Impact of Stabilization of Loess with Quicklime on Highway Construction

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The possibilities of improving the properties of highly water-sensitive loess through the addition of quicklime (CaO) are discussed. Results of laboratory tests are given to show the influence on the mechanical and physical properties of the soil through the addition of lime. These include the modification of grain size distribution (coagulation), modification of plasticity, change in compaction characteristics, and influencing of water absorption capacity and dependent strength properties. Addition of 3 percent by weight of CaO improves the soil so that a new and better construction material results.

Improvements in construction progress result by using lime stabilization. Whereas construction work as a rule would have to be stopped during periods of rain, building activities can be continued during such periods when lime is used. The cost of lime stabilization is only a fraction of the losses which result from such delay.

Use of lime stabilization has resulted in an increase of quality, building progress, and efficiency in the case of the road construction work done on the section of the Northeim-Hannover, Autobahn.

● IT HAS BEEN NOTED that major earth construction difficulties are experienced in loess areas when this very water sensitive soil changes to a liquid state through precipitation or through a water bearing stratum. The haul roads become impassable and also expert placing and compacting of the overly wet loess into embankments is no longer possible.

A radical solution consists in removing such soils and replacing them by some other suitable material. But this solution is as uneconomical as it is technically unsatisfactory even if such materials are available in sufficient quantity close to the construction site. If such a substitution cannot be made, another solution must be found in any case.

For the construction of the section Northeim-Seesen of the North-South Autobahn from Hamburg to Goettingen, the local loess has improved and stabilized with lime. The following is a report on the experience gained on this job.

GEOLOGICAL SURVEY OF THE JOB SITE

The Autobahn section Northeim-Seesen runs through the foreland of the Harz which is a hilly country. The hills belong to the Triassic and Jurassic formations. The lower plains, where the Autobahn runs entirely, are covered by immense loess deposits with underlying marly clays.

PROPERTIES OF THE RAW SOIL

Based on test results, the properties of a soil sample, typical for the above-mentioned job site, are described in the following:

Table 1 shows the chemical and mineralogical composition of the tested soil.

Figure 1 shows the grain size distribution. According to this the tested loess is almost single-size silt. It should be noted that the raw soil contains 15 percent of clay minerals (Table 1) although size fraction "clay" amounts to 6 percent only.

TABLE 1

CHEMICAL AND MINERAL COMPOSITION OF THE RAW SOIL

Constituent	Percent by Weight	Constituent	Percent by Weight
Chemical		Mineral	
Loss on ignition	6.32	Quartz	54
SiO_2	75.45	Feldspars	18
R_2O_3	10.83	Calcite	8
CaO	5.18	Dolomite	5
MgO	1.36	Kaolinite and Illite	15
Not determined	0.86	Total	100

The average specific gravity was determined to be 2.585 g/cm^3.

The plasticity test (according to Atterberg) gave the following results:

Liquid Limit	LL	=	22.8 percent
Plastic Limit	PL	=	18.0 percent
Plasticity Index	PI	=	4.8

PROPERTIES OF LIME USED

The lime used was a calcitic quicklime according to German specification DIN 1060 with 97.75 percent passing sieve 0.09 mm and the following chemical composition (in percent by weight related to the oven-dried material):

Loss on ignition	3.78	
CO_2		2.01
Non-soluble in HCL	0.94	
Total CaO	92.39	
Available CaO		89.83
MgO	0.55	
SiO_2	1.29	
Fe_2O_3	0.52	
Al_2O_3	0.25	
Not determined	0.28	

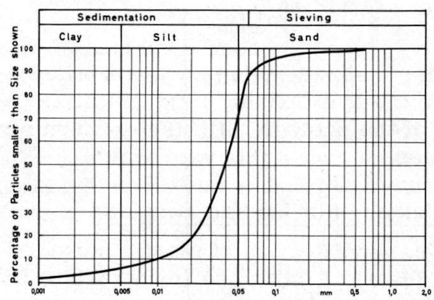

Figure 1. Grain-size distribution.

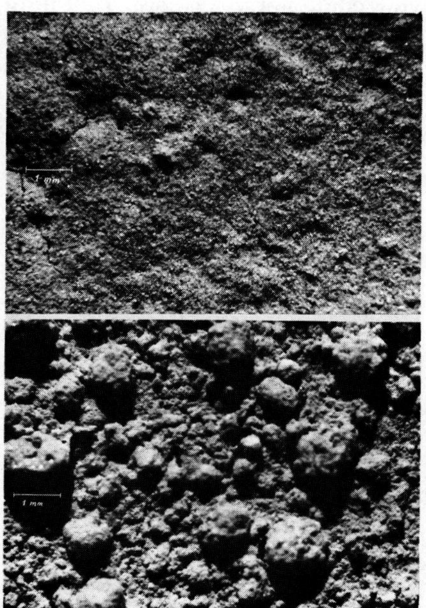

Figure 2. Flocculation of loess by lime. Above: Raw soil. Below: Soil treated with 3 percent lime.

