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PROPERTIES AND BEHAVIOUR OF SILTY SOILS ORIGINATED FROM LOESS FORMATIONS

Propriétés et Comportement des Sols Silteux dérivés de Formations Loessiques

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Summary

The large deposits of loess formations that constitute the Argentine plains, offer an opportunity to follow the transformation of a wind blown loess up to its re-deposited position. Laboratory properties and actual behaviour in engineering projects of three types of silty soils originated from loess formations are given. Special attention is drawn to the behaviour of an ML soil resulting from erosion, transportation and modification of a loess material. It is pointed out that index properties are not sufficient to predict the mechanical properties of silty soils derived from loess formations.

Sommaire

Grâce aux vastes dépôts de loess qui constituent les plaines de l'Argentine, il est possible de suivre les transformations subies par le loess au cours de ses déplacements sous l'action du vent. Cette communication concerne les caractéristiques déterminées au laboratoire et le comportement au cours des travaux, de trois types de sols silteux d'origine loessique. On remarque plus particulièrement le comportement d'un sol type ML résultant de 1'erosion, du transport et de la modification d'un matériau loessique. On fait ressortir que les indices d'Atterberg ne permettent pas a eux seuls de prédire les propriétés mécaniques des sols silteux d'origine loessique.

Introduction

The most accepted geological explanation for the origin of the large deposits of silty and clayey soils that constitute the Argentine plains indicates that all the zone called the pampa is a consequence of the subsidence of the bedrock and the simultaneous filling by eolic, fluvial and lacustrine deposits. This subsidence was interrupted periodically by temporary upliftings which in terms resulted in erosion and re-deposition. As a consequence of these movements the plains are formed by very thick deposits of materials ranging from true wind blown loess to very active clays.

This paper deals mainly with the properties of the silty material that resulted in such a process as a product of the erosion of the original loess and its subsequent re-deposition. The material comprises soils that have index properties which places them in the *ML* group of the unified soil classification system; however their behaviour does not resemble that to be expected on the basis of those properties. It is thought that one of the main causes for this different behaviour is from the effect and alterations produced by the calcium carbonate which together clay binds the particles of these re-deposited soils. Another cause arises from the fact that the re-deposited soil has in the field a much lower natural void ratio than that pertaining to the original loess in the same condition.

Index Properties

Fig. 1 is a plasticity chart in which are represented the results of tests on loess and re-deposited modified loess. The samples of loess were obtained from the central and western part of the country where the soils have the grain size, the structure and typical behaviour of loess that has never been submerged or of loess whose only modification has been its temporary immersion.

The samples of re-deposited modified loess were obtained from the eastern part of the country where the temporary uplifting process of the bed rock and the consequent erosion and re-deposition of eolic soils has been most active. Since the climate in this zone is rather humid, the re-deposited loess is covered by a B horizon of active to very active clay, over which rest an A horizon layer of top fertile soil of medium plasticity.

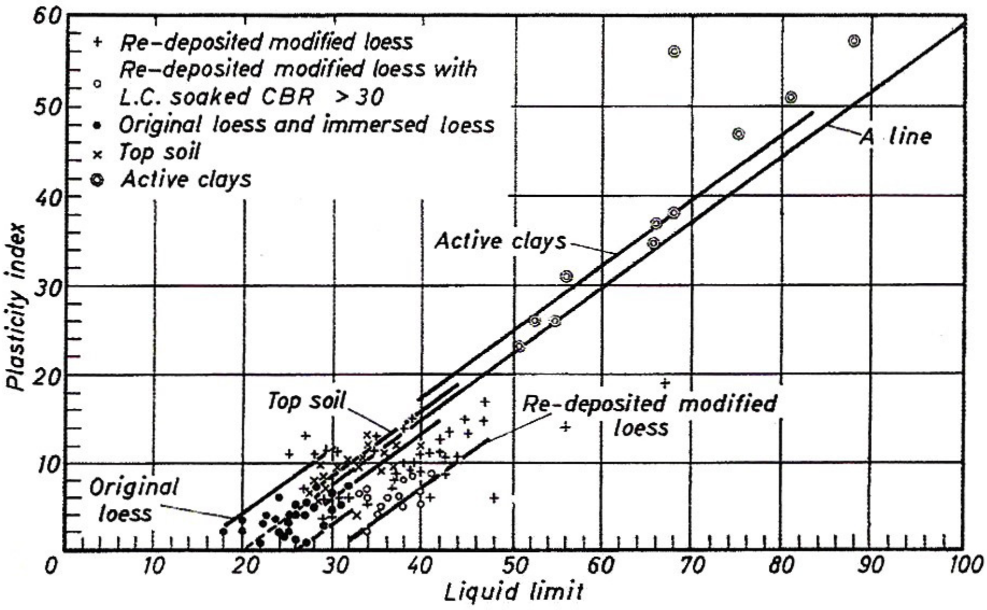

Fig. l Plasticity chart showing the position of original and modified loess, top soil and active clays
Diagramme de plasticité du loess (avant et après transport éolien) du sol en surface et de l'argile active

