Proceedings of the Iowa Academy of Science

Volume 65 | Annual Issue Article 47

1958

Miniature Triaxial Shear Testing of a Quaternary Ammonium Chloride Stabilized Loess

J. M. Hoover
Iowa State College

D. T. Davidson
Iowa State College

J. V. Roegiers
Iowa State College

Recommended Citation

Hoover, J. M.; Davidson, D. T.; and Roegiers, J. V. (1958) "Miniature Triaxial Shear Testing of a Quaternary Ammonium Chloride Stabilized Loess," *Proceedings of the Iowa Academy of Science*: Vol. 65: No. 1 , Article 47.
Available at: https://scholarworks.uni.edu/pias/vol65/iss1/47

Miniature Triaxial Shear Testing of a Quaternary Ammonium Chloride Stabilized Loess[1]

By J. M. Hoover, D. T. Davidson, and J. V. Roegiers

INTRODUCTION

Compressive bearing characteristics of a stabilized soil may be determined by several methods, in each of which the soil specimens are loaded to failure. The resistance to failure of the stabilized soil depends on the maximum cohesion and internal friction between the soil particles after compaction. The Triaxial Shear Test is employed to provide a measure of these two soil properties. In most highway base and sub-base design problems, or in any similar soil foundation study, the capacity of the underlying soil to withstand and support vertical and/or lateral forces is directly related to the cohesive and frictional forces present in the soil mass.

The purpose of the investigation was to determine the effect of a quaternary ammonium chloride soil stabilizing agent on the cohesive and frictional properties of a sample of western Iowa loess. A miniature triaxial shear testing apparatus, developed by the Iowa Engineering Experiment Station Soil Research Laboratory, was used for the investigation.

MATERIALS

Soil

A sample of friable, calcareous, C-horizon Wisconsin loess from Harrison County, Iowa, was used. X-ray diffraction analysis indicated montmorillonite to be the predominant clay mineral in the loess sample. Properties of the sample are given in Table 1. Table 1 shows calcium to be the predominant cation associated with the loess clay.

Chemical

The quaternary ammonium chloride stabilizing agent used in this study is known commercially as Arquad 2HT (1, 2). It is an organic

---

[1] The data presented in this report were obtained as a part of the research being done under Project 283-S of the Iowa Engineering Experiment Station at Iowa State College. The project is sponsored by the Iowa Highway Research Board as Project HR-1 and is supported by funds supplied by the Iowa State Highway Commission and the U. S. Bureau of Public Roads.

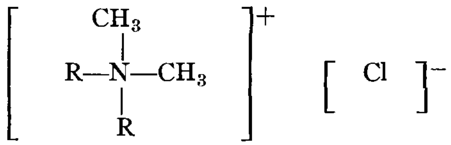
Table 1

Properties of Whole Wisconsin Loess Sample

	Properties	Soil
Physical Properties	Liquid Limit, %	30.8
	Plastic Limit, %	24.6
	Plasticity Index, %	6.2
	Shrinkage Limit, %	22.3
	Specific Gravity, 25°C/4°C	2.71
	Standard Proctor density test:	
	Max, dry density lbs/ft^3	108.4
	Opt. Moist. content, %	18.0
Chemical Properties	Organic Matter, %	0.17
	Carbonates, % $CaCO_3$	10.2
	Oxidation	Oxidized
	pH	8.7
	Cation exchange capacity, m.e./100g.	13.4
	Exchangeable cation, m.e./100g.	
	Na	1.5
	K	1.6
	Ca	10.3
Textural Composition[a]	Sand, %	1.4
	Silt, %	78.8
	Clay: Finer than 5 μ, %	19.8
	Finer than 2 μ, %	16.0
Engineering classification	(AASHO)	A-4(8)

[a] Sand—2.0 to 0.074 mm, silt—0.074 to 0.005 mm, clay—finer than 0.005 mm.

