Stabilization of difficult soils in developing countries

Stabilisation de sols difficiles dans les pays en voie de développement

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INTRODUCTION: Soil stabilization is the improvement of the physical properties of soil most commonly utilized in highway and road construction. The final aim is improved long term resistance of the soil to mechanical stresses. A research team at the University of Hannover has been investigating the feasibility of stabilization of difficult soils to create economical methods in developing countries. Research has focused on the reactivity of admixtures of lime, cement and fly ash both alone and in combination. The research shows that certain combinations of admixtures increase soil bearing resistance remarkably. Regression analysis is used to evaluate the results. Statistically based empirical equations for predicting undrained vane shear strength are presented. Both soils investigated were soft clayey silt, a sediment found in many coastal regions. The grain-size distrubtion for soil 1 and soil 2 is shown in Fig. 1. The natural water content of such sediments, called "Schlick" lies between 100 % and 230 %. The samples were taken at a depth of about 1 m. The soil characteristics of the untreated soils have been analysed and are shown in Table (1).

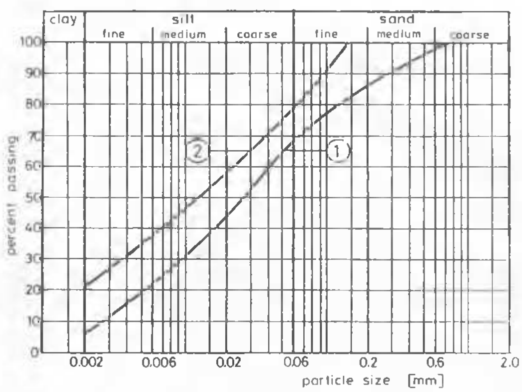

Fig. 1: Grain-size distribution of investigated soft sediment soil 1 and soil 2

Table (1)

Soil Characteristics	Laboratory results Soil 1	Soil 2
Water content (%)	135	140
Unit weight of wet soil γ (kN/m³)	13.5	14.3
Unit weight of dry soil γ_d (kN/m³)	5.8	7.8
Loss on ignition (%)	13	18
Unit weight of solids γ_s (kN/m³)	23.9	24.1
Consistency state	liquid	liquid
Void ratio (e)	2.53	2.71
Activity Index (I_A)	10.6	2.9
Unconfined shear strength		
a-Laboratory vane test (kN/m²)	6.4	2.3
b-Field vane test (kN/m²)	8.7	5.1
Shear strength Parameters		
c-Effective angle of friction φ (°)	25	23
d-Effective cohesion c' (kN/m²)	1.8	1.1

PRETREATMENT OF THE NATURAL SOIL

Due to the wide range of grain-size distribution, the natural soil had to be remolded to improve specimen homogeneity for laboratory tests. After this process, the soil was preconsolidated till the water content decreased to a range between 110 % to 120 %. The admixtures chosen for soil stabilization, cement, lime and fly ash are commonly found, economical materials in most developing countries. Admixtures between 2 % and 10 % were used. Additional laboratory investigations were conducted with the combination cement + fly ash, lime + fly ash.

INFLUENCE OF ADMIXTURES ON THE SOIL CHARECTIRISTICS

Some general conclusions can be stated relating to the effects of admixtures on the water content, the consistency and shear strength properties of the fine-grained sediments. The results indicate the following.

Fig. 2 shows the influence on the liquid limit. The effect depends mainly on the admixture content. It seems that a combination of lime and fly ash is not so significant on the liquid limit compared to a combination of natural soil with pure lime or pure cement.

Fig. 3 shows the influence on the plastic limit. The plastic limit increases very significantly in combination with pure cement or lime, but usually decreases when the pure fly ash admixtures is higher than 6 %. A combination of lime and fly ash seems to have no large influence on the plastic limit.

