ENGINEERING CHARACTERISTICS OF LOESS

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION AND DISTRIBUTION

Loess is a windlaid material that has derived its name from German origin, where people along the Rhine valley used to apply it for the fine grained, yellowish slightly loamy clay that showed some vertical jointing without stratification. Now this term is applied to the fine grained soil consisting primarily of silts that is transported and deposited by wind. Therefore silts that form Loess deposits are generally suspended in the air as dust and deposited on areas that may be located quite far from their origin.

Figure 1 shows the relationship between the size of a particle of a soil and the height at which it can be carried in the atmosphere. From this figure, it is worth noticing that the silt-size particles can reach a height which ranges between 200 and 8,000 meters, which is quite a considerable distance in the atmosphere. Figure 2, shows the relationship between particle size and the distance to which it may be transported; it is clear that silt-size particles may travel thousands of miles.

Although Loess is predominatly made up of silts, yet it has a certain amount of clay, this clay together with calcium carbonate gives some cohesion to the Loess; colloids and chemicals leached by rainwater from the upper weathered zone and precipitated in lower zones cause some cohesion too. There are four conditions to be satisfied in order to

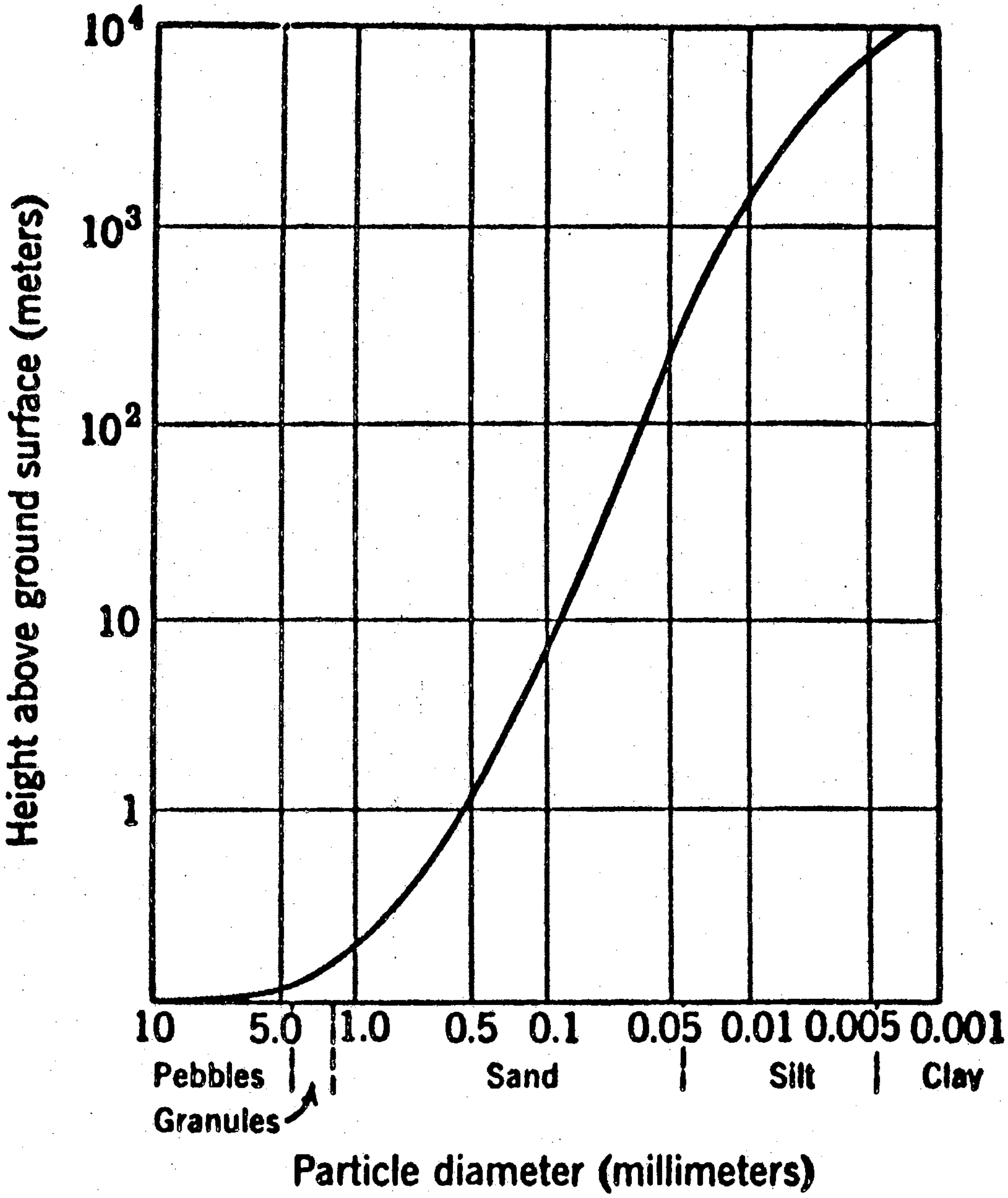


Figure 1 (10). Height above ground a particle of a given size may be carried by wind.

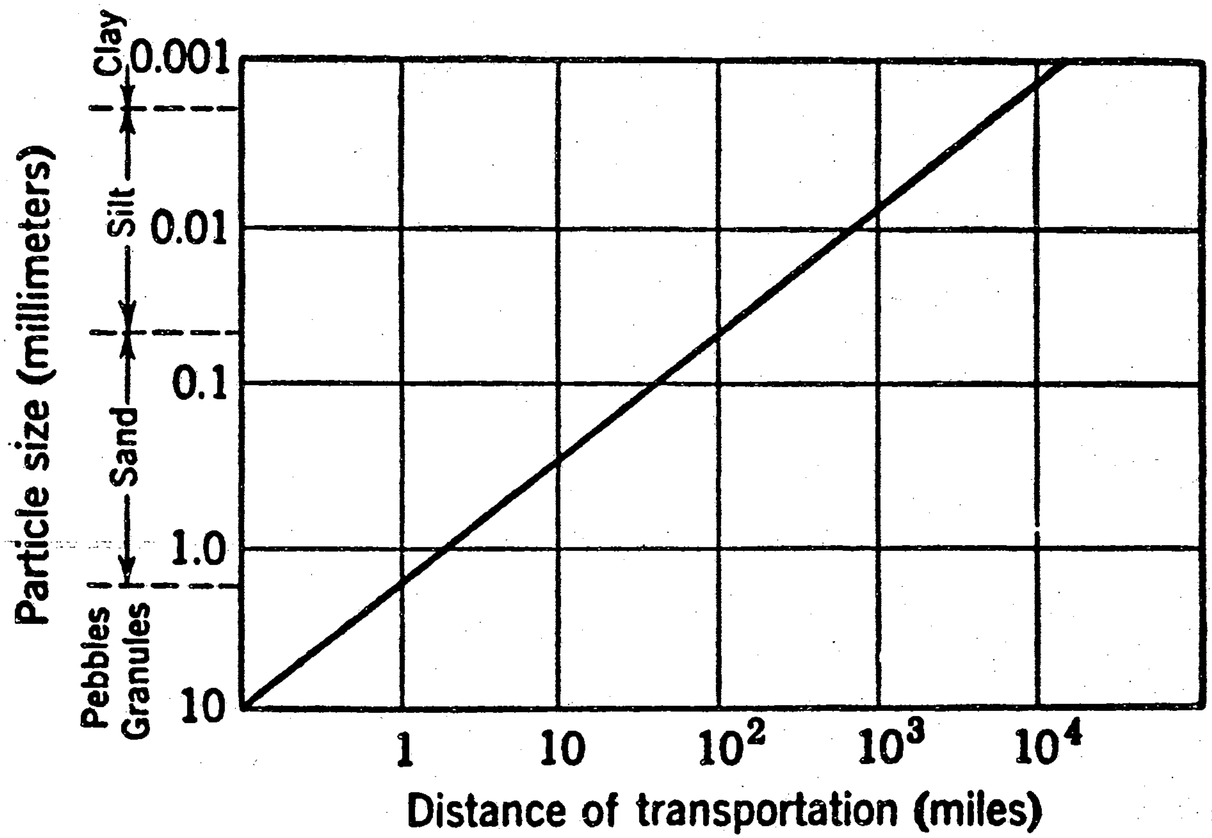


Figure 2 (10) - Distance a particle of a given size may travel from its source.

have Loessial deposits; these conditions are (16):

1. A source of intermixed silt and clay adequate enough to account for the known deposits.
2. A period of strong winds prevailing from one direction.
3. A place of deposition.
4. Arid to semi-arid conditions at least following the issuance of silt from the glaciers and all times following deposition.

Although people may differ on the origin of Loess, yet there is a wide spread agreement that the fine grained material which makes up most of this deposit nowadays, was originated by different processes of geological activity. Large mountains of glaciers moved along and fine particles were produced as a result of the abrasion action of these glaciers with the underlying rock. Later when these glaciers retreated, the fine particles were deposited in outwash plains, where wind and water acted upon them. The silt and fine material which was carried away by water, mainly by streams, and redeposited somewhere along the floodplains of these streams, was picked up later by wind and redeposited again; while the silts that were left over after the outwash plains of the glaciers dried out, were carried directly by air. Silts mixed with clay that are deposited on the surface of the ground to form Loess have different characteristics from those that are deposited under sub-aqueous conditions, and it is noticed that once a Loess deposit has been formed, an arid or semi-arid climatic conditions are essential to have the Loess retain its properties.

About 9 per cent of the earth's land surface consists of Loess and Loess-like soils. Many engineering problems are encountered during construction on these deposits due to their unique properties, and because not much is known about them from the engineering point of view. Therefore research coupled with laboratory and field tests are necessary before Loess is used as a construction material.

The principal areas of Loess in the United States are located along the Ohio, the Mississippi, the Missouri, and the Columbia River Valleys; In South America, they are located in the Pampas country of Argentina; In Europe, along the Rhine and Danube River Valleys; In Asia, in the Huang Ho watershed of China, in Turkestan and near the Caspian Sea. Loess deposits are also found in Egypt, Lybia, Algeria, Eastern New Zealand and the Central portion of Australia. Figure 3 shows the distribution of these deposits all over the United States of America.

