IDENTIFICATION OF COLLAPSIBLE SOILS IN LOUISIANA

Ara Arman, Division of Engineering Research, Louisiana State University; and Samuel I. Thornton, Department of Civil Engineering, University of Arkansas

In southwest Louisiana, experience with widespread surface deposits (as thick as 5 ft) for use in earth structures has shown that some soils can withstand the design load, but others exhibit characteristics of a collapsible soil in the presence of load and moisture. All of these soils are classified as silt; the collapsible soils cannot be distinguished from normal silts by using routine tests. The known and conjectured areas containing collapsible silts fall within a 30-mile band through the coastal prairie terrace, the Mississippi River terraces, and the loessial hills. The dominant clay mineral in the collapsible silts is montmorillonite; kaolinite and illite are also present. These silts attract and suspend moisture in their pores by electrochemical forces. They become virtually impermeable when a polar liquid, such as water or ethylene glycol, is added. If a collapsible silt is mixed in a solution of sodium hexametaphosphate (Calgon) and allowed to settle, the liquid turns black. This color change is attributed to lignin. Along with a determination of the presence and location of collapsible soils in Louisiana, criteria for distinguishing these soils from normal silts are established. When two of the following four conditions are met, these soils may be considered collapsible: in situ unit weight of the undisturbed silt is less than 80 lb/ft^3; maximum dry density is less than 104 lb/ft^3; after the solids of the suspected soil have settled out in a 3 percent solution of sodium hexametaphosphate (used in routine hydrometer analyses), the supernatant liquid is black; and a total strain of at least 15 percent occurs at the end of the 16-tsf loading in a collapse test.

•IN southwest Louisiana, the wooded flats, coastal prairies, and low-profile hills that border salt marshes have surface soils of alluvial silt. A gray soil, classified as silt, covers an area about 30 miles wide and 100 miles long in this region. The thickness of the soil varies from 6 in. to 5 ft. Although this soil has a uniform appearance and gradation, its stability may differ among small areas.

New highway construction through these areas has highlighted the seriousness of these differences in stability. During the early stages of Interstate highway construction, isolated silty areas became unstable; no equipment could travel over the material when it became wet. Yet only a few hundred feet away from an unstable area, equipment could operate, under similar wet conditions, on material that had a gradation, classification, and Atterberg limits like the unstable one. In one section of Louisiana, more than \$2.5 million had to be added to the contract cost of the highway (after construction had started) to remove the unstable silts.

The records of the regional office of the U. S. Department of Agriculture indicate that farmhouses and drainage structures built in this region have experienced considerable damage from failures of foundations on seemingly stable silt. These failures occurred during the rainy season. (The annual rainfall in this region is more than 60 in.)

The problem of soil instability gained considerable prominence as the land use in the area slowly changed from farming to residential and industrial and became intensified because of the lack of methods for identifying the unstable silts.

Sponsored by Committee on Exploration and Classification of Earth Materials.

This report covers the investigation of the engineering properties of the material and a proposed identification method.

INITIAL INVESTIGATION

At the outset of the study, the effect of the soil instability was known, but the cause was unknown. After interviews with highway soils engineers, samples were obtained from small areas, within 30 ft of each other (Fig. 1), known to contain either stable or unstable silt. Moisture, according to early reports from construction engineers, was thought to be the cause of instability. Unstable silts were too wet for construction equipment to traverse (i. e., they underwent large volume changes when subjected to loads), and they could not be drained. These silts seemed to hold moisture suspended in the pores. As a result of the preliminary investigation, the following facts were established:

1. Both stable and unstable silt deposit areas are intermingled in the region. Both types of silts are surface deposits and are massive (homogeneous) in structure and are usually about 3 to 4 ft deep.
2. The AASHO classification of both types of soils is silt.
3. The gradation, Atterberg limits, and appearance of both soils are the same.
4. Failures occur only when the unstable soil is wetted.
5. Structural and slope failures take place soon after the unstable soil is wetted. These same soils, in a dry state, have sufficient strength to support heavy construction equipment or structures.
6. Both types of silts have low permeabilities.

