

/ STATE OF THE ART SOIL INVESTIGATION *the*
IN KANSAS /

by

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INTRODUCTION

One of the requirements of Advanced Soil Testing, Civil Engineering 724, offered at KSU during the spring of 1983, was for participating students to visit each commercial testing laboratory serving Kansas engineers. The students were directed to observe the available equipment and to determine, from the principal of the firm if possible, the methods of sampling, testing and analysis. These students were well acquainted with "state of the art" soil tests and analytical procedures, and their goal was to determine how Kansas geotechnical firms rated with regard to the "state of the art" as defined in the commonly used soil mechanics textbooks.

It is obvious that the practice of geotechnical engineering in Kansas is some forty years out-of-date with most firms relying heavily on the split-tube sampler and pocket penetrometer for determining the bearing capacity of the soil. It also is obvious that the "state of the art" needs to be defined.

Following this study, the students in Foundation Engineering (spring 1983) were asked to contact foundation engineers in Kansas with a single question: What is the engineers' definition of the bearing capacity of the soil. The answer was to be more specific than "the load the soil can hold up." The students were enthusiastic, and there were very few foundation engineers that were not contacted. The survey indicated that, for the most part, few engineers understand that bearing capacity is a function of the shearing strength and compressibility of the soil, with an appropriate safety factor applied; almost all agree it can be, and is being, determined by the split-tube sampler.

It is the purpose of this paper to review the literature to identify what the "state of the art" actually is, and based upon the surveys described, to compare the practice in Kansas with the "state of the art."

LITERATURE REVIEW

The scope of the study was a review of the literature from the Terzaghi work of 1925-1950 and a specific enumeration and classification of papers in the ASCE Geotechnical Journal during the past five years as evidence of the direction of research in this area.

The rationale for this approach is that the preliminary review indicated great strides in geotechnical knowledge and a wide dissemination of this knowledge during Terzaghi's life in the U.S. and a general regression and stagnation since he became inactive.

It is commonly accepted that Erdbaumechanik by Terzaghi (99), published in 1925, was the beginning of soil mechanics as we know it today. Terzaghi (98) introduced the material to U.S. engineers, which resulted in Terzaghi accepting a position as Associate Professor of Foundation Engineering at MIT. Erdbaumechanik and "Modern Concepts Concerning Foundation Engineering" were followed by papers in the Engineering News Record and the Boston Society of Civil Engineers (96, 97). The work by Terzaghi was based upon the works of Coulomb (20), Rankine (79), Prandtl (74), Boussinesq (10) and others who worked in the area of solid mechanics.

In 1932 and 1933, Casagrande (13, 14) published two papers giving the basic equipment and analytical methods still in use today for determining the consolidation of clay soils. In 1933, Proctor (76) developed the moisture density relationship; in 1937, Tolman published Ground Water (101), a textbook; Casagrande (15) published the flow-net concept; Taylor (95) published Stability of Earth Slopes; and Newmark (65), in 1940, presented charts on stress distribution.

When World War II began, the pressure of war "crash-program" building of huge free-span airport hangers and pavement led to the development of test

procedures that were easy and quick, the results of which could be used directly in design. The thin-wall tube was developed by H. A. Mohr (64) in 1936, the split tube by Sprague and Henwood (91) in 1937, and the piston sampler by Raymond Concrete Pile Company (80) in 1942. Inasmuch as the split tube was reusable and was simple enough for use by unskilled personnel, it came into very wide usage during the after World War II.

Methods for using the data from the split-tube sampler were developed by Terzaghi and Peck (100) and Mohr (63). The use of the split-tube became a standard method for determining the allowable design soil pressure. In 1949, Hvorslev (37) presented a comparison of the analytical methods in use.

Taylor (94) in 1948 showed that the bearing capacity of the soil is a function of the shearing resistance of the soil in terms of friction angle and cohesion and the settlement of the soil under loading. He dismissed the split tube as giving "an idea of the stiffness of the sample."

Spangler (90) ignored the split-tube sampling and analyzed the bearing capacity of the soil by conventional friction angle, cohesion, and settlement criteria. In 1958, the standard test method for the penetration of soil (ASTM D-1586-58) (3) was adopted. In 1957, Hough (34) presented figures showing the presumptive bearing values of silts, clays and sands based upon the "N" value. In Hough's text he also shows the accepted Terzaghi analysis for shear and compressibility. Hough (35) included the chart of presumptive bearing values in the second edition of his book and during 1957 he became a recognized expert in soil consolidation (36).

In 1965, Fletcher (26) began a movement to accept the standard penetration test as ideal for computing bearing capacity, but he insisted that certain mechanical procedures needed to be improved.

REVIEW OF ASCE GEOTECHNICAL JOURNALS

Issues of the American Society of Civil Engineers Journal of Geotechnical Engineering for the years 1979 to 1983 were reviewed to learn more of what is considered the "state of the art" in soil mechanics. In the last five years, 74 articles were published that described new research and testing in the field of soil mechanics.

The subjects of the articles and number of articles on each are listed in Table 1. The articles were then categorized into eight major groups in order to establish which areas of interest were receiving the greatest and least concentration.