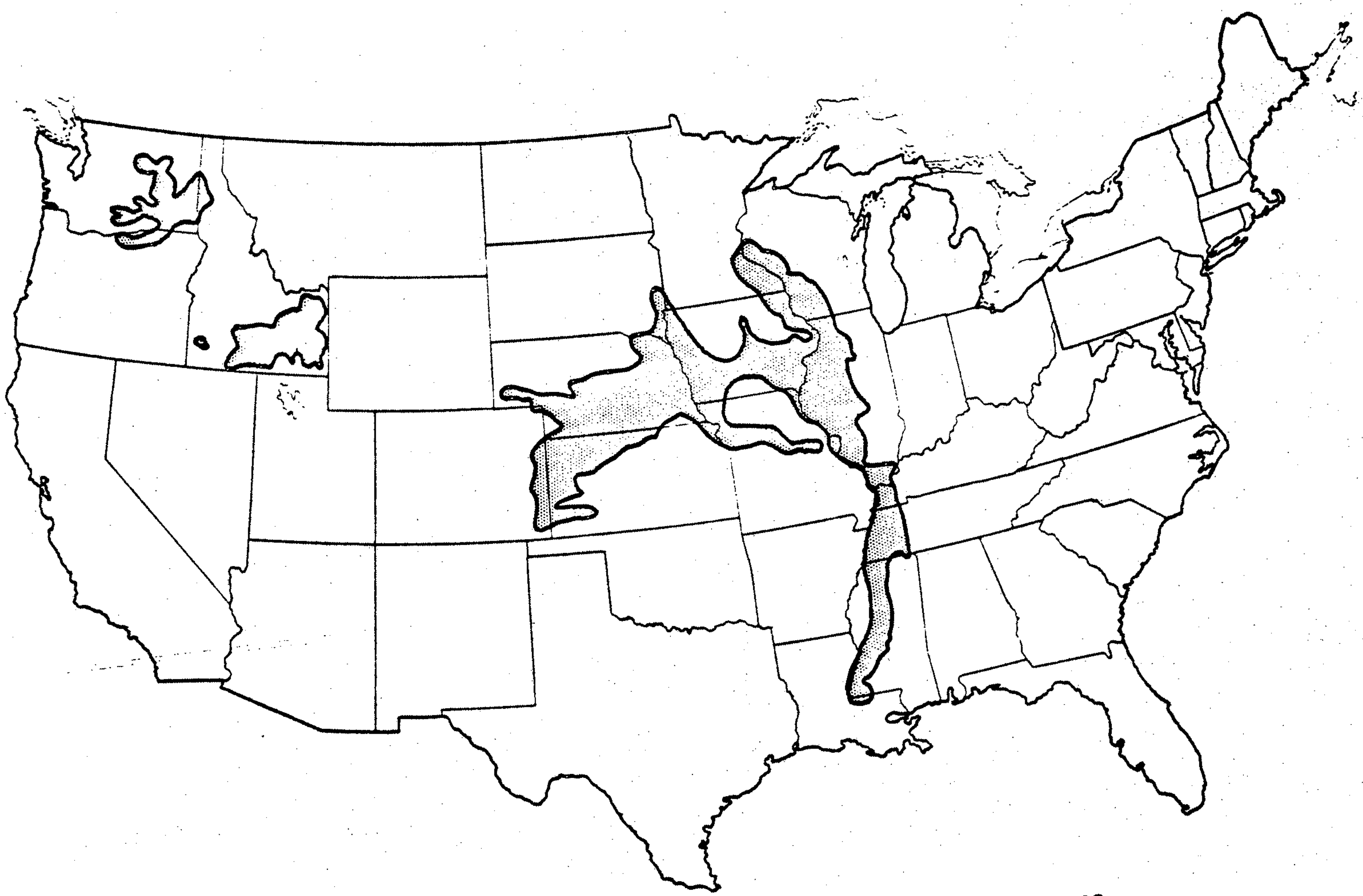


Figure 3 (16). OUTLINE OF MAJOR LOESS DEPOSITS IN THE UNITED STATES

CHAPTER II

CHARACTERISTICS OF LOESS

1. General Characteristics (10)

Color: Yellow or yellow buff characteristic, also ash gray, gray buff, or brown. "A" horizon often very dark.

Texture:

a. Friable

b. Dominantly silt but also contains clay and sand sized particles. Ordinarily the fraction .01 to .05 mm makes up at least 50 per cent of the material by weight.

c. An aggregate of clay particles appears to surround each large silt or sand grain.

d. Silt and sand particles are angular to sub-angular.

e. Microscopically shows an open structure with little interlocking of grains and many intergranular voids.

Composition:

a. Silt fraction consists of quartz ± 50 per cent; feldspar as abundant as ± 20 per cent, calcite, dolomite, micas less than 10 per cent, chert, hornblend; chlorite and pyroxene are minor.

b. Clay fraction is somewhat variable, but montmorillonite and illite are most abundant.

c. Chemical composition: Calcite is an important constituent although not always present. Occurs as silt grains concretions, tubes, snail shells, and cement.

Structures:

a. Stands with vertical faces principally in artificial cuts and banks undercut by streams.

b. Vertical jointing is noted in most exposures.

c. Tubular structures may reach a maximum of 30 to 40 ft below the surface.

d. Incrustations of carbonate appear on fracture faces, around exposed roots, and below overhanging walls, often as stalactitic growths.

e. Concretions, particularly of calcite, are very common, and the depth from the surface to their first occurrence is directly proportional to rainfall.

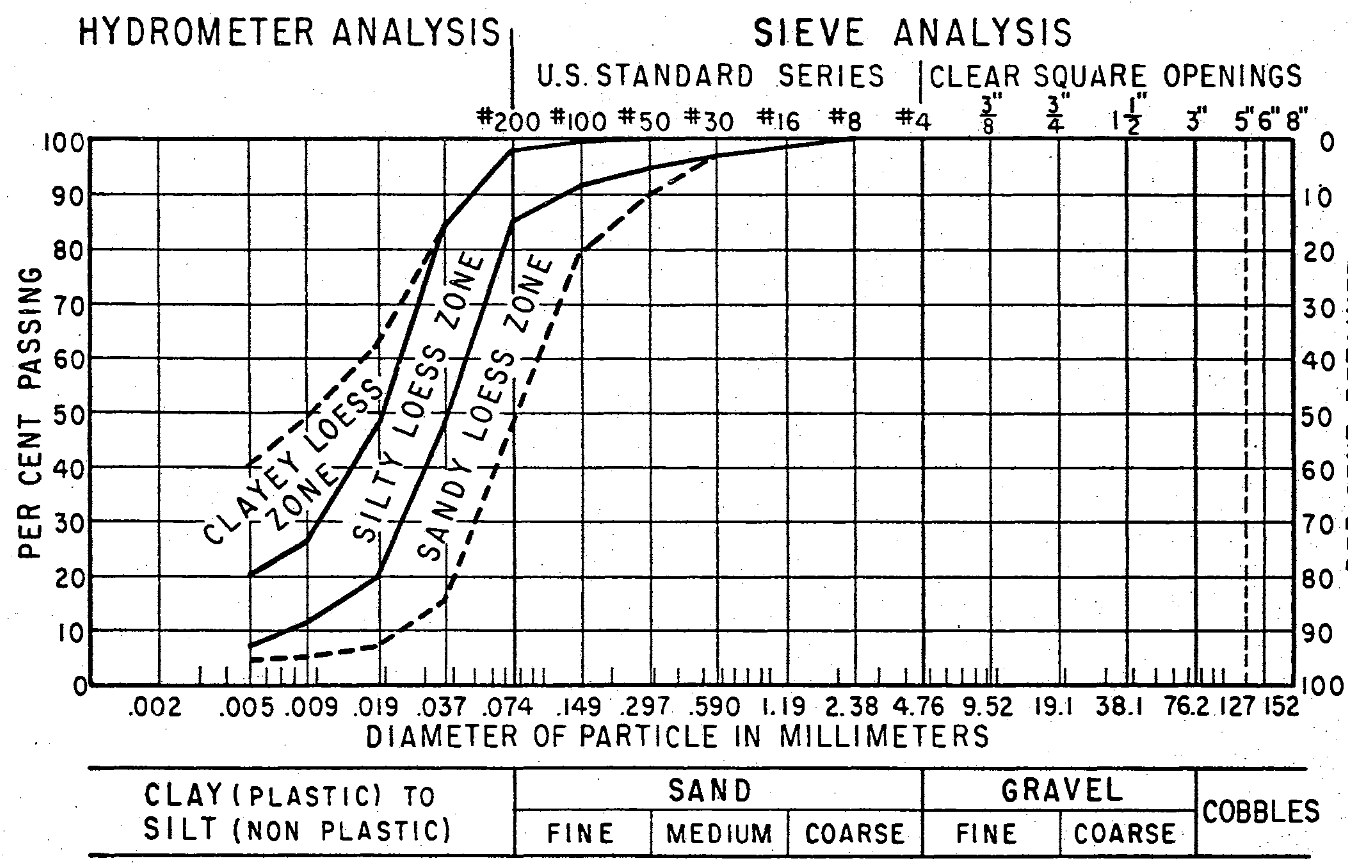
Topographic Forms:

a. Chimneys or pipes occur along valleys, narrow ravines, and sharp divides.

b. Intricate drainage pattern, especially in the tributary system. Slopes show steplike terraces due to minor land sliding.

2. <u>Engineering Characteristics</u>

Loess soils are of uniform particle size, made up mostly of silt with little amount of sand and clay as mentioned before. Figure 4 shows the uniform gradation of this soil and the zones of sandy Loess, silty Loess and clayey Loess. The specific gravity of the solid particles ranges between 2.57 and 2.69, but it is 2.65 on the average (20). Generally the liquid limit ranges between 25 and 38, and the plastic limit between 12 and 25. Loess of low liquid limits and low plasticity



Gradation data was obtained on 148 samples from projects in the Missouri River Basin area
The curves generally take the direction shown by the boundary lines

For all samples tested,
76% were in the silty loess zone
18% were in the clayey loess zone
6% were in the sandy loess zone

Figure 4 (16) - Trends of gradation curves for Loess indices are designated as Sandy Loess. Those of high plasticity indices and high liquid limits are designated as clayey Loess, and the ones that have intermediate values of liquid limit and plasticity index, the name Silty Loess is applied to them. The amount of fines found in the Loess is dependent on the distance traveled from the source, the farther the distance, the more clayey the Loess is.

Loess has appreciable cohesion despite the high void ratio, this is believed to be due to the calcareous or clayey binder present in most deposits. It can sustain big loads of several kips per square foot without appreciable amount of settlement if wetting of the loess is prevented. The binder has a different quality between one location and another even in the same deposit, because of the variation in the leaching action of water; which means that these different locations have strengths that may vary even within short distances. Direct shear tests of the controlled strain type run on Nebraska Loess (39), showed that shear and cohesion values obtained from one set of curves that represent unconsolidated quick tests on an undisturbed sample and another set of curves that represents consolidated quick tests on a remolded sample, were quite similar, which is probably due to the drainage features of the direct shear machine and the drainage characteristics of the Loess. The results of the test are shown in Figure 5, where curves 1 and 2 show undisturbed, unconsolidated quick shear in saturation condition, and curves 3 and 4 show remolded, consolidated quick shear in saturation condition. Other tests of unconsolidated quick shear type were run in the same area on undisturbed silty Loess at its natural moisture content. These tests were run in three directions: one in horizontal, another in vertical and the third at an angle of 45° (39). Due to the high value

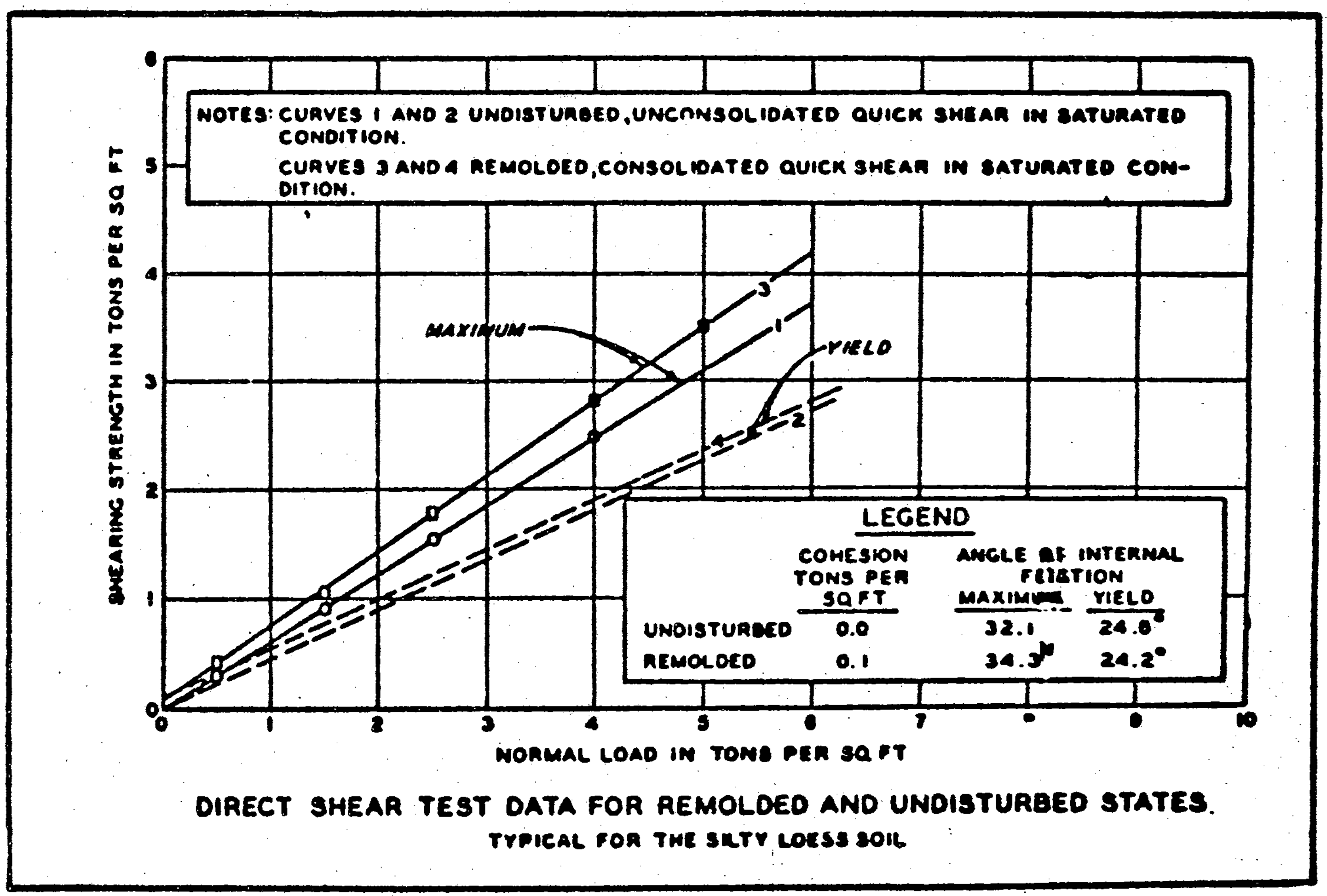


Figure 5 (39) - Strength Envelopes for typical Loess of cohesion that this Loess possesses the direction of shear did not have any effect on the angle of friction as demonstrated by Figure 6. It should be noted that the value of cohesion for the field moist state ranged from 0.4 to 0.6 tons per square foot (39).

