International Journal of Engineering & Technology
CENTRE OF PROFESSIONAL RESEARCH PUBLICATIONS
ISSN 2049-3444

International Journal of Engineering and Technology Volume 2 No. 4, April, 2012

Effects of Forage Ash on Some Geotechnical Properties of Lime Stabilized Lateritic Soils for Road Works

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ABSTRACT

This research was carried out with a view to studying the effect of forage ash on the geotechnical properties of lime stabilized lateritic soil in order to discover a conventional and cheaper stabilizer for road works. Preliminary tests were performed on three soil samples collected from Ile-Ife, Nigeria designated as sample A, B and C. Atterberg's limits and some strength tests (compaction, California bearing ratio, and triaxial) were also performed on the samples at their unstabilized state, after which the samples were stabilized with lime in 2, 4, 6, 8 and 10% by weight of sample to determine the optimum lime percentage. The soil samples were further stabilized with lime-forage ash mixture using the optimum lime of each sample and varying forage ash additive in 2, 4, 6, 8, 10 and 12%. Atterberg's limit and other strength tests were repeated on the samples to observe the effects of the lime-forage ash combination on the soil geotechnical properties. The results showed that the lime-forage ash combination increased the plasticity of all soil samples; this is not a good improvement parameter. However, CBR values (both soaked and unsoaked) were significantly increased for samples A, B and C even though none of the samples met the requirements for road construction. The shear strengths of the samples were also increased but there was a reduction in the maximum dry density of the soil samples. In conclusion, forage ash was found effective in lime stabilized soils and will significantly improve their shear strengths and CBR values. However the combination of lime-forage ash will be ineffective in stabilizing soils for road works where a higher maximum dry density is needed.

Keywords: *Forage ash, geotechnical properties, lime, stabilization, lateritic soil.*

I. INTRODUCTION

The materials used in the construction of a highway are of intense interest to the highway engineer, in contrast to many other branches of civil engineering where the engineer may not be deeply concerned with the properties of the materials being used [1]. All highways have to be found on the soil, and all require the efficient usage of locally available materials if great distances are to be covered up and economically constructed facilities are to be obtained. A thorough knowledge of the soil and aggregate properties which affect pavement stability and durability is required as well as the properties of the binding materials which may be added to improve these pavement features. Since the main objective of road construction material selection is aimed at ensuring overall economy and stability of pavements, selection of locally available lateritic materials that will require minimum haul and also require little or no treatment to improve their strength is very important. When these materials do not satisfy the requirements, it becomes necessary to investigate the possibilities of improving their engineering properties by finding a way of stabilizing the lateritic soils to suit the engineering purposes for which it is meant for. Many things have been used to stabilize lateritic soil in the past and thus the idea of using forage ash, which is an agricultural waste in developing a better and more economic stabilizer, is not unusual. In addition, the use of forage ash for stabilization will find use for grasses that constitute wastes in the environment which may result into lower road construction cost. The aim of this research is therefore to discover a conventional and cheaper stabilizer for road works.

II. METHODS

The materials used are: lateritic soil samples, lime and forage ash. Three different types of soil samples were dug from the campus of Obafemi Awolowo University, Ile-Ife, Osun State, Nigeria. These were taken at different depths greater than the natural formation level (with at least 300mm top soil removed) to obtain representative samples of the soil stratum. They were kept in clean plastic bags properly sealed with adhesive tape and kept safe and dry in jute bags in the geotechnics laboratory at the Department of Civil Engineering, Obafemi Awolowo University, Ile-Ife. Sample numbers with soil descriptions, sampling depths and dates of sampling were marked clearly on papers and stapled to the plastic bags. The samples were later taken out of the bags, slightly pulverized with minimal pressure to break up lumps which had formed during storage and spread out on jute bags at the

laboratory to facilitate quick air drying. The samples were then sieved with sieve No. 4 (4.76mm opening) to obtain samples for the relevant tests. Hydrated lime was purchased from Ibadan, Nigeria and was properly covered to prevent false setting due to absorption of atmospheric water. Lumps formed during storage were removed from the lime before used. Forage ash was obtained as a product of burnt elephant grass available locally. The dried grass was burnt in open hearths where potted clay pots and figurines are glazed. The ash obtained was sieved to remove foreign materials such as stones, wood and others.
Preliminary tests were performed on the three soil samples at their unstabilized states. Atterberg's limits and strength tests (compaction, California bearing ratio, and triaxial) were also performed on the samples. They were later stabilized with lime in 2, 4, 6, 8 and 10% by weight of sample to determine the optimum lime percentages of the three samples. The soil samples were then stabilized with lime-forage ash mixture using the optimum lime of each sample and varying forage ash in 2, 4, 6, 8, 10 and 12%. Atterberg's limit and other strength tests were repeated on the samples to observe the various effects of the lime-forage ash combination on the soil properties.