The first group, Analytical Testing Methods, included the following topics: finite element analysis, computer modeling, and model testing. These articles described methods that are being researched and about which much new information is being discovered. A large number of the articles was found to fall in this group. Much work was being done with the finite element method (5, 6, 7, 9, 17, 22, 29, 49, 50, 51, 55, 67, 89, 102) with the use of a computer, and with computer modeling (72, 77, 87). It can be seen that much of our research in Soil Mechanics is being concentrated on the computer. The third topic listed in this group was model testing (31, 38, 52, 68, 69). The model tests were used to predict bearing capacity, settlement, and uplift of shafts, topics about which additional research would reveal more about soil characteristics.

Group two was titled Sampling Methods. In this group only three articles (12, 24, 92) related to techniques of sampling. Sampling methods are important and should be uniform. Research was concentrated on ways of getting samples that are less disturbed. If an economical method can be found that will reduce the disturbance of the sample, then it will be widely used. Results of tests

Table 1. Topics of ASCE Geotechnical Journals

Group	Subject of Articles	Number of Articles
1. Analytical Testing Methods	Finite Element Method	14
	Computer Modeling	3
	Model Testing	5
2. Sampling Methods	Sampling	3
3. Field Testing	Stepped Blade	1
	Vane Shear	1
	Piezometer	3
	Dutch Cone	1
	Dilatometer	2
	Pressuremeter	4
	Standard Penetration Test	8
4. Fundamental Soil Properties	Permeability	3
5. Fundamental Strength Properties	Soil Strength	7
	Dynamic Testing	3
	Young's Modulus	3
6. Fundamental Compressibility Properties	Consolidation	6
	Stress Path Method	1
	Impact Densification	2
7. Footing Design	Yield Line Analysis	1
8. Project Descriptions	Project Descriptions	3

are affected by the amount of disturbance to which a sample is subjected.

Group three, titled, Field Testing, included abundant literature. The following field testing devices were reviewed: stepped blade (30), vane shear (2), piezometer (32, 42, 54) Dutch cone (4), dilatometer (58, 83), pressuremeter (11, 18, 19, 75), and split tube (25, 33, 46, 47, 61, 81, 84, 85). These devices were being evaluated and studied to determine what improvement can be made in the device and in techniques related to their application.

The stepped blade, dilatometer, and pressuremeter are all devices in which some sort of membrane is used to measure pressure at various depths. Each of the three is placed into soil and the pressure that is being exerted on them read at the surface. These three devices do not give any valid soil parameters; they just record what the pressure is on the device. These devices do not give friction angle or cohesion.

The vane shear, Dutch cone, and split tube (standard penetration test) are field-test instruments that supposedly give a shear strength or bearing capacity of the soil. Much research is being done with the split tube to find the amount of energy delivered to the hammer. The split tube gives a blow count "N", which tells how many blows are required by a 140-pound hammer dropped from a height of 30 inches, to drive the tube 12 inches. This value can then be used to find the bearing capacity of the soil.

The Dutch cone is a similar penetration test that is used to find soil density. The vane shear is a device in which the amount of torsion required to fail the soil is recorded.

The last testing device in this group is the piezometer. The piezometer is buried in the soil to measure pore-water pressure, information useful in design.

Groups 4, 5 and 6 were titled Fundamental Soil Properties, Fundamental Strength Properties, and Fundamental Compressibility Properties, respectively.

Group 4, Fundamental Soil Properties, included articles only on permeability (27, 44, 93); nothing was found on void ratio, porosity, saturation, water content, grain size, or Atterberg limits.

Group 5, Fundamental Strength Properties, included papers on soil strength (8, 28, 39, 48, 60, 82, 86), dynamic testing (16, 73, 88), and Young's modulus (21, 59, 62). These articles basically described new methods of dynamic testing to find Young's modulus and the shear modulus.

Group 6, Fundamental Compressibility Properties, topics of consolidation (1, 41, 45, 66, 70, 71), stress-path method (53) and impact densification (56, 78) were all related to the compressibility of the soil, an important soil characteristic for the soil investigator.

The last two groups, Footing Design and Project Descriptions, were reviewed. Yield-line analysis is a method that was being researched for square footing design (40); three project descriptions (23, 43, 57) constitute the papers in Group 8.

WRITTEN SURVEY OF COMMERCIAL TESTING LABORATORIES IN KANSAS

A survey was made of geotechnical laboratories in the Kansas area to identify their use of current technology in soil investigations; 14 letters were mailed to geotechnical laboratories in the state (Figure 1). Each firm was asked to fill out a short, one-page survey of their use of tests, drilling equipment, and methods of analysis. An example of the survey form is shown in Figure 2. Nine of the fourteen surveys were returned, which provided a reasonable representation of the testing laboratories in Kansas.

After review of the surveys it was found that all of the laboratories owned some sort of drilling equipment and could do all of their own drilling. Question 3, Methods of Analysis, was unclear to those who replied and was left blank by several. Anticipated answers were, e.g. "Terzaghi's equation for bearing capacity" and "method of settlement analysis." Instead, answers were received that were more related to specifications such as: ASTM, AASHTO, and MIL STD. These were not useful answers.

Question 2, the heart of the survey, was designed to identify which soil tests are considered to be important and which tests are not. The laboratories were asked to place a number by each of the tests to indicate how commonly each test was conducted in a typical soil investigation. A number 1 indicated that the test was never used, 2 meant the test was seldom used, and 3 indicated regular usage of that test. The results of question 2 are summarized in Table 2. In this table, the number of answers received from the 9 replies was totaled, then averaged. As an example, the specific gravity was never used by two labs, seldom used by three labs, and regularly used by four labs with an average of 2.22. The average shows the relative importance placed on the test as compared with the other tests.

