Heaving of Soil Due to Acid Contamination

Soulèvement du Sol à cause de Contamination par Acide

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SYNOPSIS The importance of the prediction of volume change behaviour of soils in geotechnical engineering need hardly be stressed. This paper deals with the investigations carried out to find out the causes for distress to the floors, beams and upheaval of foundations at number of places in a fertilizer plant. Detailed chemical tests revealed that soil contained high phosphate content in acidic environment which in turn could be linked up with phosphoric acid as the source of contamination. This resulted in heaving of soil. Since the structures built were essentially lightly loaded with uneven loading in certain cases, the resultant effect was to cause differential movement. Conducting the effluents from various zones through closed conduits, which otherwise thought to be insignificant and left to seep through the soil, was an economical practical remedial measure.

INTRODUCTION

Prediction of volume changes in geotechnical engineering when reduced to its simplest form can be recognized as that due to equilibrium attained between external stresses applied and the internal forces mobilized in the process of achieving equilibrium states. Several factors are responsible for volume changes in natural and compacted soil systems. Volume changes could occur due to changes in effective stresses brought about either by changes in external loading applied to the soil or due to environmental changes during and after construction like changes in ground water table, seepage forces, leaching action and due to inflow of and contamination by effluents.

Most of the above parameters have received considerable attention and concentrated efforts have been made in prediction of heave (Johnson and Snethen, 1978). Practically no detailed study could be readily be located in published literature with regard to the effects of inflow and contamination by effluents on volume changes of in situ soil systems already in equilibrium under external loading. The present study is one in which the effects of acid contamination on heave of structures of a fertilizer plant have been investigated. Being a fertilizer plant there were ample opportunities for soil contamination by water effluents carrying low concentration of phosphoric/sulphuric acid.

In a general sense phosphrous fixation in soils has received considerable attention in the field of agriculture due to necessity of determination of its availability for plant growth and their replenishment through fertilization(Puri 1949, Rubins 1953 and Sauchelli 1965 to name a few). The problems associated with accurate measurement of the availability of phosphrous by chemical means still confront the soil chemist(Seatz 1954, Hemwall 1957 and Sauchelli 1965). Since most of the studies had direct bearing on agricultural applications, the engineering implications did not receive due attention. Even in the present investigation the approach has been mainly to find out the causes for external manifestations of distress to engineering utilities founded on soil prone to contamination by water effluents and the associated remedial measures to arrest the distress to structures housing plant and machinery.

FIELD OBSERVATIONS AND SAMPLING

The affected area is a fertilizer plant of large capacity. The distress to various structures could be summarized as follows:

(a) Location 1: In this location the ground floor which is primarily to house switch gears, has been lifted up to an extent of 15 to 30 cms. The end of column foundations have been lifted up. Although there are are no cracks in the columns and beams, the partition walls have been severely cracked. The distress is maximum in this area.

(b) Location 2: This is just outside of location 1, consisting of a pavement of 5m. in width. Underneath this, there is a drain carrying effluent from the plant. This pavement has heaved more than 30 cms. Although the drains are lined, it was not impervious due to joints and damages. The effluent had ample scope to seep and contaminate the soil. The natural ground water level in this area is estimated to be 9m. below the natural ground level and about 7m. below the bed of the drains.

(c) Acid Storage Tanks: In this plant there are three acid storage tanks of capacity about 270 cubic meters and diameter of 6m. and height of 10m. All of them are out of plumb. The top of one of the tank is nearly 45cm. out of plumb. When the tank is empty, the intensity on the foundation is of the order of 0.1 kg/cm^2 and 0.7 kg/cm^2 while full. On the south side of the tank the polluted water flows in an open drain saturating the soil. When the tank gets filled with phosphoric or sulphuric acid there is a possibility for acid overflow and in turn increase the concentration of the acid in the effluent. On the north side of these tanks, the soil is fairly dry. The natural ground water level is about 9m below ground level. There is ample scope for the drain water to saturate the foundation soil with pollutants. Two locations were identified viz. location 3 (south side of tanks) and location 4 (north side of tanks) for sampling and detailed testing.

(d) Similar to the above there are other locations(5 and 6) wherein superstructure has been damaged. In these locations open drains exist carrying polluted water.

<u>Undisturbed Sampling</u>

Undisturbed soil samples were collected by accessible exploration from location 1 to 6 at about the foundation level(1.5m) to carry out compressibility/swellability tests, strength tests, in situ density tests and other classification, free swell and chemical tests.