MODIFICATION OF LOESS PROPERTIES BY ADDITION OF LIME

In order to study the possibilities of soil property modification, the raw soil was mixed with 1, 3 and 5 percent respectively of the calcitic quicklime described in Properties of Lime Used. Then the properties of the soil-lime mixtures were examined.

Modification of Grain Size Distribution (Flocculation)

Immediately after mixing lime with the humid raw soil, a considerable flocculation was observed (Fig. 2). As shown in Figure 3, this flocculation proved be be

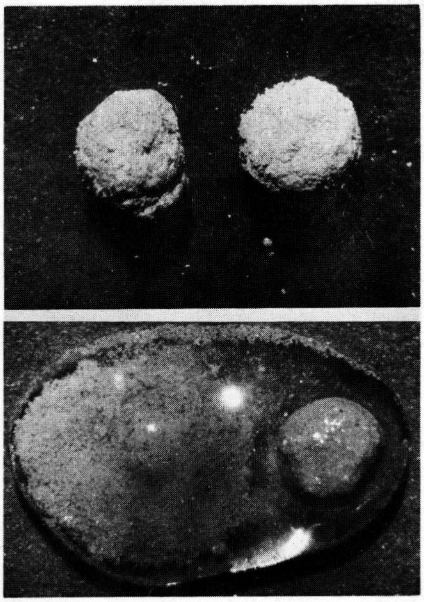

Figure 3. Water resistance of flocculation (Left: raw soil; Right: lime treated soil)
Above: Particles before influence of water.
Below: Particles 5 min after influence of water.

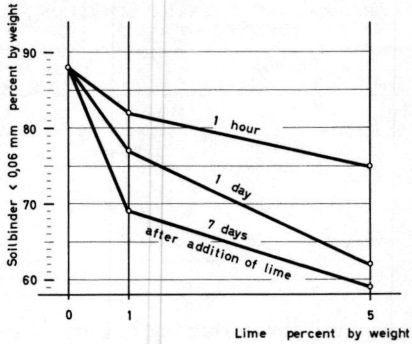

Figure 4. Flocculation of loess by addition of quicklime.

water-resistant. Figure 4 shows the relation between intensity of flocculation and the amount of lime added as well as curing time. The uncompacted soil-lime mixture was cured in airtight containers until sieving; then sieving with a 0.06 mm sieve took place under water. As shown in Figure 4, the soil-binder content was reduced considerably by the addition of lime.

In the course of this examination it turned out that the soil had acquired hydrophobic properties through the addition of lime. Figure 5 shows the ready absorption of water by the raw soil (left half of the photograph) while the hydrophobic lime-stabilized soil repels the water drop like quicksilver (right half of the photograph). The reason for this behavior could not yet be satisfactorily explained.

Modification of Plastic Behavior

The modification of plastic behavior through addition of lime is shown in Figure 6. The Plastic Limit rose from 18.0 to 22.0, the Liquid Limit rose from 22.8 to 24.0 which reduced the Plasticity Index from 4.8 to 2.0. The soil-lime mixtures were tested 24 hours after addition of lime.

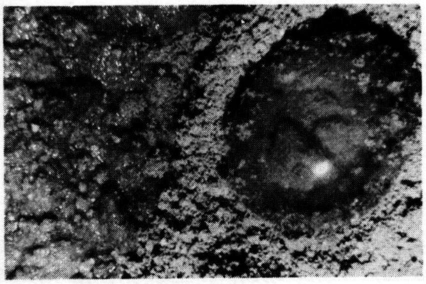

Figure 5. Water repellency of soil by lime treatment.
Left: Raw soil; Right: Lime treated soil.

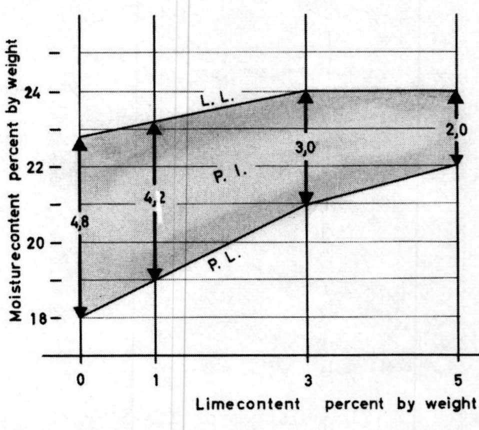

Figure 6. Changement of plastic properties by addition of lime.