cationic chemical that will retain its surface activity at either high or low pH and is not precipitated by calcium or magnesium hardness in water. Arquad 2HT is a di-hydrogenated tallow di-methylammonium chloride which is easily dispersible in water up to about 8 percent by weight and is normally supplied by the manufacturer as 75 percent active in isopropanol. It has an average molecular weight of about 585 and has the following general structural formula:



$$\left[\begin{array}{c} CH_3 \\ | \\ R-N-CH_3 \\ | \\ R \end{array}\right]^+ \quad \left[\ Cl\ \right]^-$$

Preparation of chemical. Previous research has indicated that preparation of the chemical in a water solution is desirable prior to its incorporation in the soil (4, 5, 6, 7). Six water concentrations of the chemical were prepared; 0, ½, 1, 2, 3, and 5 percent by weight. The relationship between chemical concentration in water, percent dry weight of soil, and percent saturation of cation exchange capacity for each water concentration of chemical used with the loess are shown in Table 2.

The quantity of chemical needed for one liter of the desired concentration was placed in a beaker of adequate size and then was diluted with a small quantity of distilled water heated to 60° C. After the chemical was entirely dispersed, the mixture was washed into a 1000 ml. volumetric flask and was again diluted with the heated distilled water to 1000 ml. An extra 13 ml. of heated water was also added to compensate for the volume change of the mixture between 60° C. and room temperature. The mixture was allowed to cool to room temperature prior to incorporation in the soil.

Table 2

Relationship Between Chemical Concentration in Water, Percent Dry Weight of Soil and Percent Saturation of Cation Exchange Capacity for Friable Loess and Arquad 2HT

Concentration of chemical in water, percent by weight	Concentration of chemical in soil, percent of dry weight of soil	Percent saturation of soil cation exchange capacity
0	0	0
½	0.08	0.8
1	0.16	1.6
2	0.32	3.2
3	0.49	4.7
5	0.81	7.8

METHOD OF TESTING

Mixing

The quantity of chemical solution necessary for standard optimum moisture content was added to the loess which had been air dried and passed through a No. 10 U. S. Standard sieve. Mixing was done in a Hobart model C-100 mixer at moderate speed for two minutes.

Molding

Six 1.312 inch diameter by 2.816 inch high cylindrical specimens were molded for each combination of soil and chemical concentration evaluated. The Harvard Miniature Compaction Apparatus (9) was used for molding. Each specimen produced in this apparatus is molded in two equal layers with ten 40-pound tamps per layer using a half inch diameter spring scaled rod. A compacted sample at approximately standard Proctor density results.

Curing

Six specimens of each soil-chemical combination were cured under each of the following conditions: (a) no curing; (b) 1 day air-dry; (c) 3 day air-dry; (d) 5 day air-dry; (e) 7 day air-dry; and (f) 5 day air-dry, 24 hours immersion in distilled water.