Auger boring was done at these locations upto significant depths from foundation level to get information of beneath soil. Undisturbed samples were collected at about 1.5m. below the natural ground level away from the drains and unaffected by the polluted water(Location 7).

TEST RESULTS AND ANALYSIS

Table 1 presents certain relevent chemical test results. The chemical test results clearly show that the phosphate content to be high. Comparing different locations, location 1 contained highest percent and the distress to the superstructure is also maximum in this area. It is interesting to note that the phosphate content is zero in location 7, which is uncontaminated. A careful comparison between the phosphate content and the extent of distress to the buildings and floors or pavement showed good agreement. It should be noted that the total soluble salt is maximum for location 1(where the distress is maximum and least for location 7 which is uncontaminated. The pH of contaminated soils is as low as 2.45 whereas the uncontaminated showed a value of 7.75.

TABLE I

Chemical Analysis Data

No	pH	Phosphate %	Sulphate %	BEC (meq/ 100gm	TSS %
1	2.65	0.416	0.438	x	1.186
2	3.20	0.216	Trace	x	0.492
3	2.45	0.220	1.027	x	0.594
4	2.85	0.195	0.927	x	0.695
5	6.00	0.166	-	x	0.597
6	7.55	0.065	-	8.4	0.386
7	7.75	0.000	0.061	9.0	0.087

(x) Not determinable since soil was highly contaminated with acid.

The classification results(Table II) clearly indicate that the plasticity index is quite low considering the level of liquid limit values. All these soils lie below 'A' line in the plasticity chart except location 1 which is near to 'A' line. The liquid limit is high primarily due to floculation(Sridharan and Rao 1975) due to acid contamination. This could be due to extra salt concentration also(eg. presence of phosphate). The other results are normal. The low level of dry density for location 1 indicate that the soil in this location is under swollen condition wherein the distress is maximum.

Most of the consolidation test results showed that the preconsolidation pressure to be much higher than its overburden pressure. The soils in these areas are essentially normally consolidated and to some extent desiccated. This indicates that polluted water effluent deposited salts generated by the acid which in turn increased the intrinsic effective stress at the 'near contact points'.

Figures 1 and 2 present results of specially conducted consolidation tests with consolidometers with a provision to circulate desired fluid from the bottom, through the sample (Sridharan and Rao 1973). The desired fluid replaces the pore fluid of the sample. The figures 1 and 2 indicate that when the phosphoric acid is replaced by the pore water, swelling occurred and when water replaced the acid compression took place. In other words with the acid as pore medium the equilibrium void ratio is larger than that with water as fluid. It was noticed that the swelling which occurred when acid is circulated was a very slow process and the rate is about 0.1 percent per day of the height of the sample.

Table III presents results on free swell tests with the natural soil without prior washing and after thorough washing. It is seen that the soil has higher swelling potential in natural state compared to washed and dried state.

TABLE II

In Situ Properties, Classification Tests and Shear Strength

	In Situ Properties		Index Properties			Grain Size Distribution			Shear Strength	
No	In Situ Dry density (gm/cc)	Natural Moisture content %	W_L %	W_P %	PI %	Gravel %	Sand %	Silt and Clay %	c′ (kPa)	ϕ′ (deg)
1	1.58	56	108	71	37	6.0	46.0	48.0	0	30
2	1.70	21	95	75	20	12.0	59.4	28.6	13.8	26
3	1.70	39	50	44	14	25.0	47.7	27.3	0	40
4	1.90	20	80	71	9	8.0	63.4	28.6	6.9	31
5	2.20	20	32	25	7	25.2	48.8	26.0	0	42
6	2.13	23	49	30	19	21.0	53.7	25.3	31.0	25
7	1.82	37	84	46	38	7.0	4.7	88.3	0	24

TABLE III

Free Swell Test Results(in ml/gm of dry soil)

Location	Natural Soil	Washed and dried soil
1	6.1	2.5
2	5.1	1.6
3	1.7	1.4
4	2.3	1.8
5	0.9	0.8
6	1.3	0.9
7	3.3	2.2

Free swell potential pattern is of similar trend as of liquid limit. The free swell is maximum for location 1 where the distress is also maximum.

