A REVIEW REPORT ON COLLAPSIBLE SOILS FOR THE DESIGN AND CONSTRUCTION OF ROADS

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ABSTRACT

Some subgrade soils can withstand the design traffic while others show the properties of a collapsible soil in the presence of vehicular loads and moisture. These soils are classified as silts. The collapsible soils cannot be distinguished from normal silts by using routine tests. The dominent clay mineral in the collapsible silts in montmorillonite, although kaolinite and illite are also present to some extent. The collapsible silts attract and suspend moisture in their pores by eletrochemical 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 becomes black. The colour change is atributed to ligin. When two of the following four conditions are met with, these soils may be considered as collapsible : (1) In situ unit weight of the undisturbed silt is less than 80 pcf, (2) Maximum dry density is less than 104 pcf, (3) After the solid of the suspected soil have settled in a 3 percent solution of sodium hexametaphosphate the supernatant liquid is black, and (4) A total strain of at least 15 percent occurs at the end of the 16-tsf loading in a collapse test.

1. General

The alluvial silts differ in stability as subgrade soils although they have a uniform appearance and gradation.

New highway construction through such areas has highlighted the critical nature of these differences in stability during the construction of embankment and subgrade, isolated silty areas become unstable, no equipment could traverse over the material when in a wet condition, Yet only a few hundred feet away from the unstable area, equipment could operate under similar wet conditions on material that had a gradation, classification, and Atterberg limits like the unstable area. The areas indicate that even houses and drainage structure built on such soils have experienced considerable damage from failures of foundations. These failures occur during the rainy season. This report covers the investigations of the engineering properties of the material and a proper indentification method. Most of these investigations have been carried out in the U.S.A. and U.S.S.R.

2. Preliminary Investigations.

At the outset of study, the cause of instability was unknown. After interviews with the highway soil engineers, soil samples were obtained for stable and unstable areas. The construction engineers, however, maintained that moisture was the cause of instability. The unstable silts were too wet for construction equipment to traverse (due to large volume changes, when subjected to loads) and these soils could not be drained. These silts seemed to hold moisture suspended in the pores. As a result of preliminary investigations, the following facts were established.

1. Both stable and unstable silt areas are intermingled, both types of silt are surface deposits which are massive (homogeneous) in structure.
2. The A,A.S.H,O. 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 in a wet condition.
5. Structural and slope failure take place soon after the unstable silt is wetted. These soils, when in a dry state, have sufficient strength to support heavy construction equipment or structure.
6. Both types of silts have low permeabilities.

These facts indicated that the unstable soils are silts and collapsible in nature.

3. Results of Previous Studies

A collapsible soil is defined as one that undergoes appreciable amount of volume change on wetting, loading or both.

A low in-place unit weight has been used as one criterion to identify them. For silty soils, an in-place dry unit weight of 80 pcf or less indicates a collapsible soil. Dry unit weight of 80 pcf or less indicates a collapsible soil. Dry unit weights of 80 to 90 pcf are transitional values. Settlement is negligible in a silty soil (loess) when dry unit-weight is 90 pcf or more. Moisture content has also been used as a criterian. A moisture content of less than 10 percent of unit weights indicates stable soil, but greater than 20 percent indicates collapsible soil.

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

$$K = \frac{el}{eo}$$

where el = the void ratio at the liquid limit, and

eo = the natural void ratio.

A value of 0.50 — 0.75 indicates a highly collapsible soil, and 1.5—2.0 indicates a non-collapsible soil.

Both the dry unit weight and the moisture content were used successfully to identify the collapsible soils. 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 per cent.

The Soviet Building Code (1962) 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. Accordingly,

$$\lambda = \frac{eo - el}{1 + eo}$$

where eo = the inital void ratio and

el = 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.

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

4. Theory of Collapse Mechanism

Although the addition of water as a triggering action is commonly used to explain soil collapse but collapse may also occur without water and by increasing the stress above the compressive strength.

One hypothetical collapse mechanism involves clay-covered silt particles.

Because the soil strength would result from the electrochemical binding capacity of the clay, it would ultimately depend on percentage of clay. If water is added to such a soil, the absorbed water film becomes thicker, the bond between the particle weakens, and the soil thus loses its strength.

