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Measurement of Autogenous Healing in Stabilized Soils

Mésure de la Guérison Autogénique dans les Sols Stabilisés

A.A. HAMMOND Senior Research Officer, Building & Road Research Institute (CSIR), Kumasi, Ghana

SYNOPSIS Autogenous healing has been known to occur in lime and cement stabilized soils. The extent of, and factors affecting its occurrence are however not adequately documented in the literature. This paper describes a laboratory study of this property using a lateritic soil, lime, and cement.

The stress/strain properties of the stabilized soil specimens were measured after periods of initial curing. The tested specimens were further cured for various periods and a second stress/strain measurement undertaken. The autogenous healing was then computed. From the results of the study it was found that short initial curing periods and long curing periods after flawing enhanced the healing process.

It is inferred from the study that beyond seven days curing a lime or cement stabilized base over stressed to failure will not heal up but deteriorate. Light traffic may be allowed however, within seven days of laying a lime or cement stabilized base without danger of any flaws being healed up later.

INTRODUCTION

Soil stabilisation involves the alteration of soil properties to specific engineering requirements such as reduction of plasticity of fine-grained soils, improvement of workability and increase in strength as well as bearing capacity of the soil. There are many methods whereby this alteration can be achieved. One of the most common and effective of these methods is by addition of such hydraulic binders as lime and cement to the soil.

Generally, however, when lime or cement stabilized soils are used for pavement construction cracks are developed in the layers. These cracks are due to shrinkage or fatigue and stresses caused by over loading. In some cases, these cracks are so severe as to undermine the structural integrity of the pavement. It has been observed however that although cracks are developed in the stabilized pavements their occurrence do seldom make the pavement structurally or functionally inadequate. This characteristic is due to the fact that the flawed lime or cement stabilized soils have the ability to regain strength with time.

This ability to regain strength with time is termed autogenous healing and it may be defined as a ratio of increase in strength of flawed to unflawed stabilized soil of the same materials placed, compacted (moulded) and cured under the same conditions and over the same period. The expression for it is given as follows:

$$H = \frac{U_1 - U_0}{U_2 - U_0} \times 100\%$$

where H = Percentage healing over a given condition
 U_0 = Compressive strength of unflawed material after initial curing
 U_1 = Compressive strength of flawed material after additional period of curing
 U_2 = Compressive strength of unflawed material cured for a period equal to the sum of the initial and additional curing periods of the flawed material.

Autogenous healing occurs in lime and cement stabilized soils because of chemical reactions that go on during and after the soils have been stabilized. A brief review of the chemical reactions that occur in lime and cement stabilized soils is therefore necessary towards the understanding of this healing process.

Essentially, the reaction of soil-lime mixtures proceeds in two stages, namely, the rapid and slow stages. The reactions at the first stage are rapid. Here, through physico-chemical processes the clay size of particles is improved by means of flocculation and agglomeration of the particles. The effect is instant reduction of plasticity and tendency to swell and shrink. These changes are generally accompanied by little or no strength development. The second stage, however, is a slow process involving formation and accumulation of cementitious products leading to the hardening and stabilization of the soil (Diamond and Kinter, 1965). During this second stage, cracks developed in a flawed soil-lime

mixture will be filled with the cementitious products so formed thereby "healing" them.

Similarly, two main reaction processes may be identified during the hardening of a soil-cement material and these may be termed as the primary and secondary reaction processes. The hydrolysis and hydration of the cement is regarded as the primary reaction process. During the hydrolysis and hydration of cement calcium hydroxide, Ca(OH)_2 , is released resulting in a rise in the pH. This reaction is rapid and it involves ion exchange and flocculation.

The high pH and Ca(OH)_2 concentrations provide the necessary environment for the secondary reaction process to proceed. Under this condition the calcium ions produced by the cement hydration first converts the clay to the calcium form thereby intensifying the flocculation initially brought about by the addition of the cement to the soil. The Ca(OH)_2 attacks the clay particles combining with the amorphous silica and alumina to form additional cementitious products. This process is believed to be pozzolanic. By this, it is meant that the reaction involves siliceous or aluminous materials which by themselves are not cementitious but will combine with lime when finely divided and in the presence of moisture to form cementitious material (Herzog and Mitchell, 1963; Noble, 1967; Hammond, 1977). Here again, a soil-cement material which has developed cracks during this stage will get them filled up with the cementitious products derived from these reactions.