Everything points to the conclusion that the shifting of points on Fig. 1 gives a picture of what happens with the index properties when a material originally deposited as a loess is transformed by transportation and re-deposition into a modified loess. It also shows how those properties change in the surface as the soil develops into a mature profile.

The change from loess to a re-deposited modified loess increases both the liquid limit and the plasticity index, but this increase does not imply a similar change in the grain size characteristics. The loess usually contains 80 per cent of particles between 0.06 and 0.002 mm with about 10 per cent clay particles and 10 per cent of fine sand particles. The re-deposited modified loess has about the same grain size characteristics with a slight increase in the clay content for the more plastic types. There is, however, a net difference in the natural void ratio of both types of materials. The natural void ratio of loess varies between 1.15 and 0.80, with the larger values corresponding to the upper meters of the deposits; that of the re-deposited modified loess is usually smaller than 0.80, with very frequent values ranging from 0.65 to 0.75. The unit weight of the solid particles is in both cases 2.63 as an average value.

Re-deposited Modified Loess as a Foundation Material, and as part of Stabilized Bases for Highways and Airport Pavements on Areas not subject to Frost Action

Since about 1935, highways in Argentina have been designed and constructed following American specifications. Of these specifications, those recommended by the A.S.S.H.O. were based on grain size characteristics (per cent passing the 200 mesh) and on the liquid limit and plasticity index, as the present unified and A.S.S.H.O. classifications systems. Failure of several projects with bases of fine aggregate mixtures that complied with the above specifications led to the study of the reasons for such unexpected behaviour. The mixtures were composed of sand and of the top soil represented in Fig. 1. This top soil was also widely used as a selected subgrade material.

With the expectation of slightly improving the quality of these bases and subgrades the soil entering the mixture and constituting the subgrade was changed to the re-deposited modified loess lying in the C horizon. As can be seen in Fig. 1, the re-deposited modified loess includes some types of soil with lower plasticity than the top soil and consequently better potential properties could be expected. The design of the paved areas of the International Ezeiza Airport near Buenos Aires required a very careful study of these potential properties because there are not coarse aggregates available within 200 miles.

For this purpose the CBR test was resorted to with the result that it was possible to locate borrow pits of re-deposited modified loess of good quality. The above mentioned soils have, as indicated in Fig. 2, a laboratory compacted soaked CBR that varies between 10 and 30 plus.

As an average 70 to 80 per cent of their particles pass the 200 sieve and they have a liquid limit ranging from 34 to 40 and a plastic index varying between 4 and 8. These latter values place them in the ML group of the unified classification system and on the A4 group of the A.A.S.H.O. classification. Their mechanical properties however are far better than those to be expected from ML or A4 soils.

These conclusions have been confirmed by further studies and led to the general practice of not judging the expected behaviour of ML soils only from the values of the liquid limit and the plasticity index. For highway and airport construction the CBR test has proved sensitive enough to differentiate the satisfactory from the unsatisfactory types of ML soils and is widely used as a criterion for this purpose.

As has been said, the materials under consideration are ML soils originated from loess deposits and consequently carry with them a certain amount of calcium carbonate. In the process of re-deposition and modification this calcium carbonate, besides changing the properties of the soil, is concentrated more in some areas than in others and its content in these soils varies between wide limits. In some places this calcium carbonate content is so high that the soil can easily be judged by visual inspection; in others, however, the content is small and only mechanical tests, such as CBR or triaxial tests, will detect its presence.