5. **Tests On Collapsible Soils :-**

Three sites were selected for sampling and in-situ testing. Two of these sites contained deposits of stable and unstable silts, as indentified by construction experience. The third site contained silts similar to the first site from the standpoint of sedimentation, formation and physical characteristics, but they were known to be stable under all conditions.

The tests performed on these soil samples are given as follows :-

1. Atterberg limits, grain size asalysis, Standard compaction test, X-ray diffraction, Electron Microscopy, Differential thermal analysis, Infra-red analysis, and Qualitative chemical analysis.

2. The undisturbed soil samples were tested both in direct shear and in collapse.

3. The in-place density and natural moisture content were measured at all sites of collapsible silts and neighbouring stable silts. Samples of underlying clays, taken during a Subgrade profile survey in the same region, were subjected to routine mechanical, pH organic content, Qualititative and Quantitative chemical analysis to determine if a soluble soil binder might have been leached out of the overlying silts and redeposited in them.

It was observed that these silts did not exhibit colour or textural differences in natural or dried condition. However, after they had been soaked in 3 percent water solution of sodium hexametaphosphate (Calgon), which is normally used to disperse soil particle for hydrometer analysis, each type of soil had a different colour.

The mixture of stable silt and sodium hexametaphosphate solution produced a light brown suspension that settled and left an almost clear supernatant liquid after 24 hours. However, the mixture 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. Infra/red and chemical analysis of the black liquid showed that the black colour 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.

4. Permeability of remoulded specimens was determined in a falling head permeameter.

Test Results

About 1800 tests were run to provide the results. These test results are given as follows :—

1. The A.A.S.H.O. classification of all the soils is SILT (averaging 70 percent silt, 18 percent sand and 12 percent clay).

2. Differential thermal analysis and X-Ray diffraction indicated that the predominent mineral in the silt and sand portions was quartz (average 60 percent). The clay portion of the unstable silt was mostly montmorillonite, with some illite and kaolinite. The clay in the stable silt was vermiculite and illite.

3. Electron microscopy indicated that the silt grains of both soils are alike in shape and have surface weathering similar to weathered silt elsewhere.

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

5. The maximum density, obtained by standard compaction (A.S.T.M. D-698) was higher in the stable silts (108 pcf) than in the unstable silts (102 pcf). The consistent difference of 6 pcf in maximum densities was the finest mechanical -property formed to distinguish the two types.

6. The unit weight of undisturbed, unstable silts, measured in-place with a nuclear density device, averaged 80 pcf (8 pcf less than those for stable soils). This consistent and uniform difference in unit weight furnished another method of identifying collapsible soils.

7. Supernatant liquid produced in the Calgon test of known unstable silts was black in colour in all cases. Stable samples produced a brown or gray liquid not much different from plain soil-water mixture without Calgon.

Sample Test Results of Stable and Collapsible Silts are given in the Appendix - I.

Figs. showing the particle size Distribution, Standard compaction, Typical odometer (collapse) and Permeability test results for silts 1,2 and 3 are given in Appendix - II.

7. Discussion of Test Results

The low, in-place, dry unit weights of unstable silts, (lower than those of stable silts), indicate a loose structure and greater settlement. The standard compaction test was the most outstanding proof of the difference in the mechanical properties of the remoulded silts.

The Calgon test is practical and easily applied. During preparations for the hydrometer analysis, the colour 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.

Electron microscoyy indicated that both stable and unstable soils were formed by the same geologic process and certain articles of similar size and shape.

Chemical analysis 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 stable soils in distilled water decreases with time after initial saturation. After 30 days, the permeability (K) drops to almost a tenth of the initial values.

Correlation of collapse, Calgon, standard compaction density, and in-situ density results show that the Calgon colour standard compaction, and in-situ compaction tests are in agreement in almost all cases. The collapse test, however, does not follow a definite trend.

Field experience proved that the traffic ability and stability of collapsible silts were extremely low.

The Calgon is a colour test developed in this study to distinguish between stable and collapsible silts. The test consists of the following procedure :—

100 gms. of the prepared silt is placed in a 500 ml. beaker, 9 gms. of Calgon and 300 ml. of distilled water are added. The colour of the

supernatant liquid is observed after allowing the sample to settle overnight. A black colour in the liquor indicated that the soil is collapsible.