Occurrence of autogenous healing in lime and cement stabilized soils is well known and attempts had been made by Callahan, Morrow and Ahlberg (1962) as well as Thompson and Dempsey (1968) to measure it. However, the extent of its occurrence and factors affecting its occurrence are not adequately documented in the literature. The aim of this paper is to study this property of lime and cement stabilized soils to identify factors that affect its occurrence as well as measuring the extent of the healing with time.

In order to achieve this objective the stress/strain properties of the stabilized specimens were measured after initial curing. After flaws have been induced in the specimens which have had different periods of initial curing, further curing was undertaken for different periods and a second stress/strain measurement undertaken.

MATERIALS

A lateritic soil, hydraulic lime and ordinary Portland cement were used in the study. Classification and identification tests were carried out on the lateritic soil in accordance with the BS 1377 (1975). Chemical analysis were carried out on the lime and cement. Table I gives the properties of the soil and Table II the chemical properties of the binders. The particle size distribution of the soil is as portrayed in Fig.1.

TABLE I
Properties of the Lateritic Soil

W_L	W_P	γ_d kg m ⁻³	W_{opt}	pH	Organic Content
48.30	29.90	18.90	17.5	7.2	3.14

TABLE II
Chemical properties of the hydraulic binders

Component	Binder	
	Cement %	Lime %
SiO_2	20.80	0.76
Al_2O_3	6.14	0.40
Fe_2O_3	2.52	0.20
CaO	65.07	97.08
MgO	1.94	0.45
SO_3	1.93	0.06
Loss on ignition	1.19	-
Insoluble Residue	0.41	-
Total	100	99.77

EXPERIMENTAL

The test specimens were prepared by mixing the soil and the binders (lime and cement) thoroughly with water and casting them in cylindrical moulds

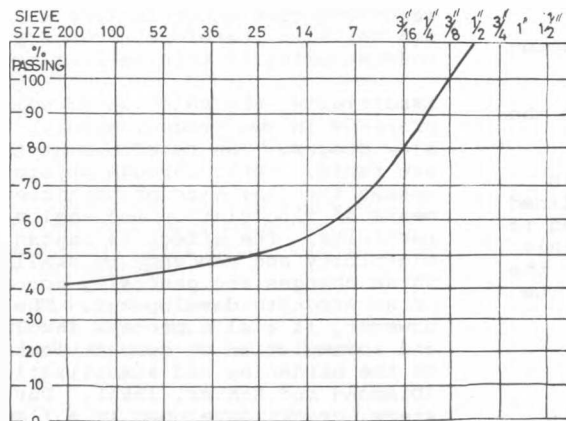


Fig.1: Particle size distribution of the lateritic soil.

measuring 101.6mm by 50.8mm diameter at the maximum dry density of 1890 kg m^{-3} and optimum moisture content of 17.5. The binders were added at three levels, 4, 6 and 8 per cent of the dry weight of the soil and allowance was made for their hydration by increasing the amount of water by 10 percent of the weight of binders. In all, 1400 specimens were cast and cured under humid and dry conditions over a period ranging from 7 to 156 days. Under the dry condition the waxed specimens were allowed to cure at the moulding moisture and at temperatures ranging between 25-30°C. whereas the specimens cured under humid condition were unwaxed but stored in plastic bags which were in turn covered with damp sacks. The curing temperature was the same as that of the dry condition.

Initial curing was carried out for periods of 7, 14, 28 and 56 days after which the specimens were tested and their stress/strain relations and unconfined compressive strengths obtained. The tested (flawed) specimens were then cured under both humid and dry conditions for additional periods ranging from 7 to 100 days. The stress/strain relations and unconfined compressive strength were again measured. A set of control specimens were also cured for 14 to 156

days, their casting ages being the same as that of the flawed specimens. However, they were cured continuously for periods equal to the sum of the initial and additional curing periods of the flawed materials. These specimens were tested and the average result of three specimen taken as in the case of flawed specimens.

The autogenous healing as already defined was then calculated from the expression:

$$H = \frac{U_1 - U_0}{U_2 - U_0} \times 100\%$$

The results of the tests are represented in both tabular and graphical forms. Tables III and IV show the percentage healing values calculated from the various strengths obtained. Figure 2 gives typical stress/strain relation of flawed and unflawed specimens. The relationship between healing and initial curing and that of healing and type and levels of stabilization as well as curing conditions are portrayed in Figs. 3 to 5.

