Available online at www.sciencedirect.com
SCIENCE DIRECT®

Engineering Geology 85 (2006) 197–203

ENGINEERING GEOLOGY

www.elsevier.com/locate/enggeo

Effect of pH on the geotechnical properties of laterite

B.M. Sunil *, Sitaram Nayak, S. Shrihari

National Institute of Technology Karnataka, Surathkal, Srinivasnagar-575 025, India

Accepted 15 September 2005
Available online 17 April 2006

Abstract

Environmental Geotechnology has emerged as an interdisciplinary science, aiming and forecasting, analyzing and solving the geotechnical problems involving the influence of environmental factors. Lateritic soil of west coast region of India was studied to investigate the effect of soaking on the engineering properties and chemical characteristics of soil, soaked in different pH solutions (pH = 5.0, pH = 7.0, pH = 8.0). 12 N hydrochloric acid and 15 M ammonia solution were used to monitor the pH of the solution for about ninety days. Results showed that the pH of the solution has strong influence on the chemical characteristics of lateritic soil. The engineering properties of soil are altered when compared with the initial characteristics of the soil. The reason for this observed behavior of the soil is addressed in this paper.

Keywords: pH; Lateritic soil; Chemical characteristics; Compressive strength; Leaching; Cations

1. Introduction

In recent years Environmental Geotechnology has emerged as an interdisciplinary science, aiming and forecasting, analyzing and solving the geotechnical problems involving the influence of environmental factors (Manassero and Deangeli, 2002). Soil pollution arises from variety of sources, which includes acid rain, unscientific method of waste disposal etc. In recent years much attention has been paid to acidification of rain, which is one of the environmental factors which will affect the properties of soil. Kamon et al. (1996) investigated the variation of the engineering properties of lime and cement stabilized soils when acid rain falls over a long period of time. Infiltration and soak tests were conducted at different pH levels of artificial acid rain to experimentally simulate the erosion process on stabilized soils. Gupta and Singh (1997) reported that the hydrogen ion concentration in the soil influences all chemical reactions and biological activities. Stalin and Muthukumar (2002) reported that the atmospheric

Table 1
Initial characteristics of lateritic soil

γ_d (kN/m^3)	16.87
w_n (%)	16.12
w_L (%)	42.00
w_p (%)	33.33
I_p (%)	8.67
w_s (%)	24.45
I_s (%)	8.88
Gravel (%)	36.40
Sand (%)	57.40
Silt (%)	5.00
Clay (%)	1.20

* Corresponding author.
E-mail addresses: ssunil8@rediffmail.com (B.M. Sunil), shrihari@nitk.ac.in (S. Shrihari).

0013-7952/$ - see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.enggeo.2005.09.039

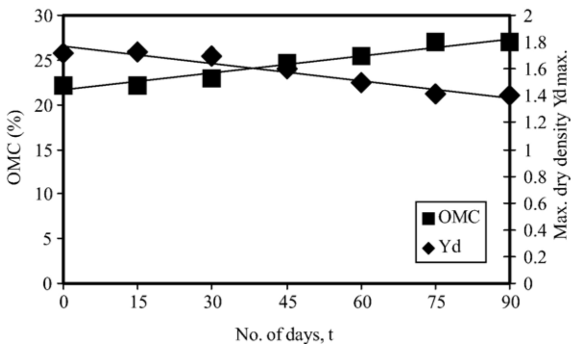

Fig. 1. Variation of maximum dry density and optimum moisture content with time (pH maintained as 5.0).

