1967

A study of the compressibility of silty soils.

Marvin L. Byington

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A STUDY OF THE COMPRESSIBILITY OF SILTY SOILS

BY

MARVIN L. BYINGTON - 1941

A

THESIS

submitted to the faculty of the

UNIVERSITY OF MISSOURI AT ROLLA

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Degree of

MASTER OF SCIENCE IN CIVIL ENGINEERING

Rolla, Missouri

1967

Approved by

Thomas S. Fry (advisor)

Ernest C. Roberts

Dr. Langerman
ABSTRACT

This study has been conducted to determine the applicability of the Terzaghi Theory of Consolidation and to determine the compressibility of silt soils with varying clay content. A pure silt was extracted from the Lebanon Silt Loam and mixed with varying amounts of the Onyx Cave Illite-Chlorite Clay. The compressibility of these mixtures was determined and an attempt made to apply the Terzaghi Theory in the analysis.

It was found that the compressibility of soils high in silt content is very low. It was also found that the Terzaghi Theory may be applied to mixtures of 15 percent or more clay, for the materials used.
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ACKNOWLEDGEMENT

The author wishes to express his sincere appreciation to Dr. Thomas S. Fry for the advice and encouragement he has given. The helpful criticisms and encouragement given by Professor John B. Heagler are also appreciated. The author also wishes to thank Howell Branum, Dale Sukow and Rohn Abbott, fellow graduate students, for the help they have given in the laboratory and the inspiring discussions they helped to provide.

The author sincerely appreciated the understanding and encouragement given by his wife.
Chapter I

INTRODUCTION

Soil mechanics has provided the foundations engineer with an invaluable tool for the solution of practical problems. There are theories and procedures in soil mechanics which aid in the solution of problems involving clays and sands. Soils classified as silt have been neglected as a subject of research and for publication in the literature.

Soils which are classified as silt are intermediate in grain size between sand and clay. The limits of silt size are approximately 0.06 millimeters for the upper limit and 0.002 to 0.005 millimeters for the lower limit. The upper limit of silt size may be taken as passing a number 200 sieve (0.074 millimeters) for practical purposes. This definition is for a pure silt. However, soils classified as silt are very rarely pure since they usually contain varying amounts of sand or clay or both.

Silt mixed with varying amounts of other soil constituents exists in a wide spread area throughout the world. Rather extensive deposits of loess cover the mid-western portion of the United States. While this material does not behave as a silt, it consists mainly of silt sized particles and upon loss of its distinctive structure it exhibits the properties of silt.

The alluvial valleys and alluvial fans in the United States give rise to another important source of silt and silty soils. Many of these areas are of limited size, but they occur in great numbers across the country.
Because of the extensive occurrence of silt and silty soils, the foundations engineer frequently faces situations involving them without adequate mechanics to lead to a well defined solution of problems concerning bearing capacity and settlement.

It has been suggested by Peck, Hanson and Thornburn that silt should be treated either as a sand or a clay depending on whether it is cohesionless or cohesive.

This investigation is conducted to determine the applicability of the Terzaghi Theory of consolidation to soils having a high silt content.
Chapter II

REVIEW OF LITERATURE

An increase in the effective stress in a soil will result in a decrease in the volume of the soil voids. Terzaghi\(^1\) states that "every process involving a decrease of the water content is called a process of consolidation". This observation and an understanding of the principle of effective stress\(^2\) led Terzaghi to the development of a theory of consolidation. This theory provides a mathematical expression for the rate of change in volume of soil voids with an increase in stress on the soil. The expression is based on the assumption that the time lag in consolidation of a clay soil is due to the inability of the water to flow rapidly from the soil\(^3\).

The consolidation process has been divided into initial, primary and secondary phases\(^4\). This arbitrary separation has been made in order to differentiate the primary portion from the others. It is essential to define primary consolidation because this is the only portion for which Terzaghi's Theory applies\(^4\).

