[Mansoura Engineering Journal](https://mej.researchcommons.org/home)

Volume 37 | Issue 1 Article 6

10-19-2020

A Comparative Analysis of the Use of Limestone Dust and Hydrated Lime in Stabilizing Bad Clayey Soil to be used for Road Embankments.

Islam Abo Elnaga
Assistant Professor., Civil Engineering Department., Higher Institute of Engineering and Technology., Kafr El-Sheikh Kafr El-Sheikh., Egypt.

A COMPARATIVE ANALYSIS OF THE USE OF LIMESTONE DUST AND HYDRATED LIME IN STABILIZING BAD CLAYEY SOIL TO BE USED FOR ROAD EMBANKMENTS

استخدام الجير الحي والجير المطفأ في تثبيت وتحسين خواص التربة الطينية رديئة الخواص لاستعمالها في إنشاء جسور الطرق

BY

ISLAM M. ABO ELNAGA
Assistant Professor
Civil Engineering Department
Higher Institute of Engineering and Technology- Kafr El-Sheikh
Kafr El-Sheikh, EGYPT

الملخص العربي

يعتبر الجير من أكثر ا' واد استخداما في تحسين خواص التربة الطينية الضعيفة لقدرته الفائقة في تقليل خواص اللدونة والمحتوى المائي وزيادة القدرة التشغيلية للتربة الطينية قبل إجراء عملية دمك الجسور الترابية لزوم إنشاء الطرق. وفي هذا البحث تم إستخدام نوعين من الجير وهما الحجر الحي والجير المطفأ في تحسين التربة الطينية الغير عضوية المستخدمة في إنشاء جسور الطرق. حيث أشارت النتائج أن كلا من نوعي الجير المستخدم لهما الأثر الكبير في تحسين خواص اللدونة والتدرج الحبيبي ومقاومة التحمل مما أدى إلي أن التربة السيئة أصبحت جيدة نسبيا ويمكن استخدامها في أعمال الطرق.

ABSTRACT

Lime is used in soil-stabilization as a rapid and economic method for improving the strength and the characteristics of clayey soil which used as highways subgrade. Lime is one of the most powerful stabilizing materials which when added to a clayed soil serves to decrease plasticity, reduce water content and increase soil workability of wet clay prior to compaction. Two types of lime, limestone dust and hydrated lime are used to improve the properties of the high compressible clayey soil, type A-7-6, which represents the most bad inorganic soil in the AASHTO soil classification system. Results show that both types of lime helps in great improvement of soil properties as plasticity, grain size, CBR value (California Bearing Ratio) and unconfined compressive strength. Moreover, hydrated lime gives slightly better results than limestone dust but it is more expensive. So, this study encourages the use of limestone dust.

KEYWORDS

Stabilization, Clayey soil, Highways subgrade, Limestone dust, Hydrated lime, Plasticity, and Grain size.

Accepted January 9, 2012

I. INTRODUCTION

The quality and life of a pavement is greatly affected by the type of subgrade, sub-base and base course materials. The most important of these are the type and quality of subgrade soil. In order to increase the life and the quality of the pavement, improving the strength and the characteristics of highways subgrade soil should be occurred by using of soil-stabilization. Soil-stabilization is carried out by physically mixing additives with the surface layers or borrow materials. Additives include natural soils, industrial by-products or waste materials, cementations and other chemicals, which react with each and/or the ground [14]. Soil-stabilization is simply, a treatment of soil whereby it is made stable such as strength, stiffness, compressibility, permeability, workability, swelling potential and sensitivity to change in moisture content. The treatment ranges from simple compaction to elegant and expensive techniques for grouting or thermal means.

Since in flexible pavement, the bituminous concrete and its under courses cannot rely on the bending resistance of a slab for load transport, but they must distribute load downward through the pavement to the subgrade soil [2]. Additional strength in the subgrade soil can lead to a prolonged pavement life [12]. Stabilization works are being for the improvement of sub-base and base materials in order to reduce the required overall pavement thickness [7]. For rigid pavement, stabilization controls pimping, frost action, drainage and ameliorates the effects of volume changes in unusable subgrade soil. Although base course aggregate may be benefited with stabilizing agents, subgrade soil at the construction site can seldom be sufficiently improved to serve as base course.

