SUB-SECTION IV d

MISCELLANEOUS

IV d 3

UTILITY OF LOESS AS A CONSTRUCTION MATERIAL

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SYNOPSIS

Field and laboratory studies on a major construction project in Nebraska demonstrated that silty loess soil could be safely used as embankment material for dams and, in the natural state, as a foundation for dams and hydraulic structures. Favorable behavior during the nine years since construction has justified the design procedures developed as a result of the preconstruction studies.

INTRODUCTION

Approximately 9 per cent of the earth's land surface consists of loess and loess-like soils; therefore they comprise one of the most important soil groups. In spite of this,little is known about this group of soils, particularly from the engineering viewpoint. Many engineers and engineering organizations are faced with construction problems in loess areas.This is particularly true of the Corps of Engineers because of its widespread activities. It is only by continued laboratory research and systematic field studies of old and now engineering structures built on and of loess that our knowledge of this very important soil can be enhanced to the point where it can be used as a construction material with a large degree of confidence.

The purpose of this paper is to review the knowledge and experience gained on a major construction project where loess was the primary soil type. Attention is directed to the fact that there are many types of loess and loess-like soils, and that they usually have the same characteristics but to a variable degree. Space is not available and it is not the intent to give a discourse on the origin and formation of loess soils. Excellent works are available on this subject. 1)

The project on which the information and experience presented in this paper were gained was a large power and irrigation development known as the Central Nebraska Public Power and Irrigation District. It was constructed during the period 1936 to 1941. and is located in south-central Nebraska in the Platte River basin. The particular portion of this project with which this paper primarily deals is known as the Supply Canal. The canal leaves the lowlands on the south side of the Platte River just east of the town of North Platte and cuts through loess ridges to the loess tableland and thence back to the lowlands for the power drops. Figure 1 shows the layout of the Supply Canal. The loess ridges separate canyons from 100 to 200 ft deep. These canyons had dry water courses running in the general direction of the canal. It was found feasible to utilize the canyons as part of the canal system by damming off the lower end of each canyon. In accomplishing this, 24 earth dams ranging in height from 25 to 80 ft were constructed out of loess and on loess foundations.

The principal soil encountèred on this work was the yellow Peorian loess of the Pleistocene age. The depth of the loess stratum under the dams ranged from 25 to 200 ft. Throughout the region the loess is underlain by a well graded and quite pervious waterbearing sand-gravel. The water table coincides quite closely with the top of the sand-gravel stratum and slopes eastward with a gradient of about 6.5 ft per mile.

DESCRIPTION OF THE LOESS MATERIAL

The natural loess banks in the area studied were observed to stand quite steeply where good drainage existed away from the top of the bank. One natural bank stood 53 ft in height and had a slope of 1 (vertical) on 1/4 (horizontal). On the face of this bank the words "June 1912" were still plainly legible, indicating that for at least 28 years there had been no disturbance of the bank face. Railroads through the area utilized steep slopes in both cut and fill sections with a high degree of success. Generally frost effects on the slopes were negligible. Columnar sloughing was quite evident and in some cases natural banks were found to be overhanging. Figure 2 shows evidence of this type of sloughing. Examination of the loess indicated the presence of a tubular type of structure, with the tubes running in a general vertical direction.

The avialable geological information indicates the bulk of the loess in this area has never been subject to complete saturation Evidence of this is shown by the consolidation of the loess due to its own weight when saturated. One striking case was found where a small irregation canal had been in operation in this area for about 15 years. This canal furnished irrigation water for a high terrace where the thickness of the loess material was about 80 ft. Level records on several farms indicated that the average surface elevation was 2 to 3 ft lower than at the beginning of irrigation. Settlement was very irregular and large cracks were found. Investigstions indicated this to be due to a process of consolidation of the soil due to its own weight within a ground water mound or saturated zone at the base of the loess. The saturated zones were caused by leakage from the surface through holes or along cracks. The consolidation together with bridge ing of the dry loess formed openings over the mound, into which soil from the surface could be carried. In instances it is believed that whole blocks of the soil tilted in toward the open crack. Figure 3 is a schematic drawing which more fully illustrates the above condition.

