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# Amorphous Materials and Lime Stabilized Soils

## Matériaux Amorphes et Sols Stabilisés à la Chaux

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**SYNOPSIS** Lime stabilization of soils has become a standard practice in Civil Engineering. Although results have been satisfactory, little is known about the significance of the soil characteristics to the stabilization process. The purpose of this study was to investigate the influence of the amorphous components (silicon, aluminium and iron) on the stabilization of soils here evaluated by unconfined compressive strength, as well as the influence of certain compositional characteristics of the soils on stabilization.

### INTRODUCTION

From a civil engineering point of view, stabilization is generally carried out to improve the workability, reduce the plasticity, and increase the strength of a soil. The lime-soil reactions which cause these changes are generally accepted as being due to the reaction of the calcium ions from the lime, with the silicon (Si) or aluminium (Al), or both, and perhaps the iron (Fe), present in the soil to form calcium compounds, (Queiroz de Carvalho and Cabrera, 1979).

A search through literature revealed that few attempts have been made to investigate the soil properties responsible for the change in the selected characteristics of the soil due to the addition of lime. Furthermore, these attempts considered the soil properties, i.e., total<sup>1</sup> (Si), (Al) and (Fe) present in the soil and no distinction was made in regard to the presence of amorphous components (Si, Al and perhaps Fe) which are known to be highly reactive with lime.

This study investigates the significance of certain compositional characteristics of red tropical soil, in particular, the amorphous components, relative to the soils when stabilized with lime.

### EXPERIMENTAL WORK

#### Soils Tested

Nineteen red tropical soils, also known as lateritic soils, from the states of Paraíba and Pernambuco in Northeast Brazil were selected and used throughout this investigation. The sites' characteristics are fully described by Queiroz de Carvalho (1979).

<sup>1</sup> Total (Si), (Al) and (Fe) refers to the crystalline plus the amorphous contents.

### Methods of Testing

Unconfined compressive strength values of the soils in the natural state and after treatment with 1.5%, 3.0%, 4.5% and 6.0% hydrated calcitic lime were obtained on triplicate cylindrical samples, 5 cm in diameter by 5 cm in height, statically compacted using an energy equivalent to the modified Proctor. The apparatus used was similar to that used in the Iowa State Compaction Apparatus test. When applicable, the samples were cured in a curing room for 28 days at a temperature of  $22 \pm 2^\circ\text{C}$ . Selected engineering properties were determined using the British Standard BS 1377, 1975.

The amorphous components (Si and Al) were determined using the 0.5N NaOH boiling method developed by Hashimoto and Jackson (1960), whilst the determination of Fe was made using the dithionite-citrate cumulative dissolution technique (Queiroz de Carvalho, 1979).

The chemical composition in terms of total elements, was determined by X-ray fluorescence. The statistical analyses were performed by simple linear regression analysis and multiple linear regression analysis using a computer programme called Statistical Package for the Social Sciences (SPSS Version 5.0).

### TEST RESULTS AND DISCUSSION

Extensive statistical analyses were carried out in order to find all possible relationships between the soil properties (Table I and Table II) and the effect of lime on the soils here evaluated by the change in unconfined compressive strength (UCS), i.e., the lime reactivity (LR) parameter (Thompson, 1966). The results obtained from the simple linear regression analysis showed that the correlation coefficients (R) / level of significance (S) between LR and clay size content, liquid limit, plastic limit, relative density, were 0.43/0.06, 0.30/0.30, -0.14/0.64, -0.04/0.87 with degrees

