ELSEVIER

Engineering Geology 60 (2001) 245–252

ENGINEERING GEOLOGY

www.elsevier.nl/locate/enggeo

Pozzolanic fly ash as a hydraulic barrier in land fills

J.P. Prashanth[a,†], P.V Sivapullaiah[b,*], A. Sridharan[b]

[a]Department of Civil Engineering, UBDT College of Engineering, Davangere 577 004, Karnataka, India
[b]Department of Civil Engineering, Indian Institute of Science, Bangalore 560 012, Karnataka, India

Accepted for publication 19 May 2000

Abstract

The liner plays an important role in controlling migration of contaminants present in the leachate in waste containment systems such as land fills and impoundments. Although questions have been raised about the performance of clay liners, they are increasingly used singly or as double liners in disposal sites. Though the clay liners possess many advantages such as low permeability and large attenuative capacity, they also possess high shrinkage potential and hence can crack under unsaturated conditions causing instability and increase in leakage rates. Further, the permeability of the clay linear can increase due to clay–pollutant interaction. This study examines the potential of pozzolanic fly ash as a hydraulic barrier in land fill. The behaviour of three different types of fly ashes, showing a range of physical properties and chemical composition from three different sources are reported in the study. Geotechnical properties, needed to evaluate the use of fly ashes as barriers, such as shrinkage, compaction, permeability, consolidation and strength characteristics are reported. The results show that fly ashes possess low shrinkage and hence do not crack. Compacted fly ashes undergo very little volume changes. They also show that pozzolanic fly ashes develop good strength properties with time. Pozzolanic fly ashes containing sufficient lime develop strength even without addition of lime. Non-pozzolanic fly ashes do not develop strength even on addition of lime. Fly ashes generally consist of silt size particles and consequently possess high permeability. However, pozzolanic fly ashes with lime exhibit low permeability on curing because of the formation of gelatinous compounds which block the pores. Thus, pozzolanic fly ashes appear to be promising for construction of liners to contain alkaline leachate. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Fly ash; Land fills; Permeability; Hydraulic barrier

1. Introduction

The land fill liners act as a barrier to minimize the migration of leachates. The liner system may utilize natural materials such as compacted clay or shale, bitumen, soil sealants or synthetic membranes (geomembranes). The main requirements of liners are minimization of pollutant migration, low swelling and shrinkage and resistance to erosion (Brandl, 1992). Compacted clay liners are widely used because of their cost effectiveness, large attenuative capacity and resistance to damage and puncture. Clay liners reduce the rate of contaminant migration by their low permeability and their sorption capacity. Bentonite is the most widely used mineral for construction of liners because of its low permeability and high cation exchange capacity. However, bentonite cracks on drying because of its high swelling potential and its hydraulic conductivity increases. Also, some leachates increase its permeability. This paper examines the suitability of fly ash, which is an abundantly

* Corresponding author. Tel.: +91-80-3092437; fax: +91-80-3600404.
E-mail address: offmail@civil.iisc.ernet.in (P.V. Sivapullaiah).
† Former lecturer. Since expired.