8. Conclusion

The results of the study substantiate the following conclusions :—

1. The unstable soils are collapsible silts.

2. Collapsible silts have usually a loose flocculated structure.

3. The following criteria was established for indentifying collapsible silts :—

The in-situ unit weight of the undisturbed silt is less than 80 pcf.

Maximum dry density (standard compaction ASTM D-698) is less than 104 pcf.

The supernatant liquid in a settled mixture of the silt and stock solution (3 percent Calgon or sodium hexameta-phosphate and water) used in hydrometer test (or Calgon test) is BLACK.

In a collapse test, which is a modified consolidation test of an oven dried sample that has been saturated under pressure, total strain of at least 15 percent occurs at the end of the 16 tsf loading.

4. Both collapsible and stable soils are of the same origin.

9. Remedial Measures Against Collapsible Silts

Samples of the unstable silts, drawn from the Punjab alluvium, have been subjected to the Calgon test. It has been observed that the soft and unstable silts show a black colour whereas the stable silts yield the usual light brown colour. The unstable or collapsible silts are encountered in pockets or limited areas confined by the normal or stable silt. The collapsible silts, in the alluvium draw their moisture from the shallow ground-water table or from contiguous high-level irrigation canal or distributory. The coarse silt, which is almost single-sized in grain, can show the quick sand condition under the critical hydraulic gradient. These collapsible silts are sometimes also termed as "quacky" or "quick" silts. The C.B.R. value may be as low as 1-2 percent.

The collapsible silts are responsible for subgrade failures under the adverse moisture conditions. The corrective treatment or remedial measures include the removal and replacement of these collapsible silts with granular materials such as sand, sand gravel mix or pit-run gravel. These silts have also been treated with hydrated lime (lime stabilization) prior to construction. However, it is preferable to remove the soft, unstable and collapsible silts and replace them with granular materials to obtain the required stability of the embankment foundations and subgrade. The rational structural design demands the removal and replacement of these collapsible silts prior to construction. These silts should not be used for embankment and subgrade.

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SAMPLE TEST RESULTS SHOWING THE PROPERTIES OF STABLE AND COLLAPSIBLE SILTS

In-Place Dry Density (Pcf)	Moisture Content (%)	Calgon Test Colour	Type of Silt
1	2	3	4
SILT No. 1			
104	20	Natural	Non-Collapsible
101	21	Natural	Non-Collapsible
99	16	Natural	Non-Collapsible
96	22	Natural	Non-Collapsible
95	18	Natural	Non-Collapsible
83	18	Black	Collapsible
82	15.3	Black	Collapsible
79	12.2	Black	Collapsible
78	20.5	Black	Collapsible
76	22.6	Black	Collapsible
75	21.3	Black	Collapsible
73	20.0	Black	Collapsible
67	18.0	Black	Collapsible
SILT No. 2			
83	14	Black	Collapsible
78	17	Black	Collapsible
78	20	Black	Collapsible
77	18	Black	Collapsible
SILT No. 3			
91	20	Natural	Non-Collapsible
90	22	Natural	Non-Collapsible
88	23	Natural	Non-Collapsible
87	24	Natural	Non-Collapsible

In-Place Dry Density (Pcf)	Max. Dry Density (Pcf) (Standard Compaction)	Collapse Test (Strain %)	Type of Silt
SILT No. 4			
107	110	6	Non-Collapsible
103	112	6	Non-Collapsible
101	110	9	Non-Collapsible
98.4	113	11	Non-Collapsible
95	111	17	Collapsible
83	105	24	Collapsible
78	103	22	Collapsible
73	103	20	Collapsible
67	102	—	Collapsible