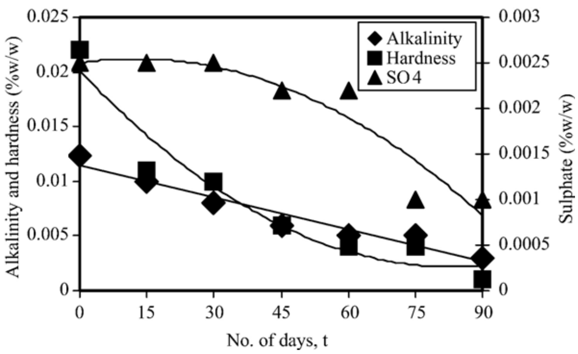

Fig. 2. Variation of alkalinity, hardness and sulphate in soil with time for soaking of laterite soil blocks (pH = 5.0).

pollution has resulted in the precipitation having pH less than 5.6 which resulted in acidification of soils and thus altering the physical and engineering properties. Very little research has been conducted to determine the behavior of laterite soil soaked in solution of different pH. The study aims in bringing relevant conclusions of the behavior of laterite.

2. Methodology

The laterite soil blocks (40 × 20 × 20 cm) used in this study were obtained from sites nearby Surathkal. The wet strength of laterite blocks was determined in the laboratory as per Bureau of Indian Standards (BIS, 1987, 1988). The crushed material was oven dried sieved using 20 mm IS sieve. The down size material is used for sample preparation. The consistency properties of laterite soil were determined for the soil fraction passing 425 μm sieve. Representative soil passing 20 mm IS sieve was used to obtain the dry density moisture content relationship by standard Proctor compaction test. The chemical analysis of lateritic soil was done for the soil fraction passing 425 μm sieve. The initial characteristics of the lateritic soil collected at 1 m depth are summarized in Table 1. The initial chemical characteristics of lateritic soil are summarized in Table 3. All the chemical tests conducted are as per the Standard Methods (APHA et al., 1998).

3. Experimental procedure

Laterite soil blocks were soaked in three tanks (1.2 × 1.2 × 0.6 m) C_1, C_2, C_3. The initial characteristics of water in which laterite soil blocks were soaked are summarized in Table 5. In tank C_1, pH was maintained as 5.0 and in tank C_2 and C_3 the pH was maintained as 8.0 and 7.0. The pH of the water was monitored daily using pH meter. The pH of the water in the tanks was maintained constant (for soaking period up to ninety days) using 12 N HCl and 15 molar ammonia solution. Also certain other parameters like alkalinity, chloride, electrical conductivity, hardness and sulphate were analyzed daily (up to ninety days). At the end of fifteen days six laterite blocks from each tank were tested for compressive strength in compressive testing machine. The crushed material was oven dried and sieved using 20 mm IS sieve. Similar procedure of sample preparation was followed for all the samples.

4. Moisture–density relationship

Fig. 1 illustrates the relationship between maximum dry density and OMC with time. It is observed from Fig. 1 that maximum dry density decreases and OMC

Table 2
Variation of specific gravity

	pH maintained as 5.0	pH maintained as 7.0	pH maintained as 8.0
Initial (unsoaked)	2.55	2.55	2.55
15 (days)	2.54	2.30	2.50
30 (days)	2.50	2.30	2.50
45 (days)	2.38	2.30	2.50
60 (days)	2.23	2.30	2.35
75 (days)	2.26	2.30	2.34
90 (days)	2.21	2.23	2.26

Table 3
Initial chemical characteristics of lateritic soil

pH	5.21
EC (μS/cm)	93.20
Chlorides (%w/w)	0.018
Alkalinity (%w/w)	0.0124
Hardness (%w/w)	0.031
Sulphate (%w/w)	0.0014
Nitrogen (%w/w)	0.0036

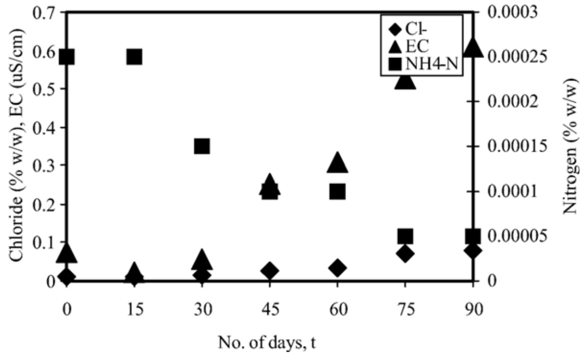

Fig. 3. Variation of chloride, electrical conductivity and nitrogen in soil with time for soaking of laterite soil blocks (pH = 5.0).