III. RESULTS AND DISCUSSION

The results of the preliminary tests (natural moisture contents, specific gravity, grain size analysis, soil classification and Atterberg's limits) as well as the strength tests (compaction, California bearing ratio, triaxial and unconfined compression tests) are presented and discussed below.

Preliminary Tests

The summary of the preliminary tests on the soil samples are shown in Table 1. The natural moisture contents of the samples A, B and C are 22.19, 22.63 and 12.30% respectively. This shows that sample B has the highest natural moisture content and sample C the lowest. This could be due to the void ratio and specific gravity. Sample B probably has the largest void ratio compared to the others. The specific gravities of sample A, B and C are 2.50, 2.63 and 2.78 respectively. This value falls within the value given in [2] for clay minerals. The particle size analysis showed that more than 35% of the three samples passed the 200μm sieve. All the samples fell within the SILTY OR CLAYEY GRAVEL AND SAND mineral under the general AASHTO classification and belong to the A-2 group. Based on their LL and PI, the soil samples were further classified as A-2-6(3), A-2-7(3) and A-2-7(3) for sample A, B and C respectively as shown in Table 1.

Table 1: Summary of the preliminary analysis of soil samples

Sample	Natural Moisture Content (%)	Specific Gravity	Liquid Limit (%)	Plastic Limit (%)	Plastic Index (%)	AASTHO Classification
A	22.19	2.50	35.70	17.59	15.12	A-2-6(3)
B	22.63	2.63	50.30	34.79	15. 51	A-2-7(3)
C	12.30	2.78	48.80	27.90	20.90	A-2-7(3)

The liquid limit (LL), plastic limit (PL) and the plastic index (PI) of the natural soil samples are 35.70, 17.59 and 15.12% respectively for sample A, 50.30, 34.79 and 15.51% respectively for sample B and 48.80, 27.90 and 20.90% respectively for sample C. This shows that samples A, B and C are intermediate plastic soils.

According to [3], liquid limit between 35 and 50% indicates intermediate plasticity, 50 and 70% high plasticity and 70 and 90% very high plasticity. The addition of lime to the samples mostly increased the liquid limits the samples, liquid limit increased to optimums of 40.00 55.50 and 51.00% for samples A, B and C respectively. The plastic limits increased to 21.46% for sample A, and decreased to 25.89 and 26.06% respectively for samples B and C.

The effects of lime-forage ash stabilization on the Atterberg's limits of the samples are shown in Table 2. At the optimum percentage of lime stabilization, the addition of forage ash generally increased the liquid and plastic limits of all the samples. Plastic limits increased from 21.46 to 34.79%, 31.51 to 33.50% and 27.88 to 40.02% for samples A, B and C respectively. This could be the effect of the high affinity of forage ash for water. However, the PI decreased from 16.54 to 5.21%, 19.49% and 20.62% to 10.03% for samples A and C respectively. It has been said that a reduction in plastic index is an indicator of improvement [4]. This shows that the mixture of lime-forage has ability to improve lateritic soils in stabilization.

Strength Test

The summary of the compaction results are shown in Table 3. Samples A, B and C have natural OMC of 15.76, 20.50 and 16.00% and MDD of 2100, 1665 and 1725kg/m^3 respectively. The addition of lime to samples A, B and C at optimum percentages increased OMC to 17.89, 21.65 and 18.43% and decreased MDD to 1900, 1590 and 1710kg/m^3 respectively. The combination of forage ash and lime for stabilizing the samples caused OMC to increase and MDD to decrease consistently.