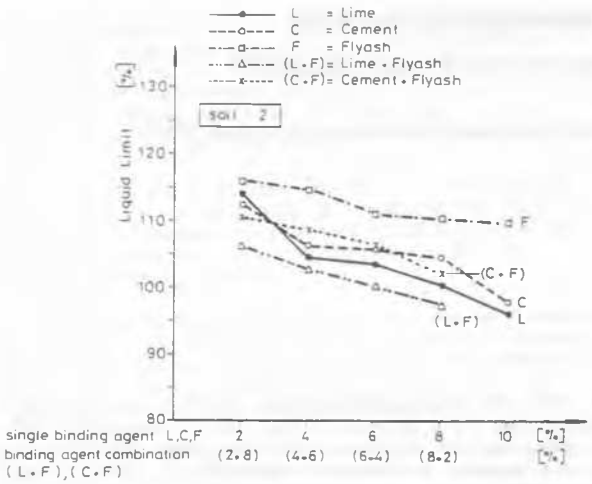

Fig. 2: Influence of different admixtures on the liquid limit

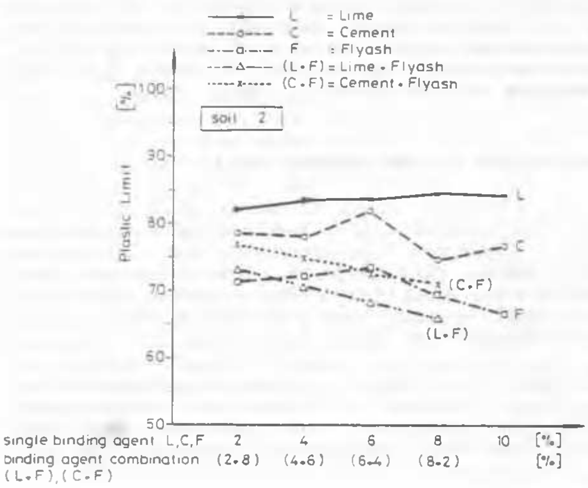

Fig. 3: Influence of different admixtures on the plastic limit

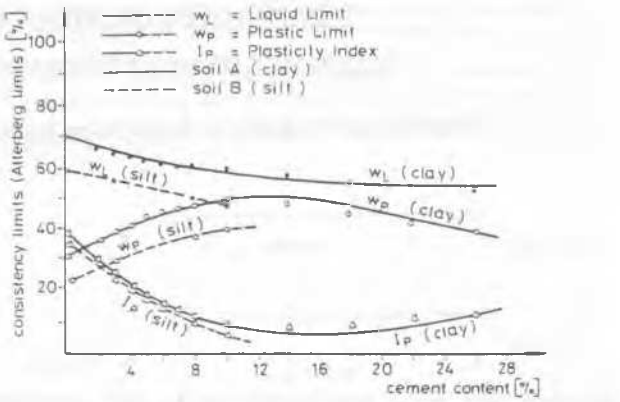

Fig. 4: Effect of cement content on consistency (ATTERBERG) limits (after OSMAN 1983)

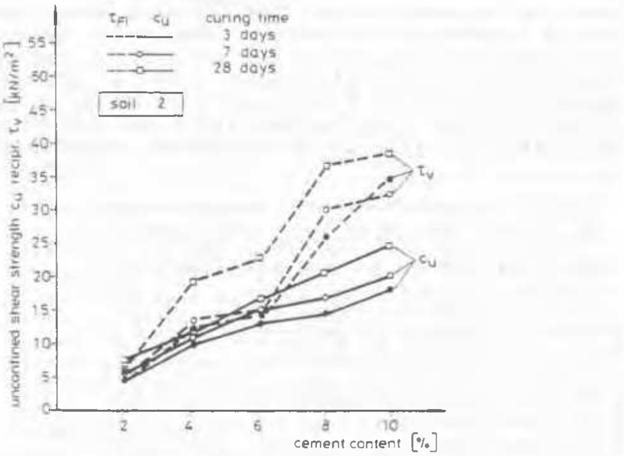

Fig. 5: Effect of cement content and curing time on the unconfined shear strength c_u recipr τ_v

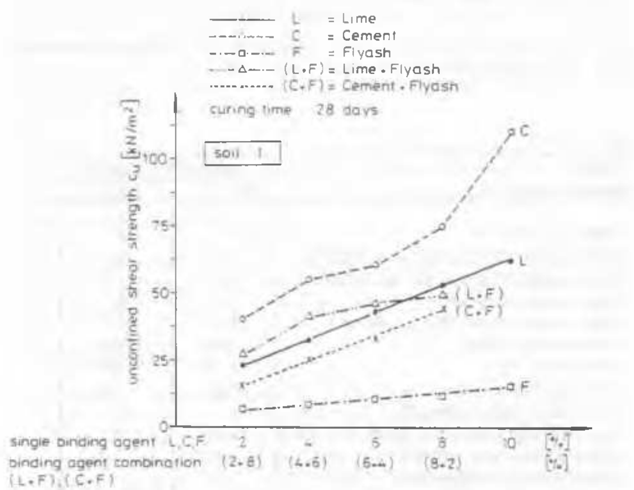

Fig. 6: Effect of the different admixtures on the unconfined shear strength c_u

Fig. 4 shows the influence of pure cement on silts and clays after OSMAN (1983). The effects of the fundamental soil interaction are, to some extent, comparable for clay and silt. For both soils there is a parallel decrease of the consistency when cement content increases.