## Compaction and Strength Characteristics

| Soil Symbol | Relative Density | Liquid Limit % | Plastic Limit % | Sand/Silt/Clay % | Natural Soil               |                    |          | Lime Treated Soil          |                    |          | Lime Reactivity kPa |
|-------------|------------------|----------------|-----------------|------------------|----------------------------|--------------------|----------|----------------------------|--------------------|----------|---------------------|
|             |                  |                |                 |                  | γd(max.) kN/m <sup>3</sup> | w, % for γd (max.) | UCS, kPa | γd(max.) kN/m <sup>3</sup> | w, % for γd (max.) | UCS, kPa |                     |
| JPA         | 2.99             | Non-Plastic    |                 | 79/14/7          | 18.74                      | 10.35              | 290      | 18.64                      | 10.50              | 1210     | 920                 |
| JPM         | 3.10             | 33.8           | 20.4            | 60/12/28         | 19.89                      | 13.20              | 1800     | 19.06                      | 16.50              | 5390     | 3590                |
| JPB         | 3.04             | Non-Plastic    |                 | 81/10/9          | 18.25                      | 7.70               | 100      | 18.43                      | 10.10              | 510      | 410                 |
| CT          | 2.94             | 22.9           | 17.1            | 68/20/12         | 19.44                      | 13.85              | 410      | 18.67                      | 15.35              | 1140     | 730                 |
| AI          | 2.95             | 35.3           | 24.9            | 50/20/30         | 18.03                      | 17.35              | 1550     | 17.77                      | 18.55              | 2050     | 500                 |
| AII         | 3.09             | 28.0           | 17.6            | 65/18/17         | 19.43                      | 14.20              | 510      | 17.53                      | 17.25              | 1600     | 1090                |
| SIA         | 2.95             | 23.8           | 18.6            | 66/18/16         | 19.41                      | 11.00              | 550      | 18.81                      | 14.70              | 590      | 40                  |
| SIB         | 2.92             | Non-Plastic    |                 | 86/7/7           | 18.36                      | 4.80               | 80       | 19.12                      | 6.75               | 210      | 130                 |
| SII         | 2.72             | 25.7           | 20.9            | 56/20/24         | 19.43                      | 10.25              | 800      | 18.98                      | 11.35              | 2960     | 2160                |
| NF          | 3.05             | 27.1           | 18.2            | 68/19/13         | 20.21                      | 13.30              | 500      | 19.28                      | 15.25              | 990      | 490                 |
| JI          | 2.86             | Non-Plastic    |                 | 58/32/10         | 19.01                      | 10.10              | 520      | 18.51                      | 13.80              | 1140     | 620                 |
| JII         | 3.16             | Non-Plastic    |                 | 76/15/9          | 20.38                      | 12.35              | 200      | 20.06                      | 12.10              | 780      | 580                 |
| TI          | 2.75             | 30.4           | 22.2            | 48/30/22         | 17.98                      | 13.95              | 1260     | 17.47                      | 15.40              | 3220     | 1960                |
| TII         | 2.82             | 32.4           | 24.6            | 41/28/31         | 17.19                      | 16.60              | 1280     | 16.87                      | 16.85              | 1750     | 470                 |
| RC          | 2.81             | 32.9           | 19.0            | 60/10/30         | 18.80                      | 12.80              | 890      | 18.43                      | 14.40              | 2590     | 1700                |
| USM         | 2.69             | 33.8           | 23.2            | 46/20/34         | 17.08                      | 17.30              | 1850     | 16.77                      | 18.40              | 2100     | 250                 |
| SB          | 2.69             | 29.4           | 17.5            | 49/13/38         | 18.79                      | 12.50              | 1920     | 18.15                      | 13.45              | 3910     | 1990                |
| PH          | 2.80             | 26.8           | 22.7            | 64/15/21         | 17.92                      | 14.30              | 1110     | 17.42                      | 16.50              | 840      | 0000                |
| SM          | 2.99             | 34.0           | 25.4            | 58/19/23         | 18.81                      | 15.30              | 940      | 18.29                      | 17.10              | 2490     | 1550                |

γd(max.)/w = Maximum Dry Unit Weight/Corresponding Moisture Content  
 UCS = Unconfined Compressive Strength

Table I - Selected Engineering Properties of Soils Studied

| Soil Symbol  | pH, units | CEC, meq/100g | Organic Matter % | Total / Amorphous Content, % |                                  |                                  |
|--------------|-----------|---------------|------------------|------------------------------|----------------------------------|----------------------------------|
|              |           |               |                  | SiO <sub>2</sub> %           | Al <sub>2</sub> O <sub>3</sub> % | Fe <sub>2</sub> O <sub>3</sub> % |
| JPA          | 5.2       | 8.62          | 0.15             | 36.04/2.81                   | 35.88/3.10                       | 6.23/0.22                        |
| JPM          | 5.3       | 8.94          | 0.07             | 35.32/10.91                  | 30.00/7.97                       | 13.85/0.85                       |
| JPB          | 4.9       | 18.20         | 0.19             | 22.80/6.71                   | 21.84/6.11                       | 36.96/1.06                       |
| CT           | 5.2       | 7.11          | 0.10             | 38.40/7.84                   | 34.20/4.12                       | 9.85/0.31                        |
| AI           | 4.7       | 6.23          | 0.23             | 37.40/8.11                   | 34.16/6.95                       | 9.31/0.21                        |
| AII          | 5.1       | 15.22         | 0.27             | 35.50/9.69                   | 34.06/5.89                       | 8.82/0.62                        |
| SIA          | 4.8       | 22.21         | 0.62             | 36.14/2.08                   | 31.20/3.28                       | 7.98/3.18                        |
| SIB          | 4.7       | 16.10         | 0.07             | 31.98/4.13                   | 20.25/3.97                       | 30.37/0.63                       |
| SII          | 5.1       | 9.90          | 0.11             | 39.82/11.29                  | 34.35/7.56                       | 6.52/0.09                        |
| NF           | 5.4       | 7.31          | 0.57             | 35.06/8.31                   | 30.86/7.02                       | 13.56/0.48                       |
| JI           | 6.1       | 11.39         | 0.10             | 33.56/5.02                   | 28.54/6.11                       | 18.10/0.31                       |
| JII          | 5.0       | 9.11          | 0.17             | 26.64/6.69                   | 20.76/4.07                       | 34.88/0.60                       |
| TI           | 6.1       | 7.31          | 0.27             | 39.14/8.12                   | 32.18/6.98                       | 10.82/0.36                       |
| TII          | 4.7       | 10.11         | 0.33             | 31.38/4.68                   | 27.48/4.02                       | 18.31/0.78                       |
| RC           | 5.1       | 6.71          | 0.06             | 40.70/9.21                   | 34.94/6.16                       | 5.45/0.04                        |
| USM          | 4.6       | 9.39          | 0.30             | 40.28/3.71                   | 34.96/4.41                       | 4.18/0.13                        |
| SB           | 5.1       | 7.10          | 0.06             | 42.02/8.19                   | 35.50/6.84                       | 4.87/0.07                        |
| PH           | 4.6       | 13.94         | 0.39             | 39.92/2.91                   | 30.86/3.80                       | 9.50/2.18                        |
| SM           | 5.1       | 16.30         | 0.15             | 34.04/7.98                   | 30.76/6.48                       | 8.97/1.01                        |
| Corr.Coeff.  | 0.31      | -0.38         | -0.49            | 0.46/0.79                    | 0.43/0.69                        | 0.12/-0.31                       |
| Significance | 0.22      | 0.11          | 0.03             | 0.05/0.0001                  | 0.07/0.0001                      | 0.62/0.19                        |
| Deg.Freedom  | 17        | 17            | 17               | 17/17                        | 17/17                            | 17/17                            |