Lambe\(^4\) suggests that laboratory consolidation studies are of value only for soils of low permeability. Lambe further suggests the use of a ratio of primary compression to total compression (primary compression ratio) as an indication of the portion of the total consolidation considered by the Terzaghi Theory.

*Number designates the references listed in the bibliography
The application of the Terzaghi equation to consolidation analysis is achieved by means of curve fitting techniques involving plots of the rate of void volume decrease. The most usual forms used are the dial reading-log of time plot presented by A. Casagrande and the dial reading-square root of time plot as presented by D. W. Taylor. The square root of time plot has the advantage of decreasing the amount of time needed to conduct a consolidation test. The principle advantage of the log of time plot is the sharp definition which it gives to secondary compression. Secondary compression is linear on a dial reading-log of time plot.

Lambe and Dawson outline methods for conducting a laboratory consolidation test. Olson outlines the design criteria for consolidation apparatus and suggests refinements to the testing procedure. Leonards and Ramiah report on the effect that duration of load increment and the load increment ratio have on the results of consolidation tests.

Van Zelst discusses the effect of sample disturbance on consolidation tests and concludes that the volume of disturbed soil relative to the total volume is of principal importance.

Published literature concerned with the Engineering Properties and behavior of silt is very limited. Several engineering geology reports giving the classification and index properties of silts encountered in Alaska have been published by the Iowa Engineering Experiment Station. Although the reports are of great interest from the view point of natural soil deposits, they contribute little to a knowledge of the engineering behavior of silts.
Schultze and Kotzias published a paper giving a statistical survey of the compressibility of Lower Rhine alluvial silt deposits. This article is a very brief treatment giving average properties taken from several hundred specimens of Lower Rhine silts. An attempt is made to derive an empirical relationship for the consolidation properties of these silt soils. The compressibility was found to be rather low with a permeability in order of \(10^{-8}\) cm/sec. The grain size distribution curves given in this paper indicate that the actual soils tested varied from 95% sand to 35% clay with the remainder being silt. The influence of the clay and sand on the properties of the material tested was not considered.

Bolognesi and Moretto published a paper concerned with the behavior and properties of silt derived from loess. This article describes techniques used for evaluating the behavior of an eroded and water deposited silt material. A void ratio-log of pressure curve is shown which indicates a very low compressibility for silty soils.
Chapter III
MATERIALS AND TESTING

In order to have a homogenous soil of known or predetermined grain size, it is necessary to extract each size fraction and then remix using the desired proportions. The most abundant soil having predominantly silt size particles and an obvious choice was loess. Loess from near Jefferson City, Missouri was obtained and the clay fraction was extracted by repeated sedimentation and withdrawal of the fluid which held the clay particles in suspension. The sedimented material was passed through a No. -200 sieve and the fraction passing was silt size material. Loess is of Eolian origin and as a result is nearly uniform in grain size and the average particle diameter of this loess falls in the upper range of silt size and for this reason does not filter clay well. The action of dilatency causes excess pore water to flow out of the sample which can result in a change in clay content if water flowing out of the soil carries a substantial amount of clay. Even at rather high clay contents (20%) there was an obvious loss of clay during the mixing of soil and water on a glass plate.

Because of this change in clay content of the sample, a silt with a higher uniformity coefficient was obtained and used for the testing program. This silt was obtained from the southeast corner of the Tau Kappa Epsilon property, located North of Rolla, Missouri. The source from which the silt was obtained is from the "A" horizon of the Lebanon Silt Loam. This material is light
brownish gray in color and resembles ashes in appearance. It is very loose and can be excavated easily by hand. This soil contains an appreciable amount of coarse organic matter in the form of sticks and roots. No traces of decaying leaves were present.

The clay used in this study was obtained from a water laid deposit in Onyx cave at Boiling Springs, Missouri. This clay occurs as a deposit of relatively pure red clay, stratified at intervals of about one foot with silt and fine sand. The clay was concentrated by sedimentation to remove the silt and sand. This was accomplished by placing the clay in a weak solution of calgon and stirring it until it stayed in suspension. The sand and silt settled out rather rapidly, allowing the clay-water suspension to be drawn off. The excess water was then evaporated from the suspension by placing it in large pans open to the atmosphere. The result was a soil containing predominantly clay sized material.