Lime is one of the most powerful stabilizing materials which when added to a clayed soil serves to decrease plasticity, reduce water content and increase soil workability of wet clay prior to compaction.

The aim of this study is centered on the improvement of the properties of soil type A-7-6, according to the AASHTO soil classification system, using both limestone dust and hydrated lime to act as a good subgrade soil for all highway subgrades. Soil A-7-6 is chosen since it represents the worst soil in the classification table having very poor properties and covers large area of Egypt. Moreover, natural limestone dust is available in large quantities in Egypt.

Samples of soils have been taken from different parts and those of type A-7-6 were considered. Some samples have been mixed with limestone dust and others with hydrated lime in different percentages ranging from 1% to 11% by weight. Tests were performed on each sample to determine Atterberg limits, maximum dry density, optimum moisture content, sieve analysis, California Bearing Ratio (CBR) and unconfined compressive strength. Comparisons were held and a set of conclusions and recommendations are listed to enable engineers in design and supervising highway construction to reach as safe, convenient and economic construction.

II. LIME STABILIZATION MATERIALS AND ACTIONS

The addition of lime to a moist clayey soil has three primary effects: (1) hydration-the reaction with water in soil. This drying action is particularly important in treatment of moist clay then, enhance the consolidation effect; (2) flocculation-the rearrangement of the structural components of the clay minerals through a cation exchanges process then, reduce the clay's plasticity. This makes the clay more easily workable and increasing its strength; and (3) cementation-a soil-lime pozzolanic reaction which forms various cementing agents [13]. The first and second mechanisms cause immediate improvements in soil plasticity, workability, strength and load-deformation properties. The third is a prolonged effect that depends on the reactivity of the soil in term of the amount of available silica with time, cementation tends to be the largest contributor to the strength of a lime-modified soil. Field demonstrations [8 & 11] indicate that the improved soil properties are maintained over as many as 20 to 40 years.

Lime is often as an all inclusive term, including lime-stone dust, calcium carbonate, hydrated lime, calcium hydroxide and quicklime. However, in lime stabilization work, lime is usually taken to mean as calcium hydroxide. Quicklime, obtained by heating limestone to about 1800° F, is a very effective stabilization agent. It can also be used as a powerful dehydrating agent for wet soils but is very dangerous. Calcium hydroxide is usually formed by adding water to quicklime that produce a drying action and act with the soil as hydrated lime. All types of lime should be pure and fine enough for obtaining good results with plastic soils.

Clay should not be less than 12% in any soil to be stabilized; otherwise artificial pozzolan like fly ash can be added with the lime [6]. Fly-ash, a fine grey dust resulting from burning pulverized coal at electric power plants, is composed of very fine particles of noncrystalline silica and alumina with little amount of carbon. Over 80% of used fly ash should pass sieve No. 325 and carbon content should be less than 10%.

III. USED MATERIALS AND TESTING PROGRAM

Soils sample were taken in a distributed condition from a depth of one meter below the ground surface with shovels and placed in plastic bags were sealed and transported to the laboratory of "The General Authority for Highways and Bridges, Nasr city, Cairo" for testing. The physical properties of the used soil are shown in Table (1). The table shows that the soil is A-7-6 according to the AASHTO System while it is (OH & MH) according to the Unified System and E-11 in FAA Classification System. Organic matter is 0.96% and natural water content is averaged 6%. Actually the soil lies at the lowest till of all classification tables with the worst properties of swelling, strength and workability.

Two stabilizing materials, limestone dust and hydrated lime were used to stabilize the soil. The limestone dust was sampled naturally from El-Mokhattam region (South of Cairo) while the hydrated lime was manufactured by "Cairo Sand Bricks Company, Cairo".

Chemical analysis of the used soil, limestone dust and hydrated lime is shown in Table (2). It is clear that silicon dioxide represents 70% of the soil while calcium oxide and carbon dioxide are 2.17% and 1.5%, respectively. Limestone dust contain^{n} 48.53% calcium oxide, while it is 40.12% in hydrated lime. Carbon dioxide represents 42.8% of the limestone dust and only 17.1% of the hydrated lime. Moreover, silicon dioxide is found in limestone dust and also in hydrated lime with percentage of 0.7% and 16.15%, respectively. Actually, it is clear that the used soil and stabilizing additives contain the same chemical components but with great variations.