TABLE III
Autogenous Healing in a Stabilized Soil Cured under Dry Conditions

Curing Period (Days)		Stabilization Agent					
		Lime			Cement		
		$H = \frac{U_1 - U_0}{U_2 - U_0} \times 100\%$			$H = \frac{U_1 - U_0}{U_2 - U_0} \times 100\%$		
Initial	After Flawing	4%	6%	8%	4%	6%	8%
7	7	12.67	17.14	23.07	-6.66	-4.00	9.41
	14	38.00	23.85	42.50	8.00	15.29	11.72
	28	43.50	50.43	48.57	23.00	48.46	46.67
	56	50.40	62.18	61.42	38.67	77.94	39.13
	100	61.93	75.11	43.94	35.89	82.35	40.70
14	7	-110.00	-133.33	-366.67	-390.00	-137.14	-113.33
	14	-11.40	-25.45	-82.22	-22.22	-43.33	-43.00
	28	18.18	-4.21	-20.00	-6.67	-10.00	-10.47
	56	48.00	10.67	7.90	9.23	4.38	5.00
	100	69.28	13.84	15.51	17.64	5.77	4.92
28	7	-380.00	-316.00	-283.33	-228.00	-630.00	-405.00
	14	-130.00	-187.5	-110.00	-213.33	-297.50	-192.86
	28	-33.33	-107.69	-54.74	-100.00	-181.67	-101.82
	56	-15.29	-51.81	-8.50	-45.00	-79.20	-21.25
	100	-21.81	-18.18	-2.4	-33.84	47.43	-21.18
56	7	-680.00	-1550.00	-500.00	-853.33	-1346.67	-406.67
	14	-420.00	-516.67	-185.33	-500.00	-663.33	-242.22
	28	-150.00	-333.33	-122.86	-302.50	-298.18	-192.73
	56	-53.33	-148.00	-77.42	-173.84	-180.00	-132.41
	100	-24.70	-111.11	-51.18	-117.78	-103.70	-106.97

TABLE IV

Autogenous Healing in a Stabilized Soil Cured under Humid Conditions

Curing Period (Days)		Stabilizing Agent					
		Lime			Cement		
		$H = \frac{U_1 - U_0}{U_2 - U_0} \times 100$			$H = \frac{U_1 - U_0}{U_2 - U_0} \times 100$		
Initial	After Flawing	4%	6%	8%	4%	6%	8%
7	7	15.21	18.88	26.25	6.85	10.00	22.22
	14	46.66	31.43	58.33	16.00	24.44	50.77
	28	71.00	71.67	75.91	61.90	60.69	72.30
	56	84.67	87.78	85.63	66.31	72.27	81.61
	100	94.00	97.20	87.25	86.67	86.44	87.25
14	7	-8.00	-96.00	-97.50	-300.00	-223.33	-172.50
	14	-6.67	-46.00	9.00	-54.00	-50.00	-35.00
	28	46.67	32.22	28.75	11.76	12.73	30.67
	56	69.60	63.45	58.33	11.11	22.29	61.67
	100	84.57	79.11	49.41	21.62	42.00	72.81
28	7	-290.00	-404.00	-305.00	-380.00	-508.00	-375.00
	14	-186.67	-192.5	-160.00	-182.85	-186.00	-164.29
	28	-96.36	-42.67	-27.27	-109.09	-100.00	-41.82
	56	-46.31	-21.76	-34.00	-40.00	-43.57	22.63
	100	-25.00	-48.78	-53.57	-13.79	-15.12	38.43
56	7	-786.67	-1710.00	-786.67	-705.00	-1306.67	-896.67
	14	-460.00	-770.00	-436.00	-460.00	-636.67	-500.00
	28	-275.00	-327.5	-217.78	-295.56	-330.90	-286.25
	56	-120.00	-62.22	-121.54	-141.38	-166.00	-140.77
	100	-86.67	-18.82	-60.00	-117.00	-104.13	-80.00

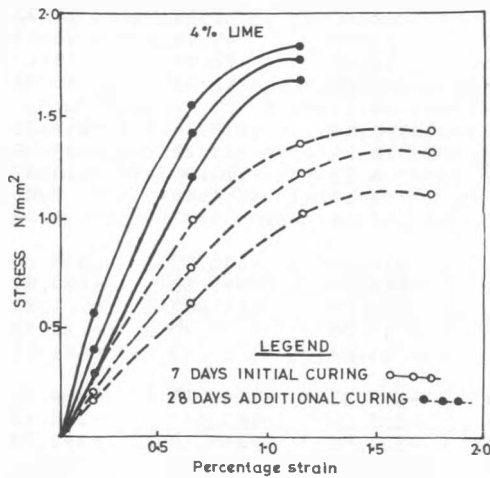


Fig.2: Typical stress-strain curves for the lime stabilized soil.