PII: S0013-7952(00)00105-8

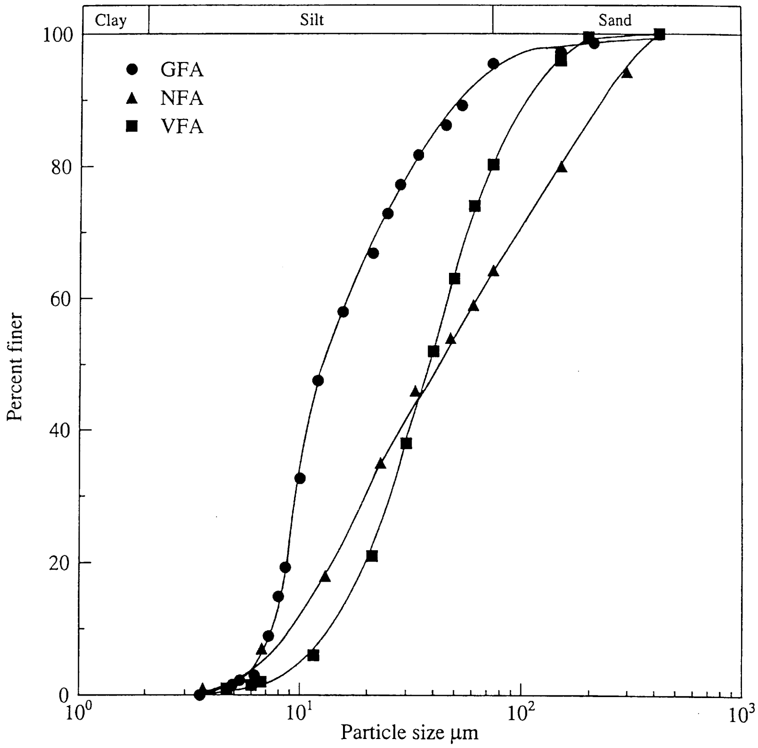

Fig. 1. Grain size distribution curves of the fly ashes.

available waste product of the generation of power by burning of coal, for the construction of hydraulic barrier in land fills. Under the high alkaline conditions which prevail in fly ashes, most of the toxic elements that are present in leachates precipitate and are not allowed to migrate (Pandian et al., 1995). The suitability of fly ashes as hydraulic barriers needs to be established from detailed geotechnical investigations.

Table 1
Chemical composition of the fly ashes

Constituents	Fly ash		
	GFA	NFA	VFA
Silica (SiO_2)	51.06	50.40	58.88
Alumina (Al_2O_3)	20.29	18.81	29.67
Ferric oxide (Fe_2O_3)	10.82	16.61	5.87
Calcium as CaO	7.11	9.00	3.03
Magnesium as MgO	2.32	1.41	0.24
Titanium as TiO_2	0.26	0.28	0.27
Potassium as K_2O	0.25	0.23	0.28
Sodium as Na_2O	0.25	0.18	0.21
Loss on ignition	7.19	2.60	1.41

2. Fly ashes used

Three different types of fly ashes have been obtained for the study. The fly ashes were obtained from thermal Power Plants located in Gulbarga, Karnataka state, Neyveli in Tamilnadu state and Vijayawada in Andhra Pradesh state of India and hence the names Gulbarga fly ash (GFA), Neyveli fly ash (NFA) and Vijayawada fly ash (VFA), respectively. While GFA and NFA were collected directly from dry dumps, VFA was collected from an abandoned ash disposal pond.

3. Physical properties

The specific gravity of the fly ashes used was 2.58, 2.67 and 2.03 for GFA, NFA and VFA, respectively.

Table 2
Liquid limit, shrinkage limit and shrinkage index of the fly ashes

Fly ash	Weight basis			Volume basis		
	LL (%)	SL (%)	SI (%)	LL (%)	SL (%)	SI (%)
GFA	62	52	10	160	134	26
NFA	44	38	6	117	101	16
VFA	49	42	7	99	85	14

Like most fly ashes, the particles of the fly ashes used are of silt size. GFA is finer than the other two. NFA and VFA possess almost a similar gradation. Fig. 1 gives the grain size distribution curves of the fly ashes used.

4. Chemical composition

Table 1 shows the chemical composition of the fly ashes expressed as a percentage with respect to weight. Like many other fly ashes, these fly ashes contain abundant silica and alumina. Reactive silica (part of total silica) of GFA, NFA and VFA was found to be 5.30, 4.98 and 1.84%, respectively. The free lime content (part of total calcium) was found to be 0.5, 3.92 and 0.86% for GFA, NFA and VFA, respectively The reactive silica content and free lime contents of fly ashes were measured as per the method of Sivapullaiah et al. (1998).