Testing

Following the various curing periods, the cohesion, the angle of

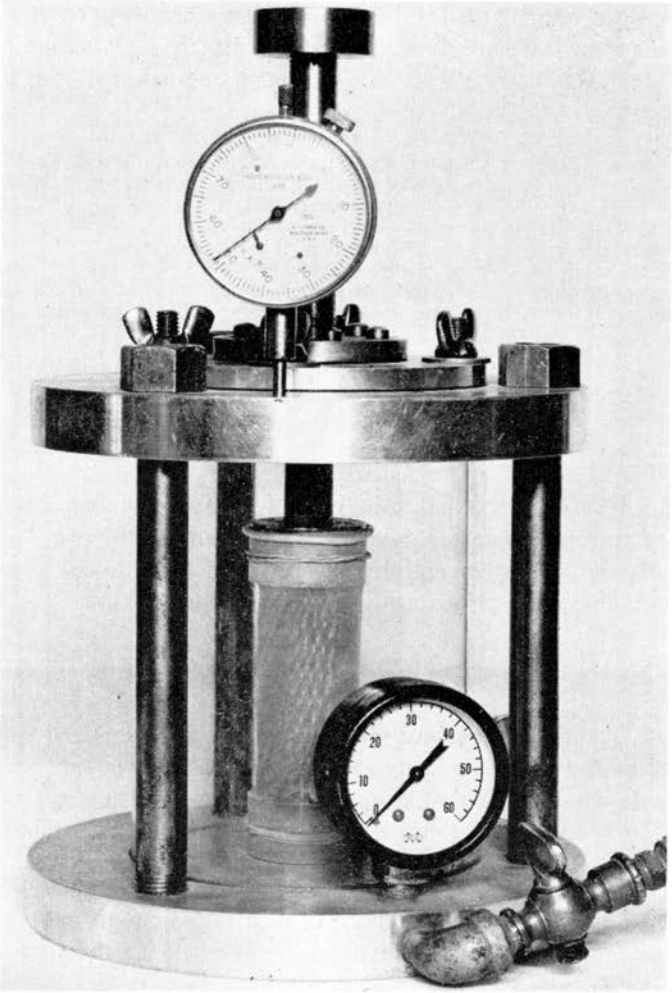


Figure 1. Iowa Engineering Experiment Station Miniature Triaxial Shear Testing Apparatus.

internal friction, and the modulus of compression of the stabilized soil for each combination of curing and concentration of chemical were determined by the miniature triaxial shear testing apparatus shown in Figure 1.

The soil specimen is placed in a thin rubber membrane and sealed inside the plexiglass cylinder where it is subjected to constant lateral and dynamic axial stresses. In the triaxial compression test a liquid is ordinarily used to obtain lateral or minimum principal stresses (8). With the I.E.E.S. apparatus compressed air is substituted for the liquid and is applied by a tire pump attached to the hose shown in

Figure 1. Constant air pressures of 10, 20, and 30 pounds per square inch were used and were checked by the air pressure indicator at the base of the apparatus. At each of the three lateral pressures duplicate specimens for each curing condition and chemical concentration were run and the results were averaged. A constant rate of vertical or maximum principal stress was applied to the sample through the loading piston (Figure 1) and was maintained until failure had occurred. Deformation of the sample was observed through the strain dial mounted on the loading piston. Applied loadings were read and recorded at each 0.01 inch of deformation.

DISCUSSION

No attempt is made in this paper to determine numerically the shearing resistance of each chemical treatment. The general effects that each treatment had on the shearing resistance through changes in the modulus of compression, internal friction angle and cohesion are discussed.

Modulus of Compression

Loading of a specimen during a triaxial compression test produces a fairly constant ratio of unit stress to unit strain. In the early stages of the test a straight line relationship is shown in a graph of these two properties. After that the unit strain increases at a faster rate than the unit stress. The relationship of stress to strain in the straight line portion of the curve is measured as the slope of the secant line most nearly coinciding with this portion of the curve, and is designated as the modulus of compression. It is a property of soil similar to the modulus of elasticity of other engineering materials. Because soil is not elastic in the ordinary sense, the modulus of compression is only applicable during loading phases and does not apply during unloading. As the slope of the stress-strain curve increases, the modulus of compression decreases indicating a greater degree of shearing resistance.

Table 3 shows the average modulus of compression for each curing method and the water concentration of the chemical used. The modulus decreases considerably as the length of air-drying increases for each chemical concentration. Five day air-drying appears to give about the minimum modulus. Five day air-drying followed by 24 hours complete immersion in distilled water increases the modulus above that obtained by five day air-drying only. However, at two and three percent chemical concentration, the modulus is about one-half that with no curing. This would indicate a maximum chemical benefit to the soil specimens within this range of chemical concentration and with at least five days air-drying. A separate study of moisture loss versus length of air-drying gave maximum moisture losses at about five days; after five days air-drying no appreciable loss in weight occurred.

Cohesion and Internal Friction

Shearing resistance, S, of a soil specimen subjected to the triaxial compression test is assumed determinable by the Coulomb equation, $S = C + N \tan \phi$ in which C is a constant called the cohesion, N is the stress normal to the failure surface developed in the specimen, and ϕ is the angle of internal friction. The values of C and ϕ are assumed entirely independent of the states of stress which precede failure of the soil specimen. Because of this assumption, the interpretation of a triaxial test on the basis of the foregoing equation is different for different soils. Also, the results may be slightly erratic within the same soil. It may further be assumed on the basis of the Coulomb formula that an increase in cohesion and friction angle will in turn result in an increase in shearing resistance of a soil specimen.