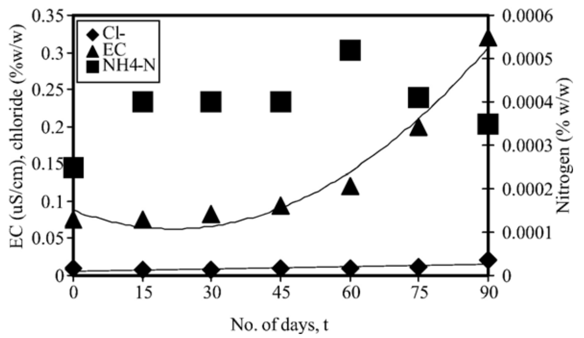

Fig. 5. Variation of chloride, conductivity and nitrogen in soil with time for soaking of laterite soil blocks pH = 7.0.

increases from an initial value of 16.87 kN/m^3 (unsoaked condition) to 13.93 kN/m^3 (after soaking for ninety days). Similarly the experimental results of max. dry density and optimum moisture content were plotted (not shown) when the pH of the water was maintained as 7.0 and 8.0. The decrease in maximum dry density was higher when the pH was maintained as 5.0. Thus it was observed that in all the three pH conditions the maximum dry density decreased. The decrease in maximum dry density is attributed due to the following reason; a typical laterite profile is very rich in iron. The initial iron content (as Fe_2O_3) of the soil was about 31.62% (unsoaked). Moh and Mazhar (1969) reported the coating of iron oxide on the surface aggregates the particles into clusters. Thus the soil particles in their natural condition are held together because of the presence of free iron oxide which on oven drying tends to coagulate the particles into strong clusters (Moh and Mazhar, 1969). Since the soil mixture lacks a suitable soil binder to fill all the voids between the grains, the maximum dry unit weight will decrease and the optimum moisture content will increase. The specific gravity values determined show slight variations. The specific gravity of natural laterite soil was in the range of 2.50 to 2.55. The decrease in specific gravity could be attributed to decrease in iron content of the soil. The iron content of soil (as Fe_2O_3) decreased from 31.62% to 20.10% for soaking up to ninety days. The variation of specific gravity with time under different pH conditions is summarized in Table 2.

5. Chemical characteristics of lateritic soil

Fig. 2 illustrates the variation of alkalinity, hardness and sulphate content of lateritic soil with time when the pH of the water is maintained as 5.0. It was observed from Fig. 2 that the alkalinity of soil decreases with time from 0.0124% w/w (unsoaked) to 0.0030% w/w (after soaking for ninety days). The relationship is linear. Again as observed from Fig. 2, the sulphate content and hardness of soil decrease with time. Decrease in soil alkalinity is probably due to the low pH of the water. Chloride ion can replace the carbonate (CO_3) ions to give calcium chloride ($CaCl_2$). As a result carbonic acid will be formed and hence alkalinity may decrease. This can be expressed by the following chemical equation.

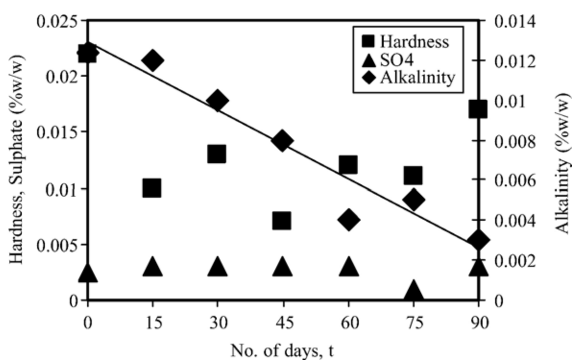

Fig. 4. Variation of hardness, alkalinity and sulphate in soil with time for soaking of laterite soil blocks (pH = 7.0).