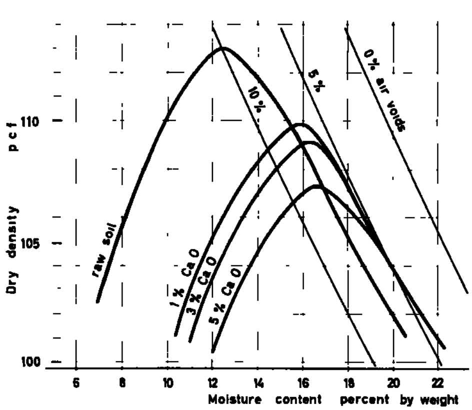

Figure 7. Moisture-density relationship (proctor test).

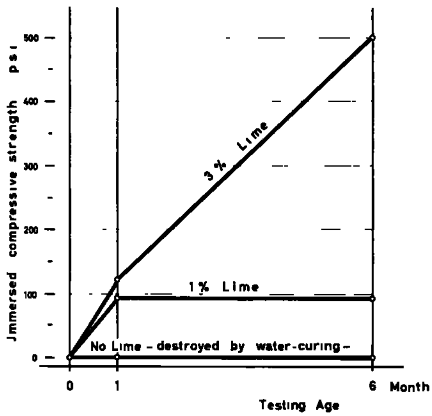

Figure 8. Immersed unconfined compressive strength related to age and amount of lime.

Modification of Dry Density-Moisture Content Relationship

The moisture-density curves of the Proctor test are plotted in Figure 7 for the raw soil and the tested soil-lime mixtures. The mixtures were tested 24 hours after addition of lime.

Maximum dry densities were somewhat reduced by lime whereas the optimum moisture contents were noticeably increased. For high water contents, soil-lime mixtures show a greater compactibility than the raw soil.

Modification of Immersed Strength

Cylinders, 3 by 3 in., were used as specimens. The raw soil and the soil-lime mixtures were compacted at optimum water content to 100 percent Proctor density. The specimens were cured at first in moisture-saturated air and immersed in water prior to the unconfined compression test. Loading speed during the unconfined compression test was 14 psi per sec.

In Figure 8, immersed strength is plotted against curing time. The raw soil specimens were decomposed without exception during immersion in water. The specimens treated with 1 percent lime were water resistant and showed a compressive strength of 98 psi after 28 days; upon further curing, no additional increase of compressive strength was noticed. This indicates that the small amount of 1 percent of lime had already been used up for flocculation and an initial hydraulic strengthening. For a further hydraulic strengthening no more lime was available (1). The specimens treated with 3 percent lime showed a steady further strengthening up to 500 psi after six months and it is safe to assume that this process would have continued further.

The above test results clearly show that loess may be improved considerably by adding small amounts of lime. In particular, the following properties can be improved: (a) soil structure; (b) plasticity; (c) compactibility at high water content; (d) water resistance; and (e) strength and bearing capacity.

In the following the effects of a soil treatment with lime upon the performance at the above mentioned earth-work job will be described.

EFFECTS OF LIME STABILIZATION ON CONSTRUCTION PERFORMANCE

Exact data on the climatic conditions, earthwork performance and use of lime at the job site are plotted in Figure 9.

During the months of August and September 1957 there had been very heavy rains, amounting to up to 224 percent of the mean value taken over a number of years and reached the unusual level of 245 mm in September. Therefore, the earthworks had to be stopped because of impassability of the haul roads. The soil was soaked to a point where, even after several sunny days, no construction traffic was possible. The water content of the soil had increased from a normal amount of 14 to 16 percent to 20 to 22 percent, in some cases even 26 percent, and therefore exceeded the Liquid Limit (Fig. 6).

At the beginning of October, lime stabilization was used in order to allow a resumption of work. Areas of application were as follows: (a) construction of haul roads; (b) improvement of soaked soil for embanking; and (c) stabilization of the subgrade for fine grading.

