Geomechanics and Engineering, *Vol. 5, No. 6 (2013) 565-574*
DOI: http://dx.doi.org/10.12989/gae.2013.5.6.565

Using cement dust to reduce swelling of expansive soil

Raddi M. AlZubaidi [*1], Kawkab H. AlRawi [2] and Ahmed J. AlFalahi [2]

[1] *Department of Civil and Environmental Engineering, Sharjah University, UAE*
[2] *Department of Building Engineering, University of Technology, Baghdad, Iraq*

(*Received July 15, 2012, Revised June 04, 2013, Accepted June 11, 2013*)

Abstract. Extensive study was carried out on Clay expansive soil. This soil was silty clay and can be classified as CH. The degree of expansion was found to range from low to medium depending on the free swell and swell pressure tests. The research investigated the effect of using cement dust on swelling potential, Atterberg Limit, linear shrinkage, and mineralogical composition of expansive soil. The results showed that the swelling potential, plasticity index, linear shrinkage, and clay minerals decrease with increasing cement dust percentage. The cement dust accumulates in huge amounts as a side product in cement factories, and the disposal of this fine dust is very difficult and poses an environmental threat.

Keywords: expansive soils; cement dust; swelling pressure; swelling

1. Introduction

Expansive soil, also called shrink-swell soil, is a very common cause of foundation problems. Depending upon the supply of moisture in the ground, expansive soils experience changes in volume of up to 30% or more. Foundation soils which are expansive will “heave” and can cause lifting of a building or other structure during periods of high moisture. Conversely during periods of falling soil moisture, expansive soil will “collapse” and can result in building settlement, and damage can be extensive. Expansive soil will also exert pressure on the vertical face of a foundation, basement, or retaining wall, resulting in lateral movement. Expansive soils which have expanded due to high ground moisture experience a loss of soil strength or “capacity” and the resulting instability can result in various forms of foundation problems and slope failure. Expansive soil should always be a suspect when there is evidence of active foundation movement. In order for expansive soil to cause foundation problems, there must be fluctuations in the amount of moisture contained in the foundation soils. If the moisture content of the foundation soils can be stabilized, foundation problems can often be avoided. Variations in the moisture regime during monsoon and summer are the causes of the alternate swelling and shrinkage of the expansive soils. One of the oldest practices used is the sand cushion technique Satyanarayana (1969). In this technique, either the entire depth of the expansive soil stratum or a part of it may be removed and replaced with a sand cushion compacted to a low density, without, however, compromising the bearing capacity criterion. Rao *et al*. (2008) used a fly ash cushion stabilized with lime or cement to reduce the swelling. The studies revealed that a fly ash cushion stabilized with either lime or cement was efficacious in arresting heave substantially. Srirama Rao and Rama Rao (2010) tried

*Corresponding author, Associates Professor, E-mail: ralzubaidi@sharjah.ac.ae

http://www.techno-press.org/?journal=gae&subpage=7 ISSN: 2005-307X (Print), 2092-6219 (Online)

using a fly ash cushion stabilized with lime or cement to overcome the drawbacks of the expansive soil which affect foundation practices. The principle of this technique is the same as that of a CNS cushion. This proved to be very effective in arresting heave. However, its efficacy over a few cycles of wetting and drying needs to be established since the CNS cushion, which was found to be effective in arresting heave during the first cycle of wetting and drying, was ineffective during the subsequent cycles. They concluded that their study relates to the behavior of expansive clays under a lime- or cement-stabilized fly ash cushion subjected to several wetting and drying cycles.

Rahman *et al*. (2011) conducted a literature review on cement kiln dust usage in soil and waste stabilization and experimental investigation. They used the cement dust in manufacturing building blocks and soil stabilization. They concluded that cement dust is potentially useful in stabilizing a variety of soils (i.e., sandy and clayey soils). However, the stabilizing effect is primarily a function of the chemical composition, fineness, and amount of cement dust added as well as the type of parent soil. Baghdadi *et al*. (1995) reported that the use of between 12 and 50% cement was satisfactory to stabilize dune sand. For light applications, 12 to 30% cement dust was found to be sufficient, and for heavily loaded applications, about 50% cement dust gave satisfactory stabilization. Mohamed (2002) evaluated the potential use of cement dust for enhancing the mechanical as well as the hydraulic properties of soils in arid lands. Various tests were conducted to determine the different physical properties of the stabilized matrix, and the optimum mixture that produces maximum internal energy and minimum hydraulic conductivity was selected. The analysis showed that 6% by weight of cement dust is the optimum mix design, which increases the shear strength and decreases the hydraulic conductivity. Therefore, the treated soil could be used as a soil-based barrier layer for containment of hazardous waste.