These facts led to the conjecture that the unstable soils are loessial and collapsible.

RESULTS OF EARLIER STUDIES

A collapsible soil is defined as one that undergoes an appreciable amount of volume change on wetting, loading, or both. The magnitude of the collapse is between 4 and 20 percent of the original soil height and depends on the moisture content, load, and nature of the soil. The collapse may take from several minutes to several hours (1).

Both the identification of collapsible soils and the predictions of the amount of collapse have proved to be difficult and indeterminate tasks. A low in-place unit weight has been used as one criterion to identify them. For loess or loess-like materials, an in-place dry unit weight of 80 lb/ft^3 or less indicates a collapsible soil. Dry unit weights of 80 to 90 lb/ft^3 are transitional values. Settlement is negligible in a loessial soil when dry unit weight is 90 lb/ft^3 or more (2). Moisture content has also been used as a criterion. A moisture content of less than 10 percent of dry unit weights indicates stable soil, but greater than 20 percent indicates collapsible soil (3).

Denisov introduced the K-coefficient of subsidence with a range of values that correlates with the degree of collapse. This is expressed as

$$K = \frac{e_L}{e_o}$$

where

e_L = the void ratio at the liquid limit, and
e_o = the natural void ratio.

A value of 0.50 to 0.75 indicates a highly collapsible soil, and 1.5 to 2.0 indicates a noncollapsible soil (5).

Both the dry unit weight and the moisture content were used successfully to identify collapsible soils along the San Luis Canal in the San Joaquin Valley (4). If the voids were sufficient to contain the moisture of the soil at its liquid limit, the soil was collapsible. This criterion applies only if the soil is uncemented and the liquid limit is greater than 20.

The 1962 Soviet Building Code presents a relation between initial void ratio and void ratio at the liquid limit to determine the collapsibility of soils with less than 60 percent saturation (5). Accordingly,

$$\lambda = \frac{e_o - e_L}{1 + e_o}$$

where

e_o = the initial void ratio, and
e_L = the void ratio at the liquid limit.

A value of λ greater than -0.1 indicates collapse.

Milovic suggested the concept of a specific coefficient of settlement in a variation of the consolidation test (6).

The double odometer test was used to identify collapsible soils by Knight and Dahlen (1). A consolidation test is made with one soil sample at its natural moisture content; an identical sample is tested while submerged in the confining ring.

Kassiff and Henkin proposed that the product of the dry density and moisture content be used as a predictor of collapse for loess. When this product exceeds 15, collapse may occur (7).

According to Dudley the only conditions for defining a collapsible soil are loose structure and a moisture content less than saturation. Dudley also discussed a pseudo-consolidation, or collapse, test in which a fabricated sample of fine sand and montmorillonite was loaded and rebounded in a dry state. It was then flooded, and the settlement or collapse was recorded (8).

THE COLLAPSE MECHANISM

Although the addition of water as a triggering action is commonly used to explain soil collapse, it should be emphasized that collapse may also occur without wetting, by an increase of the stress above the compressive strength as well as by a decrease in compressive strength below the stress.

The strength of noncohesive soils is directly related to the effective stress. In partially saturated soils, capillary force causes tension in the pore water (negative stress). A negative pore water stress increases the total effective stress, thereby increasing the shear strength. If the capillary forces are destroyed, as by saturation, the shear strength is reduced, and collapse may occur.

One hypothetical collapse mechanism involves clay-covered silt particles. Because the soil strength would result from the electrochemical bonding capacity of the clay, it would ultimately depend on percentage of clay. If water is added to such a soil, the adsorbed water film becomes thicker, the bond between particles weakens, and the soil thus loses strength (9).