Testing program aimed at studying the effect of use of limestone dust and hydrated lime on the physical, chemical, mechanical and structural properties of the clayey soil A-7-6. Two methods of testing were developed. The first is "The One Application Method", *where the whole amount of lime is added at one stage and then thoroughly mixed until uniform mixture is obtained.* Tests then are performed after 4 hours curing time. This was implemented to investigate the effect of short time curing times which always needed in temporary road repair and smoothing or in forest roads and accesses. The second is the "Double Application Method" *where half of the lime is added to the soil to allow most of the chemical reactions to take place and to make the soil more friable and easily pulverized with 48 hours curing time, and then the other half is added and thoroughly mixed.* This is the normal case in road construction where good subgrade is required. Both methods are applied for each type of lime with percentage of 1%, 3%, 5%, 7%, 9% and 11% for the two methods of application. The following tests were performed [1]:

• Atterberg limits according to the AASHTO test T89 and T90;
• Standard AASHTO compaction test to determine the maximum dry density and optimum moisture content according to the AASHTO test T99;
• California Bearing Ratio (CBR) test according to the AASHTO test T193 before and after soaking; and
• The unconfined compressive strength test after 7 days curing time according to the AASHTO test T208.

IV. ANALYSIS AND DISCUSSION OF RESULTS

1. Plasticity Properties

Summary of test results are given in Table (3), Figure (1) and Figure (2). It can be seen that for 4-hours curing time an amount equals 11% of either limestone dust or hydrated lime is required to increase plastic limit, reduce both the liquid limit and plasticity index and modify grain size distribution to those of the A-4 soil. While for the case of 48-hours curing time, only 7% of any type of lime may produce the same effect. Increasing of the curing time requires the fewer amounts of stabilizing additives.

2. Maximum Dry Density and the Optimum Moisture Content

The effect of both limestone dust and hydrated lime on the maximum dry density and optimum moisture content of the stabilized soil A-7-6 with different percentages of additives are shown in Figure (3) and Figure (4). Results shown in these Figures indicate the following:

(1) The Effect of Limestone Dust

The addition of greater amounts of additive for both 4-hours and 48-hours curing time decreased slowly the dry density. It has been decreased by 3% by adding 5% additive after 4-hours curing time and by 3.63% after 48-hours. By adding 11% additive the maximum dry density decreased by 3.51% after 4-hours curing time and by 4.07 % after 48-hours, as shown in Figure (3). The above results mean that the maximum dry density is decreased by increasing curing time and adding greater amounts of limestone dust. The rate of decrease becomes slow after a percentage of 7%. This decrease may be due to the fact that the addition of limestone dust to the A-7-6 soil makes it more granular due to particle accumulation and is lowered by increasing curing time due to lime chemical reactions.

Optimum moisture content of the soil has been increased by increase the additives up to 7% after 4-hours curing time. It is found that the optimum moisture content starts to decrease by increase the additives. For 48-hours curing time, the optimum moisture content increased absolutely by increasing additive percentage, as shown in Figure (4).

(2) The Effect of Hydrated Lime

The addition of hydrated lime to the A-7-6 soil decreased the maximum dry density for any additive percentage or any period of curing. It has been decreased by 4.89% by adding 11% additive after 4-hours curing. On the other hand, it has been decreased by 6.02% after it was cured for 48-hours, as shown in Figure (3). Optimum moisture content showed the same trend as in case of limestone additive at 4-hours curing time with greater values of decrease while the decrease is almost the same when 48-hours curing times for complete activation after application, as shown in F`ɜure (4).

3. California Bearing Ratio (CBR)

The California Bearing Ratio is one of the most convenient and widely methods used to evaluate soil strength. A summary of obtained CBR values for different samples is shown in Figure (5) and Figure (6). It can be seen that, the CBR value has been increased by 133.39% when 7% of limestone was added before soaking for 4-hours curing time and by 95.86% after soaking, as shown in Figure (5). When curing time was increased to 48-hours values became 143.3% and 121.28%, respectively. In the case of using hydrated lime as an additive, CBR value has been increased by 173.21% when 7% was added before soaking, as shown in Figure (6). When curing time increases to 48-hours the values of CBR became 193.39% and 169.91%, respectively. From the above values it is clear that the CBR value is increased by increasing curing time and/or amount of additive, whether it is a limestone dust or hydrated lime.