In other words, the available free lime, soluble alkalis, and fineness of cement dust influence the stabilization of soil, whether the underlying stabilization process is primarily pozzolanic, ion-exchange, or a combination of both. Albusoda and Salem (2012) investigated into the geotechnical properties of stabilized dune sand by using cement dust, they concluded that cement dust caused an increase in φ and (c). The variation in shear strength parameters became almost constant after fourteen days of curing.

2. Description of soil

The soil can be described as stiff to hard, lean to fat clay, and the water table was encountered at 1 m depth below the natural ground surface. The physical properties, grain size distribution, and classification of the soil are shown in Table 1 (Al-Falahi 2002).

Depending on the physical properties of undisturbed samples of expansive soil, the clay content (< 0.002 mm) ranges from 19.2% to 45%, the silt content ranges from 54.76% to 76.36%, the liquid limit ranges from 39.12% to 65.29%, the plastic limit ranges from 19.58% to 27.92%, the plasticity index ranges from 19.39 to 42.68%, the activity ranges from 0.77% to 1.43%, and the linear shrinkage of the samples ranges from 10.83% to 14.19%.

According to the classification chart modified by Van Der Merwe (1975), which depends on the clay fraction (< 0.002 mm) and the plasticity index, the degree of expansion of the soil was high to very high. Free swell tests were carried out and showed that the degree of expansion ranged from low to medium.

The X-ray diffraction test was carried out to determine the proportion of the various minerals present in the soil as shown in Table 2. It can be noticed that the montmorillonite is the dominate

Table 1 Physical properties of expansive soil

Depth(m)	L.L. (%)	P.L. (%)	P.I. (%)	L.S. (%)	A. (%)	Silt (%)	Clay (%)	Sand (%)	U.S.C.	AASHTO
0.5–1	39.12	19.73	19.39	10.83	1.01	76.36	19.2	4.44	CL	A-6
1.5–2.0	51.01	19.58	31.43	13.09	1.31	63.64	24	12.26	CH	A-7-6
2.5–3.0	56.14	22.23	33.91	11.23	0.92	55.22	36.8	7.98	CH	A-7-6
3.5–4.0	60.23	27.92	32.31	13.29	0.77	57.82	42	0.18	CH	A-7-6
4.5–5.0	62.24	23.65	38.59	14.12	0.92	55.96	42	2.04	CH	A-7-6
5.5–6.0	63.25	23.11	40.14	11.31	1.43	60.44	28	11.56	CH	A-7-6
6.5–7.0	56.58	24.93	30.53	11.25	1.24	73.36	24.6	2.04	CH	A-7-6
7.5–8.0	62.45	26.05	37.52	14.19	1.25	60.78	30	9.22	CH	A-7-6
8.5–9.0	65.29	22.61	42.68	14.18	0.95	54.76	45	0.24	CH	A-7-6

Table 2 X-ray diffraction results of tested expansive soil

	Mineral	Percentage
Non-Clay Minerals	Quartz	24
	Calcite	34
	Feldspar	2
Clay Minerals	Montmorillonite	20
	Palygorskite	8
	Kaolinite	12

clay in the soil and which is responsible for the expansion potential ,this montmorillonite can be classy as Na. Chemical tests were also carried out as an additional method to identify the mineralogical composition of the soil as shown in Table 3.

Table 3 Chemical compounds of the expansive soil

Compound		Percentage by weight
Silica	SiO_2	40.66
Alumina	Al_2O_3	9.82
Iron	Fe_2O_3	1.09
Lime	CaO	28.98
Magnesia	MgO	0.99
Soda	Na_2O	3.10
Potassium	K_2O	0.74
Loss on Ignition	L.O.I.	13.93
	PH	7.8

3. Prediction of swelling characteristics by direct method

The most satisfactory and convenient method for determining the swelling potential and the swelling pressure of an expansive soil is the direct method, in which free swell and swell pressure tests are conducted on undisturbed and remolded samples of the soil.

