No. Z-1

SOIL MECHANICS AS A PRACTICAL SCIENCE

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Introduction. An apparent lack of coordination of the efforts of investigators of soil mechanics, together with the seeming inadequacy of many of the results of theoretical investigation to be applied to practical problems, has prompted the author to write this paper. In it he considers the questions:

To what extent may soil mechanics be considered a science, and what can be done to make the study of soil conditions more scientific?

To what extent may soil mechanics be applied to foundation problems, and what can be done to make the study of soil conditions more useful in solving such problems?

The discussion deals primarily with the subject of settlement estimates.

Sampling. The author advocates the use of undisturbed samples 3 inches in diameter rather than the more costly 6-inch samples, recognizing, however, the advantages of the larger samples.

Observations of clay samples from core borings indicate that consolidation tests should not be made on samples kept in their original containers.

From both practical and theoretical considerations it is advisable to maintain the water in a core boring at the normal groundwater level.

Core borings should always be in charge of a trained soil technician who should remove the samples from their original tube in the field and prepare them for shipment to the laboratory.

Although satisfactory core samples of cohesionless materials have occasionally been obtained, no device has been developed to insure satisfactory samples.

An investigation involving the testing of samples obtained by the various methods and correlating the results with test results of samples taken from a test pit is suggested as a means of solving these problems.

Mechanical Analysis. The information obtained from sieve and hydrometer tests could more quickly and more economically be obtained by employing a trained man to classify soils according to a standard scale and on the basis of visual inspection only.

The use of dried and pulverized samples is not allowable for either hydrometer or specific gravity tests of cohesive material.

Soil Classification. A classification scale, according to grain size, using natural division sizes between materials and terms familiar to practical engineers is recommended, as shown, in comparison with other classifications, in Fig. 1.

The importance of adopting some standard is emaphsized, and the hope expressed that this conference may take some appropriate action.

Atterberg Limits. The significance of these tests in defining the physical characteristics of soils remains to be proved. The author suggests the establishment of a clearing house for Atterberg limit results correlated with moisture content, overburden pressure and consolidation data.

Shrinkage limit determinations should always be made on both undisturbed and remolded samples in an effort to determine any relation which may exist between these and the effect of remolding.

Consolidation Tests. The dial readings observed during consolidation tests should always be checked by weight readings taken before and after the tests.

The existing overburden load should be applied to samples in consolidation tests. Fig. 2 shows the results of a test made by the author to study the effect of reconsolidation. Fig. 3, illustrating the consolidation curve obtained by Professor Casagrande for Laurentian clay, shows clearly the error which might be introduced if the existing overburden load is overlooked.

Shearing Tests. Recent research has done much to increase our knowledge of the ultimate bearing capacity of soils. Continued study is needed to yield more reliable and complete information.

In the lower ranges of loading it is certain that some degree of adjustment or plastic flow must occur causing settlement. Professor Housel has attempted to analyze this flow. No settlement analysis can be complete which does not include a consideration of settlement due to flow as well as settlement due to consolidation.

Stress Distribution. The general rules of stress distribution across the base of a footing are not capable of specific application to common types of foundations. Investigations of large-size footings are needed to determine the type of distribution at the base of typical foundation types such as spread footings, grillage footings, mats, caisson seals, or pile caps resting on typical soil deposits.

The applicability of Boussinesq's equation with or without a modifying parameter, n, is practically a matter of conjecture. Stress distribution is the backbone of settlement analysis. The need for experimental verification of the theoretical formulas is great.

Rate of Consolidation. An experimental check of the thermodynamic analogy expressed by the consolidation theory would be of value in establishing this hypothesis. It is suggested that a series of consolidation