Occasional lenses and strata of sandy material are found throughout the area, but the predominant soil is silty. Figure 4 shows the range in gradation of the loess soils together with a gradation curve representative of the silty loess from 4 dams on the project. This

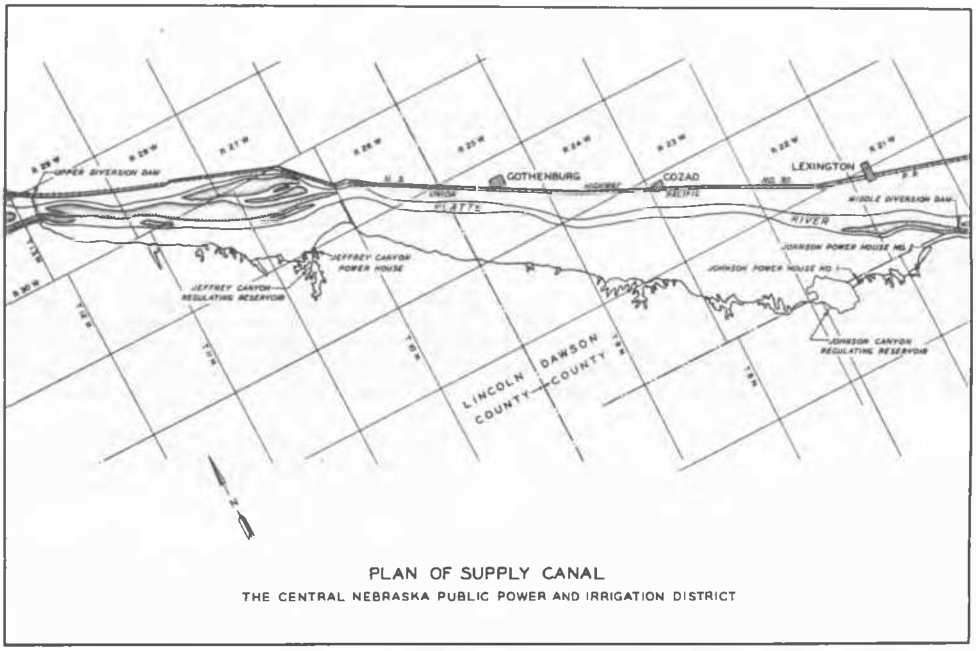


FIG. 1

Columnar slouching of silty loess bank

FIG. 2

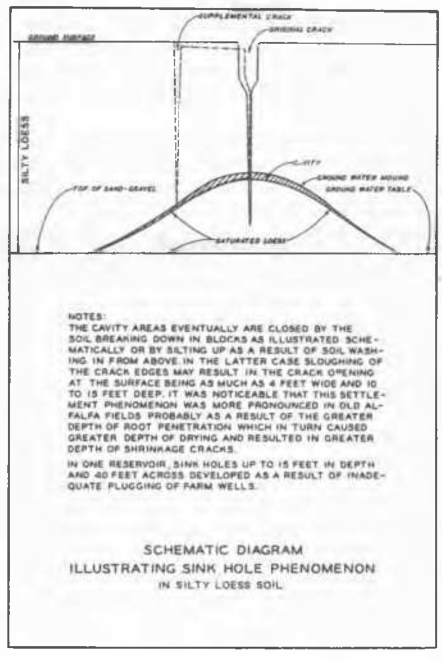
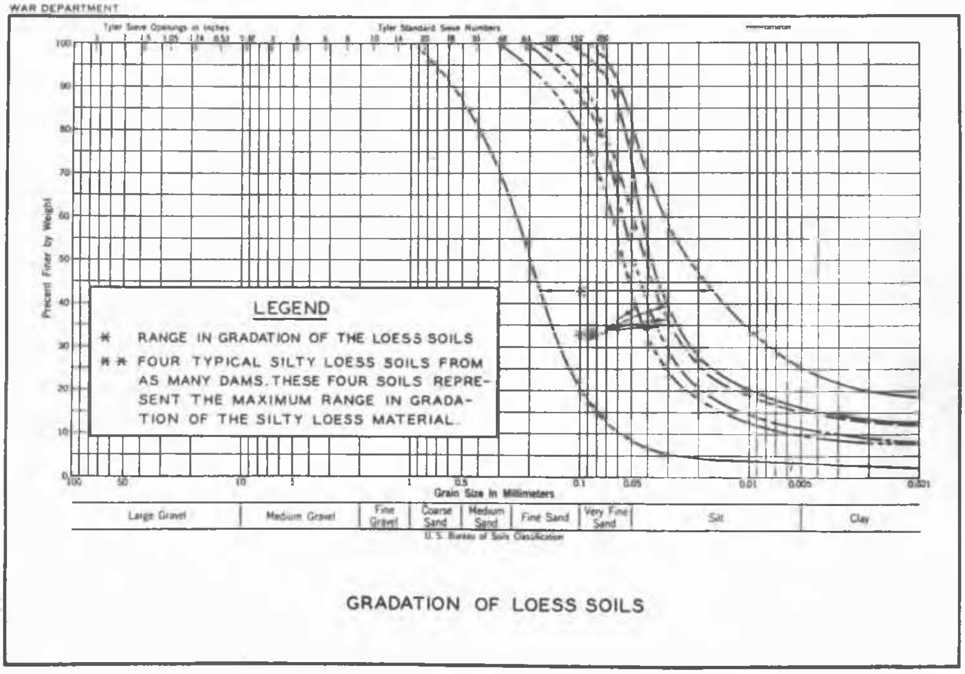


FIG. 3

material typically has a liquid limit of approximately 30 and a plasticity index of about 13 with a calcium carbonate content averaging about 2 per cent. It is classified as ML by the Corps of Engineers (Casagrande) classification. The optimum moisture content and maximum unit dry weight in the standard Proctor compaction test range from 17 to 20 per cent and 100 to 105 lb per cu