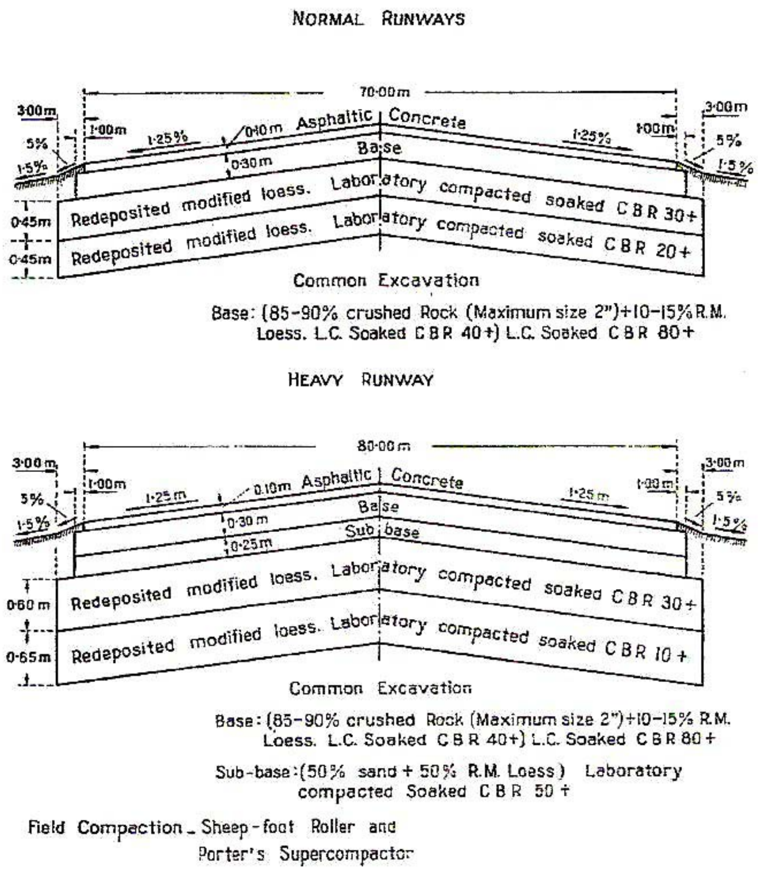

Fig. 2 Buenos Aires's International Ezeiza Airport's runways pavement design
Coup en travers du projet de la piste d'envol de I'aéroport international de Buenos Ayres, à Ezeiza

Re-deposited Modified Loess as Foundation Material

In the study of this re-deposited modified loess as a foundation material it is convenient to compare its properties with those of the original loess and with those of the loess modified only by temporary immersion. This has been possible because of the simultaneous presence in this country of the three stages through which loess can pass, as has been mentioned before.

The original loess behaves as generally reported in the soil mechanics literature. In the natural state it has a moderate bearing capacity which is totally lost when submerged or wetted. For example, irrigation canals need to be submerged before their lining is constructed and during this process very large settlements occur; water deposits must be constructed with the utmost care, avoiding a foundation in the upper layers of this loess, because otherwise a water loss can be conducive to large settlements in the structure.

Fig. 3 shows a profile of a loess deposit of this country, which usually run into some hundreds of feet deep, with the water table also located at great depth. Normally, at a certain depth, the soil increases in consistency as shown in Fig. 3.

Sometimes this increase is coupled with a slight change in the index properties. Building foundations are usually carried down to this layer of higher bearing capacity by means of piles. Bored piles are widely used. This solution puts the foundation out of the danger of a possible settlement resulting from accidental wetting of the upper layer of loess.

The loess that has suffered immersion behaves as a silt. Its properties depend on its natural density and on the relative predominance of the clay and sand fractions. Most of the deposits studied show at a certain depth the same increase in consistency as indicated for the original loess. Since the upper layer is usually of medium consistency and has already been immersed it can be used for shallow footings or raft foundations.

