Effect of Inorganic Chemicals on the Consistency Properties of an Expansive Soil Sample

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Consistency properties of a soil to a certain extent indicate the behavior of the soil for engineering construction. This paper reports the results of effect of 20 inorganic chemicals in varying amounts on the consistency properties of an expansive soil sample from Poona. Certain soluble and insoluble hydroxides make the soil friable. KCl and NaCl are also found effective in improving the shrinkage characteristic of the soil. $FeCl_3$ and $(NH_4)_2 HPO_4$ make the soil mass porous.

• A LARGE PART of central and southern India is covered with various types of soils, mostly medium to heavy clays, black in color, exhibiting excessive swelling and shrinkage, and high plasticity characteristics. Due to alternate wetting and drying conditions, deep and wide cracks are observed in these soils. Such soils are locally called black cotton soils, and similar types of expansive soils are also met with in tropical countries like Burma and Kenya (10, 15, 16).

The deleterious properties of these expansive soils are attributed to the presence of clay minerals, such as montmorillonoids or a combination of montmorillonoids and illites (2, 4, 5, 10, 11, 16). These soils have been considered as highly problematic for foundations and road-building purposes.

Consistency properties of a soil in general indicate the performance of a soil for engineering use. Winterkorn's study of changes in physical properties of Putnam soil induced by ionic substitution shows that the consistency properties of the soil change with the type of cation adsorbed on the clay fraction (13). It is also the experience of various research workers working in the field of engineering, agronomy, and ceramics that the physical properties of soils can be altered by the addition of chemical admixtures (1, 5, 6, 8, 9, 12, 13, 14, 16). Thus, these studies indicate that incorporation of certain inorganic chemicals into the expansive soils may improve their detrimental properties.

With the previously mentioned points of view in mind, a study was conducted to evaluate the effect of various inorganic chemicals on the consistency properties of an expansive soil sample from Poona. The soil was treated with amounts of inorganic chemicals ranging from 0.1 to 10 percent to take into consideration both practical and academic interests.

MATERIALS

Soil

The soil is sampled from the premises of College of Military Engineering, Kirkee, Poona. The sampling site is on a level stretch of ground near the magazine section. The sample was collected from a depth of 1 to 2 ft from the surface. The depth of black cotton soil at this location is said to be 14 ft.

The properties of this soil are given in Table 1. Texturally, the soil is classified as clay. According to AASHO engineering classification, it is a A-7-5(18) soil. Its characteristic features are its high liquid and plastic limits, and its very low shrinkage limit.

Base exchange capacity of this soil indicates that the clay minerals present in the soil may be montmorillonite or a mixture of montmorillonite and illite.

The swelling pressure recorded for a 5-in. high soil sample compacted to a density corresponding to 90 percent of standard Proctor density is 2.0008 tons per sq ft. This soil has been selected for detailed study.

TABLE 1

PROPERTIES OF BLACK COTTON SOIL SAMPLE

Property	Value
Physical:	
Liquid limit	67.2
Plastic limit	48.85
Plasticity index	18.35
Shrinkage limit	8.18
Shrinkage ratio	2.06
Field moist. equiv.	56.47
Centrifuge moist, equiv.	55.825
Specific gravity	2.72
Chemical:	
Organic matter (%)	1.422
Carbonate content[a]	6.65
pH	8.45
Base exch. cap. meq	60.0
SiO_2 (%)	50.29
Al_2O_3 (%)	21.88
CaO (%)	8.0
MgO (%)	4.37
Fe_2O_3 (%)	1.45
TiO_2 (%)	0.33
Loss on ignition (%)	13.67
Silica sesquioxide ratio	2.16
Engineering:	
Proctor density	
Pcf	82.5
Opt. moist. cont. (%)	29.4
Mod. Proctor density	
Pcf	102.5
Opt. moist. cont. (%)	24.0
Calif. bearing ratio (%):	
0.1-in. penetration	30.55
Same after soaking 96 hr	3.82
Swelling pressure (T/sq ft):	
At std. Proctor density	0.632
At 90% std. Proctor density	2.0008
Mechanical analysis:	
Gravel[b] (%)	0.0
Sand (%)	17.5
Silt (%)	43.5
Clay (%)	39.0
Effective size (mm)	0.00028
Uniformity coeff.	25.0
BPR textural class.	Clay
AASHO eng. class.	A-7-5(18)

[a]$CaCO_3$ eq per g of soil.
[b]Grain-size limits adopted are according to U.S. Bureau of Public Roads.