The most important factors that have a direct influence on the values of shear strengths obtained in the laboratory are: the density, the moisture content and the clayeyness of the Loess. This is shown very clearly in Figure 7. It is noticed from this figure that differences in clay content has a minor influence on the shear-strength properties as compared with the influence of moisture content and density of Loess soils.

An outstanding characteristic of Loess is consolidation. A generalized description given by Holtz and Gibbs (6) of the properties of the Missouri River Loess, shows that the potential settlement of a Loess foundation is governed primarily by the in-place density and by the highest moisture content attained by the soil. Looking at Figure 8, it is seen that pre-wetted low-density specimens consolidate between 15 per cent to 20 per cent, and for high-density specimens, either at natural moisture or pre-wetted condition, there is little consolidation (6). The effect of saturation can be observed from the additional consolidation that results from wetting the specimens while under a load of 100 lb. per square inch; the approximate effect of saturation at other loadings can be estimated from the foregoing curves by observing the difference in density between the natural and pre-wetted specimens at any particular load.

Sometimes the dry density and the water content form the criteria for settlement. This is the case for Kansas-Nebraska Loess as shown in

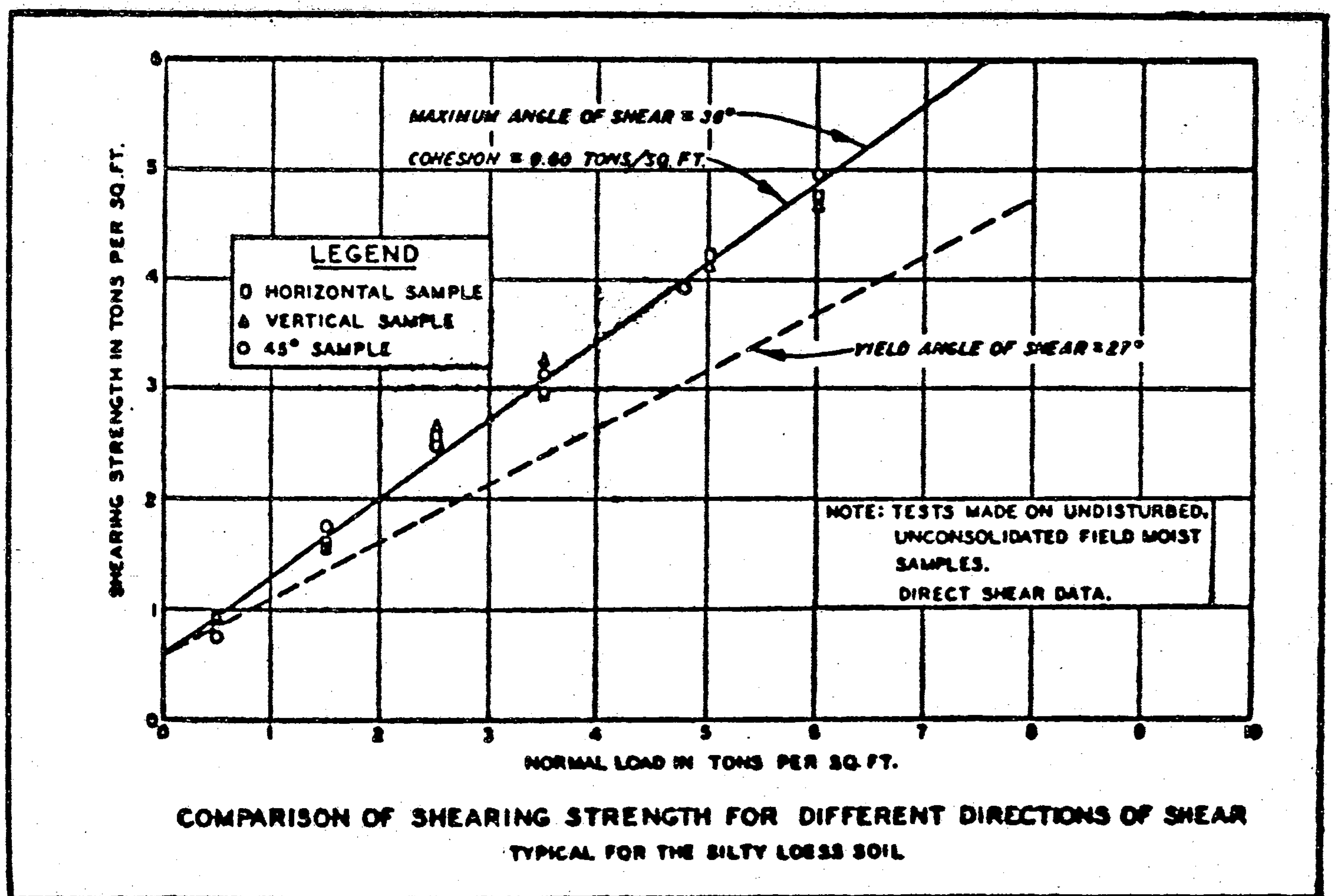
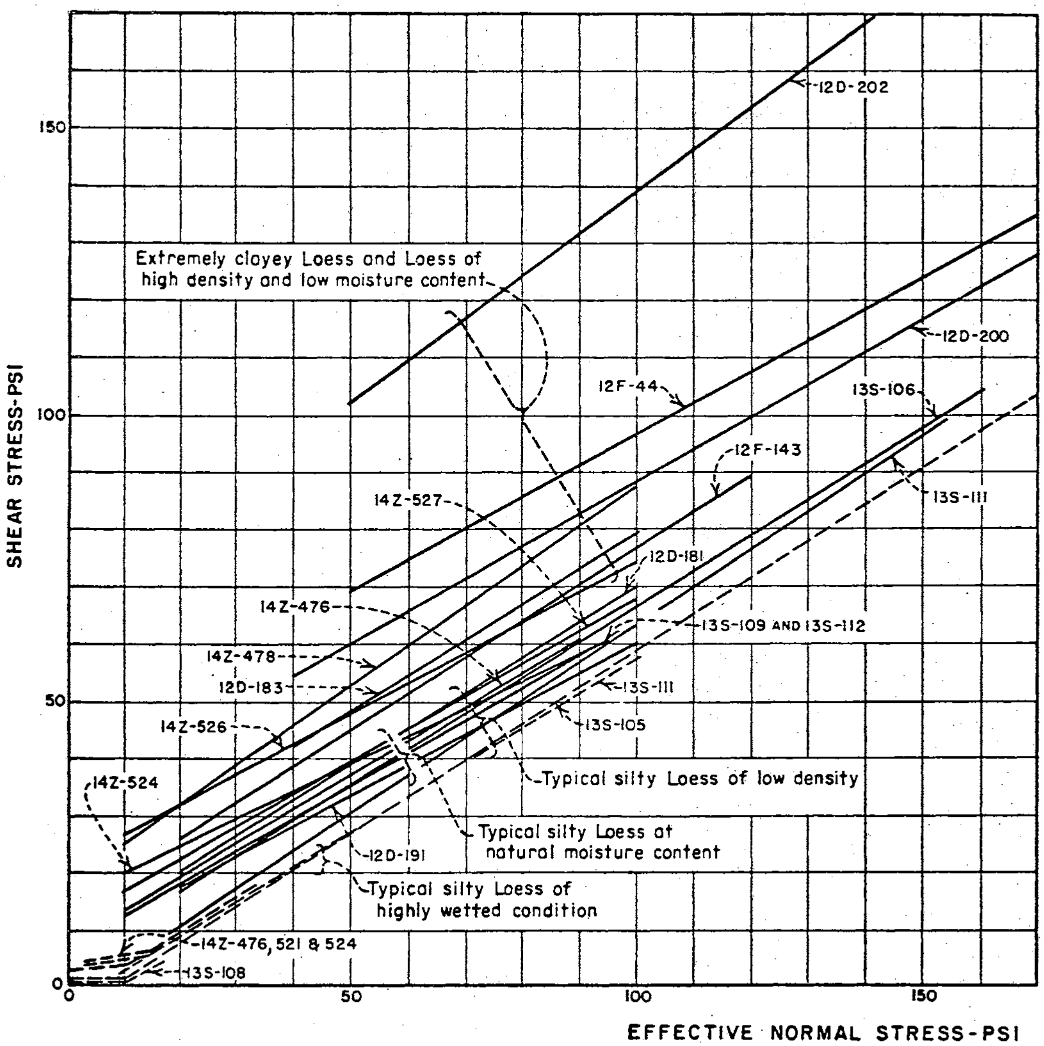


Figure 6 (39) - Strength envelopes for typical Loess



LAB. SAMPLE NO.	TEST CONDITIONS	TYPE OF LOESS	DENSITY AT TIME OF TEST	MOIST. AT TIME OF TEST	REMARKS
12D-202	NATURAL	CLAYEY	100.2	10.1	Extremely clayey Loess and Loess of high density and low moisture content
12F-44		SILTY	94.1	8.4	
12D-200		CLAYEY	84.9	8.6	
14Z-478		SILTY	90.2	7.4	
12D-183		SILTY	84.2	4.5	
12F-143		SILTY	103.5	18.0	
14Z-526		CLAYEY	83.1	13.3	
12D-181		SILTY	79.1	8.2	Typical silty Loess of low density
14Z-527		SILTY	89.5	6.9	
14Z-476		SILTY	83.8	8.6	
13S-106		SILTY	89.0	6.0	
13S-111		SILTY	81.7	6.5	
13S-109		SILTY	83.8	7.3	
13S-112		SILTY	81.3	9.5	
14Z-524		SILTY	82.0	10.6	
12D-191		CLAYEY	78.6	20.3	
13S-105	PRE-WETTED	SILTY	81.1	29.3	
13S-111		SILTY	82.5	30.4	
14Z-476		SILTY	81.6	34.8	
14Z-521		SILTY	78.2	34.9	
14Z-524		SILTY	78.0	33.9	
13S-108		SILTY	78.4	28.9	