CEC = Cation Exchange Capacity

Table II - Selected Chemical Properties &amp; Their Relationships With Lime Reactivity

of freedom (DF) equal to 17, 12, 12, 17 respectively. The dry unit weights and moisture contents were correlated at the level of 0.24 and 0.71 for R values of 0.29 and 0.09 respectively. Table II shows the values of R, S and DF for certain chemical properties. As observed from the above examples and Table II, the R values are too low, and the S values are too high to warrant any relationship between LR and those soil properties; nevertheless, highly significant correlations were found between the amorphous components silica and alumina and LR.

The following were the best equations obtained by the simple linear regression analysis using two-tailed test.

$$Y = 736.21 X_1 - 57.53 \quad (1)$$

$$R=0.79 \quad S=0.0001 \quad DF=17$$

$$Y = 880.92 X_2 - 27.85 \quad (2)$$

$$R=0.69 \quad S=0.0001 \quad DF=17$$

Where:  $Y$  = lime reactivity, kPa  
 $X_1, X_2$  = percentages of amorphous silica and alumina

The multiple regression analysis was done by using the stepwise method incorporated in the SPSS-5 computer programme. The first step selected the single soil property which was the best predictor. The subsequent steps brought to the prediction equation, the soil property which made a significant contribution to the equation. By this method and considering the variations of the method and the soil properties, the multiple correlation analysis revealed that the amorphous silica content was by far the most significant soil property to the lime-soil interaction. If the 2nd, 3rd and 4th most significant soil properties were brought to the equation, their contribution was considered insignificant. The following equation expresses the relationship between LR and the four most significant soil properties:

$$Y = 1075.8 X_1 + 132.9 X_2 + 156.3 X_3 + 511.7 X_4 - 2347.6 \quad (3)$$

$$MR=0.89 \quad F_{cal.}=13.99 \quad F_{cri.}=5.04$$

Where:  $Y, X_1$  and  $X_2$  -- previously defined

$X_3$  = % of total alumina in the clay size fraction

$X_4$  = pH, units

$F_{cal.}$  and  $F_{cri.}$  = F statistical, calculated and critical (1% level of significance)

MR = multiple correlation coefficient

If only the amorphous silica content was considered, the MR = 0.79. When the 2nd most significant soil property (% of amorphous alumina) was added, MR = 0.82. Considering the % of amorphous silica and alumina, the best prediction equation found was:

$$Y = 1397.4 X_1 - 945.5 X_2 + 95.4 \quad (4)$$

$$MR=0.82 \quad F_{cal.}=16.46 \quad F_{cri.}=6.23$$

#### Significance of Amorphous Materials to Lime-Soil Reactions

The lime-soil reaction takes place with the calcium ions from the lime reacting with the Si and Al (and perhaps Fe) from the soil to form calcium cementitious compounds. The source of Si and Al is normally the clay mineral present in the soil. The high pH system created by the addition of lime, attacks and dissolves the clay mineral which in turn liberates Si and Al. The dissolution is a function of its degree of crystallinity. The less crystalline the clay mineral, the easier the Si/Al will be available for reaction. If there is amorphous Si and/or Al in the soil, the calcium ions should first react with them as they are highly reactive compared with the Si/Al from the clay mineral. The behaviour of Fe to the lime-soil reaction is not yet fully clear or understood. Although there are differing opinions regarding the significance of Fe to the lime-soil interaction, Nwakanma (1979) showed that the reaction lime-Fe can occur, however, due to the values of volumes of Ca-Fe compound formed and presented by him, it can be concluded that the Ca tends to react first with Si and/or Al.

#### CONCLUSIONS:

The results obtained revealed that there was no relationship between lime reactivity and engineering properties such as clay size content, compaction parameters, relative density, Atterberg limits and chemical elements in terms of total contents.

This study isolated the silica amorphous content and the alumina amorphous content as the most significant soil properties to the lime-soil reaction.

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