5. Water content on volume basis

For soils, water content is usually expressed by weight (weight of water to weight of solids). Water content by volume is defined as the volume of water to the volume of solids which is conventionally called water void ratio. In this study, it has been termed as water volume content (Prashanth et al., 1998). It can be obtained by multiplying the water content on the basis of weight by the specific gravity of the solids. Comparison of water content on the basis of weight for materials of different specific gravity can be

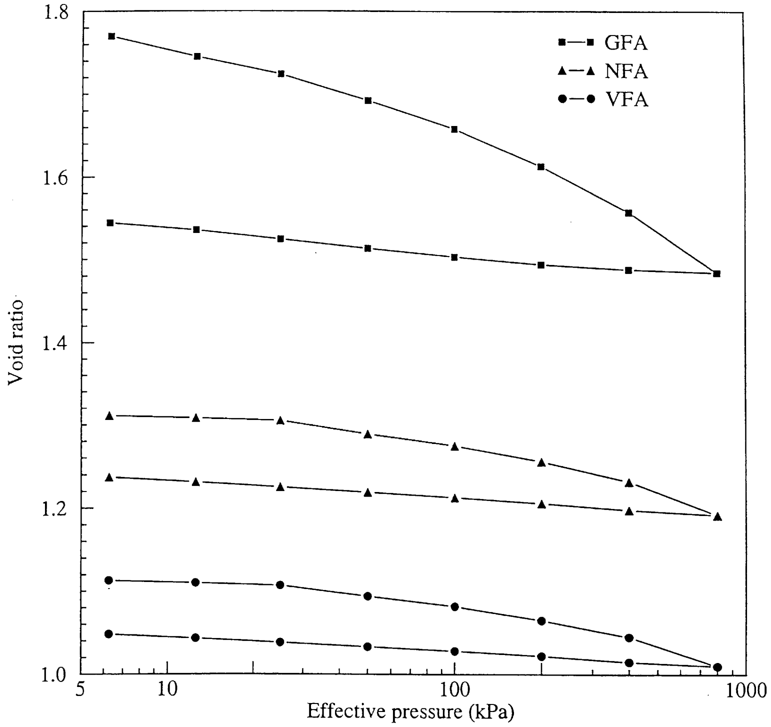

Fig. 2. Void ratio–pressure relationship of the fly ashes.

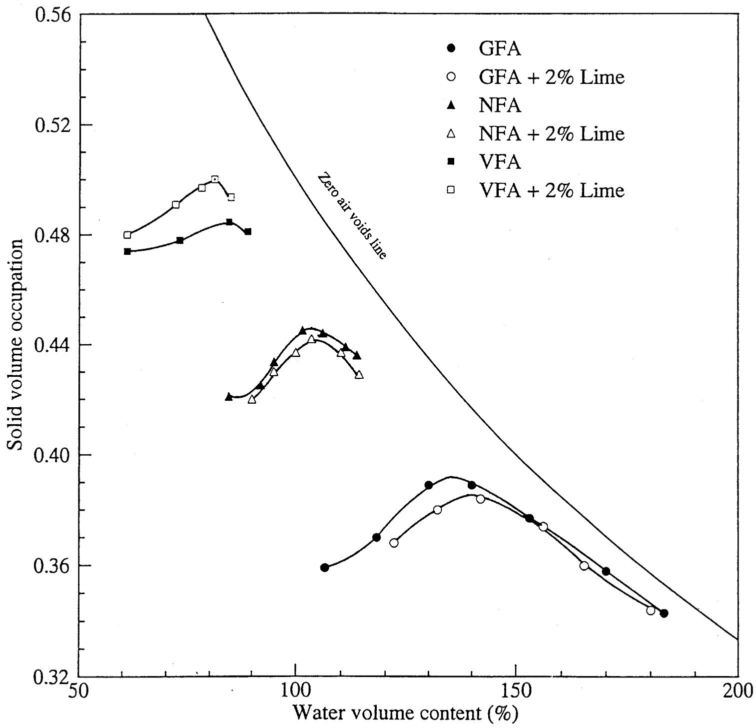

Fig. 3. Effect of lime on the solid volume occupation–water volume content relationship of the fly ashes.

misleading. (The specific gravity of the fly ashes used varied from 2.03 to 2.67) Hence, in the present study, the water content has been expressed in terms of volume.