The unconfined shear strength c_u increases as a function of cement content. In addition curing time causes a large increase in c_u values. These effects are shown in Fig. 5 for soil 2.

For a constant curing time of 28 days (see Fig. 6) the largest increase of c_u-values was observed with pure cement, especially between 6 % and 10 %. Lime as well as cement + fly ash cause a significant increase, but not so high as with pure cement.

Pure fly ash as an admixture appears to be less effective. This was also reperted by KEZDI (1974) and BRAND (1963).

Combining cement or lime with fly ash to form the admixture produces a significant improvement of properties, especially c_u. The puplished investigation results of HIRT (1969) and TSONIS et al. (1983) showed the same effects when cement or lime were added to fly ash (s.Fig. 7).

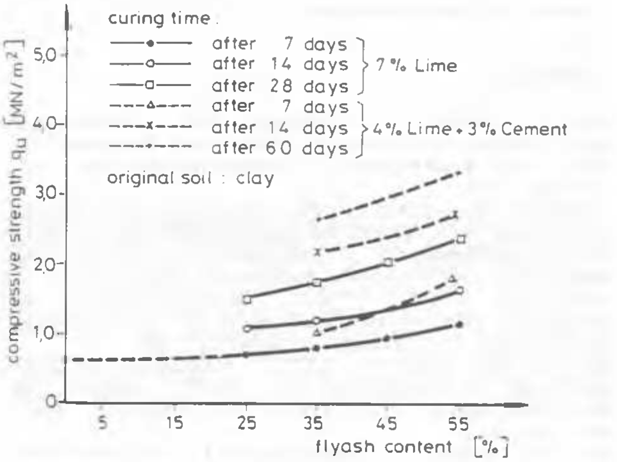

Fig. 7: Influence of ash content on clay-ash-lime or clay-ash-lime-cement admixtures (after TSONIS et al. 1983)

METHODS OF EMPIRICAL ESTIMATION OF SOIL IMPROVEMENT

Common soil stabilzation practice is to conduct several test series both in the field and laboratory in order to estimate the anticipated improvement in soil properties. This appears to be insufficient and for developing countries uneconimical. The improvement in c_u is a key criterion for assessing the relative degree of soil stabilization. As an aid to stabilization work in developing countries a predictive relationship was sought using probabilistic and statistical methods. It has been found that for both soils c_u or τ_v depend on the following parameters:

$$c_u \text{ or } \tau_v = f\,(L, C, F, w_L, w_P, w_S, I_P, \gamma, e, w, S_r, t)$$

The statistical program SPSS was used to maximize the correlation factor, r of the relationship among the parameters. Another aim was to find an estimation formula with limits of confidence interval for a probability of 95 %. This means they show the confidence interval at the 95 % level for soil 2. Both aims could be fullfilled with the following equation:

$$c_u = 1,706\,C + 0,268\,L + 0.194\,F. + 0.136\,w + 0,026\,w_P. + 0,073\,t + 13,466$$

where:

c_u = unconfined shear strength (kN/m²)
C = cement content (%)
L = lime " (%)
F = fly ash " (%)
w = water " (%)
t = curing time (days)
w_P = plastic limit (%)

By using this equation to estimate or to predict the c_u-values a correlation of r^2 = 0,96 has been reached.

Fig. 8 shows a comparison between "estimated" c_u-values with the above mentioned equation and those "measured" in laboratory tests.