Table 3

Effect of Variation of Chemical Concentration in Water and Length of Air-curing on the Moduli of Compression for Arquad 2HT Stabilized Loess.

	Moduli of compression for stabilized soil mixtures in lbs/in^2/in x 10^{-4} for chemical concentration in water[a] shown below.					
Curing Method	0%	½%	1%	2%	3%	5%
No curing	2.23	2.20	1.30	1.83	1.93	1.30
1 day air-drying	0.42	0.20	0.21	0.58	0.22	0.35
3 day air-drying	0.16	0.12	0.18	0.15	0.18	0.31
5 day air-drying	0.13	0.11	0.14	0.12	0.14	0.22
7 day air-drying	0.11	0.11	—[b]	—[b]	—[b]	—[b]
5 day air-drying and 24 hour immersion	—[c]	—[c]	1.87	1.00	0.80	2.30

[a] Percent by weight of total solution.
[b] No specimens were molded for these concentrations.
[c] Specimens failed during immersion.

A graphical solution, known as the Mohr diagram, is used to determine the cohesion and internal friction angle of the tested soil specimen (Figure 2). Using the difference between the averages of the total vertical stress at failure and the lateral stress on the specimen, a semicircle is drawn; the three semicircles representing the failure stress at each of the three applied lateral stresses. A line tangent to each of the semicircles is a locus of points representing failure of the stabilized soil and is a graph of the Coulomb equation. The slope of this line from the horizontal is the angle of internal

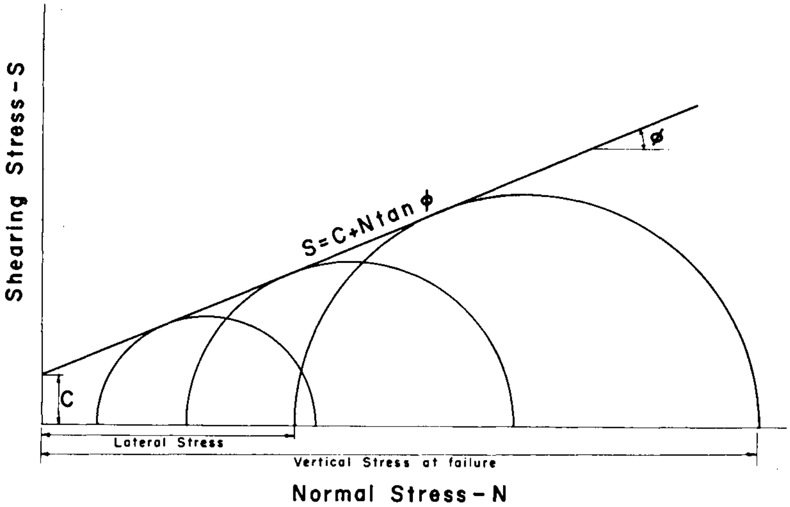


Figure 2. Sample components of a Mohr diagram.

friction and the intercept of the line on the ordinate of the graph is the cohesion.

Tables 4 and 5 give the average angles of internal friction and cohesion for each curing condition and chemical concentration used in this study. With each chemical concentration air-drying in general increases both properties due to a decreasing thickness in the water films between the soil particles. In general the chemically treated soil specimens increase to a maximum angle of internal friction at three to five days' air-drying. Also there is a general trend for the friction angle to decrease with increasing chemical concentration. With five day air-drying and twenty-four hour immersion, the friction angle increases to a maximum at about two percent chemical concentration.

Table 4

Effect of Variation of Chemical Concentration in Water and Length of Air-curing on the Angle of Internal Friction of Arquad 2HT Stabilized Loess

	Angle of internal friction for stabilized soil mixtures in degrees for chemical concentration in water[a] shown below.					
Curing Method	0%	½%	1%	2%	3%	5%
No curing	15.0	23.5	17.5	21.0	24.5	12.5
1 day air-drying	48.0	37.5	29.0	35.0	34.0	25.0
3 day air-drying	44.0	42.0	39.0	30.0	37.5	41.0
5 day air-drying	39.0	41.0	42.0	15.5	38.0	34.5
7 day air-drying	45.0	39.0	—[b]	—[b]	—[b]	—[b]
5 day air-drying and 24 hour immersion	—[c]	—[c]	21.5	42.0	29.0	20.0

[a] Percent by weight of total solution.
[b] No specimens were molded for these concentrations.
[c] Specimens failed during immersion.