ft, respectively. Figure 5 shows a typical Proctor compaction curve. The average dry weight of the silty loess in place was 85 lb per cu ft. The specific gravity of the soil particles averaged 2.64.

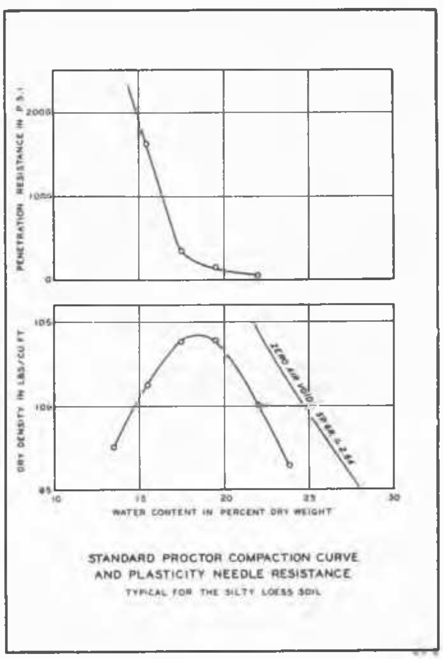
BASIC PHYSICAL PROPERTIES

Shear tests on the silty loess soil were of the controlled strain direct type. Figure 6 shows typical maximum and yield shear curves for this soil in the saturated condition. One set of curves represents unconsolidated quick tests on an undisturbed sample and the other represents consolidated quick tests on a remolded sample. It is noticed that the shear and cohesion values are quite similar for the two sets, which is probably due to the drainage features of the direct shear machine and the drainage characteristics of the loess. Figure 7 shows unconsolidated quick shear tests