It was discovered that six of the twenty tests were run regularly by

Figure 1. Letter That Accompanied
Written Survey

March 7, 1984

Dear Sirs:

I am a graduate student at Kansas State University in geotechnical engineering. I am writing my Master's Report on the "State of the Art of Soil Investigation." I am writing to each Geotechnical Laboratory in Kansas to survey present technology on this topic. Would you please fill out the enclosed survey and return it to me in the enclosed envelope. The information will be strictly confidential and will be used only in a general sense in my report.

Thank you for your time and attention. I will appreciate it if you will expedite your reply since I hope to graduate in May.

Sincerely,

Greg Swoyer

Enclosure

Figure 2. Written Survey Form

1. List drilling equipment.

2. Tests: Indicate best answer by placing the most appropriate number next to the test. Please list any additional tests.

We run the following tests: (1) Never (2) Seldom (3) Regularly

- ☐ Specific Gravity
- ☐ Sieve Analysis
- ☐ Hydrometer Analysis
- ☐ Atterberg Limits
- ☐ Constant Head Permeability Tests
- ☐ Falling Head Permeability Tests
- ☐ Proctor Density
- ☐ California Bearing Ratio
- ☐ Unconfined Compression
- ☐ Direct Shear
- ☐ Triaxial Shear
- ☐ Consolidation
- ☐ Moisture Density (Lab.)
- ☐ Moisture Density (Field)
- ☐ Nuclear Density
- ☐ Field Piezometers Installation
- ☐ Penetration Tests
- ☐ Pressure Meter Tests
- ☐ Vane Shear Tests
- ☐ Pocket Penetrometer Tests
- ☐
- ☐
- ☐

3. List methods of analysis.

TABLE 2. RESULTS OF WRITTEN SURVEY

Test	No answer	1	2	3	Avg.
Specific Gravity	0	2	3	4	2.22
Sieve Analysis	0	0	2	7	2.78
Hydrometer Analysis	0	0	4	5	2.56
Atterberg Limits	0	0	0	9	3.00
Constant Head Permeability Tests	0	1	4	4	2.33
Falling Head Permeability Tests	1	0	2	6	2.75
Proctor Density	0	0	0	9	3.00
California Bearing Ratio	0	1	2	6	2.56
Unconfined Compression	0	0	0	9	3.00
Direct Shear	0	3	4	2	1.89
Triaxial Shear	0	2	4	3	2.11
Consolidation	0	0	3	6	2.67
Moisture Density (Lab.)	0	0	0	9	3.00
Moisture Density (Field)	1	0	1	7	2.88
Nuclear Density	0	0	0	9	3.00
Field Peizometers Installation	0	1	6	2	2.11
Penetration Tests	0	0	0	9	3.00
Pressure Meter Tests	0	5	2	2	1.67
Vane Shear Tests	0	4	3	2	1.78
Pocket Penetrometer Tests	0	0	3	6	2.67

all of the nine laboratories. The tests were: Atterberg limits, Proctor density, unconfined, compression, moisture density (laboratory), nuclear density, and penetration test. It appears that results of these tests are considered very important for the soil investigator. Other tests that seem to be important are: sieve analysis, hydrometer, permeability (falling head), California Bearing Ratio, consolidation, moisture density (field), and pocket penetrometer test. The survey suggests that many of these laboratories use the standard penetration test, unconfined compression test, and pocket penetrometer test to find bearing capacity of the soil. The high indicated usage of the consolidation test is surprising inasmuch as it is the most difficult and expensive soil test.

Two tests that are used very little are the direct shear and triaxial shear tests; these tests give very valuable results in computation of bearing capacity. The values of friction angle and cohesion can be computed by these two tests, and these values can be used in Terzaghi's equation to find the bearing capacity. These two tests are seldom being run, and the most likely reason is their relatively higher cost. The relative importance of the other tests can be seen in Table 2.

PERSONAL SURVEY OF LABORATORIES

The author was a member of the 1983 (spring) Advanced Soil Testing class that visited the soil testing laboratories in Kansas. Each student was directed to visit one commercial testing laboratory and to report on the findings. The author visited three of the testing laboratories, together with Bill Brundgardt and Pat Levalley, which were also included in the written survey of this report. Of the three laboratories, one had very poor testing equipment, one had very little testing equipment, and one had excellent testing equipment.

In surveying the laboratories it was quite clear which equipment was used on a regular basis. A direct shear machine was not seen, so obviously that test was not conducted at the three laboratories. At one laboratory it was stated that they had a triaxial machine, but it was never seen by the author. At a different laboratory, personnel there stated that they could have triaxial and direct shear tests completed at their main office at a different location. All three tour guides at the laboratories admitted that they very seldom conducted triaxial and shear tests, and it was apparent that it was possible that they never ran these tests. The unconfined compression test and standard penetration test are conducted by all three laboratories and seems to be the way they determine bearing capacity. A complete explanation of the way in which the results of these tests are used to determine bearing capacity was not given.

The written survey of commercial testing laboratories indicated that the consolidation test was run quite regularly. During the visit to the three laboratories, only one machine that resembled a consolidometer was seen. Probably, at one time or another, this machine had been used, but it had been quite some time. The machine, covered with a thick layer of dust, was in a room upstairs. At the top of the stairs a pipe blocked the entry to the

room at a height of about 3 feet; entry to the room could only be obtained by ducking under the pipe. Thus, it was clear that the consolidometer test was not run regularly, despite the results in Table 2.