4. The cement dust

Cement dust is a fine powdery material similar in appearance to Portland cement. Cement Kiln Dust has a hazardous effect on human health, therefore care should be taken when dealing with this material. Fresh cement kiln dusts can be classified as belonging to one of four categories, depending on the kiln process employed and the degree of separation in the dust collection system (Collins and Emery 1983). There are two types of cement kiln processes: wet-process kilns, which accept feed materials in a slurry form, and dry-process kilns, which accept feed materials in a dry, ground form. In each type of process, the dust can be collected in two ways: (1) a portion of the dust can be separated and returned to the kiln from the dust collection system (e.g., cyclone) closest to the kiln; or (2) the total quantity of dust produced can be recycled or discarded. Large quantities of cement dust are produced during the manufacture of cement clinker by the dry process. Cement dust contains a mixture of raw feed as well as calcined materials with some volatile salts. It is derived from the same raw materials as Portland cement but, as the cement dust fraction has not been fully burnt, it differs chemically from the former. With modern manufacturing techniques, it is technically possible to introduce most cement dust back into the clinker-making cycle. However, this is not done due to the restrictions on the alkali and chloride contents of the cement. The UK cement industry has estimated that over 200,000 tons of landfill space could be saved per year if the surplus cement dust could be recycled into the clinker-making process or if alternative uses could be found (Aidan and Trevor 1995).

Approximately 15 million tons of cement dust are produced annually by the American cement industry (Portland Cement Association 1992). A medium size cement plant may produce up to 30,000 tons of cement dust annually. Based on an analysis of existing data, including data collected by the Portland Cement Association (PCA) from operators of cement manufacturing facilities, the PCA estimates that in 1995 the cement industry had a clinker capacity of 77 million metric tons and a net cement dust generation of 4.08 million metric tons, which was disposed of in landfills. The 1995 data indicate that 24 of the 110 cement plants (22%) recycle all collected dust back to the kiln, and an additional 12 plants (11%) ship all cement dust generated offsite for beneficial use. PCA estimates that the remaining two-thirds of cement plants (74 facilities) had a combined annual cement dust land-disposal requirement of 3.3 million metric tons in 1995. The obvious and best use of cement is its re-incorporation in the clinker production cycle. However, this can only be done when the existing restrictions on the alkalis and chloride concentrations in cement are revised. With regard to alkalis, it is estimated that most of the cement dust could be utilized in the clinker-making process if the cement alkali levels could be raised by around 0.1%. Similarly, the limits on the required chloride concentration with respect to the performance of cement in reinforced concrete construction need to be evaluated. The chemical analysis of the used cement dust is shown in Table 4.

Table 4 Chemical analysis of cement dust (AlZubaidi *et al*. 1991)

1. Chemical Composition	Percentage
Silica SiO_2	15.46
Alumina Al_2O_3	3.91
Iron Fe_2O_3	3.05
Lim CaO	43.4
Magnesia MgO	2.98
Sulfuric anhydride SO_3	6.34
Potassium K_2O	2.44
Soda Na_2O	1.42
Chlorides Cl	0.92
Loss on Ignition, L.O.I.	28.86
Total	100
2. Free lime (%)	2.96
3. Specific gravity	2.31
4. Percentage passing 90 μm sieve	100

5. Effect of cement dust on swell potential

The oven dried remolded soil was mixed with different percentages of cement dust: 0, 2, 4, and 5% by weight of the oven dried soil, and then water was added to the mixture to give the optimum moisture content, taking care to prevent the development of clay lumps. The mixture was cured in a sealed container for about 24 hours, the C.B.R. moulds were coated with petroleum jelly to minimize the effect of side friction, and the mixture was placed inside the mould in five layers. Each layer was subjected to 56 blows: this compaction energy was sufficient to provide the maximum dry density. Then the moulds were sealed with thick plastic papers and cured at air temperature of 33°C for 7 days. After the end of the curing period, the thick plastic paper was removed and the moulds were clamped with a perforated base plate bottom and circular perforated plate at the top of the compacted mixture in the mould. Then the moulds were immersed in a tank of water so that water could access both the top and bottom of the sample, and the water level was kept constant during the test. The dial gauge was attached to the centre of the stem of the perforated base plate and adjusted to a reading of zero, with a sensitivity of up to 0.025 mm/div. The swell was recorded with elapsed time until the swell reading was constant or the variation in successive readings was very small. At the end of the test the sample was extruded and the water content was determined. Fig. 1 shows the relationship between the swell potential and time for untreated soil and soil samples treated with 2, 4, and 5% cement dust respectively.