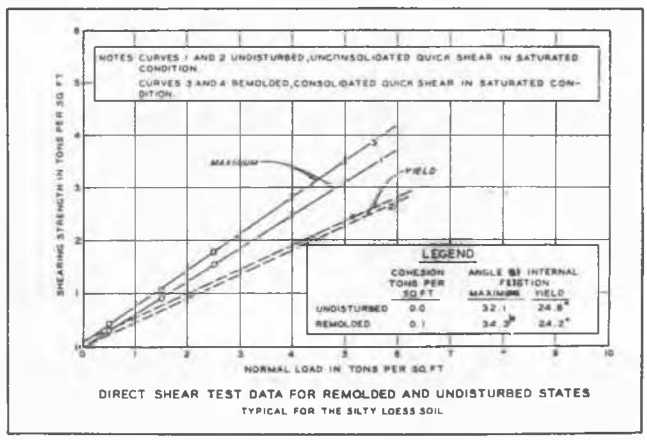
GRADATION OF LOESS SOILS

FIG.4



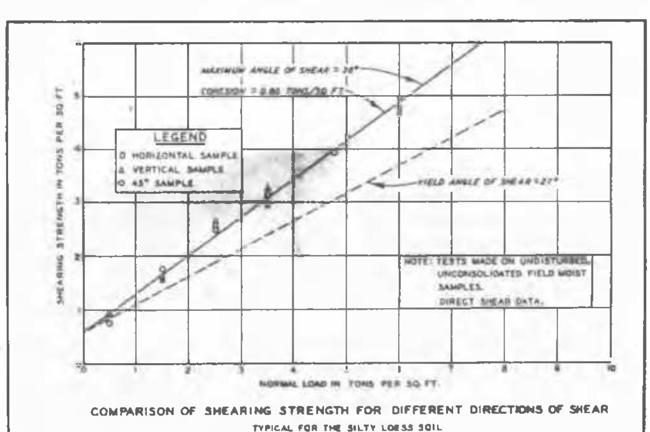
STANDARD PROCTOR COMPACTION CURVE AND PLASTICITY NEEDLE RESISTANCE
TYPICAL FOR THE SILTY LOESS SOIL

FIG. 5



DIRECT SHEAR TEST DATA FOR REMOLDED AND UNDISTURBED STATES
TYPICAL FOR THE SILTY LOESS SOIL

FIG. 6



COMPARISON OF SHEARING STRENGTH FOR DIFFERENT DIRECTIONS OF SHEAR
TYPICAL FOR THE SILTY LOESS SOIL

FIG. 7

of a typical undisturbed silty loess soil at in-place moisture content for three directions: namely, horizontal, vertical, and at 45 degrees. The test shows that the direction of shear has no effect on the friction angle. Attention is directed to the high value for cohesion. In numerous tests this value for the field moist state ranged from 0.4 to 0.6 tons per sq ft.

Typical void ratio-pressure curves for the silty loess in both the remolded and undisturbed conditions are shown on figure 8. Figure 9 shows a special loading curve developed to assist in settlement computations of the dams. The figure was included primarily to