The silt was obtained in a similar manner except that the clay suspension was drawn off and discarded. In order to keep a good control over the smallest particle size removed, the following procedure was used. A 95 gallon stock watering tank was altered by placing in it a vertical riser pipe connected to drain. The flow of water was controlled by a valve on the drain pipe. A schematic of this device is shown in Figure 1. A mark was placed 25 cm. above the top of the riser pipe and the tank was filled to this mark. A small quantity of calgon was added to the solution to keep the clay in suspension. The silt and clay mixture were
Sedimentation Tank for Removing Clay from Silt

Figure 1
mixed thoroughly both during filling by water jets, and after filling, with a paddle.

The temperature of the solution was then measured. Using Stokes Law the time for a six micron particle to fall from the surface to the top of the riser pipe, was computed. After this amount of time had elapsed a soil hydrometer was placed in the solution and read and then the valve on the drain pipe was opened. The water in the tank was allowed to drain down to the level of the riser pipe. This washing process was repeated until the change in the hydrometer reading became negligible and the wash water was clear at the end of the cycle.

The material that remained in the tank was then dried and passed through a No. -200 sieve.
Chapter IV
TESTING PROCEDURE

The silt and clay mixtures were prepared for testing by placing a measured quantity of dry clay in an evaporating dish and adding a sufficient amount of distilled water to submerge it. After the clay had been allowed to soak for about twelve hours a measured quantity of dry silt was added to the slurry in small increments, adding water as necessary to allow the mixture to be mixed thoroughly. After all of the silt had been added, the mixture was occasionally stirred with a spatula and allowed to dry in the laboratory atmosphere until a very viscous liquid was obtained. A hand held soil dispersion mixer was then used for final mixing. With this initial preparation the soil was then ready to be used for test purposes.

Tests conducted in this work were liquid and plastic limits, specific gravities, and consolidation tests. The grain size distribution of each mixture was determined by a hydrometer analysis.

The tests all were conducted in the standard manner except for a slight deviation from the standard procedure for setting up a consolidation test.

The consolidation tests were conducted in the following manner. The consolidometer ring was placed on the base and the upper porous stone and sifter paper were placed inside the ring. The vertical distance from the top surface of the porous stone to the top of the ring was measured with a dial gage mounted on a steel block. The consolidometer ring was weighed and filled with soil at
viscous liquid consistency. The ring was over filled by about one half inch to allow for surface drying under the influence of a vacuum.

The ring and contents were then placed under a bell jar and subjected to vacuum for about thirty minutes. During this period of time the vacuum was released twice and allowed to build up again. The purpose of this vacuum treatment was to remove as much of the entrapped air as possible. After removal from the vacuum the soil was trimmed on both ends of the ring. The top was trimmed slightly low intentionally. The ring and soil were placed on a glass plate and weighed.

The ring was then placed in the consolidometer. The lower stone had previously been saturated and fitted with a piece of filter paper. A special sealing ring cut from a piece of semi-rigid plastic was placed on the top surface of the sample. The plastic ring was about 0.075 inches in width and about 0.02-0.03 inches in thickness and slightly smaller in diameter than the internal diameter of the consolidometer ring. The purpose of this ring was to prevent extrusion of the sample under the influence of the stresses developed by the lower load increments.

A sheet of filter paper, trimmed to the proper size, was then placed over the top of the sample. After the filter paper was placed the top porous stone was placed and centered. The consolidometer was then completely assembled by installing the gasket ring and reservoir ring. A reservoir of water was then placed around the top stone.
After the consolidometer was completely assembled and flooded, a series of loads were applied to the sample by placing weights directly on the upper porous stone. This series of weights consisted of 50, 100, 200, 400 and 500 grams. The amount of volume change caused by each of these loads was measured by means of an Ames dial having a sensitivity of 0.0001 inches. Nearly all of the consolidation of the sample was complete in less than four hours after the application of each load increment.