Thus soil particles supported by clay minerals and associated ions may undergo collapse when saturated. Buttresses of clay-sized material, flocculated by ions, may form around silt particles as the saturated soil dries (8). Capillary forces will increase the strength of the partially saturated soil. The addition of water reduces the ion concentration and destroys the capillary forces. In turn, the supporting buttresses are dispersed, and the strength is reduced instantaneously.

TESTS ON COLLAPSIBLE SOILS IN LOUISIANA

Three sites in southwest Louisiana were chosen, at the outset of this study, for sampling and in situ testing. Two of these sites (Iowa and Sulphur) contained extensive deposits of stable and unstable silts, as identified by construction experience. The third site (Chloe) contained silts similar to the first site from the standpoints of sedimentation, formation, and physical characteristics; however, they were known to be stable under all conditions (Fig. 2).

The disturbed samples were prepared according to ASTM 2217 (with drying temperatures held below 60 C) for the following tests: Atterberg limits (ASTM D-423 and

D-424), grain size analyses (ASTM D-442), and the standard compaction test (ASTM D-698). X-ray diffraction, electron microscopy (both scanning and transmission), differential thermal analyses, infrared analyses, and qualitative chemical analyses were used to identify the chemical and mineral composition of the soils and other substances present.

The undisturbed 3-in. core samples were tested both in direct shear and in collapse. The collapse test, patterned after work done by Dudley (8), was performed in accordance with the ASTM D-2435 Consolidation Test, with the following difference: The sample, first oven-dried at 60 C, was loaded in the dry state up to 8 tsf, rebounded to 4 tsf, and then submerged in the consolidometer. The settlement as a result of wetting was recorded for pressures of 4, 8, and 16 tsf. The maximum settlements at 16 tsf were 14.5 percent for stable silts and 23.6 percent for unstable silts (Fig. 3).

Along with a field survey of all known and suspected deposits of collapsible silt (to determine their topographic and geologic features), in-place density and natural moisture content were measured at all sites of collapsible silts and neighboring stable silts. Samples of underlying clays, taken during a subgrade profile survey in the same region, were subjected to routine mechanical, pH, and organic content tests and quantitative and qualitative chemical analyses to determine if a soluble soil binder might have been leached out of the overlying silts and redeposited in them.

During the analyses, it was observed that these silts did not exhibit color or textural differences in either the natural or dried condition. However, after they had been soaked in a 3 percent water solution of sodium hexametaphosphate (the trade name is Calgon), which is normally used to disperse soil particles for hydrometer analyses, each type of soil had a different color.

The mixtures of stable silt and the sodium hexametaphosphate solution produced a light brown suspension that settled and left an almost clear supernatant liquid after 24 hours. However, the mixtures of unstable soil and the stock solution, without exception, produced a permanently black supernatant liquid, indicating the presence of foreign matter that was readily soluble. Infrared and chemical analyses of the black liquid showed that the black color was caused by a form of lignin that was dispersed in the liquid.

Thus the dispersion or Calgon test evolved as a chemical test to indicate instability.

A Calgon-washed test was also devised to determine if the material that dissolves in a Calgon-water mixture is responsible for the unstable condition of the soil. In this test, Calgon powder was mixed on a 3 percent by weight basis with dried soil, and the mixture was dispersed in a solution of 3 ml of distilled water per gram of soil. The water, along with other dissolved solids, was then removed by centrifuging for 15 minutes at 1,850 rpm. The rise with distilled water and centrifuging was repeated two more times to ensure removal of all Calgon and dissolved solids. No suspended solids or clays were removed in this process during the tests. Permeability of remolded specimens was determined in a falling-head permeameter (initial head 2 m).

TEST RESULTS

About 1,800 tests were run to provide the results given in the following discussion.