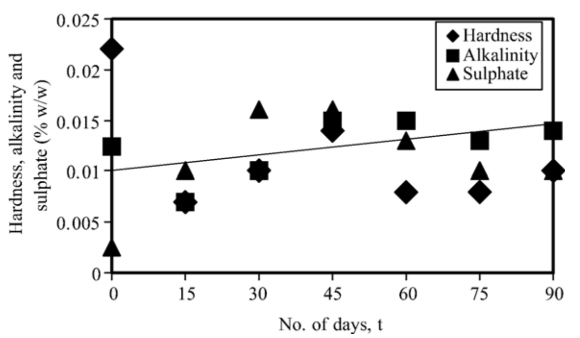

Fig. 6. Variation of hardness, alkalinity and sulphate with time for soaking of laterite soil blocks, pH = 8.0.

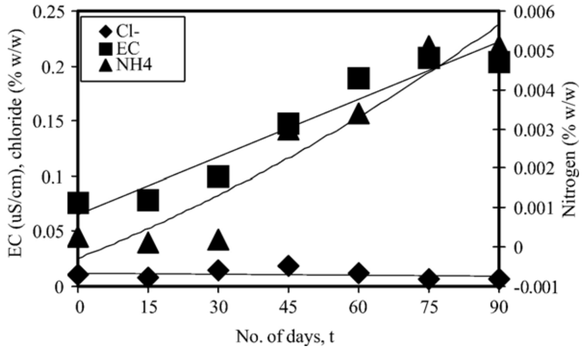

Fig. 7. Variation of chloride, electrical conductivity and nitrogen with time for soaking of laterite soil blocks (pH = 8.0).

The initial chemical characteristics of soil are summarized in Table 3.

$$CaCO_3 + 2HCl \rightarrow CaCl_2 + H_2O + CO_2$$

Fig. 3 illustrates the relationship between chloride, electrical conductivity and nitrogen content of soil with time. It is observed from Fig. 3 that the chloride content and conductivity of soil increase with time. However nitrogen (as NH_4–N) decreases probably due to the conversion of NH_4–N into nitrate (NO_3) at the end of the soaking period. Increase in chloride concentration and decrease in hardness indicate probable leaching out of metallic cations.

Similar observations were made on lateritic soil (Figs. 4 -7) when the pH of the water was maintained as 7.0 and 8.0. Thus it was observed that at lower pH values (pH = 5.0) alkalinity, hardness, sulphate and nitrogen contents of soil decrease whereas chloride and conductivity of the soil increase. The increase in chloride concentration (0.018% unsoaked to 0.080% after soaking for ninety days) of soil along with low pH conditions may be detrimental (sometimes) to the structures.

Table 4
Percentage reduction in compressive strength

	pH maintained as 5.0	pH maintained as 7.0	pH maintained as 8.0
Initial (unsoaked)	–	–	–
15 (days)	1.90	1.90	1.20
30 (days)	2.60	3.38	2.60
45 (days)	8.89	3.35	26.20
60 (days)	20.32	10.00	31.82
75 (days)	23.94	13.35	34.82
90 (days)	48.89	23.32	42.50

–: Initial compressive strength = 1565 kN/m^2.