When the person directing the tours of the three laboratories was asked why direct and triaxial shear were not run, he answered, "Money!" There is a great amount of competition, and the laboratory that charges the lowest prices will get the job. It was pointed out to him that if a thorough investigation of the soil was done, there could possibly be a considerable savings in the foundation design, which then could be passed on to the client. His reply was that this idea was very hard to sell and if this approach was tried their business would suffer. This lack of accuracy in footing design is poor engineering. Engineers should try to design a structure as economically and efficiently as possible. In Terzaghi's equation, a safety factor of three is used in determining the allowable soil pressure. These firms were using safety factors on the order of six or greater. Until better practices in soil mechanics become mandatory, poor engineering design will continue.

Two other members of the Advanced Soil Testing class also visited two additional laboratories where they saw very little equipment; those laboratories were not contacted in the written survey. A third lab visited by still another student in the class revealed basically the same conditions that had been found in others, i.e. the equipment was available but not being used.

CONCLUSION

The "state of the art" in Geotechnical Engineering was clearly defined by the Taylor textbook of 1948 (94). As with any engineering material, the designer must know the strength of the material. Unlike most engineering materials, however, soil is compressible, and the analysis of the soil must include measurements of this compressibility. Designing foundations without these values would be similar to designing concrete beams based upon the color of the concrete.

Firms in the larger cities such as New York, Chicago, Houston, and Seattle are practicing Geotechnical Engineering as outlined by Terzaghi, using the triaxial shear the consolidation testing procedures on their projects.

The firms surveyed in Kansas are not, for the most part, practicing even the barest rudiments of Geotechnical Engineering. Most of them are blaming the client and citing the competition as excuses, but it is apparent that they are reluctant to change their methods.

The "state of the art" soil investigation is one that finds bearing capacity with direct or triaxial shear tests and consolidation with a consolidometer. Surprisingly, in the review of 60 months of the ASCE journals, it was found that "state of the art" was not reflected in the contents of the articles therein.

In writing this paper it has been the intent of the author to point out the deficiencies of the practice of Soil Mechanics in Kansas. The wide usage of the standard penetration test, pocket penetrometer and unconfined compression to find bearing capacity are proof of these deficiencies.

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REFERENCES

1. American Society for Testing and Materials, Standards, September, 1983.
2. Andersland, Orlando B., and Al-Khafaji, Abdul-Amir W. N., "Organic Material and Soil Compressibility," Journal of the Geotechnical Engineering Division, ASCE, Vol. 106, No. GT7, Proc. Paper 15546, July, 1980, pp. 749-758.
3. Asaoka, Akira, and A-Grivas, Dimitri, "Spatial Variability of the Undrained Strength of Clays," Journal of the Geotechnical Engineering Division, ASCE, Vol. 108, No. GT5, Proc. Paper 17054, May, 1982, pp. 743-757.
4. Baligh, Mohsen M., Vivatrat, Vitoon, and Ladd, Charles C., "Cone Penetration in Soil Profiling," Journal of the Geotechnical Engineering Division, ASCE, Vol. 106, No. GT4, Proc. Paper 15377, April, 1980, pp. 447-461.
5. Bang, S., Shen, C. K., Romstad, K. M., Kulchin, L., and Denetale, J. S., "Field Measurements of an Earth Support System," Journal of the Geotechnical Engineering Division, ASCE, Vol. 107, No. GT12, Proc. Paper 16734, Dec., 1981, pp. 1625-1642.
6. Baus, R. L., and Wang, M. C., "Bearing Capacity of Strip Footing Above Void," Journal of the Geotechnical Engineering Division, ASCE, Vol. 109, No. 1., Jan., 1983, pp. 1-14.
7. Beacher, Gregory B., and Ingra, Thomas S., "Stochastic FEM in Settlement Predictions," Journal of the Geotechnical Engineering Division, ASCE, Vol. 107, No. GT4, Proc. Paper 16179, April, 1981, pp. 449-463.
8. Bhushan, Kul, Haley, Steven C., and Fong, Patrick T., "Lateral Load Tests on Drilled Piers in Stiff Clays," Journal of the Geotechnical Engineering Division, ASCE, Vol. 105, No. GT8, Proc. Paper 14789, August, 1979, pp. 969-985.
9. Blayquez, Rafael, Kirzek, Raymond, J., and Bayant, Zdzek P., "Site Factors Controlling Liquefaction," Journal of the Geotechnical Engineering Division, ASCE, Vol. 106, No. GT7, Proc. Paper 15577, July, 1980, pp. 785-801.
10. Boussinesq, J., Application des Potentials a l'etude de l'equilibre et de mouvement des solides elastique, Paris, Gauthier-Villars, 1885.
11. Briaud, Jean-Louis, and Shields, Donald H., "Pressuremeter Tests at Very Shallow Depth," Journal of the Geotechnical Engineering Division, ASCE, Vol. 107, No. GT8, Proc. Paper 16416, August, 1981, pp. 1023-1040.
12. Broms, Bengt B., "Soil Sampling in Europe: State of the Art," Journal of the Geotechnical Engineering Division, ASCE, Vol. 106, No. GT1, Proc. Paper 15149, Jan., 1980, pp. 65-98.
13. Casagrande, Arthur, "The Structure of Clay and its Importance in Foundation Engineering," Society of Civil Engineering Journal, April, 1933.