6. Volume change behaviour

The shrinkage limit (SL) test was conducted on fly ashes at their liquid limit (LL). The LL, as determined by a cone penetrometer, and the SL and shrinkage index (SI) of the fly ashes, by ASTM D 427-93 (1995), are shown in Table 2. The difference between LL and SL is termed SI (Ranganatham and Satyanarayana, 1965). As seen in Table 2, the SL of fly ashes are very high which indicate that the shrinkage potential of fly ashes is less.

The compressibility behaviour of fly ashes is assessed from the one dimensional consolidation test. Fly ash samples were mixed with the required amount of water to bring it slightly above the LL. Then the samples were poured into the consolidation ring and the test was carried out using load increment ratio of unity (i.e. increment in pressure is equal to the existing pressure in the sample). The void ratio–pressure relationships for the three fly ashes are shown in Fig. 2. It can be seen that the compressibility of all the fly ashes is very less (in the range of 0.1–0.2) and is comparable to that of silts (Holtz and Kovacs, 1981). The change in void ratio of GFA, NFA and VFA for change in pressure of 6.25–800 kPa, is 0.286, 0.119 and 0.113, respectively, which is of the same order as their LL (volume basis). As seen from Fig. 2 there is no straight-line portion in void ratio–pressure curves. Hence, compression indices of fly ashes were calculated for successive pressures of 400–800 kPa. The values for GFA, NFA and VFA are 0.242, 0.133 and 0.116, respectively.

Coefficient of consolidation of the fly ashes for various pressure ranges (between 6.25 and 800 kPa) was found to vary from 100 to 3000 m^2/year. The high rates of consolidation suggest that in most cases primary consolidation of the fly ash should be

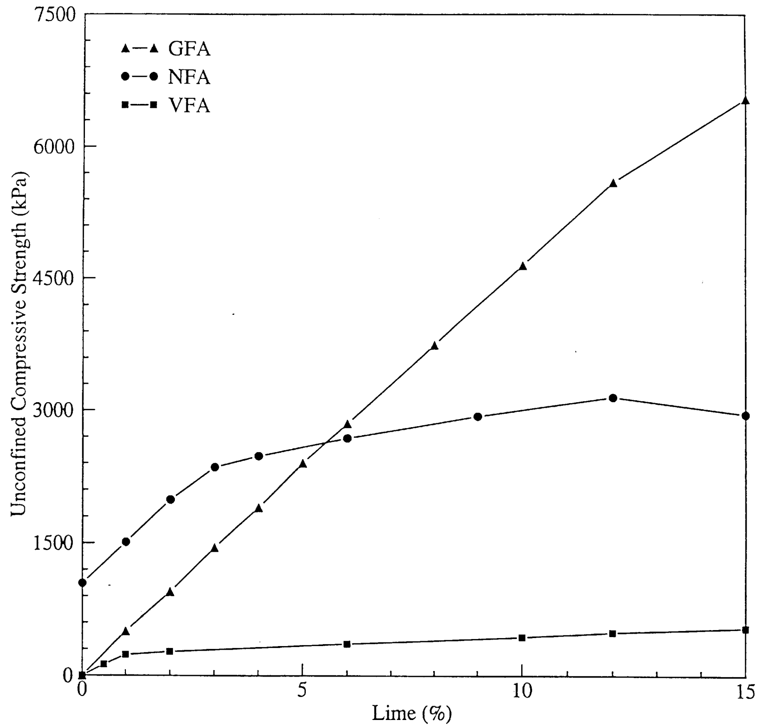

Fig. 4. Variation of unconfined compressive strength of the fly ashes with lime content after 28 days of curing.

practically complete immediately after the construction work is over.