4. The Unconfined Compressive Strength

Since A-7-6 soil was transformed to A-4 soil when a percentage of 7% of limestone dust or hydrated lime was added, so the unconfined compressive strength was carried out on sample contains 7% of additive and after 7 days curing time according to the AASHTO test T208. The unconfined compressive strength was 2.89 kg/cm^2 when no additive was used and after adding 7% limestone dust it reached 5.99 kg/cm^2. Compressive strength has been increased by more than double value (6.15 kg/cm^2) when hydrated lime was added as an additive. Generally, hydrated lime give a slightly greater results for strength than using limestone dust.

V. THE TECHNIQUE OF LIME STABILIZATION

From the above results and analyses, it seems that when lime is added to a clayey soil, an early soil modification stage, (after approximately 4-hours) where particle flocculation agglomeration and granulation occurs. This produces a reduction in plasticity, swelling potential and remarkable increase in workability. Even grain size distribution appears to be substantially altered where the soil becomes granular. Upon compaction, an increase in optimum moisture content and a decrease in dry density are usually noticed. Since sufficient lime dissolves in water a high alkaline environment forming small quantities of cementing products, but particles and flocks are not held together sufficiently well to produce the adequate cementation. Long curing periods and soil compaction allow the slow, continuing chemical reactions producing highly cementous compound to that happening in Portland cement concrete. Moreover, in situ formation of calcium carbonate in compaction clay may play a role in the cementing process which means that the organic matter will affect badly the stabilization achieved.

VI. CONCLUSIONS AND RECOMMENDATIONS

The most remarked conclusion is that lime stabilization surpasses its traditional highway utilization as a construction expedience to improve the workability of clayey subgrades. Lime improves the pavement and significantly reduces its cost by increasing the strength of subgrades. Based on the laboratory testing results, the following conclusions could be drawn:

1. Adding either limestone dust or hydrated lime to the clayey soil A-7-6 results in tremendous improvements in soil properties. These properties include plasticity, strength and workability, which means a prolonged lifetimes and better performance for the subgrade and roadway in general. Adding a percentage of 7% of limestone dust or hydrated lime, improves the A-7-6 soil properties. The improved properties are similar to those of the soil A-4 according to the AASTO classification system.

2. The use of hydrated lime as a stabilization material gives slightly better results than the limestone dust in the finished mixture. However, this improvement may be insignificant due to the lower cost and availability of limestone. The use of any of the two studied stabilizers depends on the cost-benefit analysis at each individual case.

3. Many of the deterioration problems experienced on many roads (especially those along canal banks) can be avoided by improving subgrade properties using limestone dust.

4. A saving in thickness of pavement layers may be achieved by strengthening the subgrade (increase CBR) using lime stabilization.

VIII. REFERENCES

[1] American Association of State Highway and Transportation Officials, in: Standard Specifications for Transportation Materials and Methods of Sampling and Testing, Washington D. C., USA, (1993).

[2] S. Fahmy, in: Stabilization of Silty Clayey Subgrade Soil with Lime Fly-Ash, M.Sc, Thesis, Cairo University, Egypt, (1979).

[3] M. G. Spangler, and R. L. Hardy, in: Soil Engineering, Harper and Row Publishers, p.p. 686-711, New York, USA, (1982).

[4] D. N. Little, in: Evaluation of Structural Properties of Lime Stabilized Soils and Aggregates, Volume 1: Summary of Findings, Report prepared for National Lime Association, (1999).

[5] P. Evans, in: Lime Stabilization of Black Clay Soils in Queensland, Australia, In Proceedings, National Lime Association Convention, San Diego, California, (1998).

[6] R. D. Kerbs, and R. D. Walker, in: Highways Materials, McGraw-Hill Book company, New York, U.S.A, (1971).