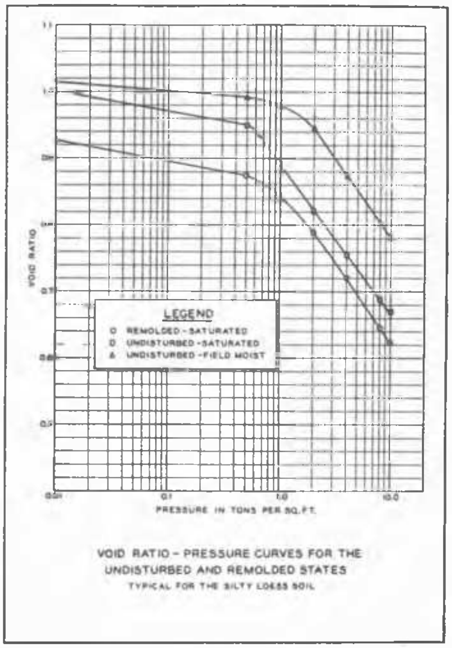


FIG. 8

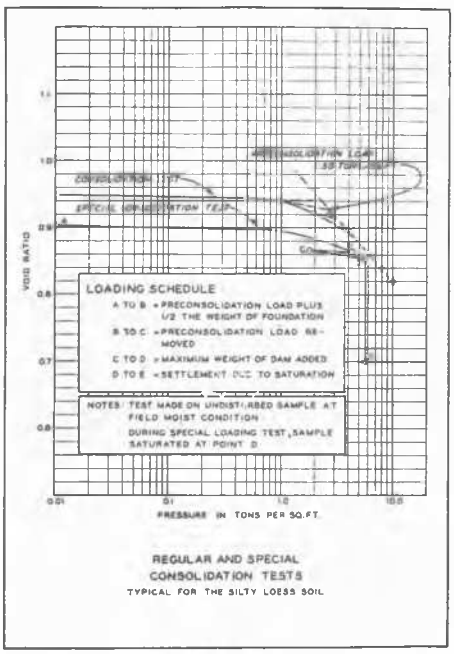


FIG. 9

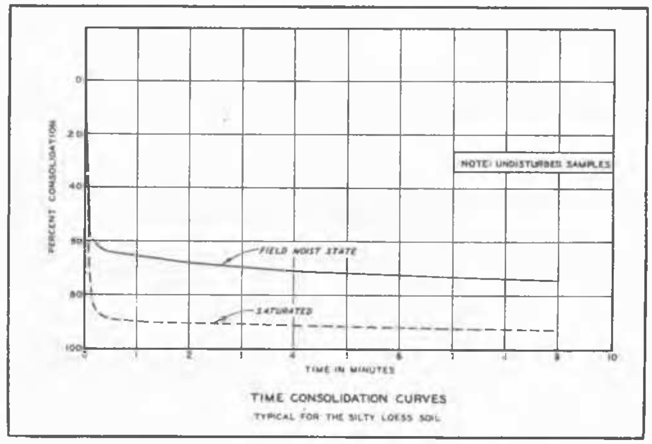


FIG. 10

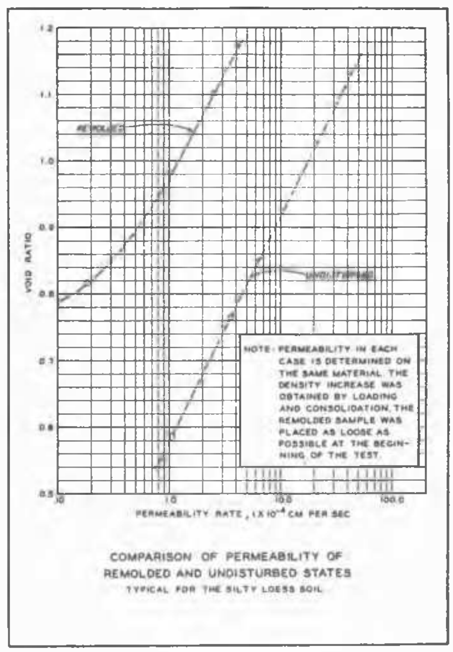


FIG. 11

demonstrate the amount of consolidation that occurs upon saturation. Figure 10 shows typical time-consolidation curves of an undisturbed sample of silty loess, one at the in-place moisture and the other for the saturated condition. Both conditions show very rapid consolidation.

The curves on figure 11 are typical of the permeabilities of undisturbed and remolded samples. It will be noted that at equal densities the remolded material has approximately one-tenth the permeability of the undisturbed material. The permeability of the undisturbed material parallel to the tubular structure (curves not shown) was two to three times greater than that across it. It was feared that the existence of this tubular structure would have a pronounced effect on seepage. Consequently a large-scale field seepage test was conducted in the largest reservoir area. Table 1 is self-explanatory and shows the results of this test which can be regarded at least as qualitative. Surface treatments of (1) scarifying and compacting, and (2) scarifying and puddling, were both quite effective in reducing seepage.