The AASHO classification of all the soils is silt (averaging 70 percent silt, 18 percent sand, and 12 percent clay) (Fig. 4). Differential thermal analyses and X-ray diffraction indicated that the predominant mineral in the silt and sand portions was quartz (60 percent average); the clay portion of the unstable silt was mostly montmorillonite, with some illite and kaolinite; and the clay in the stable silt was vermiculite and illite. Electron microscopy indicated that the silt grains of both soils are alike in shape and have surface weathering similar to weathered silts elsewhere. Only scattered microfossils having diameters of 1 to 10 microns were observed. They were similar to the siliceous diatoms reported by Beutelspacher and Van der Marel (10).

In the quick, undrained direct shear tests, both the collapsible and noncollapsible soils had an apparent cohesion of 0.4 tsf and an angle of internal friction of 30 deg.

The maximum density, obtained by standard compaction (ASTM D-698), was higher in the stable silts (108 lb/ft^3) than in the unstable silts (102 lb/ft^3). The consistent

Figure 1. Collapsible soils in the United States.

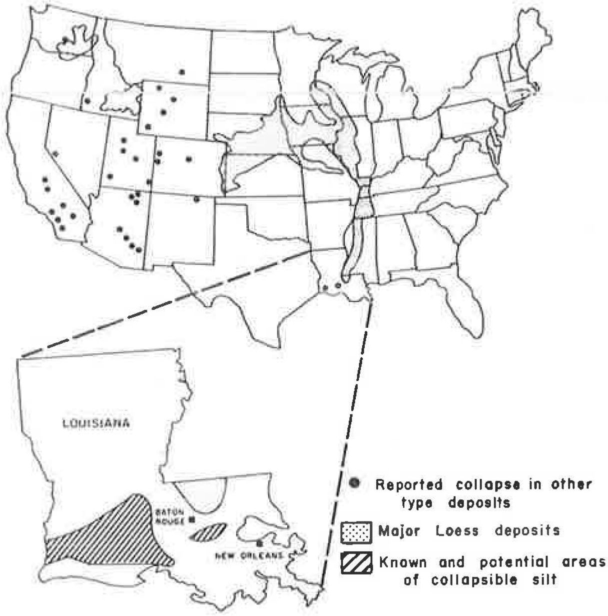


Figure 2. Sample locations and numbers.

Figure 3. Typical double odometer (collapse) test results.

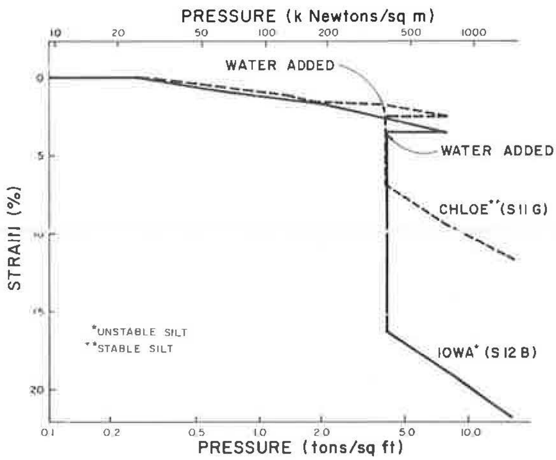
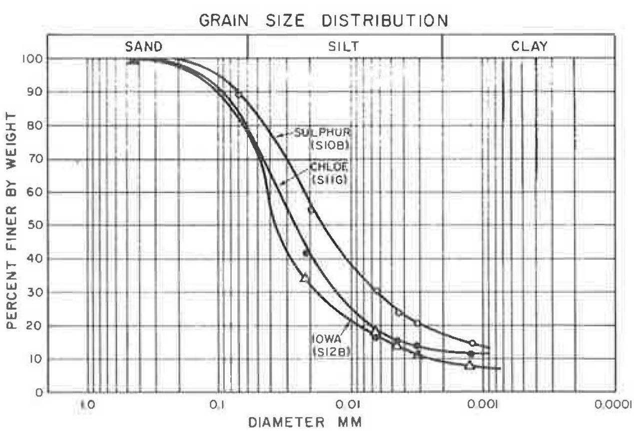


Figure 4. AASHO soil classification.



difference of 6 lb/ft^3 in maximum densities (Fig. 5) was the first mechanical property found to distinguish the two types.