All the curves showed an increase in swelling with time and reached an approximately constant value at the end of the tests. The majority of the total swelling of untreated soil had occurred by 8 days, while 15 days were sufficient to complete the secondary swelling. While the majority of the swelling of soil treated with 2% and 4% of cement dust had occurred by approximately 5 and 4 days, respectively, 15 days were sufficient to keep the final swelling percentage constant.

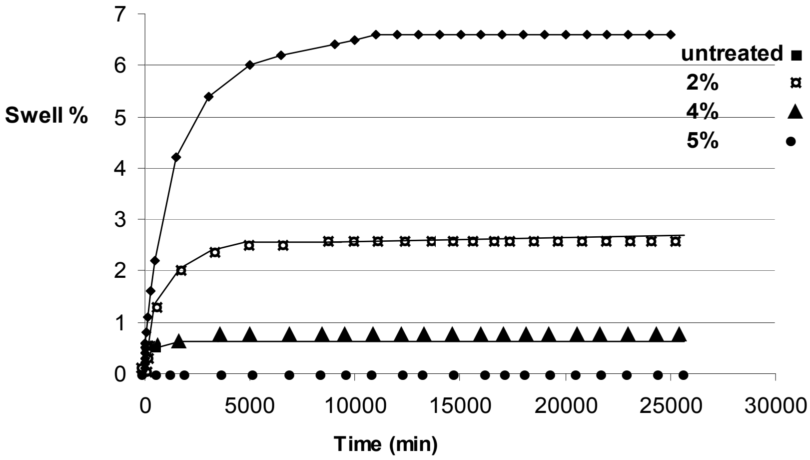

Fig. 1 Relationship between swell potential and time for untreated and treated soil with different percentages of cement dust

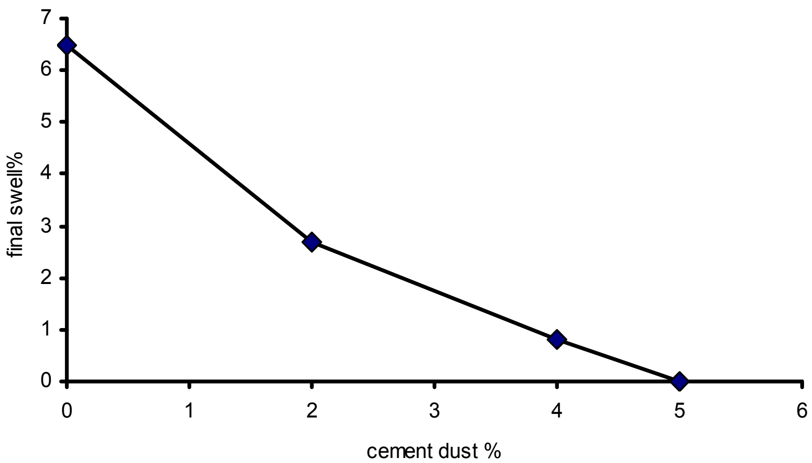

Fig. 2 Variation of final swell with cement dust

Fig. 2 shows the variation in final free swell with cement dust percentage. The addition of 2% and 4% cement dust reduced the final free swell percentages to 57.84% and 87.5%, respectively, compared with the final swell percentage of untreated soil, while when the amount of additive was increased to 5% the soil did not exhibit any swell potential, as shown in Fig. 2.

This behavior may be attributed to the effect of cement dust compounds, which is similar to that of Portland cement, but with a high quantity of alkalis such as sulfates, chlorides, and clayey alkalis. Since the effect of soil stabilization with cement dust is similar to that of Portland cement – soil reaction, addition to the effect of soluble chemicals, which exist in the cement dust that would change and reduce the action exchange capacity of clay mineral, and therefore the swelling ability of the soil was reduced.

It was also observed that the percentage moisture content (m%) varied with the cement dust percentage. Fig. 3 shows that when the cement dust increases, the moisture content decreases; this may be attributed to the chemical reaction of cement dust with the soil particles, which would alter the outer particles' surfaces by absorbing water for the reaction process, and therefore decrease the moisture content.

The moisture content of soil decreases by 53% when the untreated soil is mixed with 5% cement dust.