Special settlement model tests were made for the purpose of studying the effects of differential foundation settlement on the prototype. The model was so constructed that differential settlement could be applied to the soil model dam both longitudinally and transversely. Figure 12 is a drawing showing the general setup of the model. The soil was compacted in the model dam, using standard Proctor effort, at varying moisture contents above and below optimum. Figure 13 is illustrative of the test results after considerable differential settlement. It is noted that the models dry of opti-

TABLE I

RESULTS OF FIELD SEEPAGE TESTS ON SILTY LOESS

Test	Soil Type	Surface Treatment	1	10	20	30	40	50	60	70	100	120	130
A	Note A	Undisturbed	3.42	1.25	0.56	0.48	0.42	0,30	--	--	--	--	--
B	"	Bentonite added to surface at rate of 1 ton per acre (1/100 in. depth). Surface 2 in. was then thoroughly puddled w/water	0.26	0.26	0.28	0.25	0.22	0.25	--	--	--	--	--
C	"	Same as B, except bentonite added at rate of 10 tons per acre	0.10	0.15	0.20	--	--	--	--	--	--	--	--
D	"	Added 3-in. layer of clay loam to surface and puddled	0.26	0.15	0.12	--	--	--	--	--	--	--	--
E	Note B	Undisturbed	2.60	1.22	0.45	0.52	0,54	0.37	0.29	0.18	0.12	0.12	0.13
F	"	Surface disturbed 6 in. deep	1.78	1.80	1.10	0.66	0.51	0.39	0.29	0.27	0.18	0.15	0.15
G	"	Surface disturbed 6 in. deep and tamped	0.16	0.02	0.02	0.02	0.02	0.02	0.02	0.02		0.03	0.02
H	"	Surface puddled 2 in.	0.61	0.28	0.15	0.15	0.12	0.12	0.10	0.10	0.08	--	--

Note A: Approximately 6 inches of surface soil removed. Note B: Surface soil not removed.

Note The seepage tests were conducted in 3 ft by 3 ft water-tight boxes open at both ends. The box was placed open end down and the sides were carefully sealed into the soil at a point to be tested; water was then introduced into the box under a constant head over a period of time. The seepage loss in feet of depth per day was recorded.

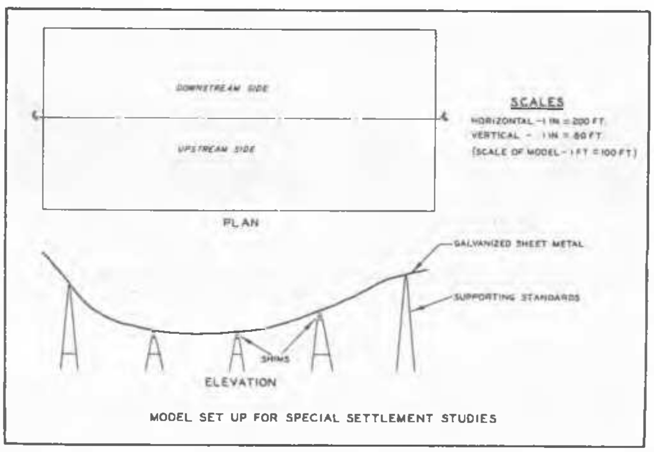


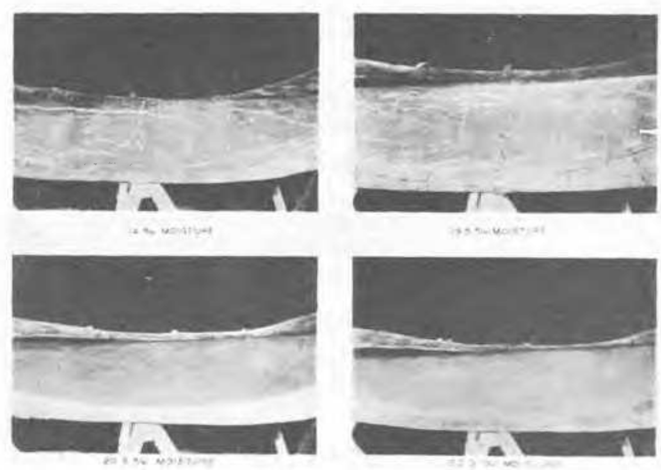
FIG.12

mum (19 per cent) showed considerable checking and cracking while those wet of optimum did not.