Table 5

Effect of Variation of Chemical Concentration in Water and Length of Air-curing on the Cohesion of Arquad 2HT Stabilized Loess

	Cohesion of stabilized soil mixtures in lbs/in^2 for chemical concentration in water[a] shown below.					
Curing Method	0%	½%	1%	2%	3%	5%
No curing	12.2	6.5	15.8	8.0	8.0	13.0
1 day air-drying	18.0	82.0	98.0	27.0	27.5	37.0
3 day air-drying	100.0	132.0	135.0	115.0	123.0	37.0
5 day air-drying	130.0	156.0	115.0	200.0	117.0	66.0
7 day air-drying	125.0	185.0	—[b]	—[b]	—[b]	—[b]
5 day air-drying and 24 hour immersion	—[c]	—[c]	20.5	8.0	25.0	25.0

[a] Percent by weight of total solution.
[b] No specimens were molded for these concentrations.
[c] Specimens failed during immersion.

The apparent cohesion (Table 5) produced in the chemically stabilized specimens shows trends similar to those observed with the friction angle. The maximum benefits appear around two percent chemical concentration with five day air-drying and at about three percent concentration with five day air-drying, twenty-four hour immersion. The latter being substantially lower than at the former but also better than three times greater than that with no curing. It must be pointed out that twenty-four hours complete immersion in water is an extremely severe test with the small specimens used in this study and that all untreated specimens failed completely within several minutes after immersion.

CONCLUSIONS

When combined with two to three percent water concentration of Arquad 2HT, compacted to approximately standard Proctor density and air cured for five days, the cohesion and modulus of compression of the friable loess were considerably improved. Similar combinations produced a slight, though not detrimental, reduction in the angle of internal friction of the loess. During the 24 hour immersion period, the three soil properties studied in this investigation were improved due to the waterproofing effects of the chemical. The Arquad 2HT would probably improve the bearing capacity and shearing resistance of the loess under load if proper curing could be attained. Such benefits may also improve the adaptability of Arquad 2HT-soil mixtures as a possible supporting medium for highway surfaces.

ACKNOWLEDGMENT

The authors take this opportunity to express appreciation to Mr. Karl M. Bierman of Armour and Company for supplying the Arquad 2HT used in this study.

Selected References

1. Armour Chemicals and Fatty Acids. Chemical Division, Armour and Company. Chicago. (Undated)
2. Arquads. Chemical Division, Armour and Company. Chicago. 1953.
3. Bishop, A. W. and Henkel, D. J. The measurement of soil properties in the triaxial test. Edward Arnold Publishers Ltd. London. 1957.
4. Hoover, J. M. and Davidson, D. T. Organic cationic chemicals as stabilizing agents for Iowa loess. Bulletin 129. Highway Research Board. 1956.
5. Kardoush, F. B., Hoover, J. M. and Davidson, D. T. Stabilization of loess with a promising quaternary ammonium chloride. Highway Research Board Proceedings. Vol. 36. 1957.
6. Nicholls, R. L. and Davidson, D. T. Polyacids and lignin used with large organic cations for soil stabilization. Presented at the 37th Annual Meeting of the Highway Research Board, Washington, D. C., January 6-10, 1958.
7. Nicholls, R. L. and Davidson, D. T. Soil stabilization with large organic cations and polyacids. Proceedings, Iowa Academy of Science. Vol. 64. 1957.
8. Spangler, M. G. Soil Engineering. International Textbook Co., Scranton, Pa. 1951.
9. Wilson, Stanley D. Small soil compaction apparatus duplicates field results closely. Engineering News Record. November 2, 1950.

IOWA ENGINEERING EXPERIMENT STATION
IOWA STATE COLLEGE
AMES, IOWA