mechanism. This paper tries to fulfill this gap.

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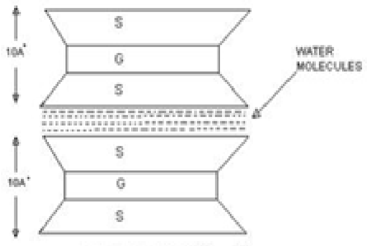
II. MONTEMORILLONITE, THE PROBLAMATIC MINERAL:

In fact any clay is a conglomerate of silicate minerals. Principal elements in clay are Silica, Aluminum and oxygen disposed in particular configuration of either tetrahedron or octahedron arranged in a particular manner. In tetrahedral structure one silicon atom is surrounded by four oxygen atoms at the tips of a tetrahedron and a tetrahedral sheet is a combination of tetrahedral units while in octahedral structure there are six hydroxyl ions at the tips of the octahedron which surround Aluminum or magnesium or other metallic atom (which in the case of Montemorillonite is aluminum). In clays tetrahedral and octahedral units are bound together in sheet structures giving rise to tetrahedral and octahedral sheets which are disposed in certain peculiar and unique manner giving rise to different clay minerals depending upon the disposition of sheets. In our case of montemorillonite, one Octahedral alumina sheet is sandwiched between two tetrahedral silica sheets giving rise to one structural unit of approximately 9.6A^0 in which tips of the tetrahedron sheet combine with the hydroxyls of the octahedral sheet to create a single layer. The dimensions in other two directions are indefinite. Two such structural units are separated by water and other exchangeable ions which can easily enter such a lattice structure causing swelling of soil which is the root cause of the problem. Interlayer bonding between the top of the silica sheets are on account of Vander Waal"s forces which are relatively weak compared to ionic or hydrogen bond . this may also give rise to partial isomorphic substitution such as Al^{3+} for Si^{4+} in tetrahedral sheet and Mg^{2+} or Fe^{2+} for Al^{3+} as it is a known fact that such a substitution results in a very large net negative charge deficiency as it can take place only by lower valence similar size metallic ions. In addition Montamorillionite clay has got a very large specific surface of 500-800 gm/m^2. All these factors taken together make such soils susceptible for water affinity and a large amount of water can enter the lattice structure and substantial volume changes may occur in such soils in presence of water. They swell when the water enters the lattice structure and shrink if water is removed somehow. Its excessive swelling potential may seriously endanger the overlying structure or pavements rendering such soils the most problematic soils for engineers.[14,Gopal Ranjan and Rao]



MONTMORILLONITE (Fig. - 1)

Table 1: Description of a few properties of expansive soil (Sample taken from Bundel Khand region of Uttar Pradesh in India)

S.No	Description of Property	Value
1	Liquid limit (%)	62
2	Plastic limit (%)	23
3	Plasticity Index (%)	39
4	Specific Gravity	2.51
5	I.S. Classification	CH
6	Optimum Moisture Content	23%
7	Maximum Dry Density (t/cu.m)	1.83
8	Unconfined Compressive strength	18.0 kg/cm^2
9	Free swell Index	87

A symbolic pictorial depiction of Montamorillonite has been given in figure -1 given above. As is clear from the figure that silica sheet shown symbolically in trapezoidal form denoted as ‘S’ is followed by alumina sheet which is

symbolically shown as rectangular denoted as ‘G’ where G stand for Gibbsite alternatively known as alumina. Then again silica sheet which makes one structural unit. This unit is separated by another such unit by a water film. This water film is responsible for swelling and shrinkage behavior of such soil and this water film gets an easy excess to lattice structure. If heated at higher temperature of more than 120^{0C} this water gets evaporated indicating that in addition to such heating which is impracticable at larger scale we can get rid of this water with other means also as it is detachable. All the methods of treatment to improve upon swelling characteristics depends upon this possible detachment of water layer from the lattice structure

I. A FEW ENGINEERING CHARACTERISTICS OF EXPANSIVE SOIL:

A few characteristics of expansive soil which are of our interest are enunciated below. The samples of the soil were taken from Bundel Khand region of Uttar Pradesh in India and tests were performed. In addition to routine testes of optimum moisture content and maximum dry density, the test for free swell index was performed which gives indication for our main area of concern that is swelling. If free swell index exceeds 50 indicates that soil is expansive and needs attention. If somehow or the other this is brought down to less than 50 we shall succeed in bringing down swelling potential of the soil and other characteristics of the soil including the strength characteristics shall automatically improve.In its entire likely hood the entrapped water in the structural lattice which is the root cause of the problem offers a solution also if somehow or the other it is replaced. Undoubtedly the character of basic structural lattice shall be changed after the improvement takes place. We shall also examine the changes in structural unit If we examine the above table 1, we find that free swell index of the soil is 87 which is1.74 times more than 50, the threshold value of free swell index making it a problematic soil and needs treatment. Now if somehow or the other by means of treatment we are able to bring down the swelling index our purpose shall be solved and we shall be in position to study the mechanism.