Table 2: Summary of Atterberg's limits test

Sample	Percentage stabilization	Liquid Limit(LL) %	Plastic Limit(PL) %	Plastic Index(PI) %
A	0%	35.70	17.59	15.12
	2% Lime	40.00	19.37	20.63
	4% Lime	38.90	18.64	20.26
	6% Lime	38.00	21.46	16.54
	10% Lime	38.50	20.75	17.75
	6%Lime+ 2%Forage Ash	40.00	34.79	5.21
	6%Lime+ 4%Forage Ash	38.75	23.07	15.68
	6%Lime+ 6%Forage Ash	39.50	27.34	12.16
	6%Lime+ 8%Forage Ash	39.65	25.17	14.48
	6%Lime+ 10%Forage Ash	50.00	27.30	22.70
	6%Lime+ 12%Forage Ash	41.20	28.07	13.13
B	0% Lime	50.30	34.79	15. 51
	2% Lime	53.50	29.58	23.92
	4% Lime	51.00	31.51	19.49
	6% Lime	55.50	33.34	22.16
	10% Lime	54.50	25.89	28.61
	4%Lime+ 2%Forage Ash	53.20	30.00	23.20
	4%Lime+ 4%Forage Ash	54.70	31.19	23.51
	4%Lime+ 6%Forage Ash	54.50	33.50	21.00
	4%Lime+ 8%Forage Ash	56.80	29.75	27.05
	4%Lime+ 10%Forage Ash	57.00	28.84	28.16
	4%Lime+ 12%Forage Ash	53.50	29.46	24.04
C	0%	48.80	27.90	20.90
	2% Lime	51.00	27.85	23.15
	4% Lime	48.50	27.88	20.62
	6% Lime	50.00	27.78	22.22
	10% Lime	47.50	26.06	21.44
	4%Lime+2%Forage Ash	50.00	34.45	15.55
	4%Lime+ 4%Forage Ash	51.25	34.29	16.96
	4%Lime+ 6%Forage Ash	50.05	40.02	10.03
	4%Lime+ 8%Forage Ash	51.80	38.60	13.20
	4%Lime+ 10%Forage Ash	53.40	37.44	15.96
	4%Lime+ 12%Forage Ash	54.40	35.79	18.61

Table 3: Summary of compaction test results

Sample	Percentage stabilization	Optimum Moisture Content (OMC) (%)	Maximum Dry Density(kg/m^3)
A	0%	15.76	2100
	6%Lime	17.89	1900
	6%Lime + 2%Forage Ash	19.50	1655
	6%Lime + 4%Forage Ash	22.00	1600
	6%Lime + 6%Forage Ash	21.00	1620
	6%Lime + 8%Forage Ash	21.50	1488
	6%Lime + 10%Forage Ash	22.50	1426
	6%Lime + 12%Forage Ash	24.00	1460
B	0%	20.50	1665
	4% Lime	21.65	1590
	4%Lime + 2%Forage Ash	22.5	1540
	4%Lime + 4%Forage Ash	23.76	1520
	4%Lime + 6%Forage Ash	19.00	1499
	4%Lime + 8%Forage Ash	22.00	1480
	4%Lime + 10%Forage Ash	23.50	1477
	4%Lime + 12%Forage Ash	28.00	1354
	0%	16.00	1725
	4% Lime	18.43	1710

ISSN: 2049-3444

C	4%Lime + 2%Forage Ash	18.97	1690
	4%Lime + 4%Forage Ash	18.42	1685
	4%Lime + 6%Forage Ash	18.50	1646
	4%Lime + 8%Forage Ash	19.00	1600
	4%Lime + 10%Forage Ash	20.00	1580
	4%Lime + 12%Forage Ash	21.00	1534

The increase in OMC is probably a consequence of the additional water held with the flocculant soil structure resulting from lime interaction and water absorption by forage ash as a result of its porous properties. Principally, increase in dry density is an indicator of improvement. But unfortunately, both lime and forage ash caused a reduction in dry density. In the opinion of [5] the change-down in dry density occurs because of both the particles size and specific gravity of the soil and stabilizer.

The results of the California Bearing Ratio (CBR) test are shown in Table 4. The CBR values for the 72 hours soaked samples were much lower compared to the unsoaked samples. These values for samples B and C were observed to be lower than the 10% CBR required for subgrade. Although the CBR values for sample A met this requirement, it however fell short of the 30% CBR required for sub-base. The CBR values of all the soil samples increased considerably on stabilization with lime-forage ash. The optimum values were observed to be higher than that for the 10% lime stabilized soil. This shows that the load bearing capacity of the soil increased with the stabilization mix. Despite this increase, the minimum requirements for CBR subgrade, sub-base and base courses which are 10% CBR (soaked), 30% CBR (soaked) and 80% CBR (unsoaked) was not achieved. It is therefore evident that none of the three soil samples qualifies as road construction material.