Chemicals

The chemicals selected for treating the soil are di-ammonium phosphate, barium carbonate, barium chloride, calcium chloride, calcium phosphate, calcium hydroxide, portland cement, copper sulfate, ferric chloride, magnesium chloride, magnesium carbonate, magnesium phosphate, potassium hydroxide, sodium hydroxide, sodium chloride, sodium silicate, sodium sulfate, and sodium carbonate.

The soil was treated with various chemicals in the amounts 0.1, 0.25, 0.5, 0.75, 1.0, 1.5, 2, 3, 5, 7, and 10 percent based on the oven-dry weight of soil. Such a large range in amount of chemicals is chosen to cover both practical and academic interests.

TESTING METHOD

Soil passing through sieve No. 40-ASTM was mixed with a predetermined amount of chemical, calculated on the oven-dry weight of soil. Liquid, plastic, and shrinkage limits were then determined for this treated soil.

The liquid limit was determined by using standard liquid limit apparatus (ASTM D 423-39). Number of blows to close the standard groove were found at four different moisture contents.

The plastic limit was determined according to ASTM D 424-39. Four tests were done and their mean value has been reported.

Duplicate pats of treated soil were prepared as specified in ASTM D 427-39. Time for both mixing the chemical and molding the pats was restricted to 10 min. To avoid cracking as far as possible during the drying process, the pats were dried in an oven, the temperature of which was gradually increased from room temperature to 110 C in a period of three days. Volume of dried pats was determined by the mercury displacement method and the shrinkage limit and ratio were calculated according to ASTM D 427-39.

RESULTS

The chemicals are grouped for analyzing and interpreting the data given in Table 2.

Hydroxides

Up to 0.75 percent addition of sodium hydroxide, potassium hydroxide, or calcium hydroxide to the soil increased the liquid limit and plasticity index and decreased the plastic limit of the soil. Within this range, variation in shrinkage limit was somewhat erratic as shown in Figure 1. In general, these results indicate that the soil-water system was in a dispersed phase. However, beyond 1 percent all three hydroxides tended to decrease the PI and increase SL. When the amount of chemical added was more than 1.5 to 2 percent, it was observed from PL test that the soil becomes non-plastic. This effect may be attributed to the aggregation brought about by the cations.

Also, from PI curves potassium hydroxide was equally effective in reducing PI compared to calcium hydroxide. Results of Winterkorn's consistency data of monionic beidellite Putnam clay (13) indicate that potassium ion is more effective than calcium ion in reducing PI. This may be attributed to the proper coordination number and ionic radium of K^+ ion, which can fit well in the hole in the silica layer of a montmorillonite-type clay mineral.

All the hydroxides improved the detrimental properties of the soil beyond 2 percent.

Chlorides

Barium, calcium, magnesium, potassium, sodium, and ferric chlorides were selected for the study.

Calcium chloride, barium chloride, and magnesium chloride, beyond 1 percent decreased both LL and PL as shown in Figure 2. PI data indicate that decrease in PL was comparatively higher than LL. Change in SL was not very prominent. In the case of calcium chloride, to a slight extent decrease in SL was observed. These observations show that in addition to cations the presence of undissociated compound and the dissociated Cl ion part also played an important role in altering the soil-water consistency. Decrease in LL is an indication that, although PI was high, the phenomenon of dispersion does not exist. The deliquescent property of most of these chemicals may be the cause for lowering of PL. Below 1 percent, the change in consistency properties was very erratic.

Unlike sodium hydroxide, sodium chloride behaves similar to chlorides of calcium barium and magnesium. However, because of its less deliquescent property, increase in PI was comparatively low.