After consolidating the sample under a load of 500 grams the reservoir ring was removed. Using a dial gage mounted on a stem, the vertical distance between the upper surface of the ring and the upper surface of the porous stone was measured.

The consolidometer was then reassembled and placed in a lever type consolidation loading frame. The remainder of the test was conducted in a standard manner.
Chapter V

RESULTS

The results of the dial reading-time observations are summarized on Figures 10A to 10. An observation of the curves plotted in these figures indicates that the consolidation tests performed can be divided into three groups. The first group consists of tests on samples that had a sufficient clay content so that 0 to 100 percent consolidation could be determined readily by conventional procedures. The second or intermediate group consists of tests for which only 100 percent consolidation could be determined by routine methods. Finally, a third group can be established for which neither 0 nor 100 percent consolidation could be determined by conventional methods. The latter test results are for mixtures containing low clay content.

The void ratio-log$_{10}$ pressure curves are shown in Figures 3A thru 3C. These curves relate the amount of void ratio change per change in pressure. The three sets of curves in this figure are arranged in the order of the respective groups that they fit.

In Figure 8, a curve of compression index-percent clay is shown. This curve related the amount of void ratio change per incremental change in pressure to the change in clay content.

Plots of the slope of secondary consolidation-log$_{10}$ pressure are shown on Figures II A thru II C. These curves indicate the effect of changing pressure and clay content on the slope of the secondary portion of consolidation.
Curves of the \( \log_{10} \) of time to 100 percent consolidation-\( \log_{10} \) of pressure are shown in Figure 7. These curves relate the effect of clay content and changing pressure on the time required to achieve 100 percent theoretical consolidation. Because data for such a curve required that 100 percent consolidation be defined this figure only includes the clay contents in the first and second groups.

As the first group considered allows definition of both 0 and 100 percent consolidation these tests may be treated in a more conventional manner. Curves of coefficient of permeability-\( \log_{10} \) of pressure are shown in Figure 4. These curves indicate the change in permeability with respect to change in clay content.

A curve of coefficient of consolidation (Cv) -\( \log_{10} \) of pressure is shown on Figure 5. These curves relate the change in rate of compression to the applied pressure.

A curve of primary compression ratio-\( \log_{10} \) of pressure is shown on Figure 9. This curve relates the relative amount of primary consolidation to the applied stress and show the change in amount of primary consolidation with change in clay content.

Curves of time to 20 percent consolidation-\( \log_{10} \) of pressure are shown on Figure 6. These curves relate the change in time necessary to achieve the earlier portion of primary consolidation to the change in clay content and pressure.

Grain size distribution curve for the mixture used in this study are shown on Figure 12.

A table of mixture properties is shown on Figure 13.
Chapter V!

DISCUSSION OF RESULTS

There are two parts to a consolidation analysis. The first is a determination of the amount of void ratio change under a given pressure. The second involves the amount of time necessary for this void ratio change to take place.

The first portion does not involve an elaborate theory. For an unidimensional consolidation test, the measurements of sample dimensions and change in height under load will provide the information required. This information is summarized in the form of a void ratio-log$_{10}$ of pressure curve.

The second part involves a time theory requiring measurements of the decrease in sample height with respect to time. Some type of curve fitting is used to determine the time required for consolidation. In order to apply a curve fitting method, it is necessary to generate a typical curve similar to the one illustrated in Figure 2. To develop this type curve two conditions must exist. A sufficient amount of void ratio change must take place under a given load increment and this void ratio change must take place over a sufficient length of time so that it can be measured by conventional means.

With silt-clay mixtures of the type used for this study no difficulty was encountered in generating typical curves for clay contents of fifteen percent or more. Lower clay contents than this amount lead to difficulty in producing a curve that could be analyzed by the Terzaghi Theory. At a ten percent clay content the
void ratio change was too small to define properly a typical curve. In order to circumvent this difficulty the load increment ratio was increased to 1.5. This modification to the standard loading procedure, a greater change in void ratio per load increment, and yielded a curve for which Terzaghi Theory was applicable. The problem encountered with this procedure is that, with increasing load, the total elapsed time for primary consolidation decreases. This causes the dial reading-log of time curve to be shifted horizontally to the left. This results in a smaller portion of the curve occurring in the region where dial readings can be taken. The log of time at one hundred percent consolidation-log of pressure curve, Figure 7, readily shows the decrease in time required for primary consolidation with increase in pressure.