7. Compaction and strength characteristics

The pozzolanic reactivity of the fly ashes which is responsible for the development of high strength can vary depending upon their chemical constituents namely reactive silica, carbon and iron contents; and physical properties like grain size etc. It is well understood that pozzolanic strength of fly ash depends mainly on the reaction between reactive silica and free lime content (Sivpullaiah et al., 1998). Thus, addition of lime may enhance the pozzolanic strength of fly ash. Hence, the effect of lime on the compaction and strength characteristics of fly ash has been studied.

Proctor compaction curves of the fly ashes in terms of solid volume occupation and water volume content are shown in Fig. 3. It can be seen that the shape of the compaction curve of the fly ashes is generally similar to that of fine grained soils (Prashanth et al., 1998). Fig. 3 also shows the effect of lime on the solid volume occupation and water volume content relationship of the fly ashes. As seen, the effect of lime is marginal on the solid volume occupation–water volume content relationship of the fly ashes. Unlike soils, fly ashes do not contain any charges on their surface. As such, addition of lime does not cause any fabric change (flocculation).

For testing the strength, samples of dry fly ash were mixed with various quantities of lime. Then the required quantity of water was added and thoroughly mixed. The samples were statically compacted from either side of a static compaction mould to get specimens of standard size, 7.62 cm in height and 3.81 cm in diameter. The dry densities and water contents of the compacted specimens were equal to their Proctor maximum dry density and optimum water content of the fly ashes. The unconfined compressive strength test was carried out after 28 days of curing. The specimens were cured in a desiccator at 100% humidity for 27 days, then soaked in water for 1 day before testing.

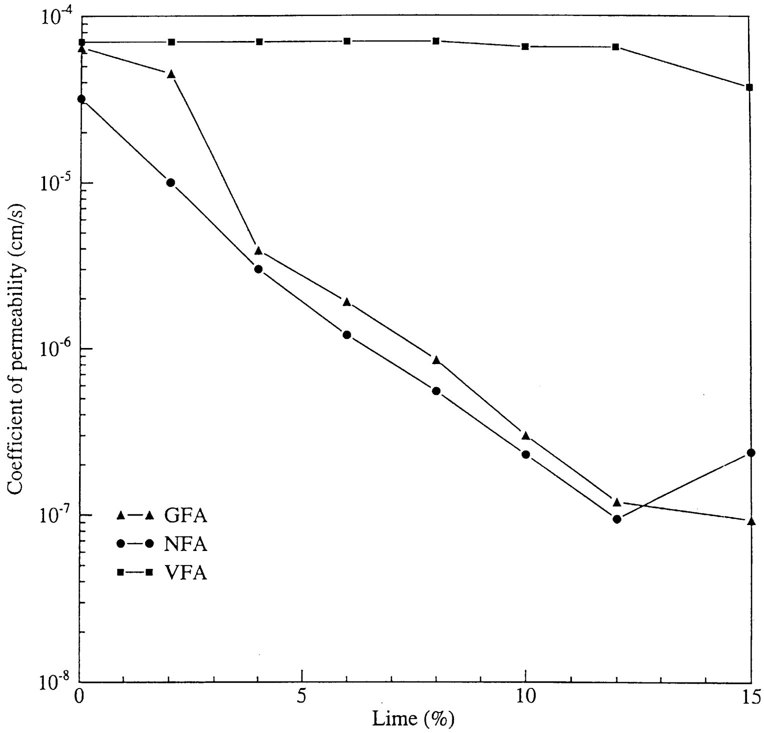

Fig. 5. Variation of coefficient of permeability of the fly ashes with lime content after 28 days of curing.