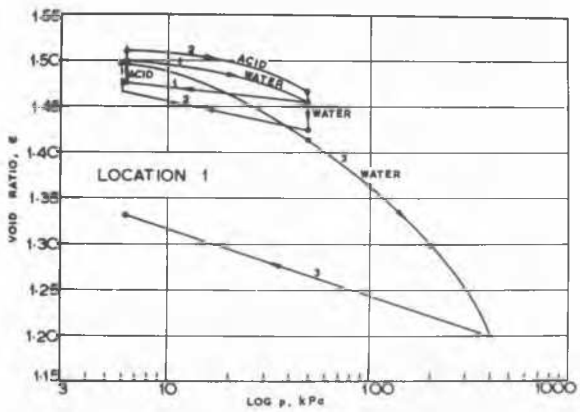

FIG. 1 - e -LOG p CURVE

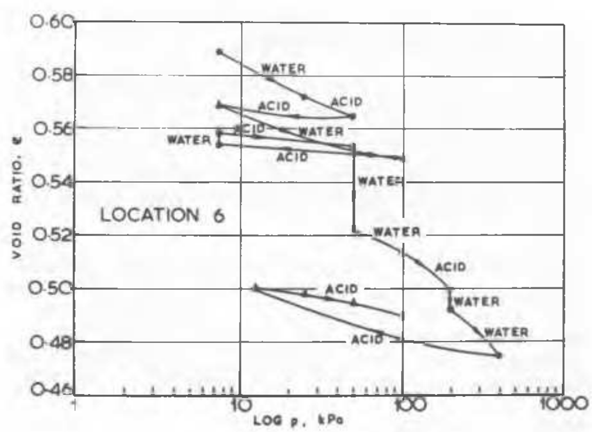

FIG. 2 - e - LOG p CURVE

AN HYPOTHESIS FOR FIELD BEHAVIOUR

An overall review of the detailed examination of the site conditions, the way the movements have taken place with regard to floors, pavements, foundations and the acid storage tanks and the detailed analysis of the various test results amount to the following observations.

In most of the places the soil has swollen resulting in distress to various functionaries. The swelling of the soil is maximum wherever the intensity of loading is less. It should be pointed out here that in the original foundation design, different sizes and types of foundation, (an individual column foundation, combined footing for two columns, combined footing for three columns and a raft) have been used leading to differential stresses at the foundation level. Further the intensity of loading is low at many places, eg. acid storage tank foundations.

The original soil over longer periods(10-12 years have been exposed to effluent waters having contamination with acids through unprotected open drains. Since the ground water level is far below(9m. below the natural ground level and about 7 to 7.5m below the bed level of the drains) the acid contaminated water drains into foundation soil. The soil particle accumulates insoluble salts like calcium phosphates by their reaction with acid polluted water. Soluble salts like sodium and potassium phosphates although formed due to acid contamination will normally be carried away by flowing water. As evaporation takes place with seasonal variation, the soil particles are exposed to more and more quantities of polluted water resulting in the formation of more and fresh deposits of different kinds of insoluble salts(especially calcium phosphate) not easily leachable. The possible mechanisms by which the insoluble phosphate accumulates in the soil system is as follows:

(i) Reaction of cations present in the soil with phosphate.

(ii) Reaction of phosphate with sesquioxides that are formed in the soil system due to weathering.

(iii) Exchange of phosphate ion with hydroxyl ion present in the clays of the soil.

Phosphates thus retained in the soil swells in the presence of water especially when the load intensity is very less. It should be mentioned here that the whole process is extremely slow resulting in slow movement of structures without any catostrophic failures.

REMEDIAL MEASURES

The upward movements of various structures have been active for over several years and from the observations monitored since March 1979, the movement seems to have reached near equilibrium state. Any sophisticated remedial measures would naturally prove to be a costly affair with appropriate technical know how at the site not readily available. Keeping this in view and also from the view point of permanent measure, it was decided to conduct the effluent polluted water through close conduits and discharge far away such that no polluted water gets into the ground below foundations. Wherever this was not possible drains with properly designed filter material was suggested to be laid below natural ground level to intercept and drain away the effluent water such that the foundation soil is free from contamination.

SUMMARY AND CONCLUSIONS

Distress to the floors, pavements and foundations have taken place at many locations in a fertilizer plant essentially by heaving of the soils. By nature, these soils are of potentially swelling type. Detailed chemical tests and free swell tests revealed that the soil contained high phosphate content at low pH values resulting in higher swelling potential than soils devoid of contamination. The source of contamination has been identified due to phosphoric acid due to effluent water in damaged open drains with joints. Test revealed that the concentration had very gradually increased due to repeated wetting and drying of in situ soil systems. Possible mechanisms like reaction with the (i) cations (ii) sesquioxides and (iii) hydroxyl ions present in the soil are responsible for accumulation of phosphate. The soil with phosphate has greater swelling potential than swelling soils devoid of such contaminations. The problem in this case has been further aggrevated by differential and low intensities of external loading.

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