Appendix—II

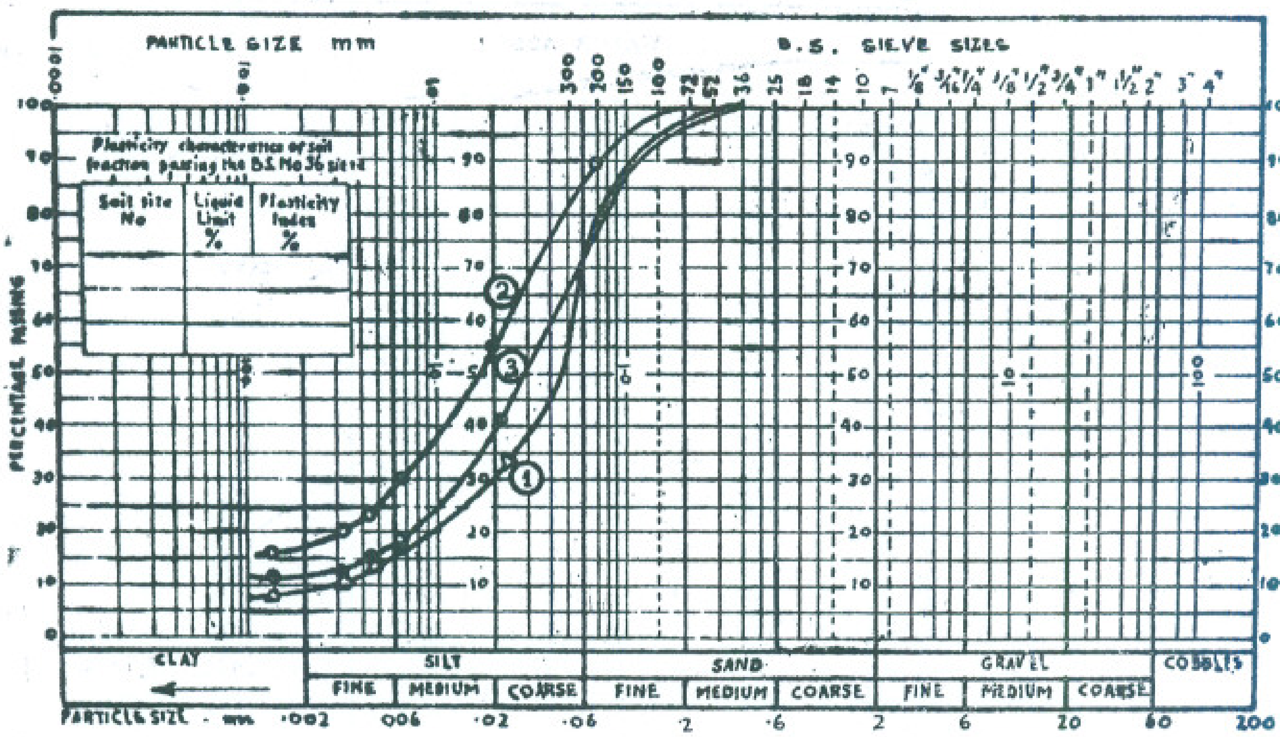

FIG I – SHOWING THE PARTICLE SIZE DISTRIBUTION

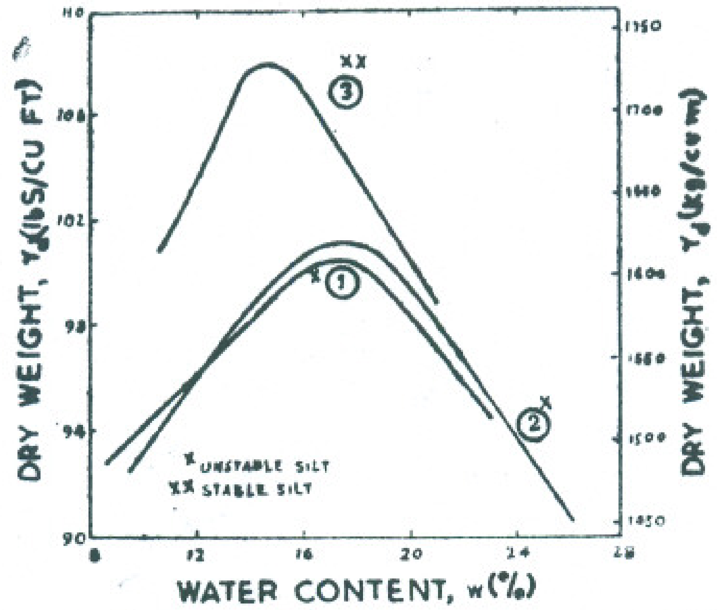

FIG. 2. SHOWING THE TYPICAL STANDARD COMPACTION RESULTS