The unit weights of undisturbed, unstable silts, measured in place with a nuclear density device, averaged 80 lb/ft^3 or 8 lb/ft^3 less than those for stable soils. Table 1 gives a sample of the results from tests at three sites. This consistent and uniform difference in unit weight furnished another method of identifying collapsible soils. The liquor produced in a Calgon test of known unstable silts was black in color in all cases. Stable samples produced a brown or gray liquor not much different from plain soil-water mixtures (without Calgon).

DISCUSSION OF TEST RESULTS

The low, in-place, dry unit weights of unstable silts—lower than those of stable silts—indicate a looser structure and greater settlement. Both the unit weights and the gradation of the unstable silts were similar to those for collapsible soils reported by Clevenger (2). The standard compaction test was the most outstanding proof of the difference in the mechanical properties of the remolded silts.

The Calgon test is practical and easily applied. During preparations for the hydrometer analysis (a routine classification test), the color of the Calgon-water-soil mixture can be observed.

The collapse test is another useful indicator of relative stability. The maximum values of collapse in this study showed that unstable silts may subside twice as much as stable silts (Fig. 3).

Electron microscopy indicated that both stable and unstable soils were formed by the same geologic process and contain particles of similar size and shape, microdiatoms, and agglomerated soil particles. The massive (unstratified) deposition of both types and their coincidence in former flood plains of the Mississippi and Red rivers point toward the same or similar geologic processes of formation.

Chemical analyses of underlying deposits failed to show that a soil binder, such as calcium carbonate, had been leached out of the unstable silts and redeposited in lower soil horizons.

Permeability of both collapsible and noncollapsible soils in distilled water decreases with time after initial saturation (Fig. 6). After 30 days, the permeability (k) drops to almost a tenth of the initial values. However, when carbontetrachloride (a nonpolar liquid) was substituted for water it drained quickly through the soil (k about 5×10^{-4} cm/sec), whereas ethylene glycol (an extremely polar liquid) would not drain through at all. Permeability samples using carbon tetrachloride and glycol were mixed with the liquids before being placed in the permeameter. The imperviousness of both stable and unstable silts indicates the presence of strong electrochemical charges that seal the pores. The permeability reduction with time in water (Fig. 6) can also be explained by the gradual polar attachment of water onto these electrochemical charges in fine particles.

As a result of data produced in this study, the Louisiana Department of Highways decided to tentatively adopt the Calgon test as a required test for all silts to determine the presence of collapsible soils; in addition dry unit weight was also used as a second indicator.

Correlation of collapse, Calgon, standard compaction density, and in situ density results (Table 2) show that Calgon color, standard compaction, and in situ compaction tests are in agreement in almost all cases. The collapse test, however, does not follow a definite trend. Although the collapse tests of known and suspected (e.g., S-11B) silts generally produced higher percentages of strain (20 percent), they also produced strain as low as 11 percent, i.e., those obtained from stable (S2G) silts. Thus the collapse test by itself was found to be unreliable for definite identification. This also applies to in situ and other test results. However, the correlation of the data and actual field experience indicates that, if two of the results of the tests given in Table 2 agree, the soil should be identified as a potentially collapsible soil.

During routine investigations on two federal aid projects in Lafayette and New Iberia, Louisiana (Fig. 2), the presence of extensive collapsible deposits was identified by

Figure 5. Typical standard compaction results.