The summary of the triaxial results are shown in Table 5. The shear stress of sample A raised from 186.36 to a maximum of 309.27 kN/m^2, sample B from 105.71 to 311.14 kN/m^2 and sample C from 93.24 to 248.40kN/m^2. The shear strengths of samples A, B and C increased considerably with lime-forage ash mixture. It is however seen that lime only stabilized sample had a larger increase in shear strength over lime-forage ash mixture.

Table 4: Summary of CBR test results

Sample	Percentage stabilization	Unsoaked CBR (%)	Soaked CBR (%)
A	0%	10.49	7.60
	6% Lime	27.64	6.70
	6%Lime+ 2% forage Ash	32.78	4.26
	6%Lime+ 4% forage Ash	40.76	12.56
	6%Lime+ 6% forage Ash	43.78	14.22
	6%Lime+ 8% forage Ash	50.98	13.56
	6%Lime+ 10% forage Ash	46.76	15.76
	6%Lime+ 12% forage Ash	43.62	12.84
B	0%	12.25	4.25
	4% Lime	15.63	5.84
	4%Lime+ 2%forage Ash	16.53	5.18
	4%Lime+ 4%forage Ash	18.96	4.89
	4%Lime+ 6%forage Ash	12.58	4.42
	4%Lime+ 8%forage Ash	24.60	8.38
	4%Lime+ 10%forage Ash	27.96	7.80
	4%Lime+ 12%forage Ash	4.59	1.57
C	0%	2.46	1.02
	4% lime	12.86	6.86
	4%Lime+2%forage Ash	23.84	6.68
	4%Lime+ 4%forage Ash	26.30	8.39
	4%Lime+ 6%forage Ash	13.38	3.84
	4%Lime+ 8%forage Ash	15.53	5.20
	4%Lime+ 10%forage Ash	13.68	4.46
	4%Lime+ 12%forage Ash	24.60	6.60

Table 5: Variation of shear strength with stabilization mix

Sample	Percentage stabilization	Cohesion, c (kN/m^2)	Internal Friction Angle(φ)	Normal Stress (σ_1- σ_2) (kN/m^2)	Shear Stress $\tau = c + (\sigma_1 - \sigma_2) \tan\varphi$ (kN/m^2)
A	0%	60	27	248.21	186.36
	6%Lime	22	36	294.16	235.65
	6%Lime+ 6%Forage Ash	35	26	245.76	154.87
	6%Lime+ 6%Forage Ash	64	36	325.37	309.25
	6%+ 6%Forage Ash	32	37	234.72	208.87
	6%Lime+ 8%Forage Ash	68	30	293.35	237.37
	6%Lime+ 10%Forage Ash	122	14	310	199.29
	6%Lime+ 12%Forage Ash	86	17	283.24	172.59
B	0%	50	18	171.45	105.71
	4% Lime	57	56	145.74	162.61
	4%Lime+ 2% Forage Ash	58	32	273	228.53
	4%Lime+ 2% Forage Ash	28	35	287.56	229.35
	4%Lime+ 6% Forage Ash	65	28	189.73	165.88
	4%Lime+ 8% Forage Ash	113	12	282.29	173
	4%Lime+ 10% Forage Ash	64	36	345.65	311.14
	4%Lime+ 12% Forage Ash	86	17	152.12	132.2
C	0%	29	22	158.99	93.24
	4% Lime	6	72	180.46	248.4
	4%Lime+2% Forage Ash	28	35	287.56	229.35
	4%Lime+ 6% Forage Ash	64	36	287.37	320.13
	4%Lime+4% Forage Ash	53	28	235.05	178
	4%Lime+ 8% Forage Ash	112	18	283.84	151.89
	4%Lime+ 10% Forage Ash	58	32	273	228.53
	4%Lime+ 12% Forage Ash	81	17	186.55	138

IV. CONCLUSION

Based on the fact that lime-forage ash mixture will not improve the quality of lateritic soil samples by increasing the plastic index, but will increase the optimum moisture content and reduce the maximum dry density. Also that lime-forage ash mixture can be used to increase the CBR values of soils to meet the specified requirements for road construction and will increase the shear strength of all soil samples. It can be concluded that forage ash can be used to significantly improve the strength of lateritic soils.