[7] D. N. Little, T. Scullion, P. V. Kota, and J. Bhuiyan, in: Guidelines for Mixture Design and Thickness Design for Stabilized Bases and Subgrades, Report 1287-3F, Texas Transportation Institute, (1995).

[8] S. J. Biczysko, in: Long-Term Performance of Lime Stabilized Road Subgrade, In Lime Stabilization, p.p. 62-71, Thomas Telford Publisher, London, (1996).

[9] C. D. F. Rogers, S. Glendinning and T. E. J. Roff, in: Lime Modification of Clay Soil for Construction Expediency, Geotechnical Engineering, Proceedings of the Institution of Civil Engineers, U. K., Volume 125, No. 4, p. p. 242-249. (1997).

[10] N. C. Consoli, and J. P. Mantardo in: Engineering Behavior of a Sand Reinforced with Plastic Waste, Geotechnical and Geoenvironmental Engineering, ASCE, Volume 128, p.p. 462-472, (2002).

[11] Y. H. Huang, in: Pavement Analysis and Design, 2nd Edition, Pearson Education, Inc., (2004).

[12] J. Mallela, H. Von Quintus, and K. P.Smith in: Construction of Lime Stabilized Layers in Mechanistic-Empirical Pavement Design, The National Lime Association, Virginia, U.S.A., (2004).

[13] The National Lime Association in: Lime-Treated Soil Construction Manual – Lime Stabilization and Lime Modifications, Bulletin, (2004).

[14] B. B. K. Huta, A. Alias, and A. Abdul Aziz, in: Evaluation Selection and Assessment of Guidelines for Chemical Stabilization of Tropical Residual Soils, American J. of Environmental Sciences, Volume 4, No. 4, p.p. 303-309, (2008).

Table (1): Physical Properties of the Subgrade Clayey-Soil

Test type	**Properties**
Atterberge Limits:	
Liquid Limit %,	55
Plastic Limit %,	25
Plasticity Index %,	30
Natural Water Content %.	6
Chemical Properties:	
P^H,	7.85
Organic Matter %.	0.96
Classification:	
AASHTO,	A-7-6
Unified,	OH and MH
FAA.	E-11
Compaction Properties:	
Maximum Dry Density, t/m^3,	1.48
Optimum Moisture Content %.	19
Specific Gravity	2.198

Table (2): Results of the Chemical Analysis of the Subgrade Clayey-Soil, Limestone Dust and Hydrated Lime.

Mineral Name	Chemical Symbol	Oxide Percentage %		
		Subgrade Soil	Limestone Dust	Hydrated Lime
Silicon Dioxide	SiO_2	69.99	0.70	16.15
Aluminum	Al_2O_3	10.52	0.68	8.75
Ferric Oxide	Fe_2O_3	3.47	0.08	0.31
Titanic Oxide	TiO_2	0.59	0.01	0.15
Calcium Oxide	CaO	2.17	48.53	40.12
Magnesium Oxide	MgO	3.79	2.59	4.00
Sodium Oxide	Na_2O	1.51	0.16	2.12
Potassium Oxide	K_2O	2.30	0.02	0.42
Sulphate Oxide	SO_3	0.03	0.06	1.88
Carbon Dioxide	CO_2	1.50	42.8	17.10
Others	L.O.I	4.13	4.17	9.00

Table (3): Atterberg Limits for the (Clayey Soil A-7-6 – Limestone Dust) Mixture and (Clayey Soil A-7-6 – Hydrated Lime) Mixture

Mixture	Clayey Soil (A-7-6) – Limestone Dust				Clayey Soil (A-7-6) – Hydrated Lime			
Curing Time	4-hrs		48-hrs		4-hrs		48-hrs	
% of Additives	7	11	7	11	7	11	7	11
Liquid Limit %	43	40	40	39	45	40	40	38
Plastic Limit %	34	33	33	35	34	35	34	36
Plasticity Index %	9	7	7	4	11	5	6	2
Classification	A-5	A-4	A-4	A-4	A-7-6	A-4	A-4	A-4