This time decrease probably is due to the increase in hydraulic gradient that occurs when the load increment is increased. The plot of coefficient of permeability of the specimen remains nearly constant throughout the test. From the void ratio-log \( \log_{10} \) of pressure curves, Figures 3A, 3B and 3C, it can be seen that approximately equal amounts of void change occur under each of the higher loads.

Applying the above observations to Darcy's Law, \( Q = k_i a \), it is immediately apparent that the coefficient of permeability and area are constant. When nearly equal quantities of water are removed from the specimen for each load increment, and if a shorter period of time is required for this to occur, it becomes apparent that a corresponding change in hydraulic gradient must develop.
For clay contents below ten percent neither the magnitude of void ratio change nor the time elapse for 100% consolidation were sufficient for application of the Terzaghi Theory. The dial reading-log of time curves produced for these tests have so little curvature that neither zero percent nor one hundred percent consolidation could be distinguished.

The void ratio-log of pressure curves provide an important means of comparing the void ratio changes due to various load applications. These curves are shown on Figures 3A, 3B, and 3C. The two curves for pure silt are very flat indicating that silt is only slightly compressible.

If it were possible to place the silt in the consolidation ring at somewhat higher void ratios, steeper curves would have been obtained. The maximum initial void ratio is limited by the testing procedure used. The disturbance that occurs during trimming is sufficient to reduce appreciably the void ratio and thus limit the maximum possible condition. Van Zelst\textsuperscript{10} found that the disturbance of a clay specimen was proportional to the ratio of the ring area to the sample volume. The disturbance of a cohesive soil is in the form of remolding only and no volume change takes place during this process. The disturbance due to the shearing action of a trimming tool will produce a void ratio change in a loose granular soil, which produces greater disturbances than Van Zelst found.

The void ratio-log of pressure curve for five percent clay shows a very small decrease in void ratio up to a pressure of 2 kilograms per square centimeter. At greater pressures the curve become steeper. This phenomenon is also apparent in the
two void ratio-log pressure curves for the ten percent clay mixture. These curves have a shape typical of remolded soils, however, the total void ratio change is small and the slope of the straight line portion, $C_c$, is very small. The void ratio-log of pressure curves for the ten percent clay content samples are steeper than the one for five percent clay. This occurs because a greater total void ratio change takes place for the ten percent mixture.

It is also noticeable that the two void ratio-log of pressure curves are approximately parallel above the two kilogram per square centimeter load. This occurs in spite of the fact that test number eight was conducted using a load increment ratio of 1.5. For stresses less than two kilograms per square centimeter, the curve for test number eight is steeper. The difference in slope between the two curves, even the light loads, is not enough to lead to a conclusion.

The void ratio-log of pressure curve for the fifteen percent clay mixture indicates rather large changes in void ratio for stresses in the one eighth to one quarter kilogram per square centimeter range. The curve then flattens until it reaches the two kilogram per square centimeter region and then becomes more steep. At stresses above $2 \text{ kg/cm}^2$ the curve assumes the shape of the curve for a typical cohesive soil having a low plasticity.

The void ratio-log of pressure curves for the two twenty percent clay samples are nearly parallel. The curve for test number two has a steeper initial portion than the other twentieth percent curve. This might have been caused by extrusion of sample
from the ring during the lighter loads. Test number eight was conducted using a sealing ring of the type described previously and no extrusion occurred.

The slope of the void ratio-log pressure curve is defined as the compression index, $Cc$. This quantity is indicative of the amount of compression that will occur when there is a stress increase. A plot of average values of $Cc$- percent clay gives a straight line. This straight line relationship might not be true for materials other than the ones used in this study.