In the case of potassium chloride, LL and PL continued to decrease and SL to increase with the increasing amount of chemical. Beyond 2 percent PI also decreased

TABLE 2

EXPERIMENTAL VALUES OF LIQUID LIMIT, PLASTIC LIMIT, PLASTICITY INDEX, AND SHRINKAGE LIMIT WITH VARIOUS MATERIALS

Chemical (%)	Barium Chloride				Barium Carbonate				Portland Cement				Calcium Hydroxide				Calcium Chloride		
	LL	PL	PI	SL	LL	PL	PI	SL	LL	PL	PI	SL	LL	PL	PI	SL	LL	PL	PI
0 0	67 2	48 85	18 35	8 18	67 2	48 85	18 35	8 18	67 2	48 85	18 35	8 18	67 2	48 85	18 35	8 18	67 2	48 85	18 35
0 1	70 8	41 26	29 54	10 3	78 5	46 06	32 44	19 5	70 8	44 18	26 62	9 13	71 2	40 9	30 3	10 25	70 0	40 95	29 05
0 25	71 0	42 4	28 6	9 3	70 5	47 7	22 8	15 15	62 0	43 95	18 05	12 6	72 2	42 15	29 85	13 45	69 9	40 7	29 2
0 5	69 5	43 25	26 25	8 95	70 6	47 8	22 8	13 25	68 0	40 7	28 3	12 8	72 9	41 01	31 89	13 1	70 0	36 57	33 43
0 75	70 0	44 18	25 82	11 7	77 5	47 55	29 95	16 40	73 0	44 3	28 7	8 62	68 0	45 13	22 87	17 4	66 5	36 5	30 5
1 0	69 0	43 48	25 52	9 35	76 2	49 2	27 0	11 6	70 0	43 45	26 55	10 97	67 0	43 67	23 33	16 8	65 2	48 76	26 44
1 5	69 0	40 1	28 9	10 5	70 5	50 82	19 68	11 8	69 5	40 73	28 77	14 1	68 0	49 97	18 03	12 07	65 4	39 06	26 34
2 0	62 8	40 9	21 9	10 1	69 5	43 87	25 60	10 1	69 2	44 43	24 77	14 27	66 0	-	-	11 1	69 0	38 5	30 5
3 0	67 0	39 75	27 25	10 1	72 0	42 55	29 45	10 8	66 0	43 53	22 47	21 7	64 5	-	-	16 3	67 9	36.1	31 8
5 0	61 0	38 68	22 14	9 8	74 3	42 75	31 55	8 5	68 0	43 65	24 35	23 0	68 0	-	-	31 62	64 0	38 0	26 0
7 0	59 3	38 83	20 47	9 4	70 8	43 02	27 78	10 25	65 0	44 16	20 84	27 1	68 5	-	-	34 0	58 0	42 0	16 0
10 0	55 8	39 17	60 63	14 15	66 0	43 65	22 35	13 8	65 0	45 63	19 37	37 4	68 0	-	-	44 5	56 3	38 93	17 37