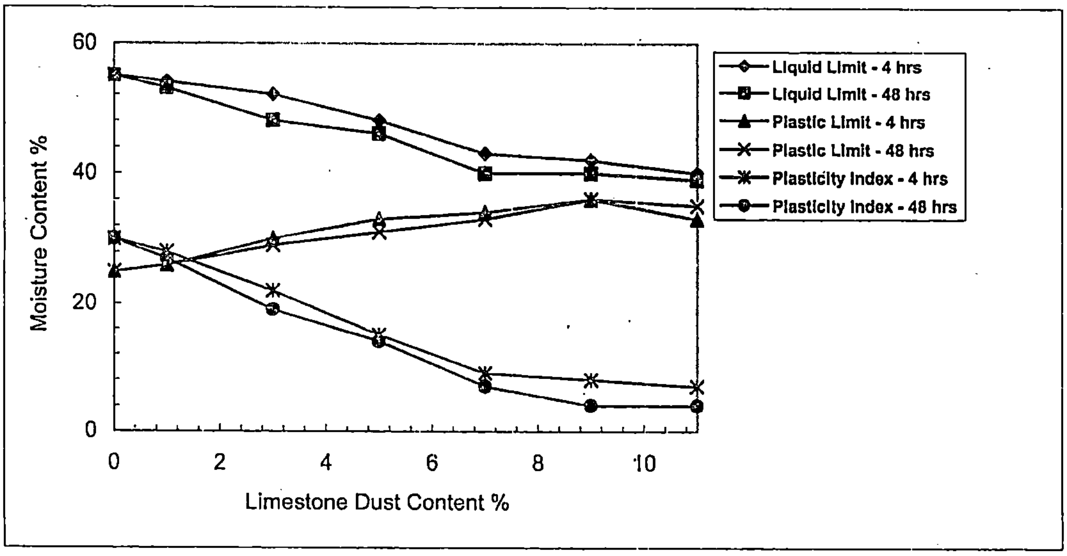

Figure 1: The effect of limeston dust on Atterberge Limits for curing times of 4 and 48 hours

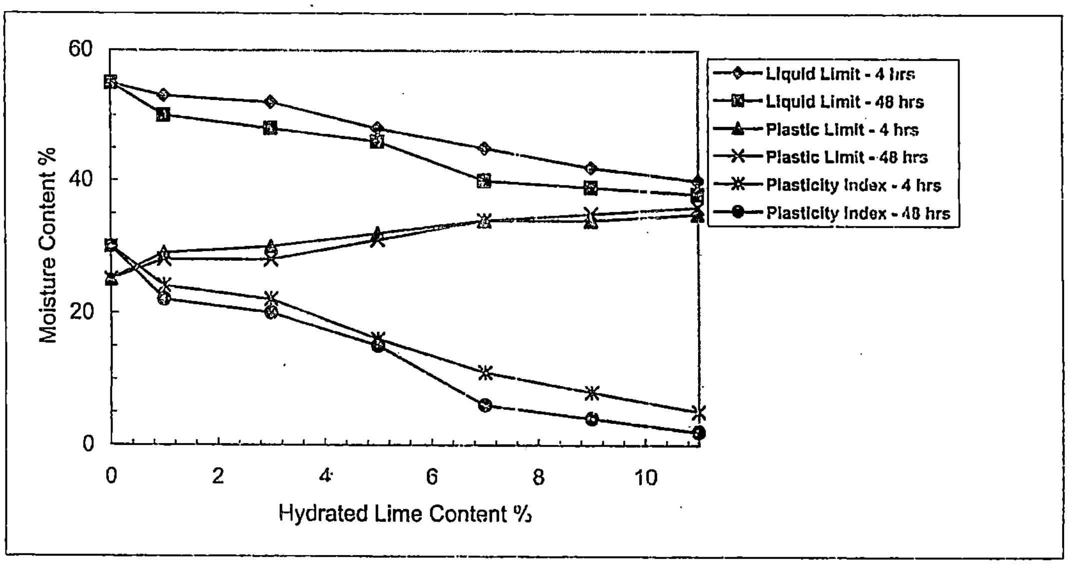

Figure 2: The effect of hydrated lime on Atterberge Limits for curing times of 4 and 48 hours