EXPLANATION

——— Tests at natural moisture condition

– – – Tests at wetted condition

Figure 7 (16) - Shear tests of representative Loessial soils

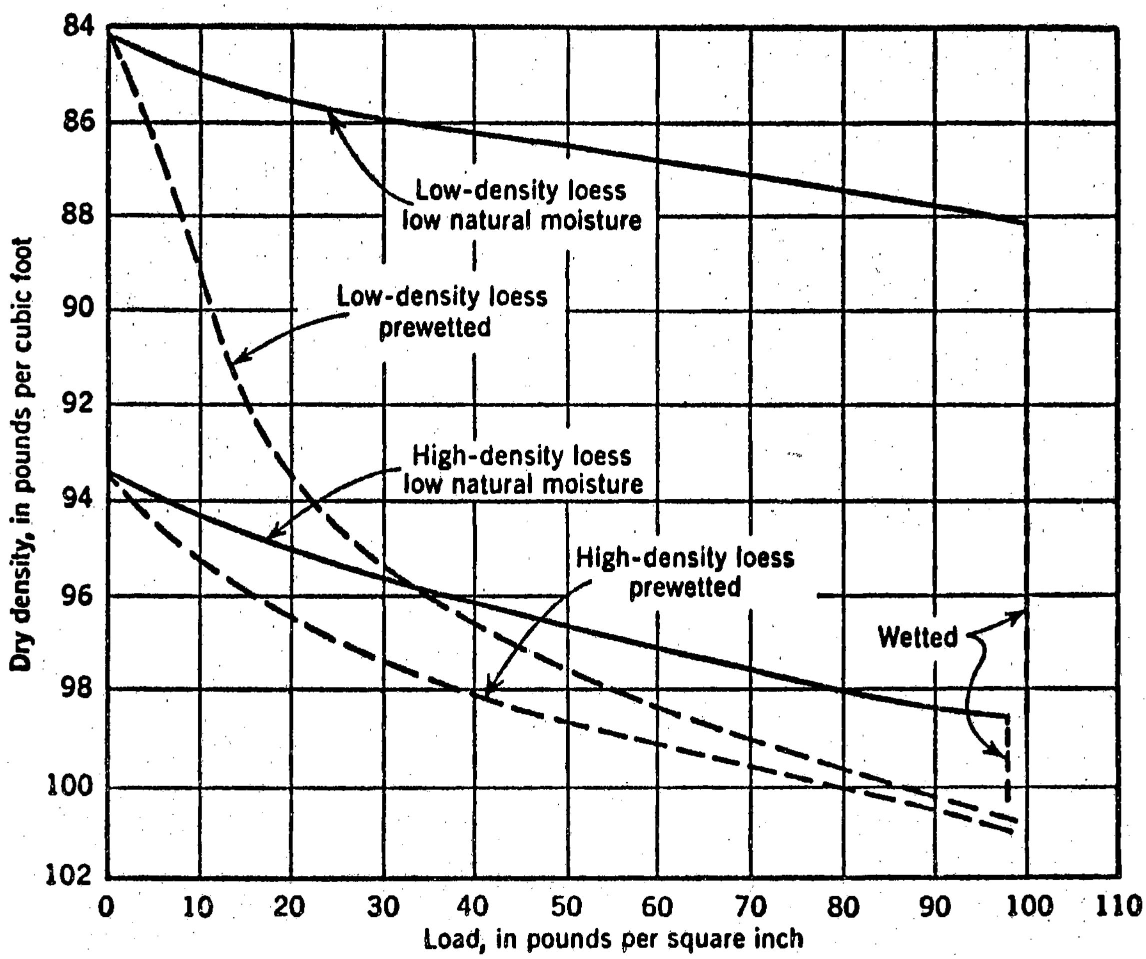


Figure 8 (6) - Consolidation Curve for Missouri Basin Loess

Table 1. If the soil has a low natural density, it will have a high porosity. If this porosity is such that the soil upon saturation will have a moisture content higher than the liquid limit, subsidence will be large, while if the soil is dense such that the expected water content upon saturation will be less than that required for the liquid limit, the soil will not subside unless large loads are applied to it. According to Denissov (14), subsidence depends upon the factor K_d where

$$K_d = \frac{\text{Porosity at Liquid Limit}}{\text{Porosity at natural density}}$$

If K_d is less than 1, the soil has possibilities of subsidence upon saturation.

In Russia, A. K. Larionov (27), wrote that the predisposition to subsidence deformations is determined by the structural system of the solid part of the Loess, the degree of its water resistance, by the volume occupied by interparticle porosity, and by the humidity factor K_o (ratio of air to liquid in the soil). When water acts on a Loess soil, it disintegrates into grains, aggregates, colloidal particles and soluble salts. Colloidal particles and salts travel freely through the pores and are able to leave the soil, together with the filtering current. If the external pressure is big enough, the grains and aggregates move in such a way as to redistribute themselves within the nearest pores. Water resistant parts of the aggregates remaining after subjection to water action are different in their nature. These are composed of aggregates which are either cemented with insoluble compounds, or bound by a complex exchange process.

$$\text{Kwat.} = \frac{W_{ba}}{W_H - W_{ba}}$$

Kwat. = Water resistance coefficient of the soil structure.

TABLE I (21)

SETTLEMENT CRITERIA FOR KANSAS-NEBRASKA LOESS

Dry Density Pounds per cubic foot	*Condition*
< 80	Loess is considered loose and highly susceptible to settlement.
80-90	Loess is medium dense and is moderately susceptible to settlement, particularly for critical or heavily-loaded structures.
> 90	Loess is quite dense and may be capable of supporting ordinary structures without serious settlement.
85	A more general criterion has been used for earth dams ; this density is used as the division between low and high density loess or the division where special foundation treatment is required for lower densities.

Moisture % of dry weight	*Condition*
< 10	Loess considered very dry and maximum dry strength and high resistance to settlement should be expected.
10-15	Loess still quite dry, giving rather high strength.
15-20	Loess is approaching moist conditions.
> 20	Loess rather wet to moist, and will generally permit full consolidation to occur under load.
	Experience has shown that moisture content of near 25 to 28 per cent can easily be obtained by surface ponding and about 35 per cent moisture (depending on density) is required for complete saturation.

W_H = Weight of monlithic soil sample.

W_{ba} = Weight of the sample after the action of water.

The value of Kwat. for Loess ranges between 0.2 to 2.0 or more. As this value gets larger, the predisposition to subsidence becomes less.

If all other conditions are kept equal, the magnitude of subsidence is dependent mainly on the humidity factor K_o as was mentioned before. A Loess with K_o value greater than 1.1 to 1.2 are not subject to subsidence, while with further reduction of K_o, susceptibility to subsidence increases.

The three types of porosity that Mr. Larionov mentioned in his analysis are:

1. The Ultra Microscopic porosity, the size ranging between .003 microns and 2.0 microns.
2. Interparticle porosity, size ranging between 2.0 microns and 0.5 mm.
3. Macroporosity.

Volume occupied by the Ultra Microscopic porosity is between 2.5 per cent to 10 per cent of the total volume, and this is always filled with moisture under natural conditions, which means that its role in deformation processes is minor. Interparticle porosity on the other hand occupies 13 to 36 per cent of the volume, and it is this porosity that plays the main part in consolidation processes. When this type of porosity occupies less than 21 per cent of the volume, the Loess soil is not subject to subsidence (27). In most cases the macropores are made up of many channels the walls of which are consolidated and often calcified, which makes them the most durable of the Loess soil structure. Certain Loess soils have the walls of the original macropores loose. Such soils are found to deform readily under the action of water.

The permeability of Loess depends on the density and upon the tubular and root like structure. For dense remolded Loess, the permeability is very low compared to Loess that is unremolded with tubular structure. Other factors that affect the permeability are: the amounts of silts, clay, and sand. Clayey Loess have lower permeabilities than either silty or sandy Loess. Figure 9 shows the relationship between the permeability and dry density for tests run on undisturbed and remolded specimens of sandy Loess and clayey Loess. It is clear that as the dry density increases, the permeability decreases.

Excavation in Loess is relatively easy, because due to the uniformity of material, no rocks or boulders are generally present. Excavation for transportation facilities involves large quantities, usually because of topography. Since the Loess has the ability to stand on vertical slopes due to its vertical columnar structure, highway cuts are made stepped-like vertical slopes. Drainage measures to divert water from the cut faces, and vegetation protection will help stabilize these slopes which are highly susceptible to erosion.

3. Underconsolidated Loess

Engineers and people working on soil mechanics in the Soviet Union, do not think that the subsidential properties of Loess are mainly because of high void ratio. Many clays have a high void ration, yet they don't show the subsidential properties of Loess. Mr. N. J. Denissov (14) said that soils could be either normally consolidated, overconsolidated or underconsolidated. He referred to Loess as it exists in its dry state as underconsolidated soil. Settlement caused by water infiltration can be characterized by the underconsolidated soils only, and it is

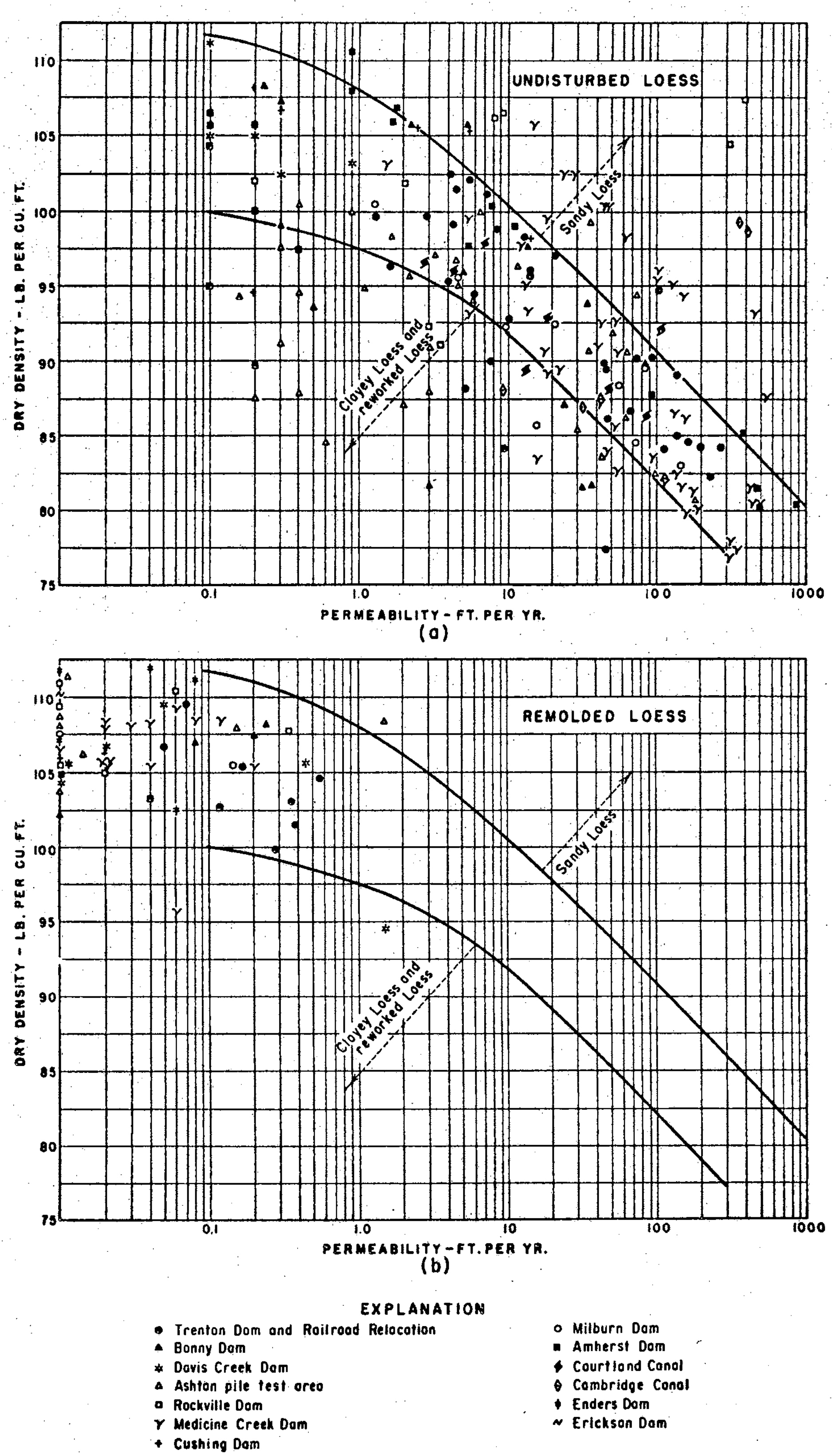


Figure 9 (16) - Trends of Permeability for Loess this state of under consolidation that is dangerous for construction and especially irrigation. When water infiltrates these soils, a drop in shear strength occurs accompanied by settlement as mentioned before. As the degree of saturation approaches unity, the soil becomes normally consolidated and loses its subsidential properties. If in this new condition the water content decreases without any shrinkage (which is a characteristic of soils with low liquid limit), Loess soils maintain a normally consolidated rate (14). Upon loading these soils in Russia and measuring consolidation, it was found that the curve of consolidation came above the curve of normally consolidated soils.