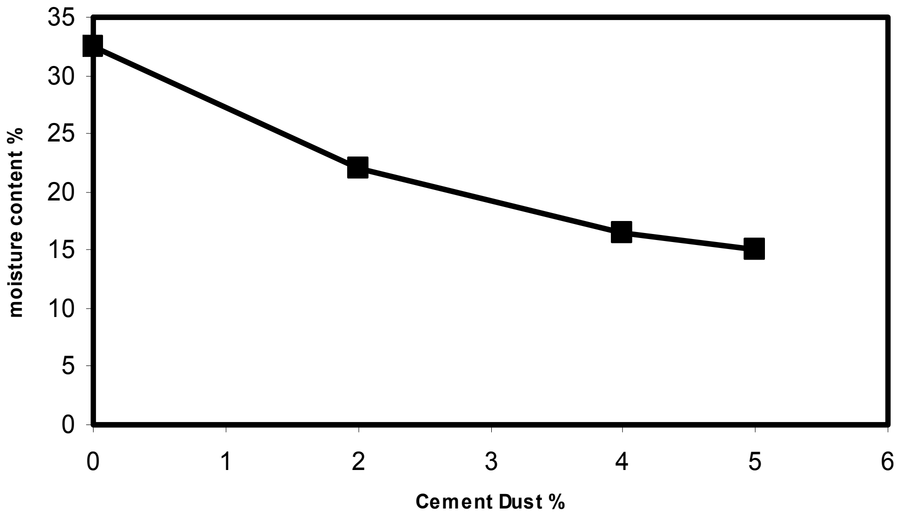

Fig. 3 Effect of cement dust percentage on moisture content of the soil

6. Effect of cement dust on Atterberg Limits

Different percentages of cement dust (0%, 2%, 4%, and 5%) were mixed thoroughly with a predetermined amount of air dried remolded soil, water was added to the mixture, and kept in a sealed container for 48 hours, the liquid limit, plastic limit, and shrinkage tests were carried out. Table 5 shows the effect of cement dust percentage on Atterberg Limits and linear shrinkage. The properties of the soil were improved by the addition of cement dust to the soil. Since the liquid limit and plasticity index decreased while the plastic limit increased, the reduction in plasticity index was observed when adding the first amount of cement dust; then the plasticity index decreased with further increases in the amount of cement dust. The plasticity index decreased from 32.4% for untreated soil to 6.7% for soil treated with 5% cement dust, as shown in Table 5.

The linear shrinkage was decreased by the addition of cement dust to the soil, since the linear shrinkage decreased from 31.8% for untreated soil to 5.4% for soil treated with 5% cement dust, as shown in Table 5. The variation in the plasticity index and the linear shrinkage was a positive sign to reduce the swelling characteristics of the soil; this reduction may be attributed to the effect of the chemical reaction and cementation on the structural composition of the soil. The modification of clay particles led to an increase in the effective particle size.

Table 5 Effect of cement dust on Atterberg Limits and linear shrinkage

Cement dust (%)	Liquid limit (%)	Plastic limit (%)	Plasticity index (%)	Linear shrinkage (%)
0	60.5	28.1	32.4	13.8
2	56.8	34.5	22.3	11.2
4	48.5	38	10.5	7.8
5	46.7	40	6.7	5.4

Sudjianto *et al*. (2011) investigated into the effect of wetting and drying of the expansive soil, they concluded that the water change has linear relation with swelling deformation, while the suction has contrary to with swelling deformation.

7. Effect of cement dust on mineralogical composition

The amount of air dried remolded soil was mixed with 5% cement dust by weight, and the analysis of the mineralogical composition of the mixture was carried out by the X-ray diffraction method.

Tests were conducted to determine the proportion of various minerals in the soil after treatment with 5% cement dust and to carry out a comparison with the minerals of the original soil.

The calculation was based on measuring the distance between the resulting lines and the angle of incident radiation of the spacing between the successive layers of atoms in the crystals by using the result of X-ray diffraction analysis. The composition of the mixture can be determined by comparing the measured distance of various diffraction lines with tables of diffraction data of known minerals. The intensity of different lines and the area under the curve of the peaks give an approximate indication of the quantity of each mineral in the sample, as shown in Table 6.

The results indicated that the non-clay minerals increased while the clay minerals decreased after treatment of the soil with 5% cement dust as compared with untreated soil (Table 2).

The content of the most important minerals (montmorillonite) decreased from 20% of the untreated soil to 9% of the treated soil, with the decrease reaching 50%. This reflected the decrease in the swelling potential of the expansive soils.