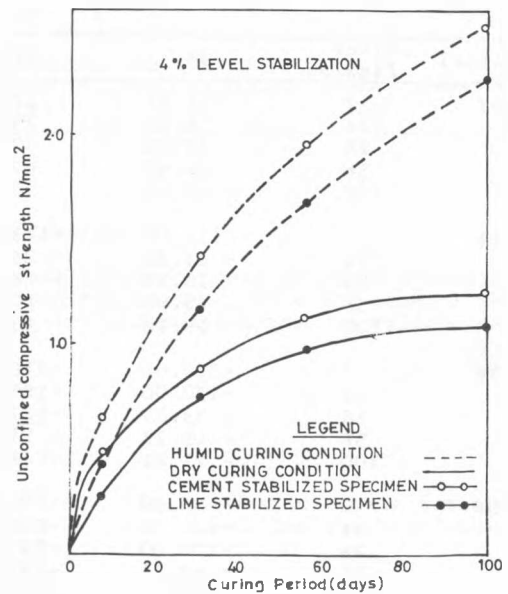


Fig.3: Relationship of unconfined compressive strength and curing period of flawed specimens initially cured for 7 days.

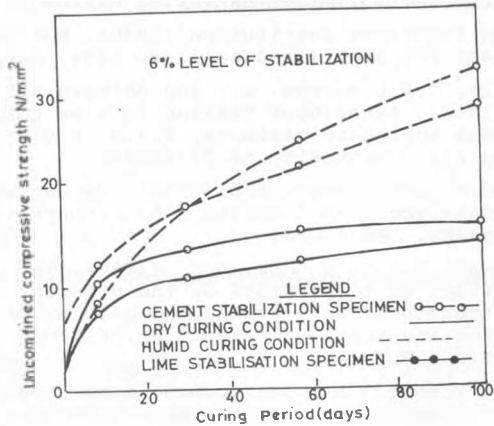


Fig. 4: Relationship of unconfined compressive strength and curing period of flawed specimens initially cured for 14 days

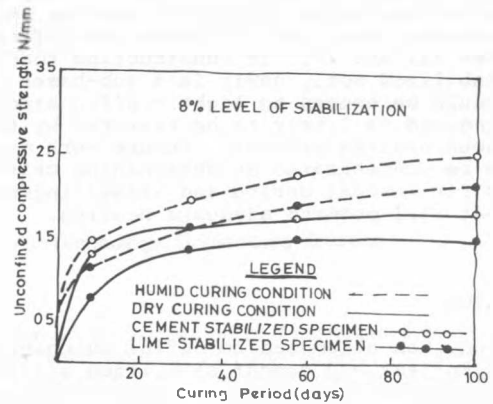


Fig. 5: Relationship of unconfined compressive strength and curing period of flawed specimens initially cured for 56 days

DISCUSSION

Four factors affecting autogenous healing in lime and cement stabilized bases are identified and considered in the discussion. These are initial curing period of the stabilized soil before inducement of flaws; length of curing period after flaws have been induced; curing conditions and type as well as levels of stabilising agent.

Considering Tables III and IV together it can be observed that autogenous healing for both lime and cement stabilized soils is considerable for specimens cured for shorter periods before flaws were induced. For example, higher percentage healing occurred in the specimens initially cured for 14 days as compared to those cured for 14 to 56 days. This may be explained by the fact that the major chemical reactions, hydrolysis and hydration, of the binders occur during the earlier curing periods of lime and cement stabilization and therefore cracks developing in the stabilized material have greater chance of being healed with the reaction products. It can further be observed in Tables III and IV that most of the specimens cured beyond 7 days registered negative percentage healing. This is partly due to high degree of brittleness exhibited by the specimens, as shown in Fig. 2, which caused wider cracks to be developed in those specimens. Evidently, as the initial curing period increased the percentage healing decreased.

Again, as would be expected the autogenous healing improved with increase in the curing period after the flaws have been induced. This is a general trend in the study. There were few exceptions where shorter curing periods, after inducing flaws in the specimens, gave higher percentage healing. It can be said therefore that the amount of autogenous healing increased

with periods of curing after flaws have been induced.

Of the two curing conditions, dry and humid, the humid condition proved favourable for the healing process as indicated in Figs. 3 to 5. The humid condition enhanced rapid formation of reaction products which helped the healing process. Under the dry condition, the specimens became drier and as a result the deficiency in moisture adversely affected the formation of reaction products which was necessary in the healing process. Lesser degree of healing therefore occurred during the dry curing condition.