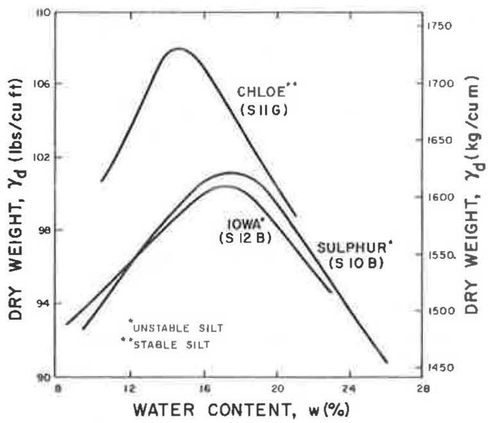


Figure 6. Effect of wetting time on permeability.

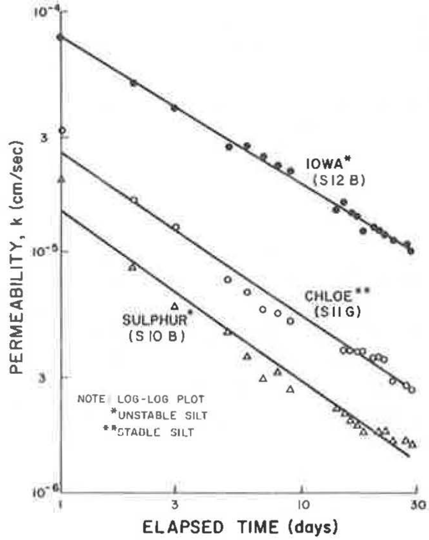


Table 1. Sample test results of silts from Iowa, Sulphur, and Chloe, Louisiana.

Iowa[a]				Sulphur[b]				Chloe[c]			
In-Place Dry Density (lb/ft^3)	Moisture Content (percent)	Calgon Test Color	Type of Silt	In-Place Dry Density (lb/ft^3)	Moisture Content (percent)	Calgon Test Color	Type of Silt	In-Place Dry Density (lb/ft^3)	Moisture Content (percent)	Calgon Test Color	Type of Silt
75	21.3	Black	Collapsible	77	18	Black	Collapsible	88	23	Natural	Noncollapsible
76	22.6	Black	Collapsible	83	14	Black	Collapsible	91	20	Natural	Noncollapsible
82	15.3	Black	Collapsible	78	17	Black	Collapsible	90	22	Natural	Noncollapsible
79	13.2		Collapsible	78	20	Black	Collapsible	87	24	Natural	Noncollapsible
78	20.5	Black	Collapsible								
95	18	Natural	Noncollapsible								
101	21	Natural	Noncollapsible								
104	20	Natural	Noncollapsible								
99	16	Natural	Noncollapsible								
73	20	Black	Collapsible								
83	18	Black	Collapsible								
96	22	Black	Noncollapsible								
67	18	Black	Collapsible								

[a]Stable and unstable deposits intermingled in this region. [b]Unstable silt deposits only. [c]Stable silts only.

Table 2. Test results of silts from Iowa, Louisiana.

Sample Number	Calgon Test Color	In-Place Dry Density (lb/ft^3)	Standard Compaction Dry Density (lb/ft^3)	Collapse Test (percent strain)	Type of Silt[a]
S2G	Natural	98.4	113	11	Noncollapsible
S4G	Natural	107	110	6	Noncollapsible
S5G	Natural	101	110	9	Noncollapsible
S6G	Natural	104	112	6	Noncollapsible
S-11B	Black	95	111	17	Collapsible
S-12B-1	Black	78	103	22	Collapsible
S-17B	Black	73	103	20	Collapsible
S-18B	Black	83	105	24	Collapsible
S-19B	Black	67	102	—	Collapsible
S-128-2	Black	—	—	12	Collapsible
S-12B-22	Black	—	—	10	Collapsible

[a]As determined by field and laboratory tests.

using criteria established by this study, and action was taken prior to construction to treat these soils (with hydrated lime) to avoid costly delays and additional work. Field experience on these projects, before treatment, proved that the trafficability and stability of their natural deposits were extremely low.