14. Casagrande, A., "Research on the Atterberg Limits of Soil," Public Roads, Vol. 13, No. 8, Oct., 1932.
15. Casagrande, A., "Seepage Through Dams," Journal of Boston Society of Civil Engineers, June, 1937.
16. Chamberlain, Edwin J., Cole, David M., Johnson, and Thaddeus C., "Resilient Response of Two Frozen and Thawed Soils," Journal of the Geotechnical Engineering Division, ASCE, Vol. 105, No. GT2, Proc. Paper 14398, Feb., 1979, pp. 257-271.
17. Chang, Ching S., Espinoza, Julio M., and Selig, Ernest T., "Computer Analysis of Newton Creek Culvert," Journal of the Geotechnical Engineering Division, ASCE, Vol. 106, No. GT5, Proc. Paper 15438, May, 1980, pp. 531-550.
18. Clough, Wayne G., and Denby, Gordon M., "Self Boring Pressuremeter Tests in Clay," Journal of the Geotechnical Engineering Division, ASCE, Vol. 106, No. GT12, Proc. Paper 15950, Dec., 1980, pp. 1369-1387.
19. Clough, Wayne G., and Denby, Gordon M., "Self Boring Pressuremeter Study of San Francisco Bay Mud," Journal of the Geotechnical Engineering Division, ASCE, Vol. 106, No. GT1, Proc. Paper 15148, Jan., 1980, pp. 45-63.
20. Coulomb, C. A., "Essai sur une application des regles des maximis et minimis a quelque problemes de statique relatifs a l'architecture mem.," Acad. Roy Pres devers Savants, Vol. 7, Paris, 1776.
21. Czajkowski, Ronald, L., and Vinson, Ted S., "Dynamic Properties of Frozen Silt Under Cyclic Loading," Journal of the Geotechnical Engineering Division, ASCE, Vol. 106, No. GT9, Proc. Paper 15702, Sept., 1980, pp. 963-980.
22. Duncan, James M., "Behavior and Design of Long-Span Metal Culverts," Journal of the Geotechnical Engineering Division, ASCE, Vol. 105, GT3, Proc. Paper 14429, March, 1979, pp. 399-418.
23. Dupas, Jean-Michel, and Pecker, Alain, "Static and Dynamic Properties of Sand-Cement," Journal of the Geotechnical Engineering Division, ASCE, Vol. 105, No. GT3, Proc. Paper 14425, Mar., 1979, pp. 419-436.
24. Espana, Carlos, Chaney, Ronald C., and Duffy, Dennis, "Cyclic Strengths Compared for Two Sampling Techniques," Journal of the Geotechnical Engineering Division, ASCE, Vol. 107, No. GT5, Proc. Paper 16234, May, 1981, pp. 563-576.
25. Fardis, Michael N., and Veneziano, Daniele, "Estimation of SPT-N and Relative Density," Journal of the Geotechnical Engineering Division, ASCE, Vol. 107, No. GT10, Proc. Paper 16590, Oct., 1981, pp. 1345-1359.
26. Fletcher, F. A., "Standard Penetration Test: Its Uses and Abuses," Journal of the Soil Mechanics and Foundation Engineering Division, ASCE, Vol. 91, SM4, July, 1965.

27. Garcio-Gengochea, Ignacio, Lovell, Charles William, and Altschaeffl, Adolph G., "Pore Distribution and Permeability of Silty Clays," Journal of the Geotechnical Engineering Division, ASCE, Vol. 105, No. GT7, Proc. Paper 14686, July, 1979, pp. 839-856.
28. Garg, K. G., "Bored Piled Groups Under Vertical Load in Sand," Journal of the Geotechnical Engineering Division, ASCE, Vol. 105, No. GT8, Proc. Paper 14786, Aug., 1979, pp. 939-956.
29. Ghaboussi, Jamshid, Hansmire, William H., Parker, Harvey W., and Kim, Kwang J., "Finite Element Simulation of Tunneling Over Subways," Journal of the Geotechnical Engineering Division, ASCE, Vol. 109, No. 3, Mar., 1983, pp. 318-334.
30. Handy, Richard C., Remmes, Bernard, Moldt, Steven, Lutenecker, Alan J., and Trott, Gary, "In Situ Stress Determination by Iowa Stepped Blade," Journal of the Geotechnical Engineering Division, ASCE, Vol. 108, No. GT11, Proc. Paper 17447, Nov., 1982, pp. 1405-1423.
31. Hanna, Adel M., "Experimental Study on Footings in Layered Soil," Journal of the Geotechnical Engineering Division, ASCE, Vol. 107, No. GT8, Proc. Paper 16447, Aug., 1981, pp. 1113-1127.
32. Houlsby, A. D., "Long-Term Performance of Embankment Dam Instrumentation," Journal of the Geotechnical Engineering Division, ASCE, Vol. 108, No. GT8, Aug., 1982, pp. 1091-1092.
33. Holtz, Wesley G., and Gibbs, Harold J., "SPT and Relative Density in Coarse Sand," Journal of the Geotechnical Engineering Division, ASCE, Vol. 105, No. GT3, Proc. Paper 14401, Mar., 1979, pp. 439-441.
34. Hough, B. K., Basic Soil Engineering, Ronald Press, 1957.
35. Hough, B. K., Basic Soil Engineering, 2nd edition, Ronald Press, 1969.
36. Hough, B. K., "Compressibility as a Basis for Soil Bearing Value," Journal of the Soil Mechanics and Foundation Engineering Division, ASCE, Vol. 85, SM4, Aug., 1959.
37. Hvorslev, M. J., "Subsurface Exploration and Sampling of Soils for Civil Engineering Purposes, Report, ASCE and Vicksburg Exp. Sta., Nov., 1949.
38. Ismael, Nabil F., and Klym, Tony W., "Uplift and Bearing Capacity of Short Piers in Sand," Journal of the Geotechnical Engineering Division, ASCE, Vol. 105, No. GT5, Proc. Paper 14568, May, 1979, pp. 579-594.
39. Ismael, Nabil F., and Vesic, Alexander S., "Compressibility and Bearing Capacity," Journal of the Geotechnical Engineering Division, ASCE, Vol. 107, No. GT12, Proc. Paper 16718, Dec., 1981, pp. 1677-1691.
40. Jain, Satish C., Singh, Kiran K., and Maity, Prabhas K., "Yield Line Analysis of Square Footings," Journal of the Geotechnical Engineering Division, ASCE, Vol. 105, No. GT11, Proc. Paper, Nov., 1979, pp. 1355-1359.