Chemical (%)	Calcium Phosphate				Magnesium Phosphate				Magnesium Chloride				Magnesium Carbonate				Potassium Chlorid		
	LL	PL	PI	SL	LL	PL	PI	SL	LL	PL	PI	SL	LL	PL	PI	SL	LL	PL	PI
0 0	67 2	48 85	18 35	8 18	67 2	48 85	18 35	8 18	67 2	48 85	18 35	8 18	67 2	48 85	18 35	8 18	67 2	48 85	18 35
0 1	73 5	42 1	31 4	13 05	70 3	43 85	26 45	17 2	62 5	42 9	19 6	11 1	66 7	40 7	20 0	12 72	68 5	42 22	26 28
0 25	73 8	43 13	28 67	10 9	69 5	43 75	25 75	14 55	67 5	42 93	24 57	10 11	63 8	43 9	19 9	17 0	68 0	42 85	25 05
0 5	73 8	47 0	26 8	10 8	71 9	44 7	27 2	13 4	65 7	42 73	22 97	1 85	66 0	40 8	25 2	15 5	67 0	42 1	24 9
0 75	69 5	44 56	24 94	11 2	72 9	45 3	27 6	17 8	70 0	40 0	30 0	9 92	69 0	42 1	26 9	12 2	67 2	40 92	26 28
1 0	72 5	43 06	29 44	13 8	71 9	44 53	27 37	16 15	66 8	36 87	29 93	8 9	70 6	42 66	27 94	14 57	66 0	40 8	25 2
1 5	73 5	45 33	28 17	13 4	65 2	43 25	21 95	15 4	65 5	35 93	29 57	11 9	68 5	44 13	24 37	14 82	63 5	40 77	22 73
2 0	72 3	45 75	26 55	13 2	70 8	43 8	27 0	12 1	69 0	37 33	31 67	10 25	69 5	45 16	24 34	11 9	63 5	39 9	23 6
3 0	68 5	44 60	22 87	14 65	68 8	43 2	25 6	15 2	67 5	36 9	29 6	11 2	72 0	44 5	27 5	10 9	58 0	41 4	16 6
5 0	72 0	45 46	26 54	14 4	68 0	43 57	25 03	15 4	16 0	38 2	21 8	9 3	76 5	47 8	28 7	15 5	52 5	41 77	10 73
7 0	70 5	46 76	23 74	14 52	66 0	44 6	21 4	14 3	58 55	38 53	19 97	10 8	78 0	48 9	29 1	28 4	48 0	38 4	9 6
10 0	72 5	46 42	26 08	15 20	66 0	44 67	21 33	12 8	54 5	32 28	22 22	12 45	82 0	49 1	32 9	24 5	43 5	32 6	10 9

Chemical (%)	Potassium Dichromate				Potassium Hydroxide				Sodium Hydroxide				Sodium Carbonate				Sodium Chloride		
	LL	PL	PI	SL	LL	PL	PI	SL	LL	PL	PI	SL	LL	PL	PI	SL	LL	PL	PI
0 0	67 2	48 85	18 35	8 18	67 2	48 85	18 35	8 18	67 2	48 85	18 35	8 18	67 2	48 85	18 35	8 18	67 2	48 85	18 35
0 1	66 2	40 6	25 6	10.4	68 8	47 33	21 47	9 8	70 6	46 92	23 68	7 75	69 2	43 5	25 7	14 3	69 5	41 7	27 8
0 25	67 5	48 05	24 45	12 6	69 8	45 5	24 3	10 4	71 0	46 30	24 70	10 0	70 5	42 36	28 14	13 47	68 0	44 26	23 74
0 5	68 0	42 3	25 7	10 1	70 0	44 83	25 17	15 15	74 5	45 12	29 38	10 26	TNP	43 38	TNP	17 25	66 0	42 6	23 4
0 75	70 5	41 0	29 9	9 75	71 0	45 7	25 3	7 4	76 0	43 87	32 13	9 9	TNP	43 4	TNP	13 35	72 0	42 1	29 9
1 0	67 0	40 8	26 2	9 5	66 5	44 17	22 33	10 07	80 0	47 25	32 75	9 75	TNP	43 30	TNP	14 05	68 8	41 27	27 53
1 5	64 8	39 4	25 4	8.15	67 2	45 8	21 4	9 7	80 0	48 65	31 35	16 5	TNP	50 0	TNP	13 7	66 5	41 0	25 5
2 0	65 2	39 75	25 45	9 16	63 8	TNP	TNP	14 9	81 0	82 33	28 67	23 0	TNP	53 56	TNP	TNP	63 2	42 16	21 04
3 0	64 5	39 02	25 48	12 85	64 7	TNP	TNP	27 69	TNP	TNP	TNP	43 1	TNP	48 35	TNP	TNP	62 3	41 17	21 13
5 0	56 5	41 2	15 3	11 9	TNP	TNP	TNP	26 4	TNP	TNP	TNP	38 35	TNP	46 2	TNP	TNP	61 4	42 11	19 29
7 0	61 8	42 0	19 8	14 92	TNP	TNP	TNP	30 5	TNP	TNP	TNP	37 9	TNP	42 6	TNP	TNP	60 3	39 85	20 45
10 0	52 5	40 1	12 4	17 7	TNP	TNP	TNP	36 4	TNP	TNP	TNP	41 67	TNP	43 4	RNP	TNP	59 0	38 96	20 05