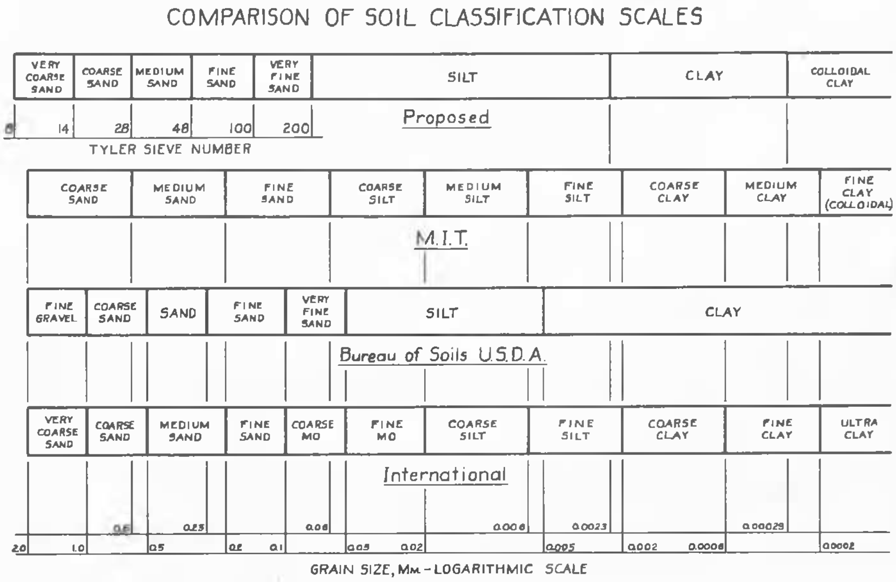


Fig. 1

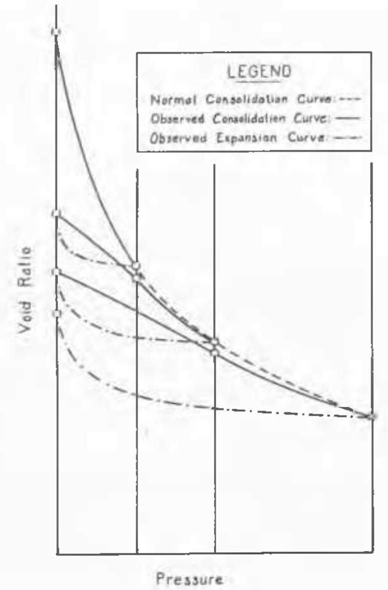
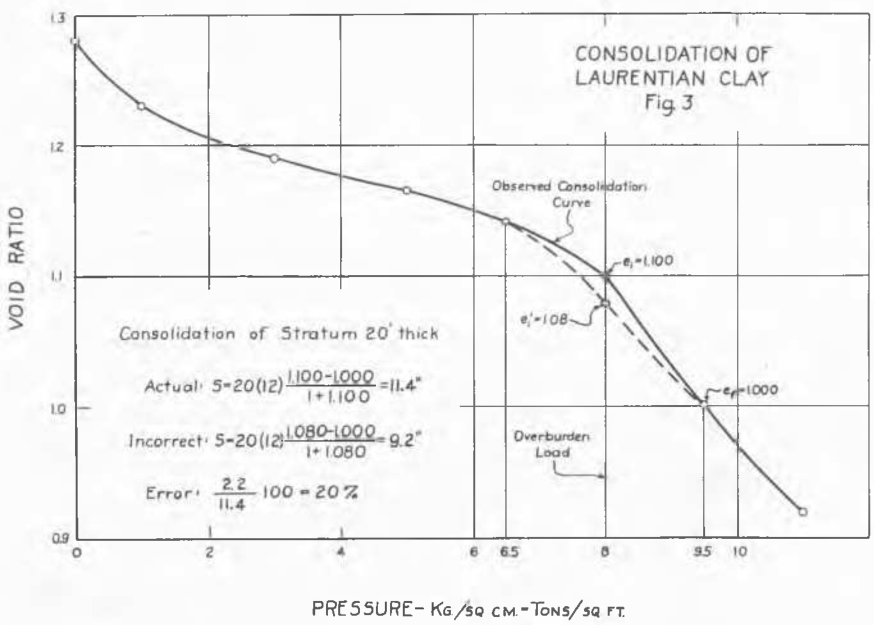
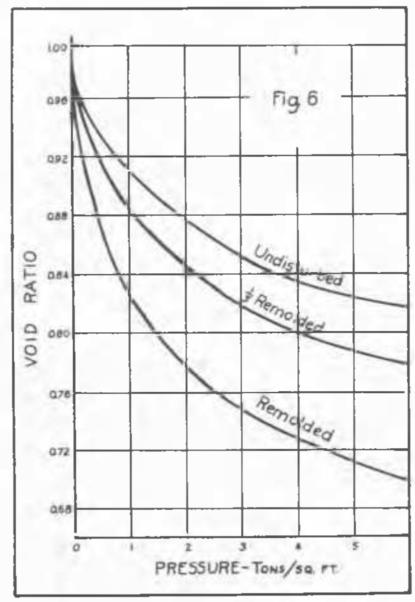


FIG. 2.