41. Kaderabek, Thomas J., and Reynolds, Richard T., "Settlements Beneath Preload Test Fill," Journal of the Geotechnical Engineering Division, ASCE, Vol. 105, No. GT6, Proc. Paper 14621, June, 1979, pp. 781-785.
42. Kleiner, D. E., and Logani, K. C., "Discussion of Piezometers," Journal of the Geotechnical Engineering Division, ASCE, Vol. 108, No. GT8, Aug., 1982, pp. 1092-1094.
43. Knodel, Paul C., "Construction of Large Canal on Collapsing Soils," Journal of the Geotechnical Engineering Division, ASCE, Vol. 107, No. GT1, Proc. Paper 15992, Jan., 1981, pp. 79-94.
44. Koerner, Robert M., Reif, Jonathan, S., and Burlingmae, Michael J., "Detection Methods for Location of Subsurface Water and Seepage," Journal of the Geotechnical Engineering Division, ASCE, Vol. 105, No. GT11, Nov., 1979.
45. Koutsoftas, Demetrious C., "H-Pile Heave: A Field Test," Journal of the Geotechnical Engineering Division, ASCE, Vol. 109, No. GT8, Proc. Paper 17260, Aug., 1982, pp. 999-1017.
46. Kovacs, William D., "Velocity Measurement of Free Fall SPT Hammer," Journal of the Geotechnical Engineering Division, ASCE, Vol. 105, GT1, Proc. Paper 14313, Jan., 1979, pp. 1-10.
47. Kovacs, William D., and Salomone, Lawrence, A., "SPT Hammer Energy Measurements," Journal of the Geotechnical Engineering Division, ASCE, Vol. 108, No. GT4, Proc. Paper 17000, April, 1982, pp. 499-621.
48. Krafts, Leland M., Jr., Focht, John A., Jr., and Amerasinghe, Srinath F., "Friction Capacity of Piles Driven Into Clay," Journal of the Geotechnical Engineering Division, ASCE, Vol. 107, No. GT11, Proc. Paper 16663, Nov., 1981, pp. 1521-1541.
49. Kuhlemeyer, Roger L., "Static and Dynamic Laterally Loaded Floating Piles," Journal of the Geotechnical Engineering Division, ASCE, Vol. 105, No. GT2, Proc. Paper 14394, Feb., 1979, pp. 289-304.
50. Kuhlemeyer, Roger L., "Vertical Vibrations of Piles," Journal of the Geotechnical Engineering Division, ASCE, Vol. 105, No. GT2, Proc. Paper 14393, Feb., 1979, pp. 273-287.
51. Kuhlemeyer, Roger L., "Bending Element for Circular Beams and Piles," Journal of the Geotechnical Engineering Division, ASCE, Vol. 105, No. GT2, Proc. Paper 14349, Feb., 1979, pp. 325-330.
52. Kulhawy, Fred H., Kozera David W., and Withiam, James L., "Uplift Testing of Model Drilled Shafts in Sand," Journal of the Geotechnical Engineering Division, ASCE, Vol. 105, No. GT1, Proc. Paper 14301, Jan., 1977, pp. 31-47.
53. Lambe, William T., and Marr, Allen W., "Stress Path Method: Second Edition," Journal of the Geotechnical Engineering Division, ASCE, Vol. 105, No. GT6, Proc. Paper 14655, June, 1979, pp. 727-738.