6. Variation of compressive strength

The condition for laterization is availability of iron-rich minerals in the parent bed rock. The cementation in lateritic soils is due to the presence of free iron oxide (Moh and Mazhar, 1969). Ola (1978) [Extracted from Bell (1992)], investigated the effect of leaching on lateritic soils. The cementing agents in lateritic soils help to bond the finer particles together to form larger aggregates. However as a result of leaching these aggregates breakdown, and leads to the destruction of the aggregate structure (Ola, 1978). Fig. 8 illustrates the decrease in compressive strength of the laterite with time for soaking up to ninety days. It is observed that the compressive strength of the laterite decreases in all the three pH conditions and the maximum reduction (48.89%) being when the pH was maintained as 5.0. The iron content decreased from 31.62% to 20.10% at the end of soaking period. Decrease in iron content means decrease in the

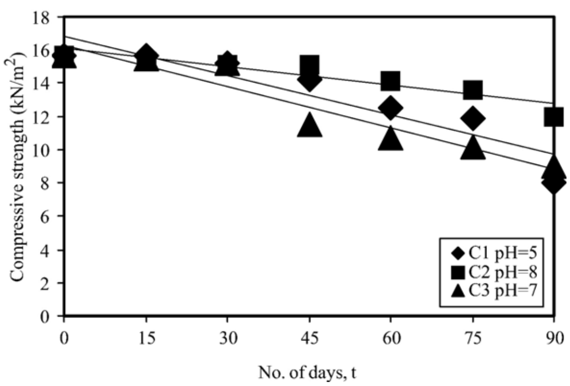

Fig. 8. Variation of compressive strength of laterite blocks with time for soaking up to ninety days.

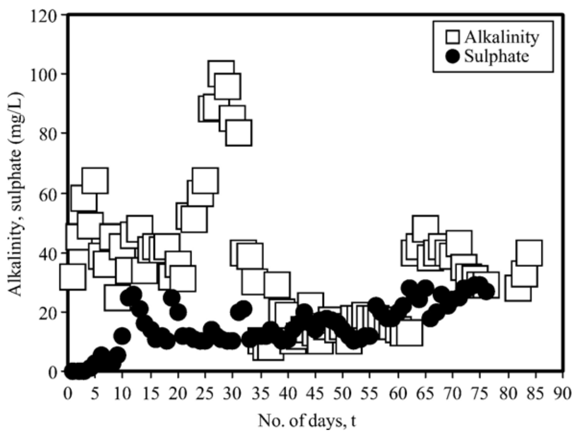

Fig. 9. Variation of alkalinity and sulphate of water with time (pH maintained as 5.0).

Table 5
Initial characteristics of water

pH	6.92
EC (μS/cm)	150.00
Chlorides (mg/L)	29.00
Alkalinity (mg/L)	37.00
Hardness (mg/L)	50.00
Sulphate (mg/L)	10.00
Nitrogen (mg/L)	2.01

cementation properties or destruction of aggregate structure. This may cause reduction in the compressive strength. This was also manifested by the decrease in hardness of the soil. Table 4 summarizes the reduction in compressive strength of laterite under different pH conditions.

7. Chemical characteristics of water

Fig. 9 shows the variation of alkalinity and sulphate in water with time. It was observed from Fig. 2 that the alkalinity of soil also decreased from 0.0124% (unsoaked) to 0.0030% (after soaking for ninety days). The sulphate concentration in water increases with time as observed from Fig. 9. This may be due to the leaching of sulphates from soil. Narayana and Suresh (1989) reported that the addition of sulphates (SO_4) to the water takes place from the breakdown of organic substances in the soil leachable sulphates. Hence increase in sulphate concentration of water is probably due to the breakdown of organic substances in the lateritic soils. The initial characteristics of water are summarized in Table 5.

Fig. 10 illustrates the variation of hardness of water with time. It is observed that the hardness of water increases with time from 50 to 4500 mg/L at the end of

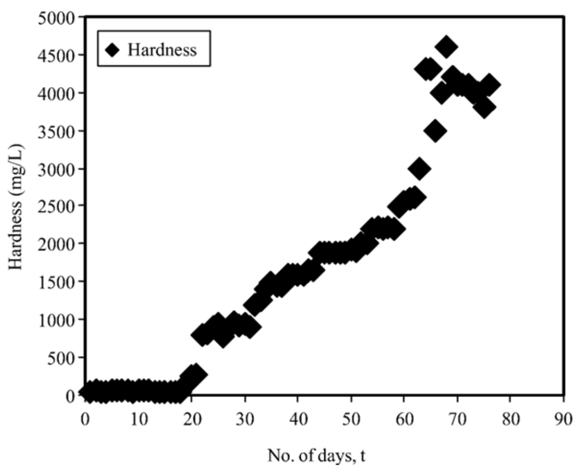

Fig. 10. Variation of hardness in water with time (pH maintained as 5.0).