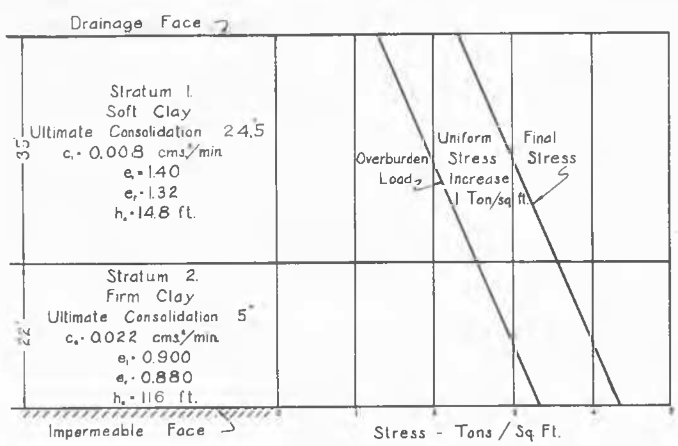


FIG. 4.

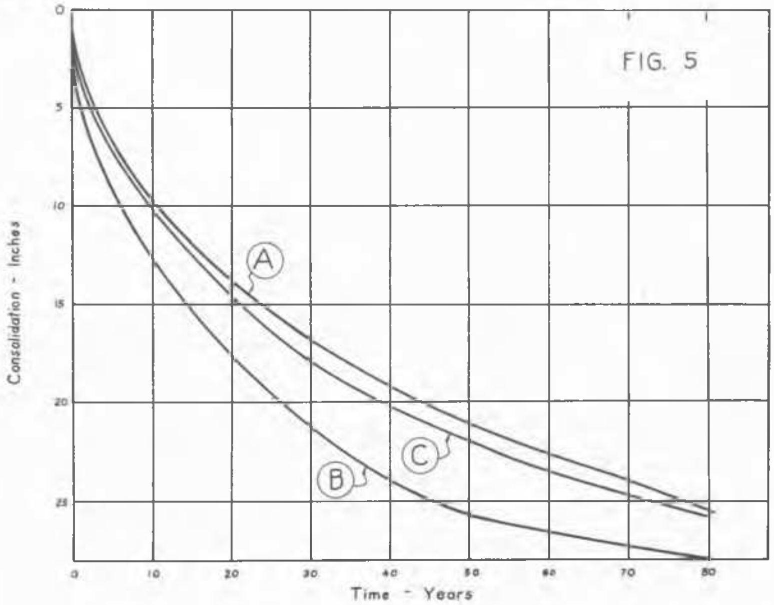


FIG. 5
Consolidation - Inches
Time - Years
A
B
C
0
5
10
15
20
25
0
10
20
30
40
50
60
70
80

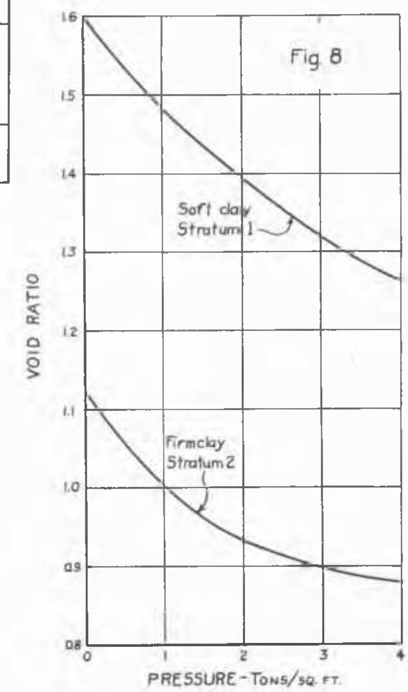


Fig. 8
VOID RATIO
PRESSURE - TONS/SQ. FT.
Soft clay
Stratum 1
Firmclay
Stratum 2
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0
1
2
3
4