DESIGN CONSIDERATIONS

Foundations

Laboratory tests supported by field observations indicated that a large amount of consolidation and resulting settlement would occur in the loess as it became saturated. The possibility of the development of cracks and open fissures due to settlement was likely. Partial or complete removal of the loess foundations was considered, as was also saturation by ponding or with well points, but both were precluded due to the economics involved. It was finally decided to design the rolled-fill structures so that they would be sufficiently plastic to take the anticipated settlement. The weight of the embankments was depended on to produce



Results of special settlement tests on typical silty loess material

FIG.13

settlement of the overlying foundation material as rapidly as the underlying saturated foundation material consolidated. For the concrete hydraulic structures located where saturation was expected to occur, a grouting procedure was developed whereby a slurry of 95 per cent loess and 5 per cent bentonite could be pumped under pressure immediately above and within the saturated zone as a maintenance measure when required. This grouting was to hasten the consolidation of the saturated loess, assist in preventing the formation of cavities, and fill any cavities which might have formed.

EMBANKMENTS

The principal design consideration for

the embankments was that they should conform to the high degree of longitudinal and transverse differential settlement expected to take place in the foundation, without rupture. This was to be accomplished by keeping the moisture content slightly above optimum to maintain a plastic mass. It was realized that placing the soil in this plastic condition would result in a material that would not be as strong as if it were placed drier; however, this was recognized in the design of the embankment slopes. Special features of the embankments were gravel blanket drains over the downstream one-quarter of the foundation and soil-bentonite cut-off trenches 2) at the upstream one-quarter point.

DEEP CUTS

The backslopes 3) for the deep cuts through the loess ridges were designed on the basis of direct shear tests on undisturbed samples at natural field moisture. The relatively low factor of safety of 1.1 to 1.2 was used because it was not believed that subsequent overloading of the banks could take place to the extent of materially infringing on the designed stability. Table 2 shows the backslopes adopted for the various types of soil encountered. The adoption of these steep slopes rather than using those usually considered by designers as necessary in this area would save in excess of 5,000,000 cu yd of excavation.The soundness of the design of the slopes for the deep cuts was questioned by many engineers,and a large-scale field test was conducted while construction was in progress. In one instance a backslope of 1 (vertical) on 1/4 (horizontal) was continued past the design height of 55 ft to a height of 62 ft, at which height sloughs were occurring quite often, the first slough having occurred at a height of 58 ft. Figure 14 shows a view of this experimental section.

TABLE II

BACKSLOPES ADOPTED FOR THE VARIOUS TYPES OF SOIL ENCOUNTERED

Type Material	Maximum Height of Slope in Ft	Slope
Sandy loess	40	1 on 1/4
Silty loess	55	1 on 1/4
Sandy loess	65	1 on 1/2
Silty loess	80	1 on 1/2
Sandy or silty loess	Over 80	1 on 3/4
Coarse sandy loess or sand	Any height	1 on 1-1/2

BEHAVIOR

Seepage

Seepage under the dams and through the abutments has been negligible. The gravel blanket drains have effectively kept the downstream toe of all dams dry. Bottom treatments of the reservoirs by scarifying and tamping, and the blanketing of sand lenses has paid dividends. Seepage from the reservoirs is more or less vertically downward to the porous water bearing sand-gravel as indicated by piezometers. Piezometers within the dam embankments have also indicated a very steep saturation line within the embankment and the foundation beneath. The underlying pervious sand-gravel has undoubtedly been a material factor in maintaining this steep saturation line.

General view of experimental section through deep cuts in silty loess. Note several sloughs along right bank and absence of slough in left bank. The latter bank was laid back toll on 1/2 at a height of 55 ft.