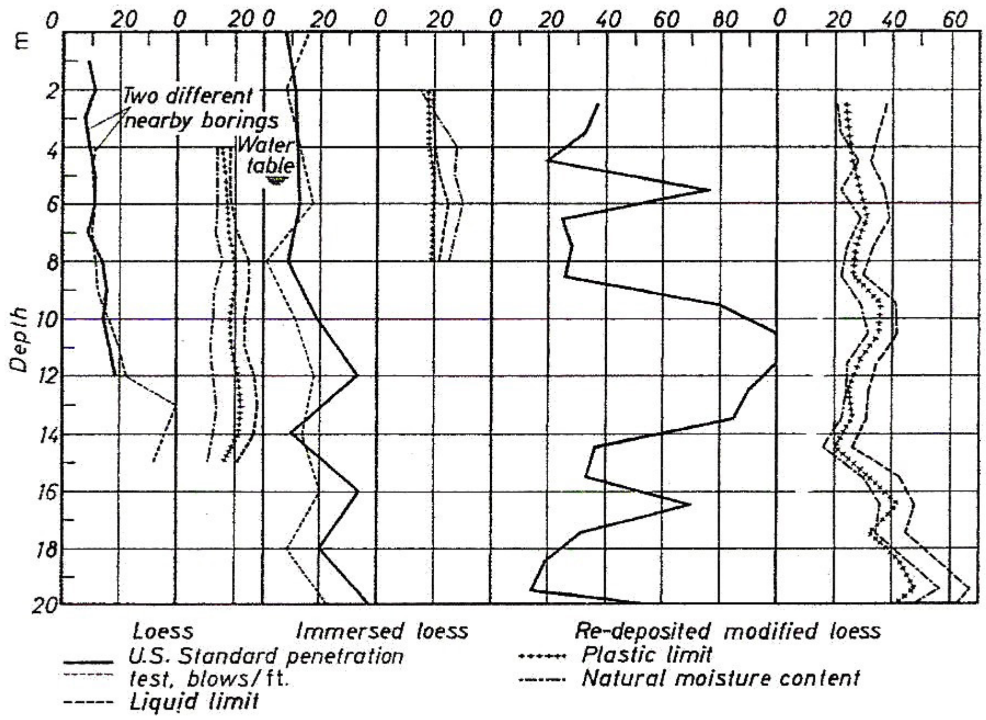

Fig. 3. Results of U.S. standard penetration tests, liquid limit, plastic limit and natural moisture content, performed on deposits of original, immersed and re-deposited modified loess
Résultat des essais normalises de pénétration, de limites de liquidité et de plasticité, et de teneur en eau naturelle, effectues sur le loess d'origine, sur le loess ayant subi une immersion, et sur le loess redépose

Normally this consistency varies rather erratically in both vertical and horizontal directions. Fig. 3 shows a typical profile.
The shearing resistance of this soil varies fundamentally with the cohesion which is given not only by the clay binder but also by the small amount of calcium carbonate which is present.
For the upper layers, for a degree of saturation of 85 to 90 cent, the angle of internal friction for the undrained test is of the order of 20 degrees. The unconfined compression strength usually ranges from 0-25 to 1.00 kg/cm^2.

Fig.4 shows the results of a load test on the immersed loess represented in Fig. 3, and Fig. 5 those of a consolidation test on a saturated sample. Settlements computed on the basis of consolidation tests give results that are too high to be valuable in forecasting the soil behaviour. For this purpose load test may be resorted to, but due to the variations in soil properties to be of value a load test programme should be very comprehensive. Yet, in those soils, extrapolation from load test on small areas is highly unreliable.

Structures constructed on immersed loess as that represented by Fig. 3, 4 and 5 have been designed with footings or rafts transmitting a net pressure of 1.00 to 1.50 kg/cm^2 to the soil. Measured settlements of these structures have been negligible. Settlement of structures where a load of 2.5 kg/cm^2 has been applied has been of the order of 1 to 2 in. The design of the important foundations are based mainly on the results of the standard penetration test and unconfined compression test, since the most important variations in this type of soil are its degree of compaction and the strength of the cement that binds its. Where there is not a definite increase in the penetration resistance, direct foundations are adapted by using the principle of flotation where needed. When, as very frequently happens, there is a very definite increase in the penetration resistance at a moderate depth, pile foundations the danger of a possible settlement resulting from are frequently used. Pile lengths are very easily determined by observing the penetration diagram.