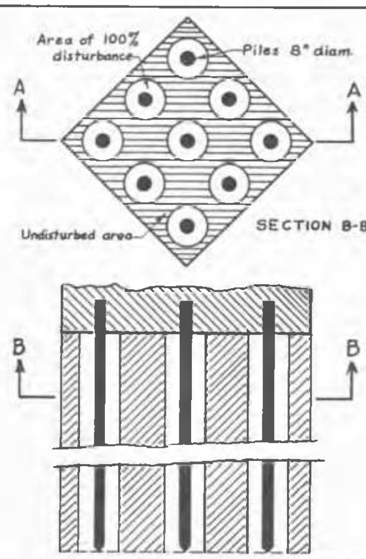
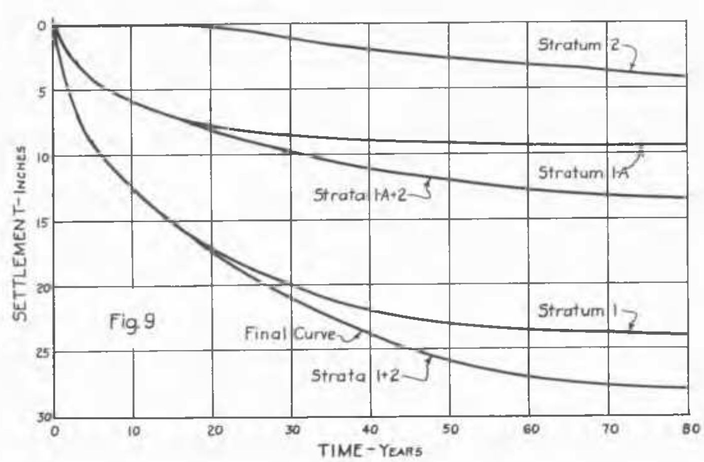

Area of 100% disturbance
Piles 8" diam.
A
A
Undisturbed area
SECTION B-B
B
B
SECTION A-A

FIG. 7


Stratum 2
Stratum 1-A
Strata 1A+2
Stratum 1
Final Curve
Strata 1+2
Fig. 9
SETTLEMENT - INCHES
TIME - YEARS
0
5
10
15
20
25
30
0
10
20
30
40
50
60
70
80

tests on specimens of varying thickness be made to see if the rate of consolidation varies as the square of thickness.

The presence or absence of drainage courses is of controlling importance in the determination of consolidation rate. The author has assumed that a rock face is an impermeable surface, that the base of a concrete footing is a drainage surface, that deposits of cohesionless sand or gravel constitute drainage courses. There is no experimental evidence to guide the estimator. Either laboratory or field investigations should be conducted to determine what constitutes a drainage course and what does not.

No scientific method has been developed for analyzing the rate of consolidation of a deposit such as illustrated in Fig. 4. The method of weighting the consolidation coefficients according to the squares of the strata thicknesses is unsound since it fails to take into consideration the location of the zone of maximum deformation relative to an available drainage face. The author suggests an approximate method described in detail in Appendix A. Fig. 5 shows the curves resulting from the various methods of analysis. Curve A represents the rate using an average coefficient; Curve B the rate using the author's method; Curve C the rate using the author's method if the location of the strata is reversed, placing stratum 2 adjacent to the drainage face.

Consolidation With Piles. Fig. 7 represents a nine-pile footing with the piles spaced 3 feet on centers. According to authorities quoted it is probable that about one-third the area consists of remolded material, two-thirds of undisturbed material. The author does not believe that the method, illustrated in Fig. 6, of assuming a consolidation curve one-third the distance between the undisturbed and remolded curves is sound. The author suggests that the solution should be based on the fact that the total load will be distributed between the columns of undisturbed and of remolded material in such proportion as to make the consolidation of both equal.

Where piles penetrate strata of varying degrees of stiffness the transmission of load to the soil is impossible to predict with reasonable accuracy. The author has assumed a small amount carried by point resistance, 0% to 25% transmitted directly to the soil at the pile cap, depending on the stiffness of the supporting material, and the remainder transmitted through skin friction also in accordance with the stiffness of the strata. These assumptions are subject to grave doubt. More definite information regarding this is needed.

Conclusion. As a general conclusion based on the specific discussion presented it seems apparent that soil mechanics, though far from an exact science, has already done much to make the solution of foundation problems more scientific and has made real contributions to the art of foundation engineering. These contributions can be augmented by further research and studies of a practical nature, perhaps along the lines suggested throughout this paper.