The straight line relationship probably does not exist for clay contents much greater than twenty five percent. For a one hundred percent clay content the $Cc$ value for this clay is several times the values shown for the range of clay contents tested.

The coefficient of consolidation $Cv$ is indicative of the amount of time necessary to reach fifty percent theoretical (primary) consolidation. There is an inverse relationship between $Cv$ and the time to fifty percent consolidation, thus a large $Cv$ indicates a small amount of time necessary to reach fifty percent consolidation. A plot of $Cv$-log $lp$ of pressure is shown on Figure 5. This curve is of the shape shown by Leonards and Ramiah\textsuperscript{19}, which is for tests performed on a "glacial silty clay". The clay content of this soil is given in the paper as twentieth percent.

The family of curves in Figure 5, indicate that a decreasing amount of time is necessary for consolidation to occur when the clay content is decreased. At low values of pressure all of the curves are fairly flat. As the pressure increases the curves for the soils
with lower clay contents begin to turn upward. As the clay contents are increased the pressure at which the curve turns up also increases. This indicates that a load exists beyond which the time to fifty percent consolidation begins to be reduced at a substantial rate. It also indicates that this load is lower for lower percentages of clay.
Chapter VII

CONCLUSIONS

The results of this study point to several conclusions, some of them may be considered rather general while others may apply only to the material used for this study.

The first, and most readily obvious conclusion is that the compressibility of soils high in silt content is very low. This is indicated by the relatively flat void ratio-log of pressure curves generated in this study.

The compressibility of silty soils, irrespective of structure, is directly proportional to clay content. This is another of the rather obvious conclusions that are substantiated by the void ratio-log of pressure curves. No statement can be made concerning the effect of structure on the compressibility of silt soils because this study was conducted using remolded soil sample which normally does not exhibit the effects of structure.

It was found in this study that the Terzaghi Theory could be applied to soil mixtures with clay contents as low as 15 percent. With clay contents of less than 15 percent the primary consolidation occurred over too short of a time interval to define 0 percent consolidation.

For a clay content of 10 percent an increase in the load increment ratio is effective in increasing the amount of time required for primary consolidation to occur. This is true up to the point where the incremental increase is so great that a reduction in the elapsed time occurs.
A reduction in the number of drainage faces or an increase in the height of a sample of the pure silt used in this study does not sufficiently decrease the elapsed time during primary consolidation to allow the use of the Terzaghi Theory.

The above conclusions apply to the materials used in this study. They may be altered somewhat if a different material is studied.
Chapter VIII
RECOMMENDATIONS

1. Conduct a similar study using natural clayey silts of varying clay contents and equivalent silt sizes to determine the effect of natural soil structure.

2. Conduct similar studies using different clays and silts to determine the effect that clay mineralogy has on the behavior of a clayey silt.

3. Develop a satisfactory method of determining the consistency limits of silt soils.

4. Develop a satisfactory method of placing a silt soil in a consolidometer ring in a loose state. This is necessary to determine the maximum potential compressibility of silt and silty soils.


8. Olson, R., Unpublished Notes.


VITA

Marvin Louis Byington was born December 10, 1941 in St. Louis, Missouri. He received his primary education in St. Louis County, Missouri. He has attended college at Southeast Missouri State College in Cape Girardeau, Missouri; Washington University in St. Louis, Missouri; and the University of Missouri at Rolla in Rolla, Missouri. He received a Bachelor of Science Degree in Civil Engineering in May, 1965 from the University of Missouri at Rolla.

He has been enrolled in the Graduate School of the University of Missouri at Rolla since September 1965. From September 1965 to March 1967 he held a Graduate Assistantship in Civil Engineering.

The author was married in 1960, to the former Claudia Gail Archibald of Webster Groves, Missouri.