Quarry dust, a wonder material for treatment of expansive soil on account of its silica content:

For our purpose we chose quarry dust as an admixture for soil improvement. In fact from every stone crusher approximately 20% is waste in form of dust. This dust is being utilized in concrete at most of the construction sites but its potential as soil improvement material has not been utilized to its fullest potential and is underestimated, though this material has got enormous potential for such an improvement, thanks to its chemical composition and other properties. For our purpose of study we used quarry dust as a material for improvement and examined whether any improvement is there and results were astonishing. We used quarry dust in varying percentages as admixture in the soil and examined various properties of expansive soil after the treatment. Before we go into the test results let us examine typical chemical composition of quarry dust. It is given below.

Table 2: Properties of Quarry Waste, Chemical Composition

No.	Description	Formula	Range
1.	Silica	SiO_2	75%
2.	Alumina	Al_2O_3	14%
3.	Lime	CaO	1.28%
4.	Magnesium Oxide	MgO	0.33%
5.	Ferric Oxide	Fe_2O_3	1.22%

6.	Sulphates	SO_4	0.9-2.0(%)
7.	Carbonates	CO_3	0.5-6.6(%)
8.	Organic Matter	-	0%
9.	Loss on Ignition	-	Not assessed
10.	PH	-	Not assessed

Improvement Process

From the above table 2, we observe that major percentage of compounds is Silica 75% and Alumina 14% in stone dust. Incidentally these two compounds only are responsible for formation of Silica Sheet and Alumina sheet in montemorillonite structure. We shall examine the exact mechanism subsequently but at the very outset it shall be pertinent to mention that in nature if any constituent material is there in any body or soil or human body and any problem occurs there, it can be very well cured by constituent material supplied externally. It is nature and the same phenomenon takes place here also. Continuity of two constituent structural units is broken by a water layer which gives rise to problem of swelling and shrinkage. If somehow are the other that continuity is maintained the problem shall be solved and quarry waste does exactly that

II. COMPARATIVE STUDY

Variation of O.M.C with Varying Percentage of Stone Dust sadded to Soil

Table3a: Stone Dust Percentage Vs OMC

Sl.No.	Percentage of Stone Dust Added	Optimum Moisture content (%)
1	20	23.0
2	30	24.2
3	40	25.1

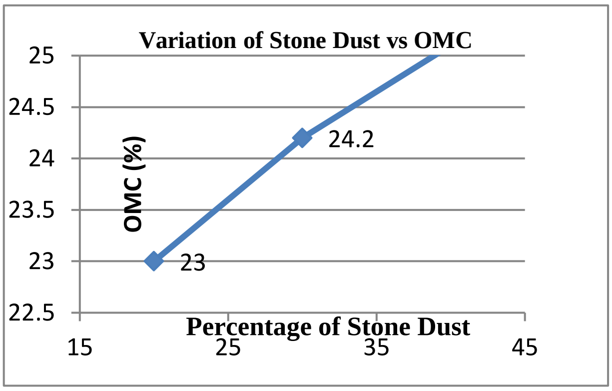


Fig2a: Stone dust percentage Vs OMC
Variation of Maximum Dry Density with Varying Percentage of Stone Dust added to Soil

Table3b: Maximum Dry Density with Varying Percentage of Stone Dust

Sl.No.	Percentage of Stone Dust Added	MDD (t/cum)
1	20	2.1
2	30	1.83
3	40	1.7

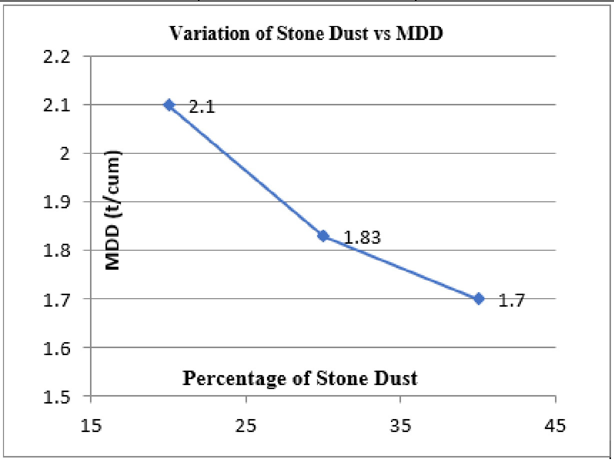


Fig 2 b: Maximum Dry Density with Varying Percentage of Stone Dust

From the above tables 3(a) and 3(b) and relevant graphs one thing is evident that on increasing the percentage of stone dust maximum dry density is decreased while OMC increases, Probably because stone dust particles need more moisture for their resettlement in to the lattice structure and consequent decrease in maximum dry density. And it is also clear from fig 2(c) that maximum UCC value is obtained at 30% stone dust by dry weight of soil and our main area of concern that is FSI is considerably brought down to 48 from 87 (Fig 2(d)). The reason of this is being discussed under the head "Mechanism" mentioned below. Variation of UCS with Varying percentage of Stone Dust added to Soil