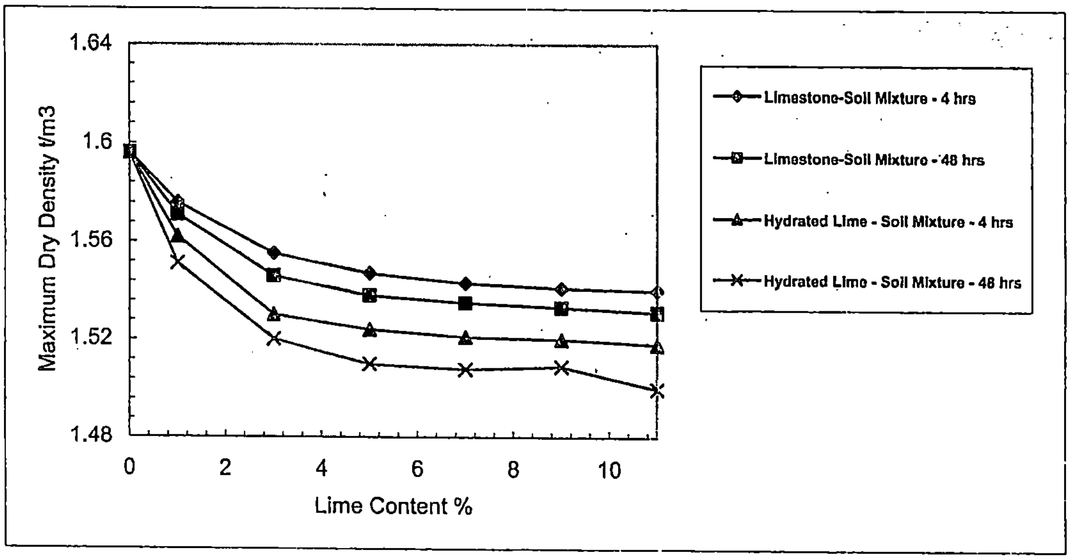

Figure 3: The effect of limestone dust and hydrated lime on Maximum Dry Densty for curing times of 4 and 48 hours

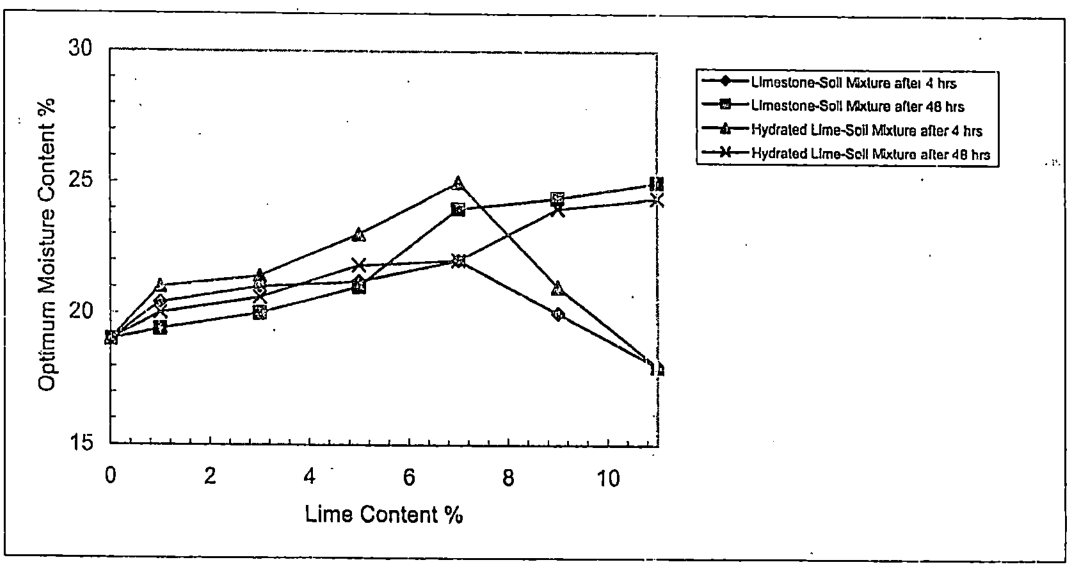

Figure4: The effect of limestone dust and hydrated lime on Optimum Moisture Content for curing times of 4 and 48 hours