The unconfined compressive strength of the fly ashes with different lime contents is shown in Fig. 4. Addition of excess lime to fly ash is uneconomical and hence the lime content was limited to a maximum of 15%. This is because NFA has an unconfined compressive strength of 1000 kPa even without addition of lime. NFA possesses sufficient reactive silica (4.98%) and free lime (3.92%) to produce cementitious compounds. These cementitious compounds bind the fly ash particles thereby increasing the strength. Addition of lime further increased the strength of the NFA. This indicates that the free lime present in the fly ash is insufficient for the reactive silica to react completely. Unlike NFA, VFA by itself has no strength and collapsed on soaking. This is because VFA contains very little reactive silica (1.84%) and free lime (0.86%). On addition of lime, VFA develops some strength. Like VFA, GFA specimens collapsed immediately after soaking. This is because GFA (although it contains high reactive silica) has a very low content of free lime (0.5%). However, due its high reactive silica content (6.42%), the strength of GFA increased drastically on addition of lime. The strength of the fly ashes without added lime lies in the order NFA $>$ VFA $=$ GFA $=0$. This is because both GFA and VFA possess very low lime contents. The strength of the fly ashes with added lime lies in the order GFA $>$ NFA $\gg$ VFA. This is because reactive silica of GFA $>$ NFA $>$ VFA. As NFA given sufficient strength even without addition of lime it can be considered as self pozzolanic fly ash. As GFA, has given high strength on addition of lime, it can be considered as pozzolanic fly ash. VFA has given only a small amount of strength inspite of addition of lime because it was collected from a disposal pond.

8. Permeability characteristics

To act as a hydraulic barrier a fly ash should have low permeability. The Coefficient of permeability of most of the fly ashes is of the order of 10^{-5} cm/s and increasing the density can cause only a 5-fold change in the coefficient of permeability (Raymond, 1961; Dayal et al., 1988, 1989; Martin et al., 1990; Chen et al., 1992; Singh, 1994; Singh and Panda, 1996). This order of coefficient of permeability of fly ashes is because they are essentially formed of silt size inert particles. This value of coefficient of permeability is too high for fly ashes to be used as a hydraulic barrier. It can be seen from Section 7 that fly ashes develop considerable amount of pozzolanic strength on addition of lime. Hence, an attempt is made to measure the decrease in the coefficient of permeability of the fly ashes caused by the addition of lime.

Dry fly ash samples were mixed with various quantities of lime. Then the required quantity of water was added to give Proctor optimum water content. Then the mixture was statically compacted in a permeability mould of internal diameter of 8.0 cm and height of 6.0 cm to Proctor maximum dry density. The compacted specimen is 8.0 cm in diameter and 5.0 cm in height. The compacted specimen along with the permeability mould was kept at 100% humidity for 28 days. After 28 days of curing, variable head permeability tests were conducted on the hardened fly ash specimen. Readings were taken when the flow reached a steady state. The hydraulic gradient was varied from 10 to 50. Variation of the coefficient of permeability with the hydraulic gradient in the range of 10–50 was found to be marginal. Fig. 5 shows the variation of the coefficient of permeability of fly ashes with percent lime at a hydraulic gradient of 40. As seen in Fig. 5, coefficient of permeability of GFA, NFA and VFA were 6.5×10^{-5}, 3.2×10^{-5} and 7×10^{-5} cm/s, respectively. The coefficient of permeability of these fly ashes are also in the same order as those reported in the literature (Mclaren and Digioia, 1987). Though solid volume occupation of GFA is considerably lower than the VFA, both the fly ashes have almost the same permeability. GFA possesses fine particles. As such, the size of the pores is also smaller. Thus, the effect of lower solid volume occupation has been compensated by the effect of smaller pore sizes of GFA. Addition of lime decreased the coefficient of permeability of GFA and NFA to a value of 10^{-7} cm/s. However, the effect of lime in decreasing the coefficient of permeability of VFA is marginal. This is because both GFA and NFA have considerable amount of reactive silica and produce large amount of gelatinous cementitious compounds on addition of lime. These cementitious compounds fill the voids between the fly ash particles and reduce the coefficient of permeability. The reduction would be even more effective if the pore fluid contains ions that can be precipitated under a high alkaline condition. In contrast, VFA which has a low reactive silica content produces only small amounts of cementitious compounds.