54. Londe, Pierre, "Concepts and Instruments for Improved Monitoring," Journal of the Geotechnical Engineering Division, ASCE, Vol. 108, No. GT6, Proc. Paper 17151, June, 1982, pp. 820-835.
55. Li, G. C., and Desai, C. S., "Stress and Seepage Analysis of Earth Dams," Journal of the Geotechnical Engineering Division, ASCE, Vol. 109, No. 7, pp. 946-960.
56. Lukas, Robert G., "Densification of Loose Deposits by Pounding," Journal of the Geotechnical Engineering Division, ASCE, Vol. 106, No. GT4, Proc. Paper 15376, Apr., 1980, pp. 435-446.
57. McDaniel, Thomas N., and Decker, Roy S., "Dispersive Soil Problem at Los Esteros Dam," Journal of the Geotechnical Engineering Division, ASCE, Vol. 105, No. GT9, Proc. Paper 14804, Sept., 1979, pp. 1017-1030.
58. Marchetti, Silvano, "In Situ Tests by Flat Dilatometer," Journal of the Geotechnical Engineering Division, ASCE, Vol. 106, No. GT3, Proc. Paper 15290, March, 1980, pp. 299-321.
59. Marcuson, William F., and Curro, Joseph R., "Field and Laboratory Determination of Soil Moduli," Journal of the Geotechnical Engineering Division, ASCE, Vol. 107, No. GT10, Proc. Paper 16591, Oct., 1981, pp. 1269-1291.
60. Matsuri, Tomotsu, Ito, Tomio, Mitchell, James K., and Abe, Nobuharu, "Microscopic Study of Shear Mechanisms in Soils," Journal of the Geotechnical Engineering Division, ASCE, Vol. 106, No. GT2, Proc. Paper 15221, Feb., 1980, pp. 137-152.
61. Meyerhoff, George C., "Scale Effects of Ultimate Pile Capacity," Journal of the Geotechnical Engineering Division, ASCE, Vol. 109, No. 6, June, 1983, pp. 797-806.
62. Misra, Banabihari, "Stress Transmission in Granular Media," Journal of the Geotechnical Engineering Division, ASCE, Vol. 105, No. GT9, Proc. Paper 14798, Sept., 1979, pp. 1101-1107.
63. Mohr, H. A., "Notes on Determination and Use of Penetration Resistance of Drive Samplers," Personal Communication to A. Casagrande, Aug., 1949.
64. Mohr, H. A., "Exploration of Soil Conditions and Sampling Operations," Soil Mechanics Series #21, Harvard University, 3rd Ed., 1943.
65. Newmark, N. M., "Influence Charts for Computation of Stresses in Elastic Foundations," Bull., University of Illinois, Nov. 10, 1942.
66. Olson, Roy E., and Ladd, Charles C., "One-Dimensional Consolidation Problems," Journal of the Geotechnical Engineering Division, ASCE, Vol. 105, No. GT1, Proc. Paper 14330, Jan., 1979, pp. 11-30.
67. Osaimi, Ayed E., and Clough, Wayne G., "Pore-Pressure Dissipation During Excavation," Journal of the Geotechnical Engineering Division, ASCE, Vol. 105, No. GT4, Proc. Paper 14509, Apr., 1979, pp. 481-498.

68. Oweis, Issa S., "Equivalent Linear Model for Predicting Settlements of Sand Bases," Journal of the Geotechnical Engineering Division, ASCE, Vol. 105, No. GT12, Proc. Paper 15051, Dec., 1979, pp. 1525-1544.
69. Pfeifle, Tom W., and Das., Braja M., "Model Tests for Bearing Capacity in Sand," Journal of the Geotechnical Engineering Division, ASCE, Vol. 105, No. GT9, Proc. Paper 14798, Sept., 1979, pp. 1112-1116.
70. Poulos, Harry G., "Settlement of Single Piles in Nonhomogeneous Soils," Journal of the Geotechnical Engineering Division, ASCE, Vol. 105, No. GT5, Proc. Paper 14575, May, 1979, pp. 627-641.
71. Poulos, Harry G., "Group Factors for Pile-Deflection Estimation," Journal of the Geotechnical Engineering Division, ASCE, Vol. 105, No. GT12, Proc. Paper 15032, Dec., 1979, pp. 1489-1509.
72. Poulos, Harry G., and Randolph, Mark F., "Pile Group Analysis: A Study of Two Methods," Journal of the Geotechnical Engineering Division, ASCE, Vol. 109, No. 3, Mar., 1983, pp. 355-372.
73. Prakash, Shamsher, and Puri, Vijay Kumar, "Dynamic Properties of Soils From In-Situ Tests," Journal of the Geotechnical Engineering Division, ASCE, Vol. 107, No. GT7, Proc. Paper 16366, July, 1981, pp. 943-963.
74. Prandtl, L., "Harte plastischer Korper., Nichtrechten Ges der Wissenschaften Zu Gottigen", 1920.
75. Prevost, Jean H., "Undrained Shear Tests of Clays," Journal of the Geotechnical Engineering Division, ASCE, Vol. 105, No. GT1, Proc. Paper 14311, Jan., 1979, pp. 49-64.
76. Proctor, R. R., "Fundamental Principles of Soil Compaction," Engineering News Record, Vol. 111, No. 9, 10, 11, 12 and 13, 1933.
77. Pusch, Roland, and Feltham, Paul, "Computer Simulation of Creep of Clay," Journal of the Geotechnical Engineering Division, ASCE, Vol. 107, No. GT1, Proc. Paper 15998, Jan., 1981, pp. 95-104.
78. Ramaswamy, Salem D., Aziz, Mohamed A., Subrahmaniam, Raja V., Khader Abdul M. H., and Lee, Seng-Lip, "Treatment of Peaty Clay by High Energy Impact," Journal of the Geotechnical Engineering Division, ASCE, Vol. 105, No. GT8, Proc. Paper 14787, Aug., 1979, pp. 947-967.
79. Rankine, W. J. M., "On the Stability of Loose Earth," Phil Trans, Royal Soc, London 1857.
80. Raymond Concrete Pile Company, "Detailed Drawings of a 1-3/4 inch Piston Sampler with Liner," New York, Sept. 1942.
81. Robertson, P. K., Campanella R. G., and Wightman A., "SPT-CPT Correlations," Journal of the Geotechnical Engineering Division, ASCE, Vol. 109, No. 1, Nov., 1983, pp. 1449-1459.