At the present time, the author is employed by the Layne-Western Company of Kirkwood, Missouri as a Soils Engineer.
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Figure 3A

Void Ratio vs. $\log_{10}$ of Pressure Curve

Legend
- 15% Clay Test 5
- 20% Clay Test 2
- 20% Clay Test 8

Pressure, Kilograms per Square Centimeter (Log Scale)
Figure 3B
Void Ratio-Log$_{10}$ of Pressure Curve

Legend
- 10% Clay Test 4
- 10% Clay Test 8
Figure 3C
Void Ratio-Log10 of Pressure Curve

Legend
- 0% Clay Test 6
- 5% Clay Test 10
- 5% Clay Test 3
Figure 4  Coefficient of Permeability-Log$_{10}$ of Pressure Curve
Figure 5
Coefficient of Consolidation - Log of Pressure Curve

Legend
- 10% Clay Test 9
- 15% Clay Test 5
- 20% Clay Test 2
- 20% Clay Test 8

Pressure, Kilograms per Square Centimeter (Log Scale)
Coefficient of Consolidation - Log10 of Pressure Curve
Figure 6  Time to 20% Consolidation—Log$_{10}$ of Pressure Curve
Figure 7

Pressure, Kilograms per Square Centimeter
Log Scale

Log₁₀ of Time to 100% Consolidation -
Log₁₀ of Pressure Curve

Legend
- △ 10% Clay Test 4
- □ 10% Clay Test 9
- ◊ 15% Clay Test 5
- △ 20% Clay Test 2
- ○ 20% Clay Test 8
Figure 8  Clay Content Percent of Dry Weight
Figure 9  Primary Compression Ratio—Log10 of Pressure Curve
FIGURE 10A. DIAL READING-$\log_{10}$ OF TIME CURVE TEST NO.2 20% CLAY
FIGURE 108. DIAL READING-\log_{10}OFTIME CURVE TEST NO.2 20% CLAY.
FIGURE 10C. DIAL READING-LOG₁₀ OF TIME CURVE  TEST NO.2  20% CLAY
FIGURE 10E. DIAL READING-LOG10 OF TIME CURVE  TEST NO.4  10% CLAY
FIGURE 10F. DIAL READING-\log_{10} OF TIME CURVE TEST NO. 4 10% CLAY
FIGURE 106. DIAL READING-LOG₁₀ OF TIME CURVE  TEST NO.5  15% CLAY
FIGURE 10H. DIAL READING-LOG$_{10}$ OF TIME CURVE TEST NO. 5 15% CLAY
FIGURE 101. DIAL READING-LOG\textsubscript{10} OF TIME CURVE  TEST NO. 6  0\% CLAY
FIGURE 10J. DIAL READING-LOG\(_{10}\) OF TIME CURVE  TEST NO. 8  20% CLAY
FIGURE 10K. DIAL READING-$\log_{10}$ OF TIME CURVE TEST NO. 8 20% CLAY
FIGURE 10L. DIAL READING-$\log_{10}$ OF TIME CURVE    TEST NO.8   20% CLAY
FIGURE 10M. DIAL READING $-\log_{10} \text{TIME CURVE}$ TEST NO. 9 10% CLAY
FIGURE 10N. DIAL READING-LOG$_{10}$ OF TIME CURVE  

TEST NO. 9  10% CLAY
FIGURE 10. DIAL READING-$\log_{10}$ OF TIME CURVE  TEST NO. 10  0% CLAY
Figure 11A  

Slope of Secondary–Log$_{10}$ of Pressure Curve

Legend

- $\Box$ 15% Clay Test 5
- $\bigcirc$ 20% Clay Test 2
- $\bigcirc$ 20% Clay Test 8

Pressure, Kilograms per Square Centimeter (Log Scale)
Figure 11B  
Slope of Secondary-Log$_{10}$ of Pressure Curve

Legend

- △ 10% Clay Test 4
- □ 10% Clay Test 9

Pressure, Kilograms per Square Centimeter (Log Scale)
Figure 11C  Slope of Secondary-$\log_{10}$ of Pressure Curve
Legend

- 0% Clay
- 5% Clay
- 10% Clay
- 15% Clay
- 20% Clay

Figure 12 Grain Size Distribution Curves