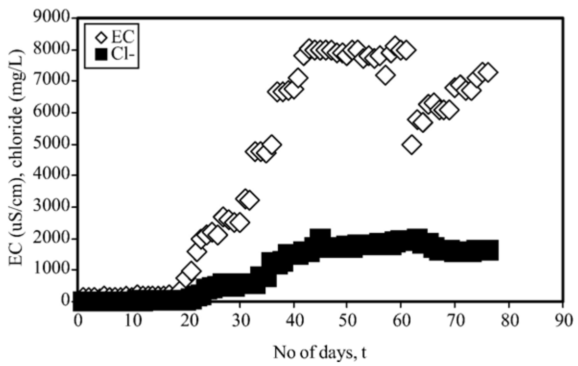

Fig. 11. Variation of electrical conductivity and chloride in water with time (pH maintained as 5.0).

soaking period (ninety days). From Fig. 2 it was observed that the hardness of soil decreases with time. Therefore when hardness of soil decreases the corresponding hardness in water increases. This may be due to the leaching action under low pH condition.

Fig. 11 illustrates the variation of conductivity and chloride of water with time when the pH was maintained as 5.0. It is observed from Fig. 11 that when the chloride concentration increases the electrical conductivity of water also increases. Again from Fig. 3 it is observed that when chloride concentration increases in water the corresponding chloride content in soil also increases. This indicates that the pH of the solution has influence on the chemical characteristics of the soil.

8. Soil pH

The pH of the soil sample tested was acidic. The reduction in the pH value of the soil indicates an increase in the hydrogen ion activity. Reduction in organic matter content and change in salt concentration might affect the pH. Fig. 12 illustrates the variation of soil pH with time

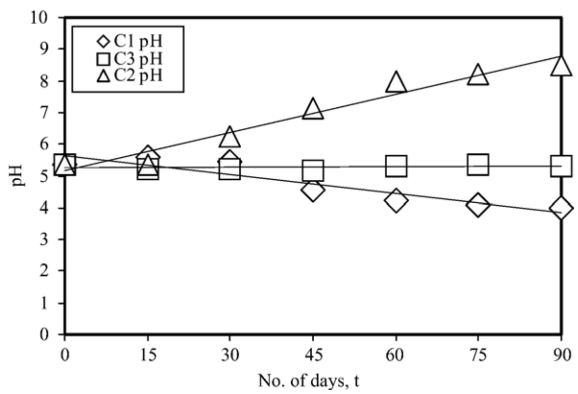

Fig. 12. Variation of soil pH with time.

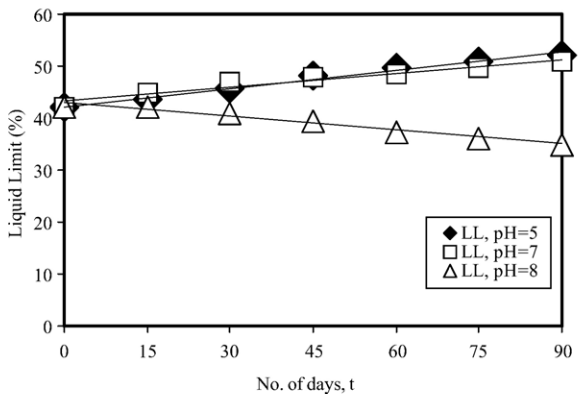

Fig. 13. Variation of Liquid Limit with time under different pH conditions.