82. Satyanarayana, B., and Barb, R. K., "Bearing Capacity of Footings on Layered C- ϕ Soils," Journal of the Geotechnical Engineering Division, ASCE, Vol. 106, No. GT7, Proc. Paper 14478, July, 1980, pp. 819-826.
83. Schmertmann, John H., "In Situ Test by Flat Dilatometer," Journal of the Geotechnical Engineering Division, ASCE, Vol. 107, No. GT6, June, 1981, pp. 831-837.
84. Schmertmann, John H., "Statics of SPT," Journal of the Geotechnical Engineering Division, ASCE, Vol. 105, No. GT4, Proc. Paper 14573, May, 1979, pp. 655-670.
85. Schmertmann, John H., and Palacios, Alajandro, "Energy Dynamics of SPT," Journal of the Geotechnical Engineering Division, ASCE, Vol. 105, No. GT8, Proc. Paper 14769, Aug., 1979, pp. 909-926.
86. Scott, James C., Altschaeffl, A. G., and Lovell, William Charles, "Soaked Strength of Laboratory Compacted Clay," Journal of the Geotechnical Engineering Division, ASCE, Vol. 105, No. GT11, Proc. Paper 14987, Nov., 1979, pp. 1273-1284.
87. Scott, Ronald F., and Craig, Michael J. K., "Computer Modeling of Clay Structure and Mechanics," Journal of the Geotechnical Engineering Division, ASCE, Vol. 106, No. GT1, Proc. Paper 15128, Jan., 1980, pp. 17-33.
88. Screwala, Fauokh N., and Khera, Raj P., "Ballistic Pendulums and Dynamic Testing of Clays," Journal of the Geotechnical Engineering Division, ASCE, Vol. 105, No. GT8, Proc. Paper 14772, Aug., 1979, pp. 927-938.
89. Shen, C. K., Bwag, S., and Herrmann, L. R., "Ground Movement Analysis of Earth Support System," Journal of the Geotechnical Engineering Division, ASCE, Vol. 107, No. GT12, Proc. Paper 16734, Dec., 1981, pp. 1625-1642.
90. Spangler, M. G., Soil Engineering, International Textbook Co., 1951.
91. Sprague and Henwood Inc., Bull. 36-4 on Sampling and Sampling Devices and Equipment, Scranton, PA, 1937.
92. Sukhmander, Singh, Seed, Bolton H., and Chan, Clarence K., "Undisturbed Sampling of Saturated Sands by Freezing," Journal of the Geotechnical Engineering Division, ASCE, Vol. 108, No. GT2, Proc. Paper 16874, Feb., 1982, pp. 257-265.
93. Sundaram, Panchanatham H., "Hydraulic and Elector-Osmotic Permeability Coefficients," Journal of the Geotechnical Engineering Division, ASCE, Vol. 105, No. GT1, Jan., 1979, pp. 89-94.
94. Taylor, D. W., Fundamentals of Soil Mechanics, John Wiley & Sons, Inc., 1948.
95. Taylor, D. W., "Stability of Earth Slopes", Journal of Boston Society of Civil Engineers, July, 1937.
96. Terzaghi, K. V., "Simple Tests to Determine Hydrostatic Uplift", Engineering News Record, June 18, 1936.

97. Terzaghi, Charles, "Well Point Method of Handling Excavation of Foundation Pit at New Pumping Sta.," Lynn, Mass., Journal of Boston Society of Civil Engineers, Vol. 14, Sept. 1927, No. 7.
98. Terzaghi, Charles, "Modern Concepts Concerning Foundation Engineering," Journal of Boston Society of Civil Engineers, Vol. 12, No. 10, Dec., 1925.
99. Terzaghi, Karl, Erdbaumechaniks, Vienna, F., Deuticks, 1925.
100. Terzaghi, K., and Peck, R. B., "Soil Mechanics in Engineering Practice," Wiley and Sons, 1948.
101. Tolman, D. F., Ground Water, McGraw Hill, Inc., 1937.
102. Vrymoed, John, "Dynamic FEM Model of Oroville Dam," Journal of the Geotechnical Engineering Division, ASCE, Vol. 107, No. GT8, Proc. Paper 16464, Aug., 1981, pp. 1057-1077.

STATE OF THE ART SOIL INVESTIGATION
IN KANSAS

by

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ABSTRACT

The "state of the art soil investigation in Kansas" is reviewed. The purpose of this report is to discover if the "state of the art soil investigation" is being practiced in Kansas. American Society of Civil Engineers journals of the years 1979 to 1983 were first reviewed to help find a definition for the "state of the art soil investigation." Fourteen geotechnical laboratories in Kansas were contacted to learn what is being practiced in Kansas. The fourteen laboratories were asked to fill out a one-page survey of their use of tests, drilling equipment, and methods of analysis. Geotechnical laboratories were personally visited and the results of these visits were recorded in this report. The conclusion of this paper is that, on the whole, "state of the art" is not up-to-date in Kansas and the primary reason is economics.