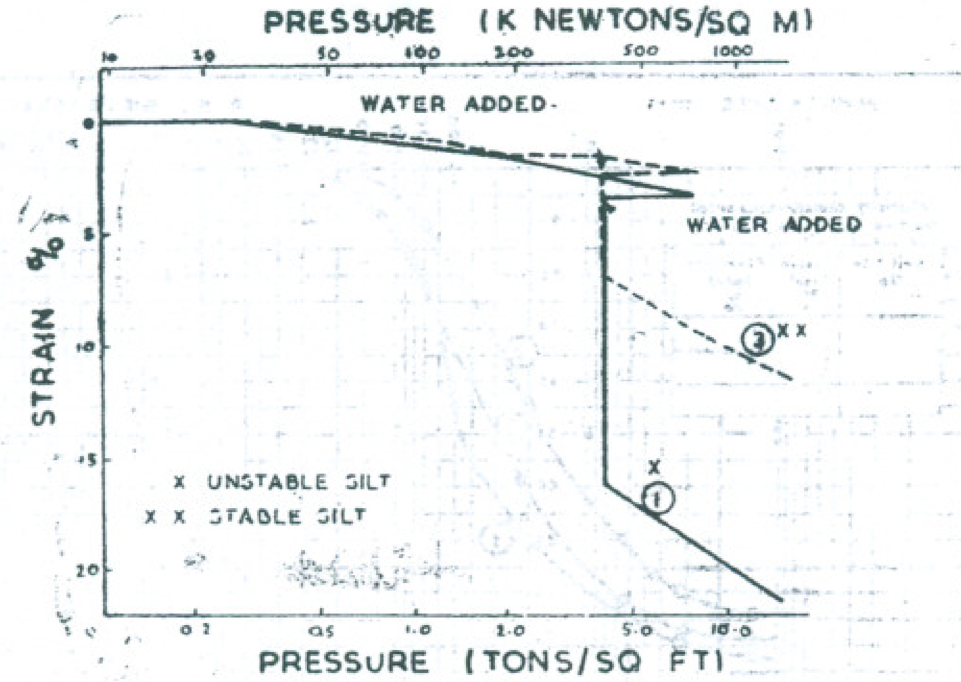

FIG. 3 – SHOWING THE TYPICAL DOUBLE ODOMETER (COLLAPSE) TEST RESULTS.

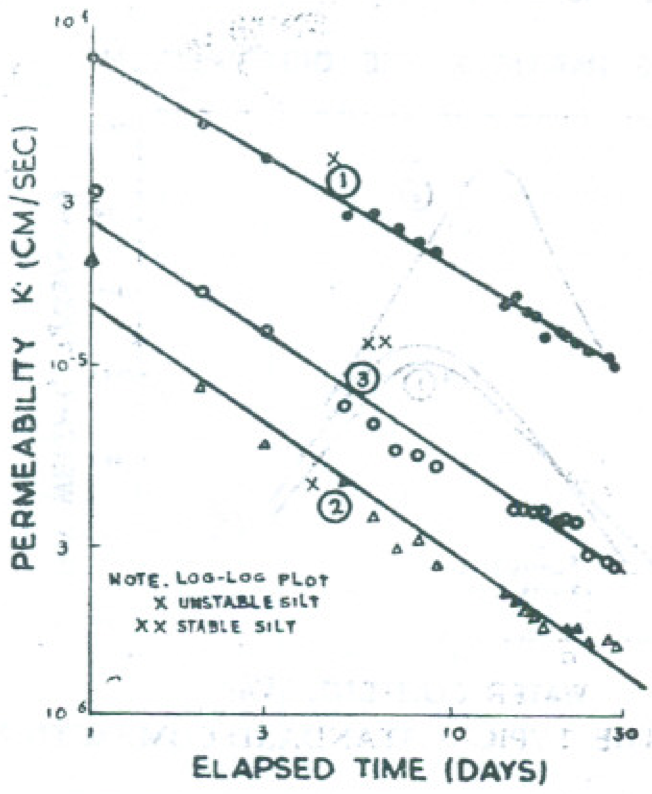

FIG. 4. SHOWING THE EFFECT OF WETTING TIME ON PERMEABILITY