V. LITERATURE REVIEW

Lateritic Soils

Lateritic soils behave more like fine-grained sands, gravels, and soft rocks. The laterite typically has a porous or vesicular appearance. Some particles of laterite tend to crush easily under impact, disintegrating into a soil material that may be plastic. Lateritic soils may be self-hardening when exposed to drying; or if they are not self-hardening, they may contain appreciable amounts of hardened laterite rock or laterite gravel. The engineering properties of a lateritic soil are determined from the particle-size distribution, plasticity and its compaction and compressive strengths. The geotechnical characteristics and field performance of lateritic soils, as well as their reaction to different stabilizing agents may be interpreted in the light of the genesis and pedological factors (parent material, climate, topography, vegetation, period of time in which the weathering processes have operated) and degree of weathering (decomposition, sesquioxide and clay-size content, degree of leaching), position in the topographic site and depth of soil in the profile [6].

Most laterite soils contain a mixture of quartz and concretionary coarse particles, which may vary from very hard to very soft. The strength of these particles has major implications in terms of field and laboratory compaction results and their subsequent performance in road pavements. Weak coarse fractions break down under rolling and traffic loading with a resulting increase in fines of the soil. The degree to which the materials break down is related to the content of iron oxide and the degree of hydration. The higher the iron oxide content and the more the degree of hydration, the harder the concretional particles become. Laterites and lateritic materials occur frequently throughout the tropics and subtropics such as East, West and Central Africa, Indonesia, Brazil [7]. The use of lateritic soils in pavement structure is dependent on their particle-size distribution, the nature and strength of the gravel particles, the degree of compaction of the soils as well as environmental conditions [6]. Well graded lateritic gravels have been found to perform satisfactorily as unbound road foundations. However their tendency to be gap-graded with depleted sand fraction, to contain a variable quantity of fines, and to have coarse particles of variable strength which may break down, limits their usefulness as pavement materials on roads with heavy traffic [7].

Geotechnical Properties of Lateritic Soils

Geotechnical properties of lateritic soils are influenced by the degree of weathering, the amount of sesquioxides and degree of desiccation in the soil, the clay-size content and the clay mineralogy, the mica content, and the position of the soil in the laterite profile. A critical assessment of the above factors may give a basis to predict the behaviour of a given laterite soil in the field. The response of a given lateritic soil to stabilization depends on the grain-size distribution, the clay-size content and the clay mineralogy, the mica and organic content, and the physico-chemical characteristics of the soil regime. Laboratory testing procedures designed for plasticity, grain-size analysis, and compactibility characteristics designed from the experience in temperate regions are inadequate for the tropical lateritic soils and may lead to erroneous conclusions. The standards that have been prescribed for soils in temperate regions should be used cautiously in determining the suitability of tropical lateritic soil for use in road bases.

Soil Stabilization

In some localities deposits of naturally occurring soils will be found which meets the requirements of the engineering purposes for which it has to be used for. More often than not, some soils, however, do not meet these requirements and therefore need to be improved by stabilizing them either mechanically or by adding additives. Soil stabilization, in the broadest sense, is the alteration of any property of a soil to improve its engineering performance [8]. It also comprises any process which increases or maintains the natural strength of the soil. In this sense, it includes compaction, drainage and sowing of grass and planting trees on banks [9].

Stabilization is employed when it is more economical to overcome a deficiency in a readily available material than to bring in one that complies with the requirement specification for the soil. It has been regarded as a last resort for upgrading substandard materials where no economic alternative was available. A continual reference to economy here denotes a careful consideration of all costs that would be incurred by importation of a compliant soil and comparing this to the cost of improving the properties of an unstable but readily available soil. In practice the methods by which soils can be stabilized for highway purpose is either by mechanical stabilization and/or chemical stabilization. If a soil cannot be made stable simply by compaction or consolidation, then additional soil or other aggregate materials may be admixed to produce a mixture having the required stability characteristics. The use of additives such as chlorides, cement, calcium lignosulphonate (lignin), bituminous material, lime and molasses is usually associated with this process.

Lime Stabilization

Lime stabilization is a widely used means of chemically transforming unstable soils into structurally sound construction foundations. Lime stabilization is particularly important in road construction for modifying subgrade soils, sub-base materials, and base materials. The improved engineering characteristics of lime-treated materials provide important benefits to both Portland cement concrete (rigid) and asphalt (flexible) pavements. Lime stabilization creates a number of important engineering properties in soils, including improved strength; improved resistance to fracture, fatigue, and permanent deformation; improved resilient properties; reduced swelling; and resistance to the damaging effects of moisture. The most substantial improvements in these properties are seen in moderately to highly plastic soils, such as heavy clays. Although lime is generally used to transform fine-grained soils permanently, it may be used for shorter-term soil modification—for example, to provide a working platform at a construction site.