It appears from the study that the healing effect is slightly more pronounced in the lime stabilized soil than in the cement one. This can be partly explained by the particle size distribution of the soil as shown in Fig. 1 and by the index properties as shown in Table I. It can be seen from Fig. 1 that the soil contains high proportion of fines. With a liquid limit of 48.30 and plasticity index of 18.40, it will plot as an MI soil on the Cassagrande soil classification chart. Such a soil will respond better to lime than to cement stabilization.

Another explanation can be found for the comparatively better performance of the lime, in the hydration processes of lime and cement. Whereas hydration is rapid in cement, it is slow in lime and therefore there is a good chance of availability of unreacted lime for the healing process to proceed within the curing period.

The effect of the level of stabilization on the healing process is more marked in specimens cured under the humid condition than the dry. This trend is pronounced particularly in the cement stabilized specimens.

It can be inferred from the study that when a lime and cement stabilized layer is over stressed to failure after 14 days initial curing, healing will be difficult. In fact, there will be drastic deterioration of the layer as indicated by high negative percentage healing shown in Tables III and IV. In constructing roads with stabilized soil, newly laid sub-bases and bases could be opened to light traffic since any flaws induced is likely to be restored by the autogenous healing process. Future work may have to be concentrated on determining critical periods for initial curing and stress intensities that will promote adequate healing.

CONCLUSION

This study has attempted to define autogenous healing in lime and cement stabilized soils and has provided an expression for autogenous healing to facilitate its calculation.

Four factors affecting the healing process were identified in this study. It was found that the initial curing period is crucial to the healing potential of the stabilized soil. As the initial curing period increases the percentage healing decreases. However, after the flaw has been induced, the amount of autogenous healing increases with increase in curing period. Again, it was found that autogenous healing is enhanced by humid curing condition and by high level of stabilization especially in cement.

It is inferred from this study that autogenous healing will be difficult to occur where a lime or cement stabilized soil layer cured beyond 14 days has been over stressed to failure. However, light traffic could be allowed within 7 days of laying a lime or cement stabilized sub-base or base without danger of strength recovery later.

ACKNOWLEDGEMENTS

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REFERENCES

- Blanks, R.F. and Kennedy (1955). The technology of cement and concrete. Vol.1, 422pp. John Wiley and Sons, New York.
- Boynton, R.S. (1968). Chemistry and technology of lime and limestone, 520pp. Interscience Press.
- Boynton, R.S. (1970). Experiences with lime-soil stabilization in the U.S.A. Zement-Kalk-Gips Heft 11/1970 Bauverlag Wiesbaden.
- British Standards Institution (1970). Methods of test for stabilized soil. BS 1924. 94pp.
- Callahan, J.P., Morrow, J., and Ahlberg, H.L. (1962). Autogenous healing in lime pozzolana aggregate mixtures. T.A.M. Report No.631. University of Illinois.
- Diamond, S. and Kinter, E.B. (1965). Mechanisms of soil-lime stabilization - An interpretative review, HBR No.92.
- Dumbleton, M.J. and Ross, N.F. (1960). The effect of temperature on the gain in strength of soil stabilized with hydrated lime and Portland cement. RN/3655/MJD NFR DSIR R.R.L.
- George, K.P. (1971). Soil cement base cracking theoretical and model studies. Proc. 50th HRB Conference.
- Glen, G.R. and Handy, R.L. (1963). Lime-clay mineral reaction products. H.R.R.29.
- Hammond, A.A. (1977). Exploratory studies of calcined bauxite-waste pozzolana for road stabilization. Proc. of Specialty Session on Soil Mechanics and Environmental Control, 9th ISSMFE, Tokyo.
- Harzog, A. and Mitchell (1963). Reactions accompanying stabilization of clay with cement. H.R.R. No.36.
- Ingles, O.G. and Metcalf, J.B. (1972). Soil stabilization principles and practice, 375pp. Butterworths, Sydney.
- Lea, F.M. (1970). The chemistry of cement and concrete. 727pp. Edward Arnold, London.
- Lee, I.K., Ingles, O.G. and Yesman, J. (1976). Materials and methods for low cost road, rail and reclamation works. Proc. of Residential Workshop, 839pp. Leura, Australia.
- McDawell, C. (1966). Evaluation of soil-lime stabilization mixture. H.R.R. 139.
- Noble, D.F. (1967). Reaction and strength development in Portland Cement-clay mixtures. H.R.R. 198.
- Taylor, H.F.N. (1964). The chemistry of cements, Vol.2, 442pp. Academic Press, London.
- Thompson, M.R. (1968). Lime treated soils for pavement construction. Journal, Highway Division A.E.S.C. Vol.94, No.HW.2.
- Thompson, M.R. and Dempsey, B.T. (1969). Autogenous healing of lime soil mixture. H.R.R. No.263.