CALGON TEST

The Calgon test is a color test developed in this study to distinguish between stable and collapsible silts in southwest Louisiana. The test consists of the following steps:

1. One hundred grams of prepared silt is placed in a 500-ml beaker,
2. Nine grams of Calgon and 300 ml of distilled water are added, and
3. The color of the liquid is observed after allowing the sample to settle overnight.

A black color in the liquor indicates that the soil is collapsible.

CONCLUSIONS

The results of the study substantiate the following conclusions:

1. The unstable soils studied are collapsible silts.
2. Collapsible silts in Louisiana have a loose flocculated structure.
3. Based on the preceding conclusions, the following criteria were established for identifying collapsible silts in Louisiana: In situ unit weight of the undisturbed silt is less than 80 lb/ft^3; maximum dry density (standard compaction, ASTM D-698) is less than 104 lb/ft^3; the supernatant liquid in a settled mixture of the silt and stock solution (3 percent Calgon or sodium hexametaphosphate and water), used in hydrometer analyses (or Calgon test), is black; and in a collapse test (modified consolidation test of an oven-dried sample that has been saturated under pressure), a total strain of at least 15 percent occurs at the end of the 16-tsf loading.
4. Both collapsible and noncollapsible soils are of the same origin.

ACKNOWLEDGMENTS

This study was conducted under the sponsorship of the Louisiana Department of Highways and the U. S. Department of Transportation, Federal Highway Administration. The authors extend their thanks to George Bass, "Skipper" Cryar, and James Melancon of the Louisiana Department of Highways for their invaluable assistance. The authors also extend their thanks to Ray E. Ferrell of the School of Geoscience of Louisiana State University and to Professor Gary G. Paulson of the Department of Engineering Science of Louisiana State University for their assistance in mineralogical studies. The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Louisana Department of Highways or the Federal Highway Administration.

REFERENCES

1. Knight, K., and Dehlen, G. L. The Failure of a Road Constructed on a Collapsing Soil. Proc. 3rd African Conf. on Soil Mech. and Found. Eng., Vol. 1, 1963.
2. Clevenger, W. A. Experiences With Loess as Foundation Material. Jour. Soil Mech. and Found. Div., Proc. ASCE, Vol. 82, No. SM3, 1956.
3. Holtz, W. G., and Hilf, J. W. Settlement of Soil Foundations Due to Saturation. Proc. 5th Internat. Conf. on Soil Mech. and Found. Eng., Paris, France, Vol. 1, 1961.
4. Gibbs, H. J., and Bara, J. P. Predicting Surface Subsidence for Basic Soil Tests. Soils Eng. Rept. No. EM658, Bureau of Reclamation, U. S. Dept. of the Interior, Denver, 1962.
5. Sultan, H. A. Collapsing Soils: State of the Art. Proc. 7th Internat. Conf. on Soil Mech. and Found. Eng., Mexico, Vol. 3 (Specialty Session 5), 1969.
6. Milovic, D. Some Engineering Properties of Loess. Proc. 7th Internat. Conf. on Soil Mech. and Found. Eng., Mexico, Vol. 3 (Specialty Session 5), 1969.

7. Kassif, G., and Henkin, E. N. Engineering and Physico-Chemical Properties Affecting Piping Failure of Low Loess Dams in the Negev. Proc. 3rd Asian Regional Conf., SMFE, 1967, pp. 13-16.
8. Dudley, J. H. Review of Collapsing Soils. Jour. Soil Mech. and Found. Div., Proc. ASCE, Vol. 96, No. SM3, 1970.
9. Kane, H. Consolidation of Two Loessial Soils. Highway Research Record 284, 1969, pp. 26-36.
10. Beutelspacher, H., and Van der Marel, H. W. Atlas of Electron Microscopy of Clay Minerals and Their Admixtures. Elsevier Publishing Co., New York, 1968.