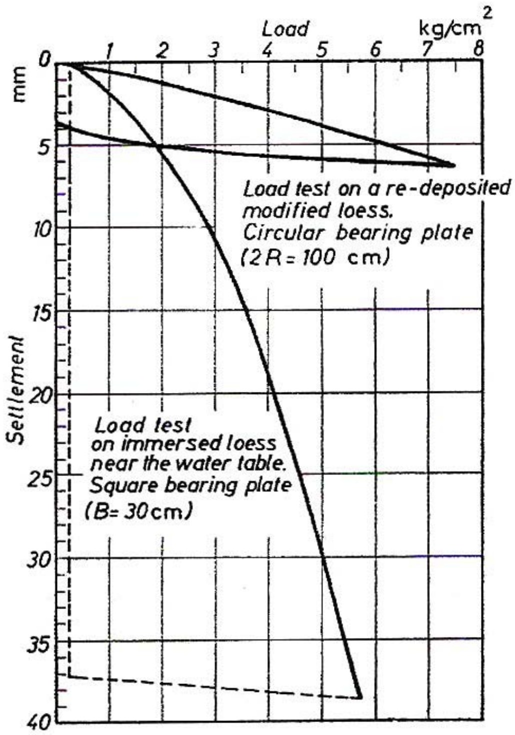

Fig. 4 Results of load tests performed on the upper layers, near the water table, of an immersed loess and on a re-deposited modified loess
Résultat des essais par plaques chargées, effectues sur les couches supérieures, au voisinage de la nappe phréatique, pour un loess ayant subi une immersion, et pour un loess redépose

The most outstanding example of a re-deposited modified loess is the one existing below a large area of the city of Buenos Aires. Figs. 3, 4 and 5 show normal values for the properties of this soil. For undisturbed samples at the natural water content the undrained angle of internal friction is always larger than 30 degrees. Likewise under the same condition the cohesion is frequently larger than 1.00 kg/cm^2.

Naturally, nothing but footing foundations are used in this type of soil. As indicated by the ø and c values, its ultimate bearing capacity is very high. Besides, its natural compressibility in the field is very low. Building regulations have up to very recently restricted the full use of the high bearing capacity of this soil. Nevertheless, recent experience indicates that at least an allowable load of 5.00 kg/cm^2 can be used without any measurable settlement being experienced by the structure. It has proved impossible to predict settlements by any of the existing methods of computation as they all give values that are too high compared with the real ones. Even settlement analysis made using the m_v values obtained from laterally confined compression tests performed on the undisturbed unsaturated soil at natural water content give settlements that are so high in comparison with the actual ones that these computations have no value at all.

Because of the above reasons, the determination of the maximum allowable pressure in these hard soils can only be reached in a step-by-step procedure. Yet, some load tests performed on a medium size area seem to indicate that the maximum load used up till now can be highly increased, if necessary, because in these hard soils the allowable load appears to depend only on the ultimate bearing capacity; settlements being unimportant when the load is limited by the introduction of the factor of safety.

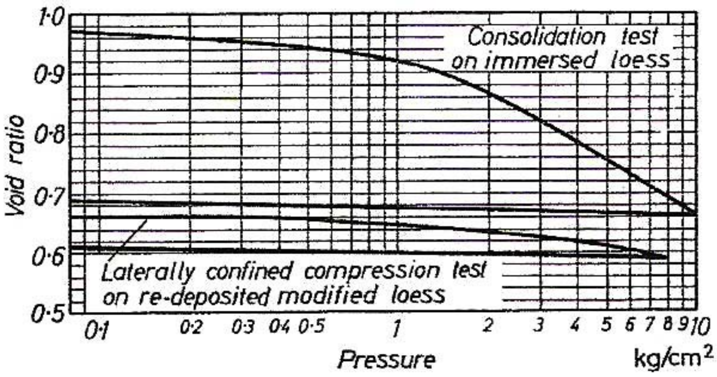

Fig. 5 Results of consolidation test on a saturated sample of immersed loess and of a laterally confined compression test on a re-deposited modified loess
Résultat d'un essai de consolidation sur un échantillon sature de loess ayant subi une immersion et d'un essai decompression dans une enceinte rigide, sur un loess redépose

Conclusions

Laboratory properties and actual behaviour in engineering projects of three types of ML soils have been given, giving special attention to the behaviour of a ML soil resulting from erosion, transportation and modification of a loess material. These types of soil are so frequently found in the Argentine that it is thought similar soil formations must exist in many other places of the world. It is consequently hoped that the content of this paper may prove useful in those areas where loess and modified loess formations exist and the climate is such that frost action is not a factor to be considered.

It has been shown that under certain conditions some of the ML soils found in nature constitute good dependable soils both for foundations and as raw materials for highway and airport construction. Their valuable properties were determined using the current tests utilized in soil mechanics. They were sufficient to detect the modifications that, while keeping them in the fine grained soils division, differentiate some of the ML described from the usually considered treacherous materials whose behaviour is difficult to forecast.

The contents of this paper indicate the convenience of qualifying the expected behaviour of ML soils, pointing out that in soils derived from loess formations index properties by themselves are not enough to predict their mechanical properties. Since loess and loess originated formations constitute an appreciable percentage of ML soils, the conclusion has apparently sufficient generality to be considered in soil classification systems.