APPENDIX A

The author's method for solving the problem shown in Fig. 4 first analyzes the consolidation rate of stratum 1 on the assumption, not strictly correct, that its consolidation is independent of the underlying material. The resulting data are shown opposite "Stratum 1" in Table I, and plotted in Fig. 9. The pressure-void ratio curves for the two materials are shown in Fig. 8. Stratum 1 is then replaced by an hypothetical stratum 1A which consolidates at the same rate as stratum 1 but possesses the consolidation coefficient and characteristics of stratum 2. The consolidation rate of the homogeneous deposit made up of strata 1A and 2 is then computed, as shown in Table I and plotted in Fig. 9. The consolidation rate of the transformed stratum, 1A, is then computed by the method used for stratum 1. These data are shown in Fig. 9 and Table I. The consolidation rate of stratum 2 is then obtained by subtracting the curve for stratum 1A from the curve for the combined strata, 1A and 2. The rate of consolidation of the actual deposit is then obtained by adding the curves for strata 1 and 2, and is shown as the "Final Curve" in Fig. 9, and as Curve B in Fig. 5.

Curve C, Fig. 5 is computed similarly. Curve A, Fig. 5 is plotted from the data shown in Table I opposite "Method of Averages" the average consolidation coefficient having been computed as 0.0105 cms^2 per min.

TABLE I

Stratum	Consolidation Rate Data											
	Percent Consolidation	0	10	20	30	40	50	60	70	80	90	95	100
	Value of factor N	0	.02	.08	.17	.31	.49	.71	1.00	1.40	2.09	2.80	
1	Time in years	0	.39	1.56	3.3	6.0	9.5	13.8	19.5	27.3	40.6	54.6	
1	Settlement, inches	0	2.45	4.9	7.35	9.8	12.2	14.7	17.2	19.6	22.1	23.3	24.5
1A + 2	Time in years	0	.63	2.5	5.3	9.7	15.4	22.3	31.4	44.0	65.5	88.0	
1A + 2	Settlement, inches	0	1.44	2.88	4.32	5.76	7.20	8.64	10.1	11.5	13.0	13.7	14.4
1A	Time in years	0	.25	.98	2.1	3.8	6.0	8.7	12.3	17.2	25.6	34.5	
1A	Settlement, inches	0	.94	1.88	2.82	3.76	4.70	5.64	6.58	7.52	8.46	8.9	9.4
Method of Averages	Time in years	0	.95	3.8	8.1	14.7	23.3	33.6	47.4	66.4	99.0	---	
Method of Averages	Settlement, inches	0	2.95	5.90	8.85	11.8	14.8	17.7	20.7	23.6	26.6	---	29.5

No. Z-2 NOTE ON THE PHYSICAL CHARACTERISTICS OF MUD FROM THE ENTRANCE BAR OF THE YANGTZE RIVER

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The delta and estuary channel of the Yangtze River is formed of alluvium brought down by the river in the course of its 3000 miles of travel from N. E. Tibet. Precipitation and erosion is most active in Szechuan, Kueichow, Hunan and Hupeh provinces and it is from those areas that most of the sediment ultimately comes. The charge in suspension rarely exceeds 2000 parts per million and the calculated annual discharge of suspended silt into the Sea is about five hundred million tons. The material deposited in the Estuary is generally a mud, of which the particles are generally less than 1/10 millimetre in diameter so that over 90 per cent of them pass a 200 to the inch screen.

The chemical composition of the sediment is generally as follows:

Silica	70%
Allumina	11%
Iron Compounds	3%
Alkaline Metal Compound	16%

The density of the constituent minerals is about 2.5 to 2.7 (Sporadic patches of fine sand less than ½ millimetre in diameter also occur, apparently due to segregation by currents.)

The density of the wet consolidated silt-mud has the value of about 1.7 to 1.8 indicating that the "voids" are about 50 per cent and that the "porosity coefficient" is about unity. The shearing strength of the settled material is about 150 grammes per square centimetre. (300 lb / sq ft).

The remarkable characteristic of the mud is the ease with which it can be made fluid. Vigorous shaking alone will sometimes make the material fluid with the highly paradoxical result that the Atterburg "plasticity" figure may be negative!

Drag suction dredging on a large scale is now being done on the bar of the Yangtze where most of the material is still finer in grain than the older alluvium on which Shanghai is built. It has been found possible to pump this mud through a 1100 mm suction pipe from a depth of 12 metres below water