9. Conclusions

Fly ashes undergo little shrinkage but not a higher volume change. However, they posses high permeability. Pozzolonic fly containing sufficient reactive silica and lime develop good strength. Further, pozzolonic fly ashes posses low permeability. Fly ashes containing reactive silica but insufficient lime content can be improved with the addition of lime. Thus fly ashes can be engineered to obtain good strength and the maximum acceptable hydraulic conductivity for use as land fill liners. Further research into their gas and chemical transport behaviour is recommended.

References

Brandl, H., 1992. Mineral liners for hazardous waste containment. Geotechnique 42, 57–65.

Chen, Y.J., Zhu, Y., Shi, F.X., 1992. Air pollution prevention during fly ash disposal. Geotechnical Engineering 23, 1–10.

Dayal, U., Jain, S.K., Srivastava, A.K., 1988. Geotechnical investigation of ash properties for dyke construction at Kobra super thermal power project. IIT, Kanpur Report for National Thermal Power Corporation Limited, New Delhi, India.

Dayal, U., Chandra, S., Bohra, N.C., 1989. Geotechnical investigation of ash properties for dyke construction at Ramagundam super thermal power project. IIT, Kanpur Report prepared for National Thermal Power Corporation Limited, New Delhi, India.

Holtz, R.D., Kovacs, W.D., 1981. An Introduction of Geotechnical Engineering. Prentice-Hall, Englewood Cliffs, NJ.

Martin, J.P., Collins, R.A., Browing, J.S., Biehl, F.J., 1990. Properties and use of fly ashes for embankments. Journal of Energy Engineering 116 (2), 71–85.

Mclaren, R.J., Digioia Jr., A.M., 1987. The typical engineering properties of fly ash. In: Woods, R.D. (Ed.), Geotechnical Practice for Waste Disposal, No. 13, Geotechnical Special Publication, pp. 683–697.

Pandain, N.S., Rajasekhar, C., Sridharan, A., 1995. Fly ash–lime systems for the retention of lead ions. In Proceedings of Indian Geotechnical Conference, Bangalore, India, vol. 1, pp. 219–222.

Prashanth, J.P., Sivapullaiah, P.V., Sridharan, A., 1998. Compaction

Curves On Volume Basis. Geotechnical Testing Journal, vol. 21 (1). American Society for Testing and Materials, Philadelphia, PA, pp. 58–65.
Ranganatham, B.V., Satyanarayana, B., 1965. A rational method of predicting swelling potential for compacted expansive clays. In Proceedings of Sixth International Conference on Soil Mechanics and Foundation Engineering, Montreal, Canada, vol. 1, pp. 92–96.
Raymond, S., 1961. Pulverized fuel ash as embankment material. In Proceedings of Institution of Civil Engineers, vol. 19, pp. 515–536.
Singh, D.N., 1994. Engineering properties of compacted Panki fly ash. In Proceedings of Indian Geotechnical Conference, Warangal, India, vol. 1, pp. 202–206.
Singh, S.R., Panda, A.P., 1996. Utilization of fly ash in geotechnical construction. In Proceedings of Indian Geotechnical Conference, Madras, India, vol. 1, pp. 547–550.
Sivapullaiah, P.V., Prashanth, J.P, Sridharan, A., Narayana, B.V., 1998. Reactive silica and strength of fly ashes. Geotechnical and Geological Engineering 18, 239–250.