Methods for determining the degree of underconsolidation in the Soviet Union are based on the viewpoint that subsidence is an external phenomena of the process of transformation of the Loess from the underconsolidated state, to the more stable normally consolidated state. Figure 10 reveals the result of the tests performed, where the normal consolidation is represented by curve 1, and curve 2 corresponds to the low moisture state of this soil. That part of curve 2 that passes over curve 1, represents the underconsolidated state.

4. Modified Loess

Modified Loess is formed from Loess under the action of immersion, erosion, and decomposition. These actions reduce the porosity and could change the mineral composition. Although modified Loess contains soils that belong to the ML group of the Unified Soil Classification system, their behavior does not resemble that to be expected on the basis of those properties. One of the main reasons for this different behavior is the effect of the alterations produced by calcium carbonate, which together with clay bind the particles of these redeposited soils. Another

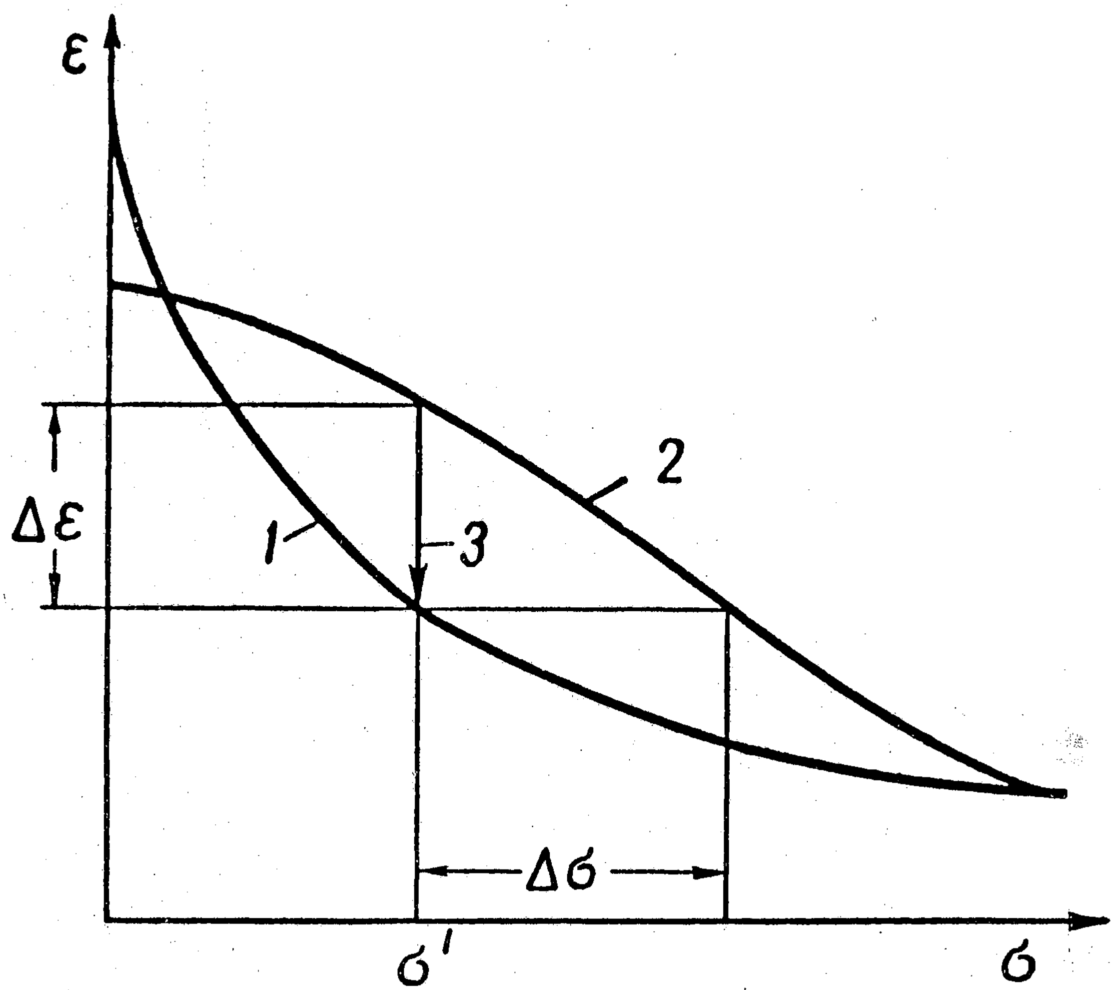


Figure 10 (14) - Consolidation Curves for a typical Loess reason is that in the field, redeposited soils have lower values of void ratio than original Loess under the same conditions. Figure 11 is a plasticity chart which shows the position of the original and modified Loess top soil in the Argentine plains of South America (5). This chart gives a clear picture of what happens to the index properties, when a material originally deposited as a Loess, is transported again and redeposited as a modified Loess. It also shows what happens to these properties when a surface soil develops into a mature profile. Although there is an increase in the liquid limit and the plasticity index as the Loess goes from original to modified, yet this does not have any effect on the grain size characteristics. Ordinary Loess usually contains 80 per cent particles between .06 and .002 mm with about 10 per cent clay particles and 10 per cent fine sand particles (5). The redeposited modified Loess has almost the same grain size with a slight increase in clay content for the highly plastic types. There is however a net difference in the natural void ratio of both types of materials. Usually the natural void ratio of Loess varies between 1.15 and 0.80, with the larger values corresponding to the upper parts of the deposits; that of the redeposited modified Loess is usually smaller than 0.8 with very frequent values ranging from 0.65 to 0.75. The specific gravity of the solid particles in both cases is 2.65 on the average.

In the process of redeposition and modification, the calcium carbonate, not only changes the cohesive properties of these soils, but its concentration is not uniform, and there could be wide variation of its content between one area and another. Sometimes the concentration of this calcium carbonate in some area is so high that it could be inspected visually, but when the content is small, some means of mechanical

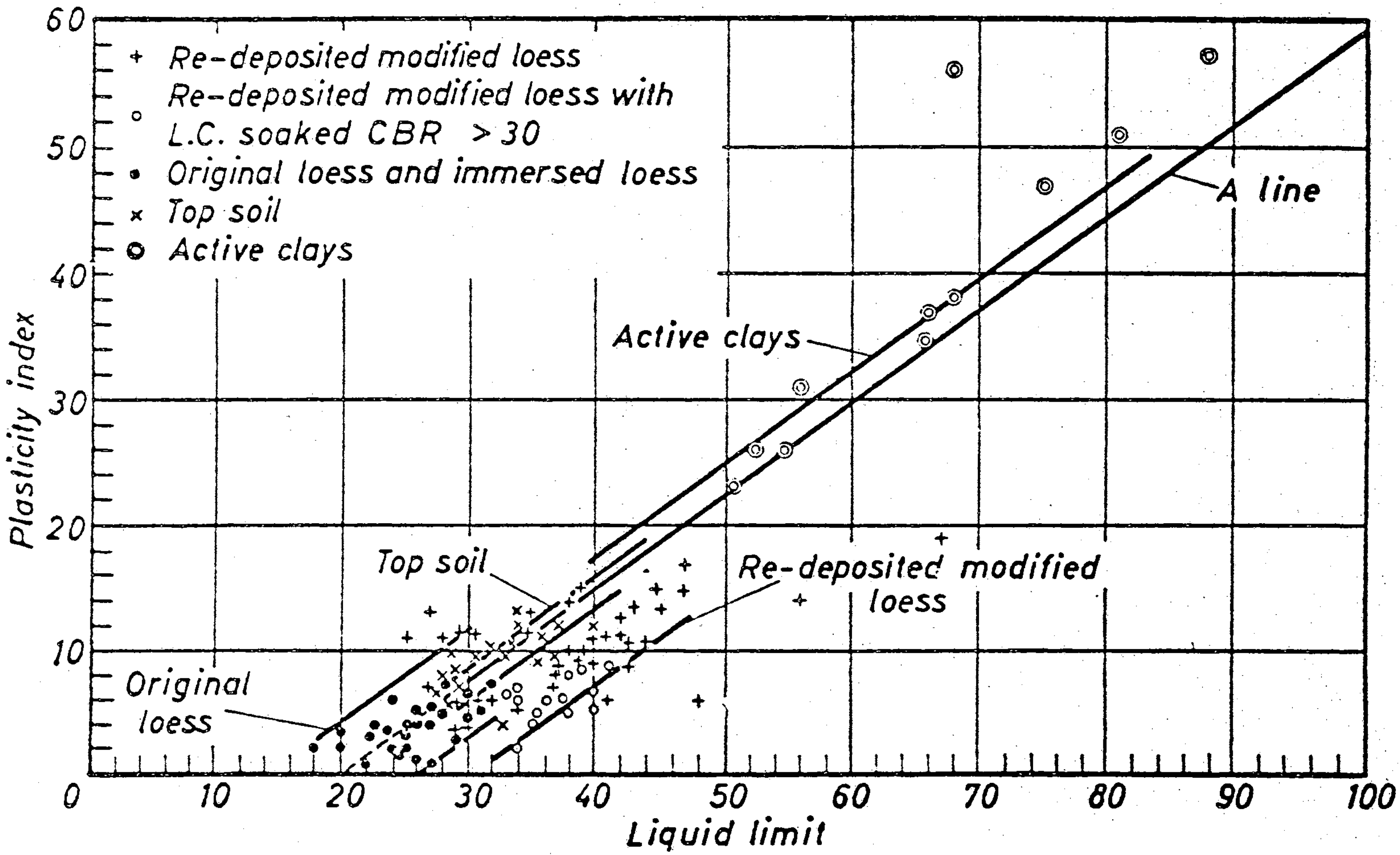


Figure 11 (5) - Plasticity Chart for Original and Redeposited Loess tests are required to predict its presence. Triaxial tests and California bearing ratio tests are good examples.

The redeposited modified Loess was used successfully as a subbase and subgrade material for both highways and airport runways in Argentina (5). It is worth noticing that the climate there is such that frost action was not a factor to be considered during construction.