Table3c: UCS with Varying percentage of Stone Dust

Sl.No.	Percentage of Stone Dust Added	UCS (Kg/m2)
1	20	18.9
2	30	19.7
3	40	19.6

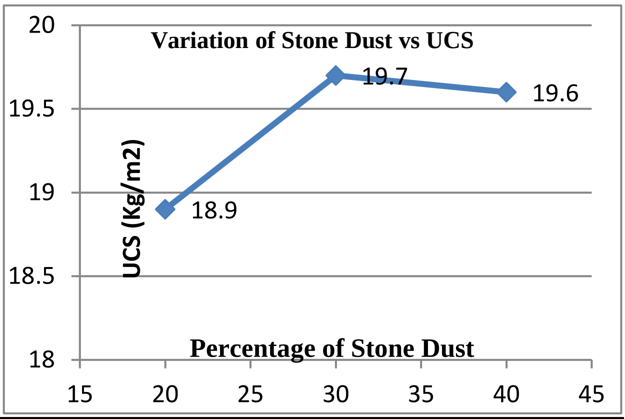


Fig2c: UCS with Varying percentage of Stone DustVariation of Stone Dust Vs FSI

Table3d: Stone Dust Vs FSI

Sl.No.	Percentage of Stone Dust Added	Free Swell Index
1	0	87.0
2	10	72.0
3	20	60.0
4	30	48.0

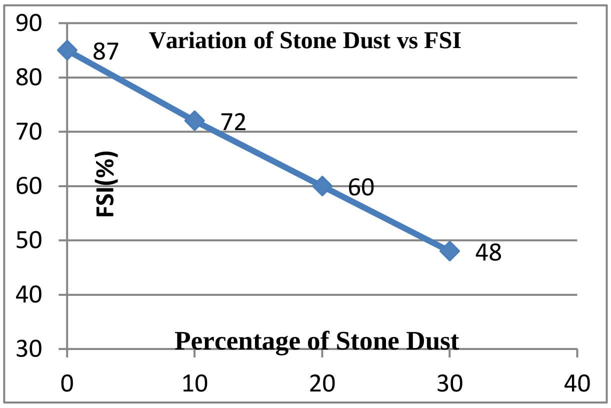


Fig2d: Stone Dust Vs FSI

III. MECHANISM:

From the aforementioned discussions it is clear that mechanism of improvement appears to be very complex but is very easy to understand. In fact montemorillonite is highly plastic and has got little internal friction. When we add stone dust that internal friction is increased. Secondly water being a dipolar molecule has got an affinity to stick to the bottom of the upper silica sheet of one structural unit and to the top of the silica sheet of lower structural unit. In addition to water other exchangeable ions can also enter between the layers. It is easy to understand that silica and alumina both contain exchangeable ions which can easily find an entry to the lattice structure and can push water out as all this bonding between water and silica sheet is on account of weak VanderWall's forces and could by easily broken for replacement with other suitable ion which has got more affinity to silica sheet than water. If we examine chemical composition of stone dust we will find that it has got 75% silica and 14% alumina which can provide sufficient ionic material for replacement and at the same time affinity of silica of stone dust to the silica sheet of structural unit shall be more than that of water to the silica sheet water being a foreign material in the above case which shall be easily replaced by silica. Ones this water is expelled from the structural lattice of montmorillonite it is readily available for reaction with other compounds like Cao available in stone dust though, in a smaller percentage, to form a cementing compound like $Ca(OH)_2$ which shall in turn increase strength characteristics of soil. Now the only question remains to be answered is how the ions are made available from stone dust to the structural unit. As has been already mentioned that none of the bonds in silica are of ionic nature and they are associated only by Vanderwall"s forces which are weaker bonds and are easy to break. In presence of dipolar water these ions are easily separated and are available in abundance for replacement. Typical structure of erstwhile montmorillonite is transformed to a symbolic structure shown below in Figure -3

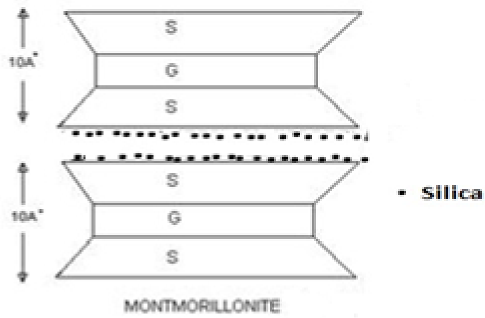


Fig 3

From the foregoing discussuion it is clear that continuity of the structural unit which was broken by water film in the structural unit is established and it is transformed for bettterment of the soil.

IV. CONCLUSION

Stone dust which is aprroximatly 20% waste from crushers which is of no use to the crusher units. Its only use presently is in manufacturing of concrete but if we use it as an improvement material to improve swelling and other characteristics of expansive soil very good results could be found. In fact from the foregoing discussion it is also clear that any such material which is waste, is not otherwise harmfull and contains silica can be used for such improvement.

V. INTERPRETATIONS:

Silaca plays a very imprtant role in additive improvement of expansive soils. More so the phenomenon behind the whole of the phenomenon could be attributed to cationic excahnge in which water is being repalced by either Si or Ca ions and probaly that is the reason that all the additives which are added to soil for improvement contain either Silica or Ca or both. The probabilty of exchange by silica appears to be more.

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