Chemical (%)	Sodium Silicate				Sodium Sulfate				Copper Sulfate				Ferric Chloride				Di-Ammonium Phosp		
	LL	PL	PI	SL	LL	PL	PI	SL	LL	PL	PI	SL	LL	PL	PI	SL	LL	PL	PI
0 0	67 2	48 85	18 35	8 18	67 2	48 85	18 35	8.18	67 2	48 85	18 35	8 18	67 2	48 85	18 35	TNP	67 2	48 85	18 35
0 1	71 4	41 0	30 4	10 4	67 0	43 5	23 5	8 9	60 0	41 8	18 2	9 8	70 0	41 4	28 6	TNP	71 0	41 7	29 3
0 25	72 8	44 43	28 37	8 8	63 0	40 3	22 7	10 3	59 2	42 56	16 64	18 67	69 5	42 5	27 0	TNP	71 0	42 35	28 65
0 5	68 0	42 8	25 2	10 5	70 8	49 0	21 8	8 8	16 5	40 65	19 85	11 1	66 0	44 3	21 7	TNP	73 2	44 22	28 98
0 75	74 5	45 0	29 5	10 7	68 5	45 6	22 9	11 4	62 0	41 7	20 3	10 3	64 8	41 0	23 8	TNP	67 5	41 97	25 53
1 0	70 9	45 9	25 0	12 15	71 9	48 1	23 8	8 35	61 5	41 8	19 7	9 15	64 0	40 70	23 83	TNP	68 5	41 76	26 74
1 5	74 2	45.9	28 3	10 8	78 2	46 6	31.6	8 8	62 5	43 5	19 0	9 75	TNP	41 75	TNP	TNP	70 5	43 60	26 9
2 0	83 2	46 73	36 47	12 0	78 5	45 5	33 0	7 5	63 0	41.18	21 22	11 55	TNP	39 6	TNP	TNP	96 0	44 5	24 5
3 0	78 0	48 11	29 89	16 25	80 0	49 0	31 0	9 4	66 0	39 7	26 3	10 5	TNP	34 15	TNP	TNP	68 5	44 86	23 64
5 0	TNP	53 0	TNP	18 7	75 2	43 0	32 2	8 7	65 0	44 45	20 55	14 5	TNP	40 80	TNP	TNP	74 5	47 50	27 0
7 0	TNP	57 05	TNP	23 8	77 2	46 5	30 7	11 45	67 5	43 33	24 17	14 05	TNP	TNP	TNP	TNP	TNP	TNP	TNP
10 0	TNP	61 8	TNP	24 8	69 5	43 0	26 5	10 7	67 5	44 15	23 35	24 65	TNP	TNP	TNP	TNP	TNP	TNP	TNP

[a]Tnp = test not possible

significantly. From this, it was realized that the net effect with this chemical was a reduction in water hull around the soil particles due to predominance of aggregation brought about the K^+ ion.

Table 2 shows that addition of ferric chloride makes the soil friable at 1.5 percent and reduces PL to 34.15 at 3 percent. Addition of more than 1 percent ferric chloride makes the soil mass porous, like bread. This may be due to the fact that with addition of $FeCl_3$ to soil, HCl is liberated which in turn reacts with the carbonates in the soil evolving CO_2, which while escaping out from the soil produces a porous structure in the soil mass. Chemical tests confirmed that CO_2 was liberated during reaction.

Carbonates

All three carbonates (namely, those of Mg, Ba, and Na) increased LL considerably. Both magnesium and barium carbonates decreased PL to a certain extent. In the case of sodium carbonate, nodules of soil are formed which are very difficult to mix. PI also increased with the addition of these chemicals. This effect may be attributed to the dispersive action of chemicals produced in the soil mass.

Only magnesium carbonate was found effective in changing SL to 28.4 at 7 percent. Both Va and Na carbonates have very little effect on SL. However, it was found that the results were very erratic in nature. Further investigation is needed to understand the cause for marked variation in the results.