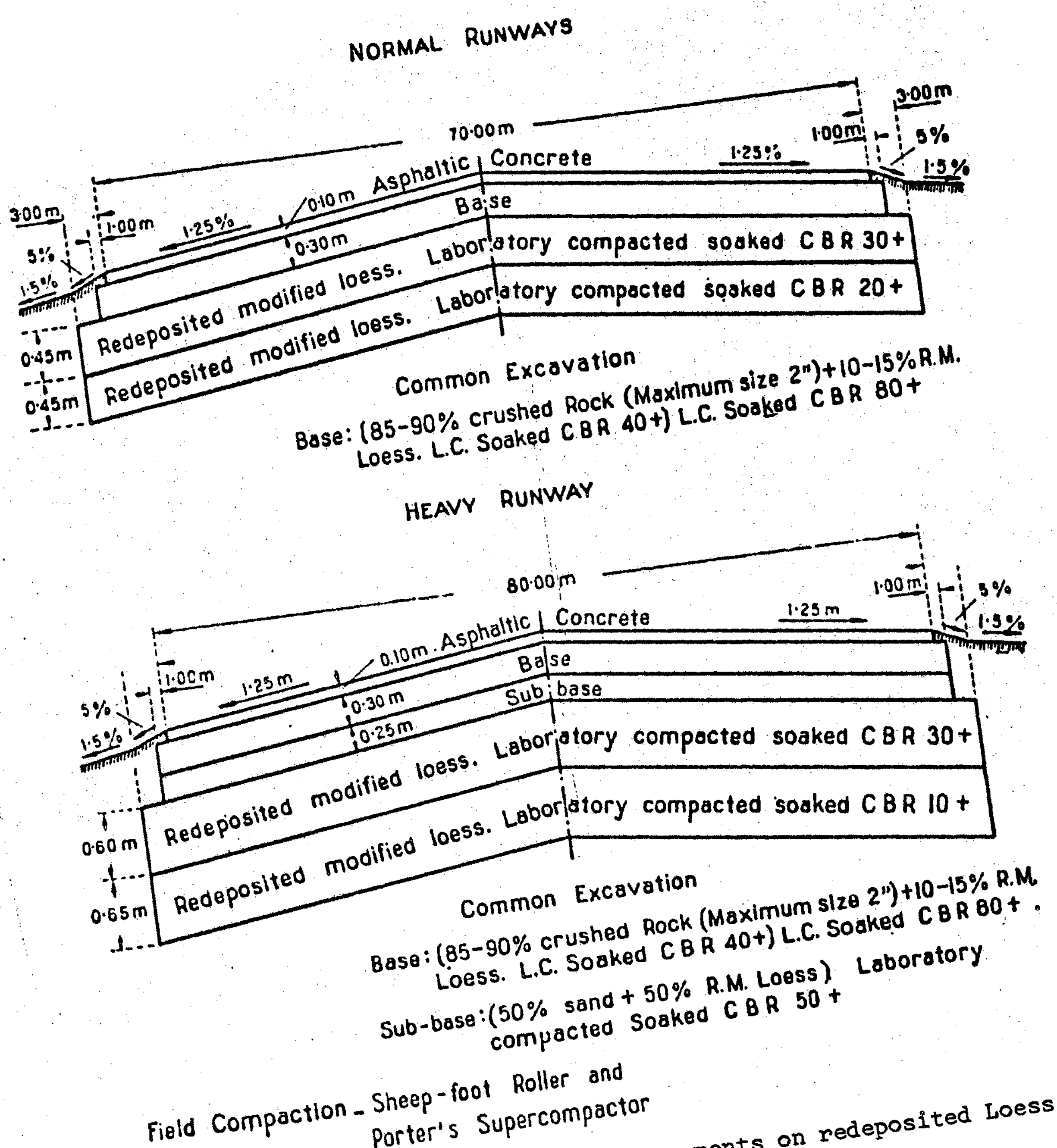


Figure 12 (5) - Cross sections of pavements on redeposited Loess

CHAPTER III

CONSTRUCTION AND FOUNDATIONS ON LOESS

In carrying on investigations on Loess foundations, it is very important that the methods utilized give numerical values of the in-situ density. Field density is obtained from measurements either from an open test pit or from an undisturbed sample. Density could be computed from direct measurements made on samples obtained by means of the auger-bore. A very economical preliminary test, is the standard penetration. It involves determining the number of blows required to drive a cylindrical sample of 2-in. outside diameter, 1 foot into undisturbed material using a 140 lb weight dropping from a distance of 30-in. The standard penetration test although economical, but it is not always reliable, because sometimes the number of blows obtained is not a good indication of the characteristic of Loess to serve as a basis for design. However this test proved to be useful in determining whether a deposit is uniform or non-uniform in both the horizontal and vertical directions. In general the number of blows (N) for typical Loess deposits vary from about 4 to 20.

Sometimes load tests are necessary after exploration by borings and penetration tests, in order to determine the allowable soil pressure. These tests are necessary especially when rafts and footings are used to support a structure. Care should be taken when using plate load tests, because different plate sizes give different results, for example settlements caused by large plates are greater than those caused by smaller plates, because the distribution of pressure under larger plates includes greater depths of compressible Loess. Values of settlement obtained from large plates are very close to values estimated, as the plate size decreases, estimated values become less accurate. These relationships are illustrated in Figure 13. It is of interest to note that curve computed from consolidation tests and the plate load test, (for example the 3 by 3 feet plate), have similar shapes for the beginning part, indicating that consolidation is the primary cause of settlement of the plate in that range of loading. For greater loadings, the plate load-test curve shows greater settlement and crosses the computed curve, indicating progressive settlement and greater effects of shear failure (16).

1. Footings and Rafts on Loess

As mentioned before, when footings or rafts are to be put on Loess soils, plate load tests should be made first. These tests are usually made in pits not smaller than 4 by 4 ft. in plan, and the bearing plate should be 1 ft. square (33). There should not be any surcharge around the loaded area, and the load should be increased until failure occurs, or until the pressure beneath the test plate is at least three times that contemplated beneath the footings or rafts (33), which means a factor of safety of three will be the minimum requirement for the foundations. Usually a curve showing load versus settlement is plotted, and the allowable soil pressure is not to exceed one third of the load that corresponds to the point on the curve at which the settlement begins to increase rapidly for small increments of load. No matter what the results are, the allowable soil pressure should not exceed half the

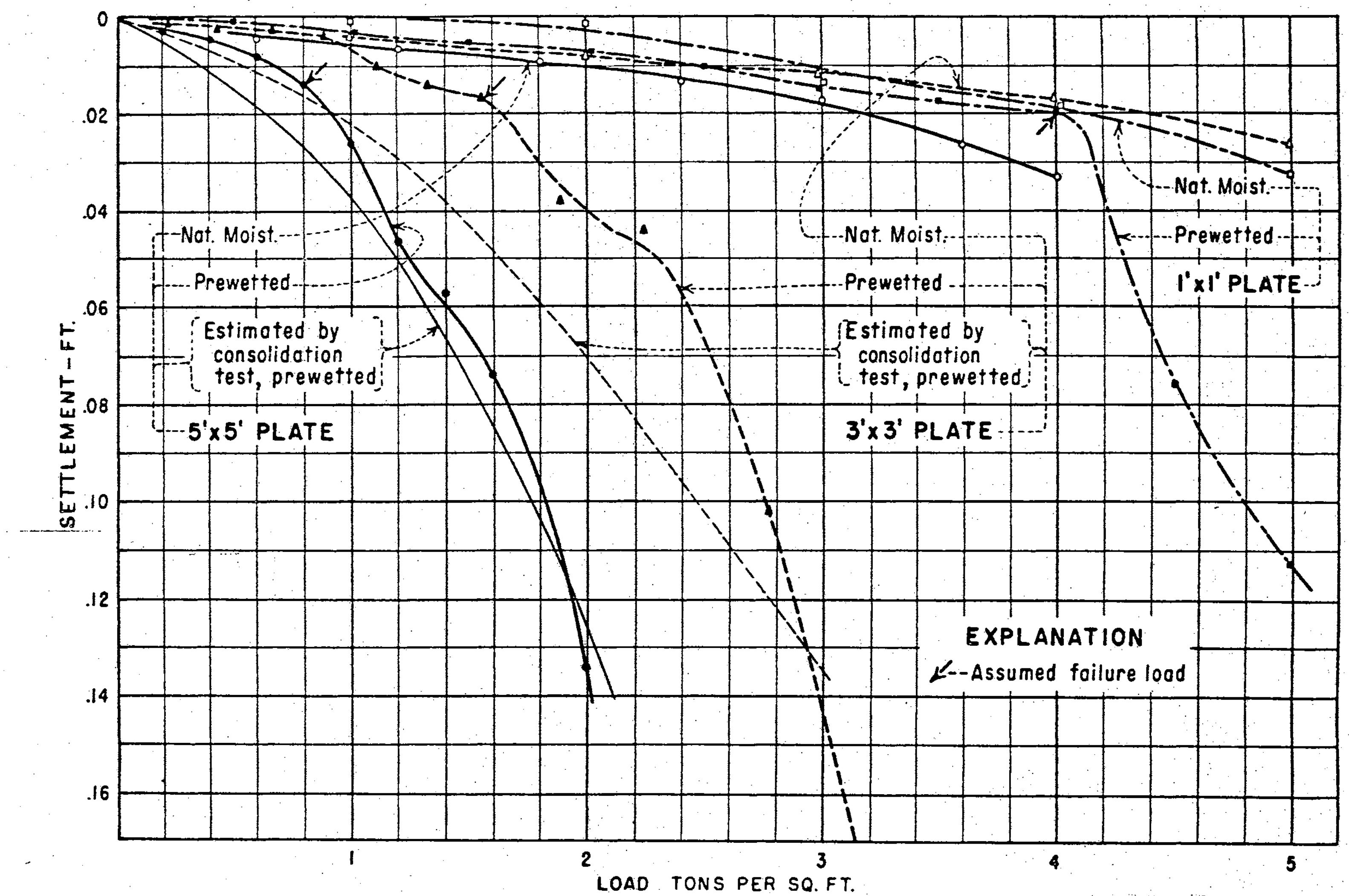


Figure 13 (16) - Plate load tests for a typical Loess deposit value at which the settlement of the plate is equal to 0.5 in. (33).

Since stresses induced by building loads are generally significant, care should be taken to make sure that the strength of the Loess deposit does not decrease an appreciable amount within the depth. The pressure at any depth must not exceed the allowable soil pressure for that depth as determined by means of the load tests. Other precautions must be taken too, to ascertain that the water table does not rise, and any activity that may lead to saturate the Loess, should be prevented to avoid subsidences.

2. Piles and Piers on Loess

Placement method has a great effect on the load carrying capacity of friction piles. This is illustrated as follows (16):

a. For displacement piles in Loess which will be wetted in the future, pre-wetting the soil is recommended, since higher strength will be obtained due to maximum consolidation of surrounding material. That is why displacement piles are not recommended for dry prebored holes in dry Loess, since weakening is expected upon wetting the soil.

b. Placing displacement piles in jetted holes, may be possible in certain instances, since holes smaller in diameter than the piles may be made from the jet water. Usually the stream of water is ejected into the ground at pressure of 100 to 200 psi, from the end of a long vertical pipe guided by the leads of the pile driver, the water is jetted in small holes to cause wetting and to aid in driving the pile.

c. Placing displacement piles in prebored holes in Loess at low natural moisture content is not recommended, since virtually no consolidation of surrounding material is obtained on driving, and in this case, after the foundation is wetted, a weak bond between the soil and the pile can be anticipated. In addition considerable weakening of the Loess surrounding the pile can be expected.

d. The use of displacement piles placed by driving alone in Loess at low natural moisture content is not recommended, since driving is extremely difficult and adequate penetration cannot be obtained, also the load bearing capacity after wetting the soil is low.

Non-displacement steel H-piles can be driven in Loess at low natural moisture content, but adequate embedment in permanently firm material is necessary since shearing resistance in loose wetted Loess is quite low (16).

End bearing piles resting on firm bearing material such as dense sand are quite satisfactory regardless of the placement method, provided they are held for adequate lateral support (19).

Timber or steel shell could be used as displacement piles, they have almost similar driving and loading characteristics but the choice on which pile to be used rests on the strength limitations of the pile itself.

Holtz and Gibbs (19) put the following rules for piles placed in Loess, assuming material underlying a pile foundation to be competent.

a. When Loess is at densities below 80 pounds per cubic foot, piles must have firm end bearing or a substantial amount of embedments of the ends in dense material of permanently high shearing resistance.

b. When Loess is at densities from 80 to 90 lb. per cubic foot, friction piles will generally be satisfactory, supported only by adequate embedment in the Loess, based on wetted conditions.

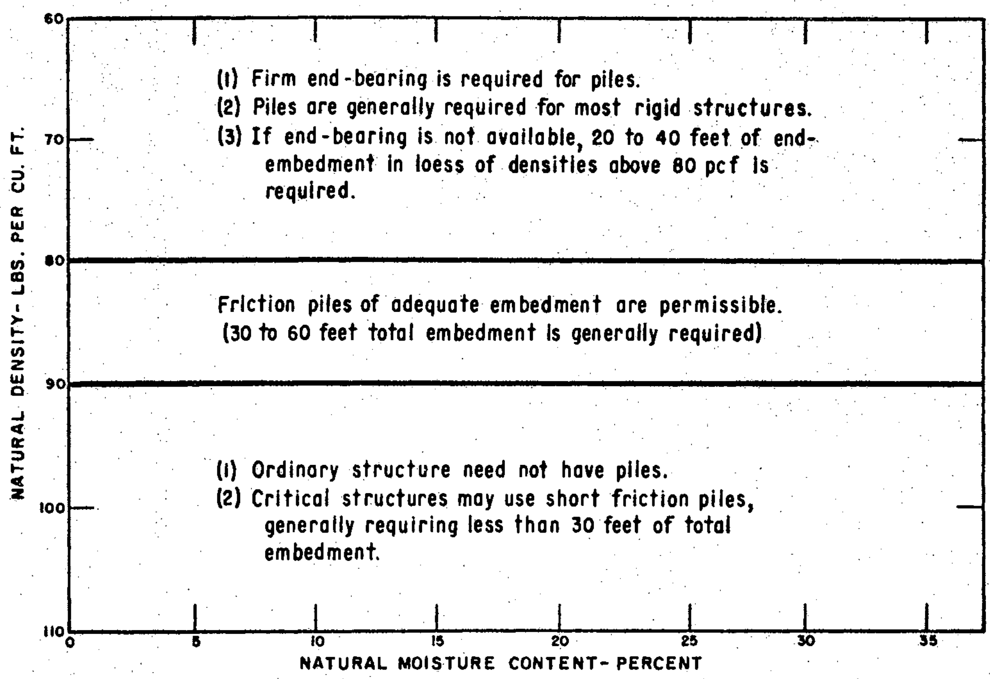
c. When Loess is at densities greater than 90 lb. per cubic foot, moderately located structures may be supported without piles; and if piles are found necessary for critical structures, relatively short lengths may be used.