FIG. 14

Typical views of deep cut canal sections in silty loess

FIG. 15

Stability

The dams were constructed with 1 on 3 side slopes and after 9 years there has been no evidence of instability. The high differential foundation settlements anticipated (2 to 5 ft) did take place and the dams proved to be sufficiently plastic to deform with the foundation. Grouting was sucessful in preventing excessive settlement on the major concrete hydraulic structures and insured their stability. The stability of the deep cut slopes has been entirely satisfactory, except for occasional sloughs and wind erosion on an occasional sand stratum. It is estimated by the writer that 90 per cent of all sloughs which have occurred on the steep back slopes occurred within the first 3 days after excavation. Figure 15 shows typical views of the deep cut canal sections.

Figure 16 shows a typical flow slide which occurred in silty loess soil at a road crossing ramp along the outer bank of a canal in side-

Flow slide in loose fill, silty loess soil

FIG.16

hill cut. The material involved in the slide was loose fill material cast from the canal section, which subsequently became saturated. The void content of the loose fill material was estimated at 55 to 60 per cent. Saturated natural and compacted soil adjacent to the slide showed void contents of 48 and 38 per cent, respectively. Since there was no evidence of the flow slides affecting the natural or compacted soil, it might be deduced that liquefaction of the disturbed silty loess under relatively low loads could occur at a void content somewhere between 48 and 55 per cent.

SETTLEMENT

Settlement plates were installed at eight dams. Figure 17 shows the location of settlement plates on one of the dams and the settlement curves for each plate. This is qualitatively of the settlements experienced.

At one dam a differential settlement of about 4 ft occurred in a distance of about 200 ft along the crest at the initial filling of the reservoir. Several other dams showed sharp differential settlement. Sink holes, settlement cracks and subsidence areas showed up in numerous reservoirs; however, all these conditions have healed with time.

It was quite noticeable that upon filling the reservoir system the settlement occurred first at the upstream toe of the dams, gradually progressing downstream. The greatest settlement eventually occurred along the center line; however, the magnitude of settlement of the downstream toe has never reached that of the upstream toe.

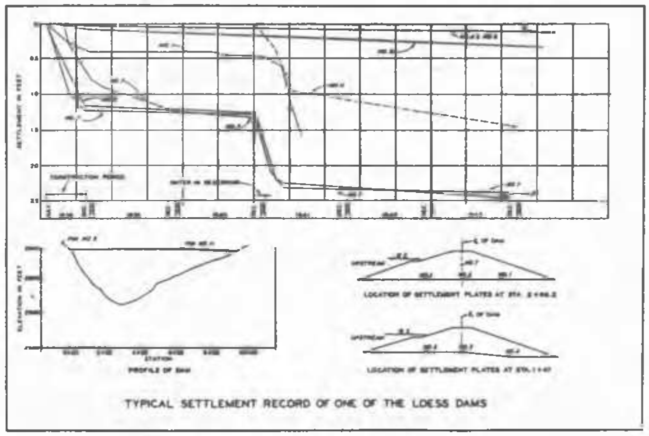


FIG.17

The outstanding feature of the settlement phenomenon is that the abutments have settled very little. This is believed to be due to the fact that the seepage gradient is so steep through the broad abutments that the bulk of the abutment soil has not become saturated, hence there has been little settlement.

CONCLUSIONS

As the result of experience gained on the silty loess soil of this project it is believed that important engineering structures can safely and economically be built of and on loess soil provided adequate investigation and design are carried out. It is pointed out that design, construction and maintenance procedures may have to be materially different than those ordinarily used for other soil types. The relatively high percentage of voids in many loess soils is the particular physical characteristic which can be most detrimental in foundation design. The high void content makes possible high differential settlement upon load and saturation with the attendant possibilities of the formation of open crevices and fissures beneath the structure.

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3) "Steep Slopes Used in Nebraska Loess Soil", by W. J. Turnbull, Civil Engineering, Vol. 11, No. 9, Sept. 1941.

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