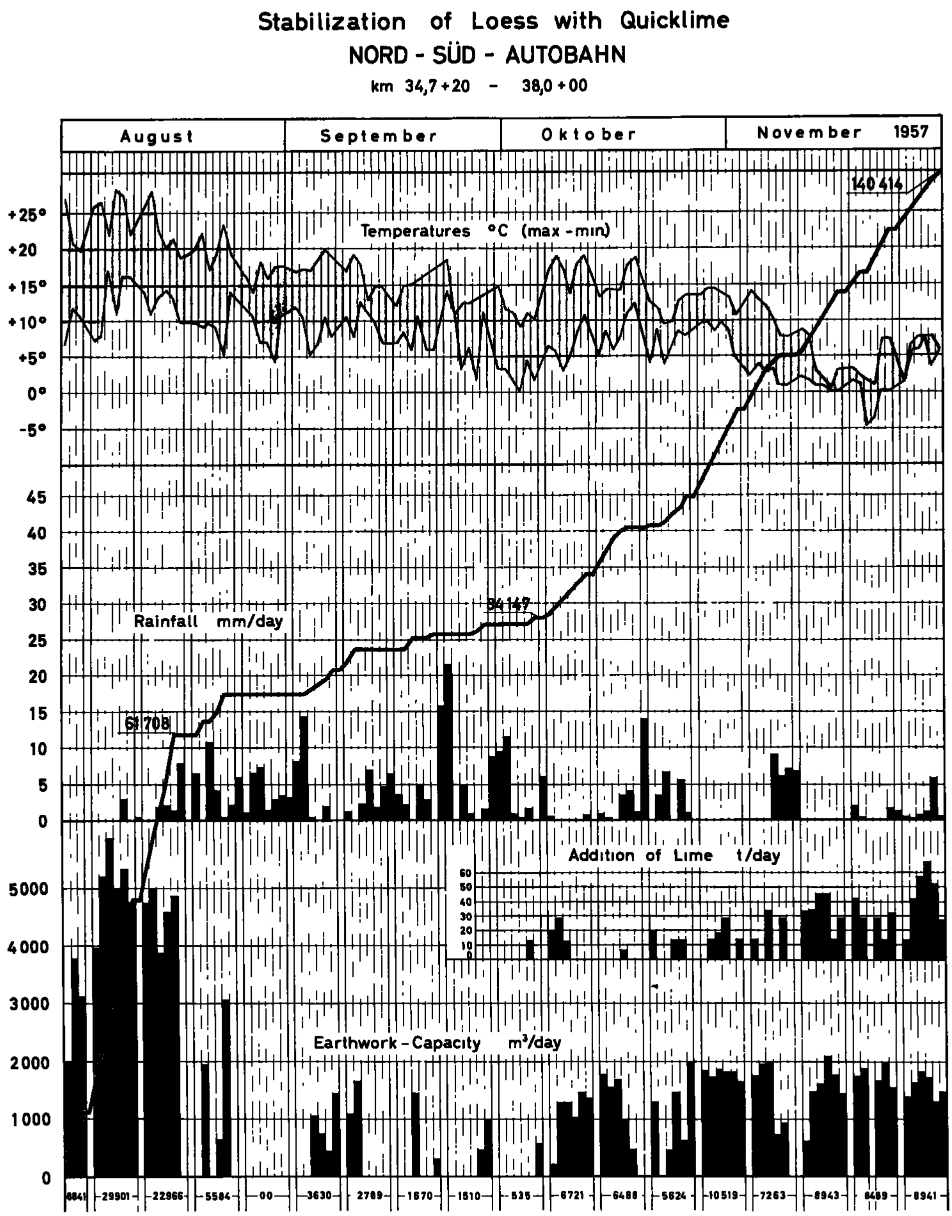

Figure 9. Effects of lime stabilization on construction performance.

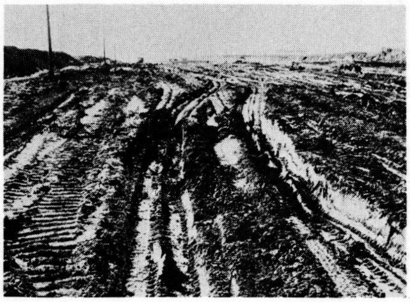

Figure 10. Situation of the job site after rainfalls (untreated soil).

Figure 11. Lime-stabilized haul road after rainfalls.

The water content of the soaked soil had been reduced by about 5 percent by adding 3 percent of calcitic quicklime. Dèsiccation was effected by slaking of the lime and the heat generated by this as well as the improved aeration through flocculation. While the raw soil at 21 percent moisture content was nearly in liquid state (LL =22.8 percent) and incompactible (Optimum Moisture Content =12.5 percent), the soil-lime mixture with 3 percent of lime at 16 percent moisture content was in solid state (PL =21 percent) and in optimum condition for compaction (Optimum Moisture Content = 16 percent).

One hour after mixing soil with lime, the haul roads were passable for heavy trucks, the lime-treated soil used for embankments was in optimum condition for compaction, and the required quality of fine grading was assured. As shown in Figure 9, it was made possible by lime stabilization to resume continuous construction work. Independent of rainfalls and greatly lowered temperatures, a soil could be employed as construction material which ordinarily would not have been used under the prevailing weather conditions. The decline in daily average performance as compared to the August performance was caused by the suppression of double shift work because of the earlier fall of darkness and a reduction in equipment.

A comparison of the additional costs arising from lime stabilization with the plant hire rates for temporary shut-down of the construction site proved that there are important economic advantages for the contractor as well as for the sponsor in employing lime stabilization.

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2. Unger, _____, "Verbesserung von Schluff durch Kalk," (Improvement of Silt by Lime). Strasse und Autobahn, (Nov. 1958).