Figures 14 and 15 show the general requirements for piles and pile driving in Loess on the basis of moisture content and density of the natural Loess.

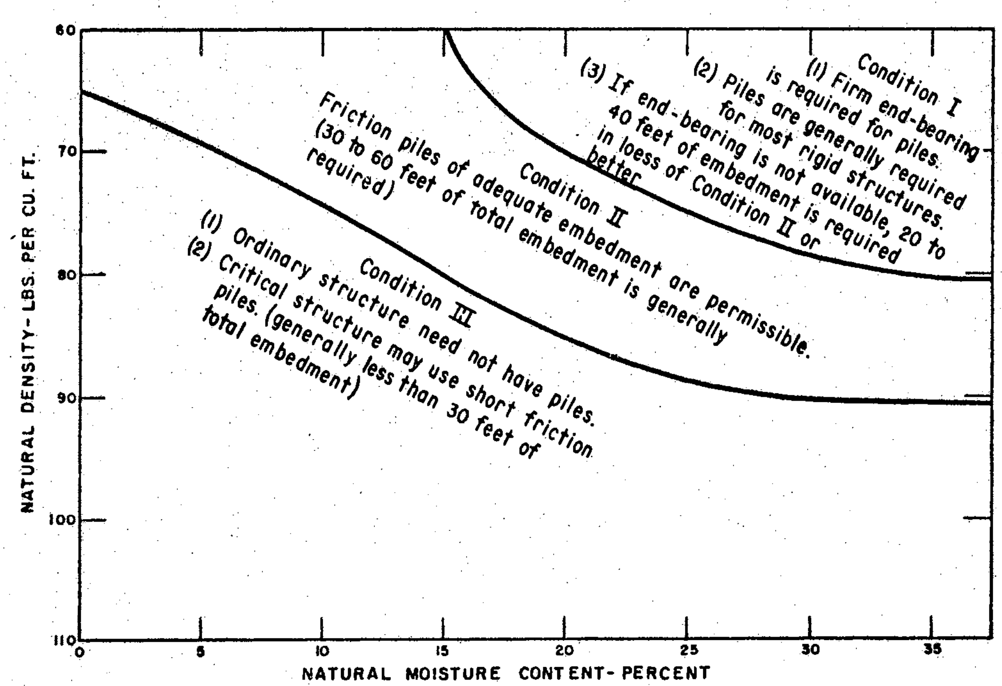
If the supporting capacity of Loess is inadequate, loads are usually transmitted by piers through the Loess to the underlying firmer materials. No difficulty is encountered in carrying out the excavations because the material, as mentioned before, has the ability to stand vertically without any lateral support. It is important that surface water be prevented from accumulating in the bottom of the excavations because such water causes the softening of the cohesive bond in the Loess and leads to construction problems and difficulties.

3. <u>Dams and embankments on Loess</u>

Before doing any construction job, laboratory tests should be run on undisturbed samples to determine whether the settlement after construction is significant or not. If the settlement is expected to be

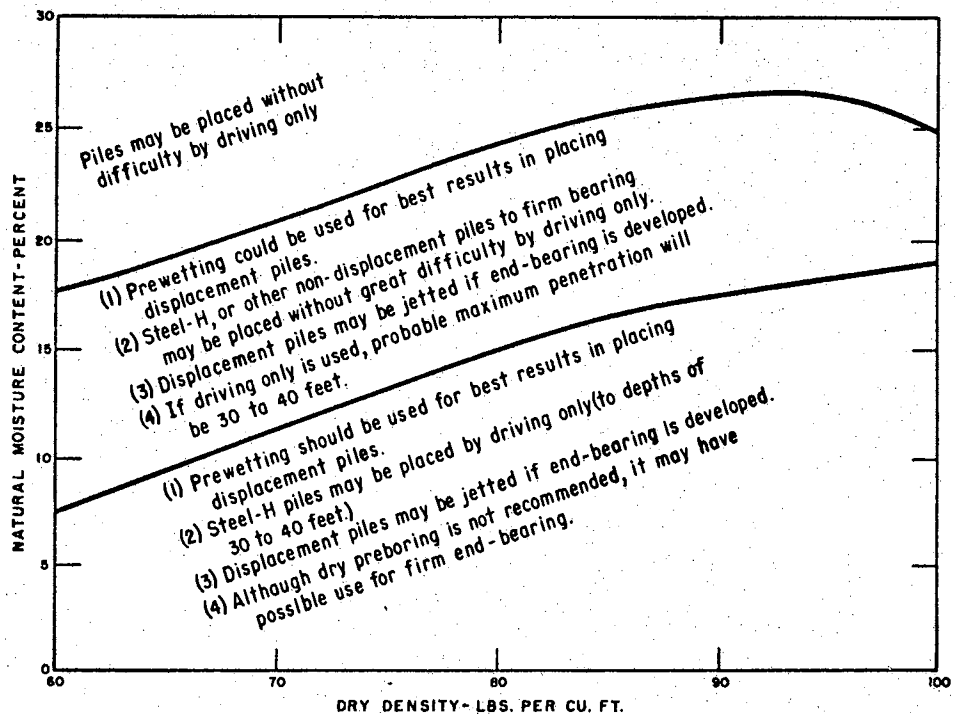


CASE 1. When higher moisture contents are anticipated.
(As in the case of hydraulic structures)

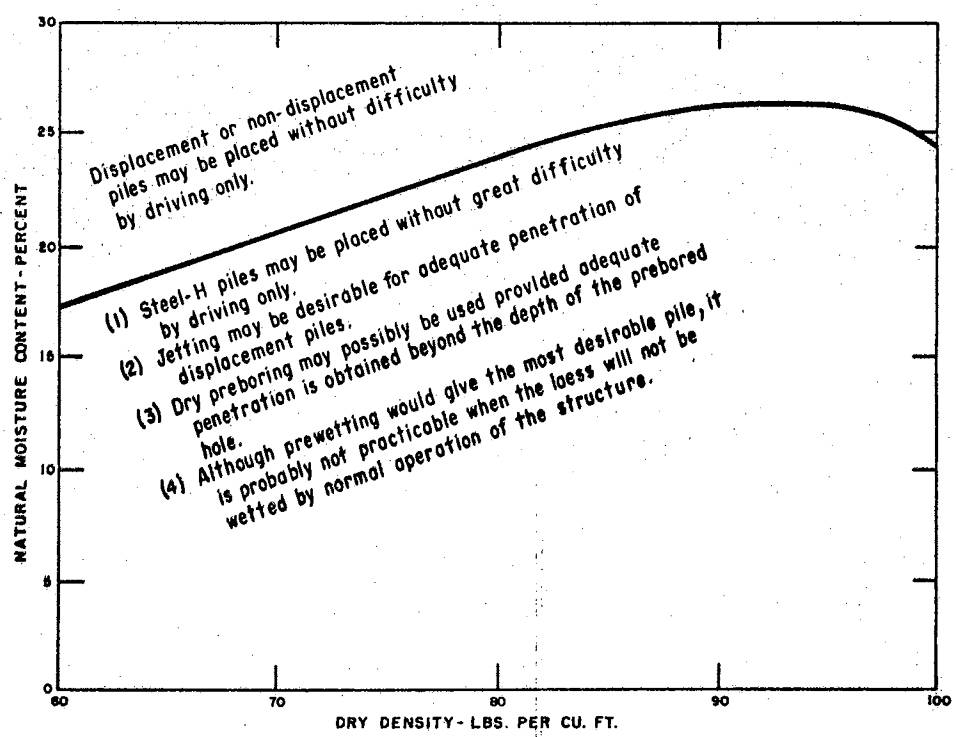


CASE 2. When natural moisture contents are not expected to increase.

Figure 14 (16) - Requirements for adequate supporting capacity of piles



CASE 1. When higher moisture contents are anticipated. (As in the case of hydraulic structures)



CASE 2. When natural moisture contents are not expected to increase.

Figure 15 (16) - Requirements for Practical placement of piles excessive on saturation, some kind of soil treatment is required. But if the upper stratum is composed of low density Loess, then it might be more economical to excavate the material and replace it with compacted embankments. As the Loess is compacted in an embankment, it acts like an impervious and stable material having a larger strength and a considerably lesser tendency to consolidate whether its saturation is full or partial. It should be borne in mind that compacting Loess into an embankment does not necessarily mean that the shear strength is retained permanently; because this compacted Loess still may lose a large portion of its strength in its wetted conditions. If the upper layer of stratum is made up of thick layer of Loess which makes it uneconomical to replace it or destruction would be brought about for a natural blanket over a pervious foundation, steps should be followed to ascertain that the consolidation is achieved during construction work. This could be accomplished by pre-wetting the foundation. Sprinkling and ponding were used very successfully in the preirrigation of foundations of dry low density Kansas-Nebraska Loess under dams (21). In order that this method could be used drainage should take place by an underlying pervious layer, but if the Loess deposit is very thick, no underlying pervious material is necessary because vertical drainage occur during the compression of the upper portions of the deposit. The period of ponding or wetting depends upon the nature of the Loess. It usually runs between 6 to 9 weeks. In Ashton, Nebraska, wetting was accomplished by continuously ponding 1 foot of water over the area; after two weeks of ponding, open drill holes were made to expedite wetting.

4. Canals on Loess

Research carried out by the Hydrochemical Institute, in Bucharest, Bulgaria (3) on canals, showed that two thirds of the settlement occured in the first year of operation, the remainder in the second year, and later settlements were not significant. This led to the conclusion, that although the sensitivity due to wetting and the thickness of the Loess layers are necessary, yet they are not sufficient conditions for producing Loess settlement under its own weight. The general equilibrium state of mass (and especially the ratio between wetted volume and its lateral surface) is decisive for the start of settlement (3). The settlement due to wetting does not occur as long as the size of the wetted soil mass does not surpass a critical value. The Loess structural resistance weakened by wetting and the tendency to settle under its own weight are counterbalanced by the surrounding unwetted mass, which has a considerable structural strength. Deformation will occur only at the moment when the general equilibrium conditions of the mass, including the moistened as well as the non-moistened surrounding zones, reach a critical value. Construction of irrigition system on Loess in Bulgaria were made in two phases. In the first year the canals were excavated to the design width but only to the minimum depth required for securing the water circulation in the system (approximately half of the final depth). Systematic flooding, accompanied by measures of silting prevention were then conducted so as to ensure that both wetting of the Loess deposit and the development of the deformation take place to as large an extent as possible. During the second year, deformations were for most part complete, and work was then produced on the excavation of the canal to its final profile, and normal operation of the system was begun. Additional structures and the eventual water proofing of the canal were done in the following years.