under different pH conditions. It is observed from Fig. 12 that the pH of the soil decreases from an initial value of 5.34 (unsoaked) to 4.0 (after soaking for ninety days) when pH of the water was maintained as 5.0. As hydrogen ion concentration increases it reacts with bicarbonates (HCO_3^-) or carbonates (CO_3^{2-}) to form carbon dioxide (CO_2) and water. This may result in decreasing the pH of the soil with time. This can be expressed by the chemical equation as below. The variation observed is about 1.34. But the pH of the soil increases from 5.34 (unsoaked) to 8.5 (after soaking for ninety days) when the pH of the water was maintained as 8.0.

$$HCO_3 + H^+ \rightarrow H_2O + CO_2$$
$$CO_3^{2-} + H^+ \rightarrow H_2O + CO_2$$

9. Consistency limits

When water is added to the soil it tends to disintegrate the particles into smaller ones with an increase in the specific surface area. Increase in specific surface area of soil leads to high adsorption of water that changes the limit values. Increased degree of manipulation would also break the particles and hence would increase the limit values (Moh and Mazhar, 1969). Ola (1978) [Extracted from Bell (1992)], reported the effect of leaching on leteritic soils. The cementing agents bind the finer particles to form aggregates. However, as a result of leaching these aggregates breakdown, which is shown by the increase in Liquid Limit after leaching (Ola, 1978). In the present case the increase in Liquid Limit of soil (Fig. 13) indicated a greater degree of manipulation during the sample preparation and also due to the leaching effect. Reduction of the Liquid Limit of lateritic soil upon oven drying (due to an apparent decrease in the clay content) has been reported. The reduction in clay content was attributed to the coating of iron oxide coagulating the particles into larger clusters during oven drying. But when the pH was maintained as 8.0 (Fig. 13) the Liquid Limit decreases. The factors responsible for this are not clear. The variation of Plastic Limit is shown in Fig. 14. For a large change in Liquid Limit of the soil a small change in Plastic Limit was observed. Increase in Liquid Limit and a small change in Plastic Limit resulted in increase of the plasticity index, as summarized in Tables 6-8. A little change in shrinkage limit values was also observed.

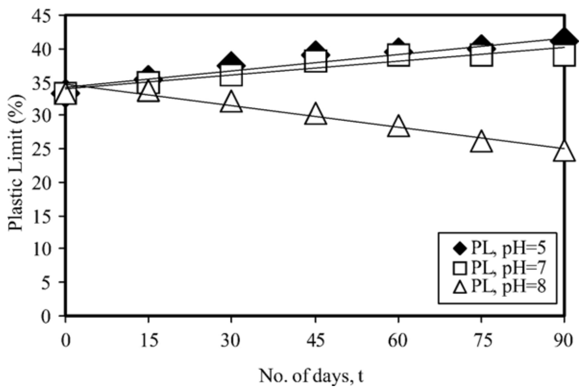

Fig. 14. Variation of Plastic Limit with time under different pH conditions.

Table 6
Effect on Atterberg limits (pH maintained as 5.0)

	w_L (%)	w_L (%)	I_p (%)
Initial (unsoaked)	42.00	33.33	8.67
15 (days)	43.50	35.36	8.14
30 (days)	45.86	37.36	8.50
45 (days)	48.10	39.00	9.10
60 (days)	49.67	39.40	10.27
75 (days)	50.80	40.00	10.80
90 (days)	52.00	41.00	11.00

10. Conclusions

The engineering properties and chemical characteristics of the natural lateritic soil are susceptible to change when compared with the initial characteristics of the soil.