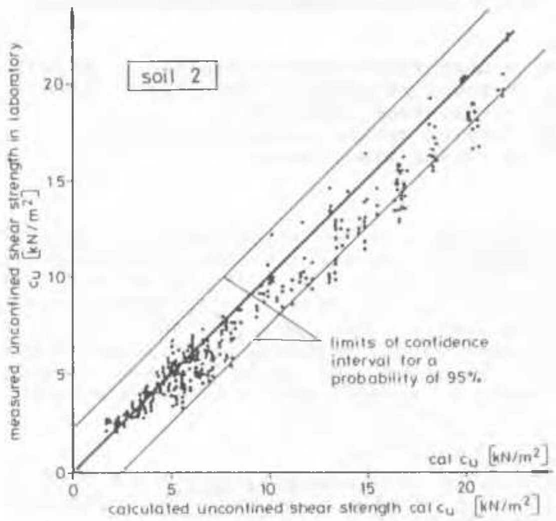

Fig. 8: Comparison between measured unconfined shear strength (c_u) and calculated value (cal c_u) with confidence interval for a probability of 95 %

Fig. 9 shows also a comparison between "estimated and measured τ_v-values" with a very good confidence, obtained with the following equation for soil 1 and 2:

$$\tau_v = 3,634\,C + 2,078\,L + = 0,269\,F + 0,578\,w + 0,232\,w_L - 0,083\,w_P - 0,262\,w_u + 0,013\,t - 51,125$$

where:

w_u = water content after mixing (%).
w_L = liquid limit

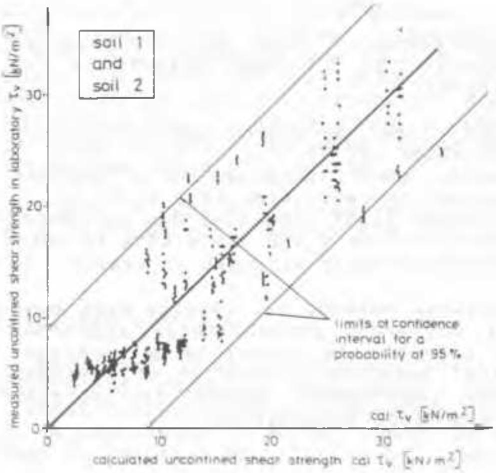

Fig. 9: Comparison between measured unconfined shear strength τ_v and calculated value (cal τ_v) from laboratory vane tests with a confidence interval for a probability of 95 %

For a preliminary estimation of the expected soil improvement we had to find a relationship between c_u and τ_v. After many attempts the following equation appears to be the most convenient and in the same time giving significant results for soil 2.

$$c_u = 0{,}510\ \tau_v + 0{,}134\ w_s - 0{,}046\ w_n + 0{,}033\ t$$

where:

c_u = unconfined shear strength (kN/m²)
τ_v = shear resistance (vane test) (kN/m²)
w_s = shrinkage limit (%)
w_n = water content after mixing (%)
t = curing time (days)

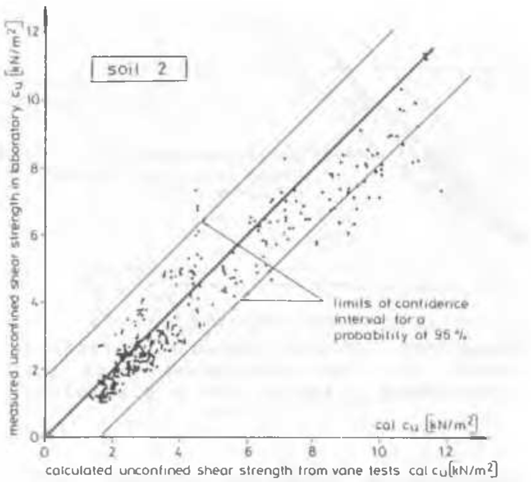

Fig. 10: Comparison between measured unconfined shear strength c_u and calculated value (from laboratory vane tests) with confidence interval for a probability of 95 %

Fig. 10 shows the results obtained for soil 2 when using the above mentioned equation.

SUMMARY AND CONCLUSION

The conducted series of tests and the obtained results indicate the following effects on the soil properties:

- The liquid limit decreases generally (from 130 % to about 100 %)
- The plastic limit increases as a function of admixture content (from 68 % to 86 %)
- The shrinkage limit increases due to admixture with L + F or C + F (from 43 % to 66%)
- The unconfined shear strength increases

Using statistical methods all results have been analysed by different probabilistic approches and it was possible to determine a covenient and economical solution to predict or estimate the expected improvement degree for certain admixtures and their combination.

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