Sulfates

Sodium sulfate and copper sulfate were selected for the investigation. In general,

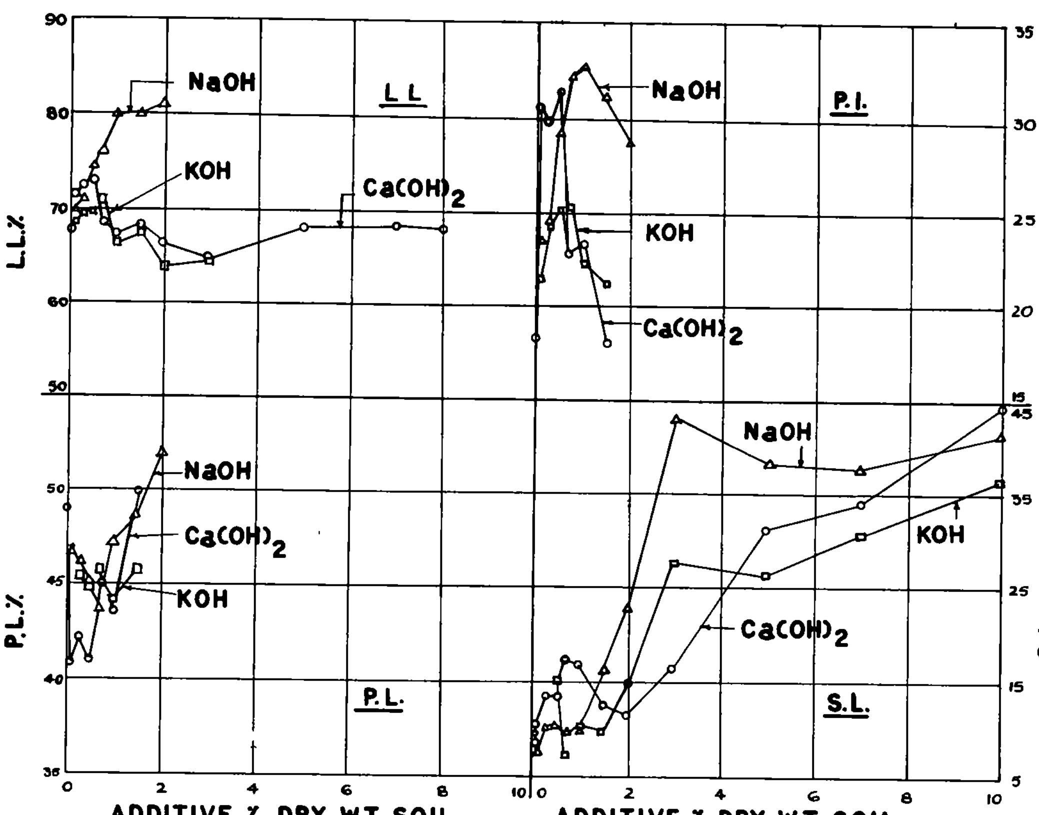

Figure 1. Variation of consistency limits of soil with varying amounts of sodium, potassium and calcium hydroxides.

sodium sulfate showed increase in LL and PI. Variation in PL and SL was not significant. On the basis of this study it may be said that sodium sulfate acts like a dispersing agent. However, in the case of copper sulfate the general trend of results shows that the chemical brings about flocculation.

Phosphates

Table 2 shows that both calcium and magnesium phosphate behaved more like dispersing agents. Just like ferric chloride, di-ammonium phosphate makes the soil mass porous, which is found to be due to evolution of NH_3.

Other Chemicals

Cement has a similar effect as $Ca(OH)_2$, but to a lesser degree. This can be due to lesser amount of free lime available from the cement.

Potassium dichromate has shown a decreasing trend in both LL and PL. The decrease in LL is very marked at 10 percent. It has very little effect on SL. The data show that sodium silicate brings about dispersion in the soil mass. Beyond 3 percent due to high dispersive action of the chemical, it was not possible to run LL and PL tests properly.