Table 7
Effect on Atterberg limits (pH maintained as 7.0)

	w_L (%)	w_L (%)	I_p (%)
Initial (unsoaked)	42.00	33.33	8.67
15 (days)	44.86	34.96	9.90
30 (days)	47.00	36.00	11.00
45 (days)	48.00	38.00	10.00
60 (days)	48.50	39.00	9.50
75 (days)	49.60	39.10	10.50
90 (days)	51.00	39.00	12.00

Table 8
Effect on Atterberg limits (pH maintained as 8.0)

	w_L (%)	w_L (%)	I_p (%)
Initial (unsoaked)	42.00	33.33	8.67
15 (days)	42.20	33.68	8.52
30 (days)	41.00	32.18	8.82
45 (days)	39.50	30.38	9.12
60 (days)	37.40	28.40	8.92
75 (days)	36.00	26.00	10.00
90 (days)	35.00	24.80	10.20

The results presented clearly indicated that under soaked conditions the pH of the water has strong influence on the chemical characteristics of lateritic soil. The influence on the engineering properties of the soil is also observed. The change in Atterberg limits of the soil is attributed to combined effect of greater degree of manipulation during sample preparation and due to the leaching effect. The chemical analysis of water and soil indicates that the leaching of metallic cations could take place under acidic conditions. This was manifested by the decrease in hardness of the soil at the end of soaking period.

Appendix A

Nomenclature

γ_d	Maximum dry density (kN/m^3)
w_n	Natural moisture content (%)
w_L	Liquid Limit (%)
w_p	Plastic Limit (%)
I_p	Plasticity Index (%)
w_s	Shrinkage Limit (%)
I_s	Shrinkage Index (%)
NO_3	Nitrate as NO_3 (mg/L)
NH_4–N	Nitrogen as NH4–N (%)
SO_4	Sulphate as SO_4 (mg/L)
Cl^-	Chloride as Cl^- (mg/L)
EC	Electrical Conductivity (μS/cm)

References

APHA, AWWA, WEF, 1998. Standard Methods for the Examination of Water and Waste water, 20th Edition, American Public Health Association, Washington DC, USA, pp. 2–27 to 4–179.

Bell, F.G., 1992. Fundamentals of Engineering Geology. Adithya Books Pvt. Ltd., New Delhi, p. 264.

B.I.S., 1987. Compendium of Indian Standards on Soil Engineering Part I. Laboratory Testing of Soils for Civil Engineering Purposes, S.P: 36 (Part I) — Bureau of Indian Standards, pp. 23–350.

B.I.S., 1988. Compendium of Indian Standards on Soil Engineering Part II. Field Testing of Soils for Civil Engineering Purposes, S. P:36 (Part II) — Bureau of Indian Standards, pp. 31–250.

Gupta, A.K., Singh, D.N., 1997. Interaction of contaminants with soils: a review. Indian Geotechnical Journal 27, 75–87.

Kamon, Masashi, Ying, Changyun, Katsumi, Takeshi, 1996. Effect of acid rain on lime and cement stabilised soils. Japanese Geotechnical Society 36 (4), 91–96.

Manassero, M., Deangeli, C., 2002. Education in Environmental Geotechnics. Proc. of Indian Geotechnical Conference, vol. 2. Allahabad, India, pp. 840–848.

Moh, Za-Chieh, Mazhar, Mirza Farrukh, 1969. Effects of method of preparation on the index properties of lateritic soils. Proc. of the VII ICSMFE, vol. 1. Asian Institute of Technology, Bangkok, Thailand, pp. 23–35.

Narayana, A.C., Suresh, G.C., 1989. Chemical quality of ground water of Mangalore city, Karnataka. Indian Journal of Environmental Health 31 (3), 228–236.

Ola, S.A., 1978. Geotechnical properties and behavior of stabilized lateritic soils. Q.J. Eng. Geol. 11, 145–160 (Extracted from Bell F.G. (1992), "Fundamentals of Engineering Geology", Aditya books pvt. Ltd., New Delhi, pp. 458–459.).

Stalin, V.K., Muthukumar, M., 2002. Effect of acid permeation on the chemical characteristics of soil and fly ash. Proc. of Indian Geotechnical Conference, vol. 1. Allahabad, India, pp. 301–304.