Table 6 Results of X-ray diffraction analysis of the expansive soil after treatment with 5% cement dust

	Mineral	Percentage
Non-clay minerals	Quartz	25
	Calcite	29
	Feldspar	2
Clay minerals	Montmorillonite	9
	Palygorskite	17.8
	Kaolinite	8

8. Conclusions

An extensive study was carried out on clay expansive soil. The research includes the effect of adding cement dust on the swell potential, Atterberg Limits, and mineralogical composition of undisturbed samples. From this research the following conclusions can be drawn:

(1) A new side product, the cement dust, which is harmful to the environment, was successfully used to reduce the swelling of expansive soil.
(2) The direct method showed a high to very high degree of expansion while direct measurement showed a low to medium degree of expansion for the tested soil.
(3) There were great changes in the clay fraction percentages of the same borehole of the tested soil: the clay content (< 0.002 mm) ranges from 19.2% to 45%, and the silt content ranges from 54.76% to 76.36%.
(4) The swelling characteristics decrease with increases in the amount of cement dust added, and thus 5% cement dust was sufficient to eliminate the swell potential of expansive soil.
(5) A distinctive decrease in the moisture content was recorded when the untreated soil was mixed with cement dust. The moisture content of soil decreased by 53% when the untreated soil was mixed with 5% cement dust.
(6) The variation in the Atterberg limit and linear shrinkage are positive indication of a reduction in the swelling characteristic, since the plasticity index and linear shrinkage decreased from 32.4% and 13.8 % to 6.7% and 15.4%, respectively, after the soil was treated with 5% cement dust.
(7) The effect of cement dust on the mineralogical composition of the soil is more pronounced for clay minerals, and thus 50% of the montmorillonite disappeared after treatment of the soil with 5% cement dust.

References

Aidan, C. and Trevor, C. (1995), “Cement kiln dust”, *Concrete*, **29**(5), 40-42.

Albusoda, B. and Salem, L. (2012), “Stabilization of dune sand by using cement kiln dust (CKD)”, *J. Earth Sci. Geotech. Eng.*, **2**(1), 131-143.

Al-Falahi, A.J. (2002), “The use of cement dust to reduce swelling”, M.Sc. Dissertation, Instruction, University of Technology, Baghdad, Iraq.

Al-Zubaidi, R., Saed, H. and Abudel Zahra. (1991), “A new brick from cement dust”, *Tech. J., F.T.I.*, **8**, Iraq.

Baghdadi, Z.A., Fatani, M.N. and Sabban, N.A. (1995), “Soil modification by cement kiln dust”, *ASCE J. Mater. Civil Eng.*, **7**(4), 218-222.

Collins, R.J. and Emery, J.J. (1983), “Kiln dust-fly ash systems for highway bases and subbases”, Federal Highway Administration, Research Report No. FHWA/RD-82/167, Washington, D.C.

Mohamed, A.M. (2002), “Hydro-mechanical evaluation of soil stabilized with cement-kiln dust in arid lands”, *Environ. Geol.*, **42**(8), 910-921.

Portland Cement Association (1992), “A new stone age: The making of Portland cement”, Skokie, Illinois, USA.

Rahman, M.K., Rehman, S. and Al-Amoudi, O.S.B. (2011), “Literature review on cement kiln dust usage in soil and waste stabilization and experimental investigation”, *Int. J. Res. Review in Appl. Sci.*, **7**(1), 77-87.

Rao, M.R., Rao, A.S. and Babu, R.D. (2008), “Efficacy of cement-stabilized fly ash cushion in arresting heave of expansive soils”, *Geotech. Geol. Eng.*, **26**(2), 189-197.

Satanarayana, B. (1969), "Behavior of expansive soil treated or cushioned with sand", *The 2nd International Conference on Expansive Soils*, Texas, 308-316.

Srirama Rao, A. and Rama Rao, M. (2010), "Behavior of expansive soils under stabilized fly ash cushions during cyclic wetting and drying", *Int. J. Geotech. Eng.*, **1**, 111-118.

Sudjianto, A.T., Suryolelono, K.B. and Mochtar, I.B. (2011), "The effect of water content change and variation suction in behavior swelling of expansive soil", *Int. J. Civil Environ. Eng.*, **11**(3), 11-17.

Van Der Merwe, D.H. (1975), "Current theory and practice for building on expansion clays", *Proceedings of the 6th Regional Conference for Africa on Soil Mechanics and Foundation Engineering*, Durban, South Africa, **2**, 160-167.

CC