Forage Ash

Forage or grasses is the common name for a large family of flowering plants that is economically and ecologically the most important in the world [10]. The grass family contains about 635 genera and 9,000 species, making it the fourth-largest family after the legume, orchid, and daisy families. Grasses are the primary source of food for wild grazing animals and domestic stock, which feed on pastures and grasslands, and which are fed hay and silage harvested from them. The total land area devoted to these kinds of crops is greater than the land area for all other kinds of crops combined, hence forage is readily available. As the seasons changes and the weather becomes dry, forage tend to loose their moisture and dry up during dry seasons, hence becoming useless for grazing animals. Forage crops mainly consist of members of the Fabaceae (Leguminosae) and Poaceae (Gramineae). Cumulatively, their value is comparable to that of non-forage cultivated plants. Nutritionally, young grass may be up to 20% protein, usually about 10%. For most parts of the world, production figures are difficult to obtain as forage crops are usually grown and consumed on the same farm. Only recently have people started to systematically fertilize, breed, make hybrid forages etc. Frequently grasses and legumes are sown together. Forage crops may be used directly, made into hay or into silage. Hay is produced by reducing the moisture content of fresh plant material down to 15% water or less. Hay quality is determined by what species are involved, the amount of leaf material in comparison to stem material, the time the forage was harvested, and the amount of weathering and handling the material has undergone. Most of the cultivated forage crops are from Europe or Asia [11].

The total mineral content of forage is known as Ash. Ash content of a forage or total mixed ration (TMR) is easy and economical to measure in a forage testing laboratory. In a general, ash content of forage or TMR is determined by a process similar to cremation. The forage or TMR is burned at 500°C for 2 hours and the residual minerals, often called inorganic material, are determined. The laboratory procedure is extremely accurate and precise but it is important to understand that the procedure measures the simple sum of all minerals in the feed. Forage ash is gotten from burnt dry grass and is considered as a valueless material. No significant use of forage ash as a stabilization agent has been recorded. Since grass is readily available everywhere, it will be very easy to get forage ash from already dried up grass that is cut from the environment As earlier stated, the use of forage ash (burnt dry grass) which usually ends up as environmental wastes, in further treatment of lime stabilized lateritic soil may be a fundamental step in finding new methods that are capable of tackling lateritic soils characteristic deficiencies.

ACKNOWLEDGEMENT

The authors wish to acknowledge the members of staff in the Department of Civil Engineering, Federal University, Oye-Ekiti, Nigeria and Obafemi Awolowo University Ile-Ife, Nigeria for their various contributions to this research work.

REFERENCES

[1] O'Flaherty C.A. (1974). Highway Engineering, London, Butler and Tanner Ltd.

[2] Braja M.D. (2000). Fundamentals of Geotechnical Engineering, USA, Thompson Learning.

[3] Whitlow R. (1995). Basic Soil Mechanics, 3rd ed, Edinburgh Gate, Addison Wesley Longman Limited.

[4] Basha R.H. and Muntohar A.S. (2002). Effect of the cement-rice husk ash on the plasticity and compaction of soil, Journal of Geotechnical Engineering, 2(4), p. 45-48.

[5] Das B. (1990). Soil Mechanics, 3rd ed, California: Brooks/Cole publishers.

[6] Gidigasu M.D. (1976). Laterite Soil Engineering: Pathogenesis and Engineering Principles, New York, Elsevier Scientific Publishing Company.

[7] Thagesen B. (1996). Highway and Traffic Engineering in Developing Countries, London, Glasgow, New York, Melbourne, Madras, E & FN Spon.

[8] Lambe T.W. (1962). The engineering behaviour of compacted clay, American Society of Civil Engineers (ASCE), Paper 66, 23.

[9] Capper P.L. and Cassie W.F. (1969). The Mechanics of Engineering Soils, 5th ed, London, E. & F. SPON Publishers.

[10] Microsoft Encarta. (2007). Soil, Microsoft Premium Office Suite.

[11] Seigler S.D. (2005). Integrative Biology, University of Illinois, Department of Plant Biology.