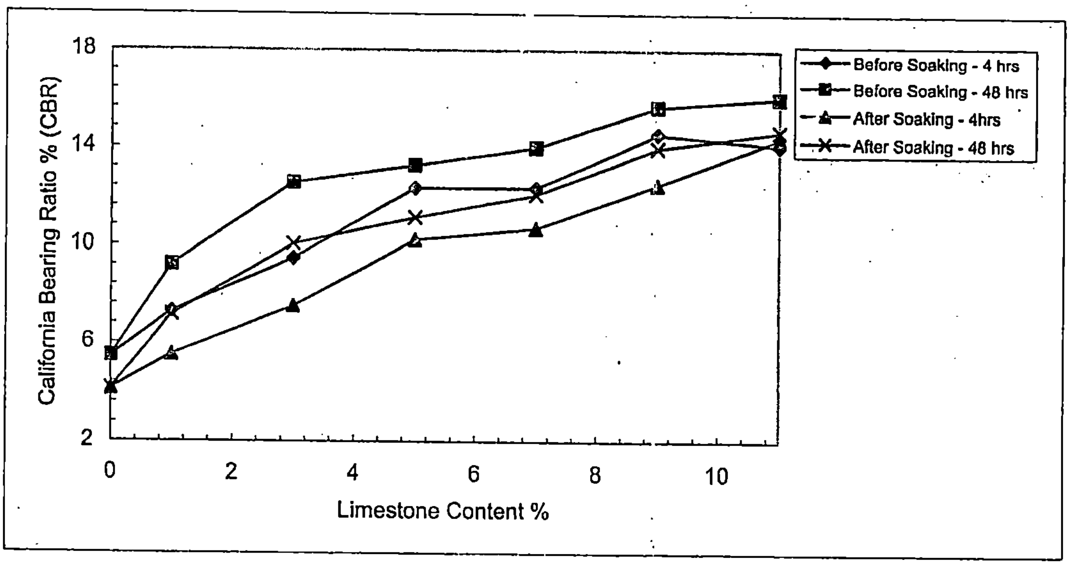

Figure 5: The effect of limestone dust on California Bearing Ratio (CBR)

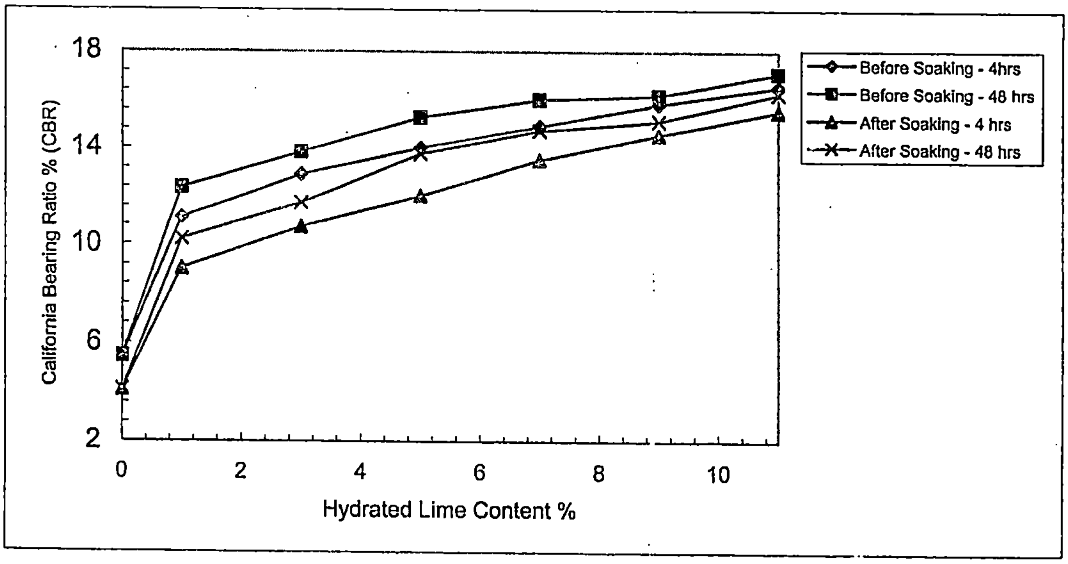

Figure 6: The effect of hydrated lime on California Bearing Ratio (CBR)