CHAPTER IV

STABILIZATION OF LOESS

1. Silt Slurry Method

The most common method of injecting silt slurry into a deposit of Loess, is to bore down four holes on a square of six feet, not less than ten feet below the depth of the structure to be stabilized (33). Water is then run into these four holes, keeping it at a level equal to the bottom of the structure to be stabilized, making sure that the soil is thoroughly wet to the bottom. A hole is then bored in the center of the four holes for the injection pipe. It may require several days of percolation to get proper moisture distribution before the injection pipe is inserted (33). For such tests it is recommended to have the slurry as thick as possible (as the pump may allow). When consolidation is complete, slurry is jetted out at least five feet below the end of the pipe (33). If the slurry breaks out, it is left to rest for twenty four hours and another injection is made. The same procedure is followed until proper density is built up to support the structure; (this might be obtained after four or more injections).

Before silt injections are used for Loess deposits, laboratory and field tests are first run to study the results which can be secured by this method of consolidation. If the soil contains an appreciable amount of colloidal particles, which might prevent the water to be squeezed out of the soil, then the soil will remain liquid and consolidation will not take place. If results obtained from mechanical analysis and laboratory tests indicate that the water would be squeezed out under pressure, then field tests should be run to determine the final results before injection.

This method of silt injection has been used very successfully in canal systems in Nebraska, to prevent subsidence of loose Loess type soils. It has been used both during construction work and during the operation period. Pressure used for injecting the slurry was 50 psi (22). Usually fine sandy silt soils are used for the slurry, because the water could be forced through the silt, and high intergranular pressures would be developed which cause the loose foundation soils to be compacted.

2. Sodium Silicate Solution Method

Loess could be stabilized by the injection of sodium silicate solution, this solution when injected produces immediately a silicate gel film which gives the Loess the following properties: increased strength, resistance to water action, incompressibility and impermeability. The solution used should be 1 N to 1.5 N, and it is injected into the macrocapillaries of the soil where coagulation occurs. The solution is easily penetrated because the soil has high void ratio or rather vertical tubular structure and the solution itself has a low viscosity. Swelling values of the Loess after using this method would be reduced markedly.

3. Thermal Method

Research in the USSR (23) showed that the thermal consolidation of Loess soils could be obtained by the process of firing the ground at a temperature of 700°C to 900°C, for a period of time during which the soil changes its physical properties. They had established that Loess loses its susceptibility to subsidence after being heated to a temperature of 300°C. The specimens of Loess which had been thermally stabilized showed no loss in strength after the soil was submerged in water for a period of eight years. Water containing sulphates did not have any adverse effects on the stabilized soils, and this result was reached to, after fifty five tests were carried out in the Soviet Union on bore holes 20 ft. long.

Treatment was run as follows: A special apparatus for firing was driven inside a 7.5-in. diameter borehole, its top portion having a diameter equal to that of the bore hole, and the lowest part insulated with asbestos, serving as a barrier between the fire zone and the upper part of the hole. The air necessary for the gas combustion and for the creation of internal pressure was provided by a compressor. The natural gas used contained 94 per cent to 96 per cent methane.

4. Foamed Asphalt Method

When asphalt cement is converted to a foam asphalt it acquires some rather new unusual properties; its volume and viscosity increases, it becomes softer at lower temperatures and remains soft for a long period of time, it becomes more sticky and more rubbery, and it acquires a surface energy which makes it adhere to the aggregates, even the moist or damp ones. The asphalt recovers its original properties when the foam bursts. Loess stabilized with this foamed asphalt was used successfully as a highway material in Sioux City, Iowa. Stabilization was conducted as follows (26):

a. A 2-in. layer of blow sand was spread over the surface to yield 33 per cent sand in the 6-in. stabilized base.

b. Sufficient water was spread over the sand to provide about

11 per cent moisture in the base prior to the application of the foamed asphalt material.

c. A single pass of the P & H stabilizer was made over the sand and Loess, in which process the Loess was cut out and blended with the sand, then 6 per cent of foamed asphalt cement (120 to 150 penetration) was mixed with the blend as the machine moved forward at a speed of twenty seven feet per minute.

d. The stabilized soil blend was then compacted by a sheeps-foot roller equipped with a drag, until the roller walked out. The rolling followed stabilization by about thirty minutes.

e. Sheeps-foot rolling was followed by light shaping of the surface by a grader and final compaction with rubber tired and steel rollers.

f. The finished asphalt base, 6-in. in depth was surfaced with a double inverted penetrator seal, using three over eight chips and RS2 emulsified asphalt.

In sections where rain was encountered, an aeration process was made after the stabilization pass was completed. The loose material was allowed to aerate until moisture was reduced to a point where satisfactory compaction could be attained.

5. <u>Mechanical Compaction Methods</u>

Measures taken to prevent wetting of the soil under foundations do not always meet success; because some factors may lead accidentally to wetting. The simplest method of eliminating settlement, is the compaction of soils by mechanical means. This method has good efficiency and was used with good results in the construction of earth dams of Loess soils in the Soviet Union. These dams have been used for many decades without damage. During their construction, only destruction of the natural soil structure took place, the granular and chemical composition of the Loess was preserved.

Compaction of thin layers of Loess was usually carried out by heavy tampers up to the point of refusal or until settlement ceases, that is after a certain number of impacts, the lowering of the tamped surface following the last impact does not exceed a certain specified value. This value is usually 1 to 1.25 cm for Loess soils (2).

The tampers used nowadays in the Soviet Union are dropped from a height of 3.5 to 4.0 m; a number of 8 to 12 impacts are needed to completely compact the soil with a tamper that weighs .35 tons. Figure 16 shows the relationship between settlement of the tamped surface and the number of impacts. The depth of the compacted layer is 1.5 times the diameter of the tamper.

Deeper layers of Loess soils are compacted by the use of mixed in place stabilized soil pile. Energy of explosion is used during compaction. A 60 to 70 mm diameter hole is drilled to the designed compaction depth, then a blasting charge is lowered into the hole. The charge consists of standard ammonite cartridges weighing 50 gm each and 42 mm in diameter. The charges are exploded and the stabilized soils piles tamped (2).

Friction piles could be used too, but their use on highly compressible Loess soils are not very effective in reducing settlements.

Consolidation of Loess by means of explosives as mentioned up, is more effective than consolidation by pile drivers with the aid of cores,

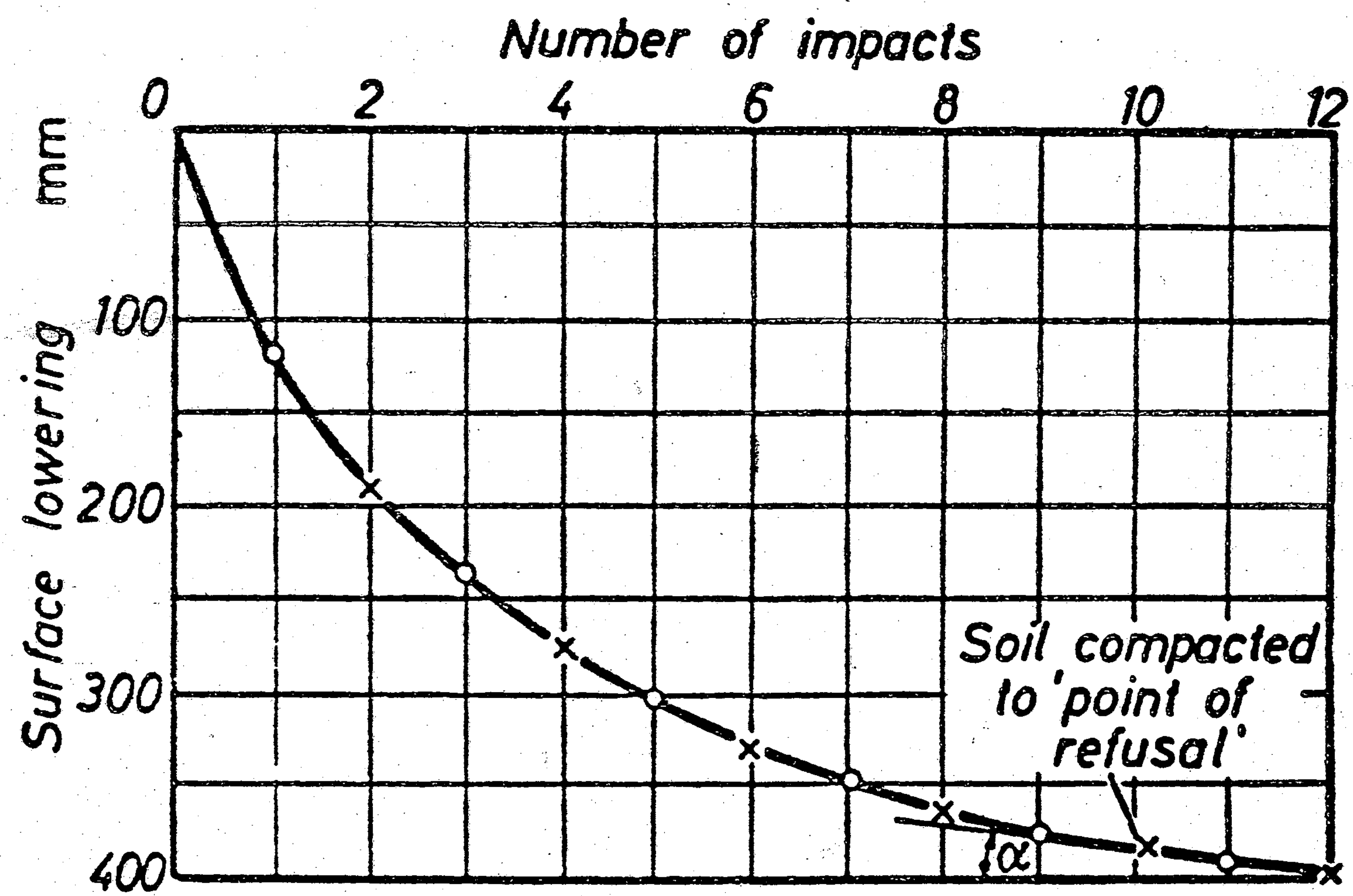


Figure 16 (2) - Settlement of tamped surface with number of impacts because the first method does not require heavy equipment, and permits the use of stabilized soil piles inside buildings in restricted conditions; it also insures uniform soil compaction for the whole depth.

CHAPTER V

CONCLUSION

Loess which is mainly composed of silt-size particles with minor fractions of clay or sand, and which is transported for long distances by wind and then redeposited, could form an adequate foundation for various engineering structures, if careful studies and investigations are carried out before any construction work. This type of soil has unique and peculiar characteristics which makes it differ greatly from other types of soils under the action of load and other natural conditions. Its high void ratio could cause a lot of damage if precautions are not taken to prevent settlement. The most detrimental factor, is the action of water which removes the clay particles and the calcium carbonate material that form the major binders of the silt-sized grains, thus resulting in large settlements. These settlements sometimes could reach a value of 3 yards.

Studies and investigations include running penetration tests, shear tests, load-plate tests, and consolidation tests; others include determination of densities, moisture contents and atterberg limits.

Shear and load-plate tests should be run on samples at their natural moisture content and at saturation. Settlements obtained from the load-plate tests should be correlated with those obtained from the consolidation tests. Many times judgement should be applied to determine whether to accept certain values obtained by a test or not, because results obtained in the laboratory do not most of the times represent the soil in the field.

Loess soils with low moisture content and relatively higher clay content, have higher shearing strength than those with higher moisture content and lower clay content.

Methods to improve the engineering properties of Loess soils, to make it suitable for supporting structures include the followings:

a. If the Loess is in a dry state, and if there is no way for moisture to reach it, then there is no danger of settlement.

b. If the layer of Loess is thin, it could be much cheaper to replace it with another soil of better engineering characteristics, under adverse conditions, than to stabilize it.

c. Ponding. This will cause the Loess to consolidate under the water before construction begins. Very good for hydraulic structures.

d. Injection with silt-slurry to prevent subsidence, especially of loose Loess deposits.

e. Injection with sodium silicate solution, to increase the strength of the Loess and make it water resistant.

f. Stabilization with foam asphalt, this will increase the strength of the Loess and make it water resistant too.

g. Consolidation of Loess by thermal action.

h. Compaction of Loess by mechanical means, this includes tamping or pile driving.

It is important to know that if the Loess is allowed to be saturated and settle before construction begins, it will have good bearing capacity. Although its strength will not be as high as dry Loess, yet there is no danger of settlement due to future wetting after the completion of the structure.

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