General Remarks

The study indicates that certain inorganic chemicals selected for investigation, im-

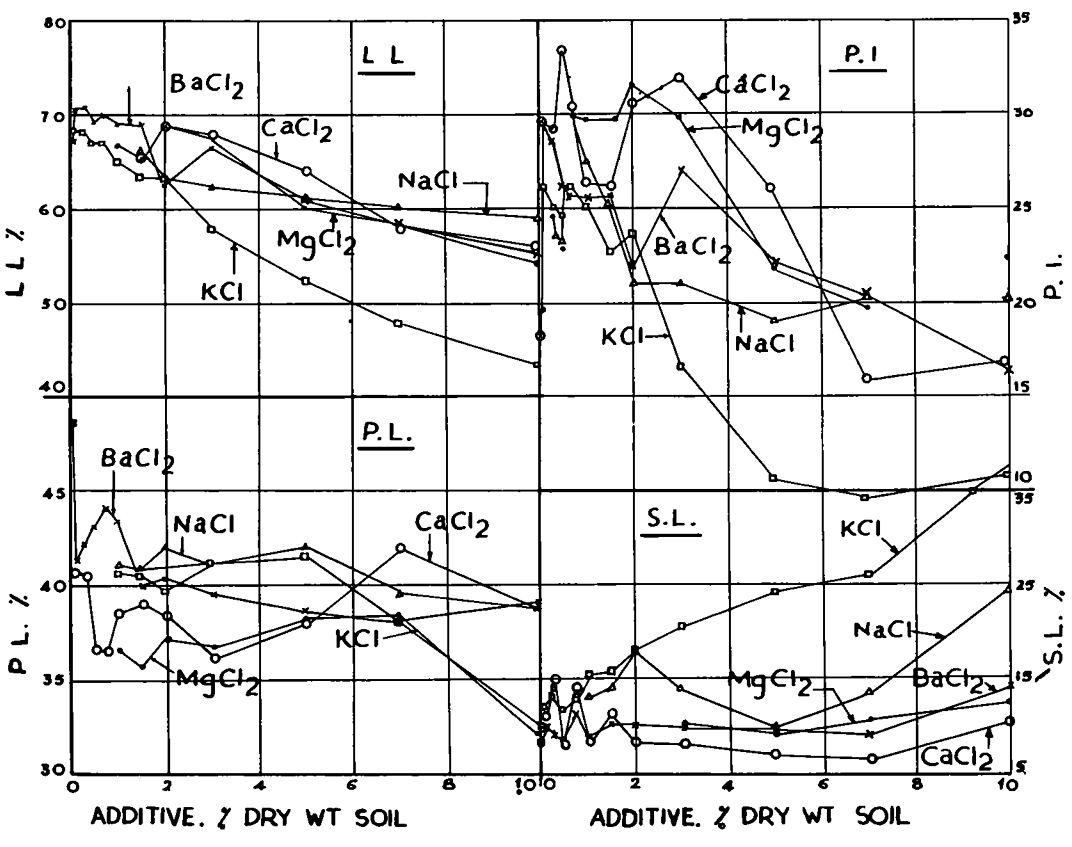

Figure 2. Variation of consistency limits of soil with varying amounts of sodium, potassium, barium, magnesium and calcium chlorides.

prove the deleterious characteristics of this expansive soil. Further investigations are needed to use some of the soluble chemicals for stabilizing foundations in place in such areas. Similarly, further work should be conducted to utilize these promising chemicals to stabilize the soil for road-building purposes.

CONCLUSIONS

1. KOH, $Ca(OH)_2$, and NaOH change the soil from a plastic clay into a friable soil and increase SL when the amount of chemical added is beyond 1.5 percent. NaOH has pronounced effect on increasing SL. At lower percentages, NaOH actually increases PI. Below 1 percent both $Ca(OH)_2$ and KOH increase PI. Cement behaves more like $Ca(OH)_2$.
2. In general, $CaCl_2$, $MgCl_2$, and $BaCl_2$ lower LL, increase PI and have little effect on SL. KCl beyond 2 percent actually reduces PI of the soil and at all percentages distinctly increases SL. NaCl behaves more like KCl as far as SL is concerned.
3. Na_2CO_3, $BaCO_3$, $MgCO_3$, and Na_2SiO_3 increase PI of the soil and make the soil highly plastic.
4. Sulfates and phosphates used in this investigation did not have much effect on SL of the soil.
5. Both $FeCl_3$ and $(NH_4)_2HPO_4$ make the soil porous.

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