

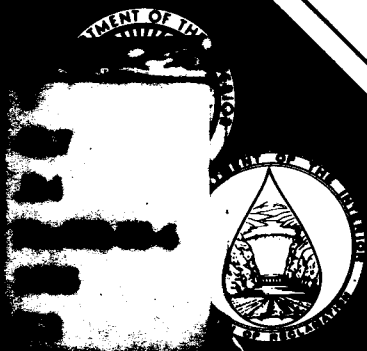
GR-85-6

# DESK-TOP COMPUTERS FOR CONSOLIDATION TESTING AND ANALYSIS OF SOILS

*June 1985*

*Engineering and Research Center*

*U. S. Department of the Interior  
Bureau of Reclamation  
Division of Research  
and Laboratory Services  
Geotechnical Branch*



1. REPORT NO. Reclamation 85-6		2. GOVERNMENT ACCESSION NO.		3. RECIPIENT'S CATALOG NO.	
4. TITLE AND SUBTITLE  Desk-Top Computers for Consolidation Testing and Analysis of Soils				5. REPORT DATE June 1985	
				6. PERFORMING ORGANIZATION CODE D-1541	
7. AUTHOR(S) Kurt von Fay, Jack Byers, and Betsy Kunzer				8. PERFORMING ORGANIZATION REPORT NO. GR-85-6	
9. PERFORMING ORGANIZATION NAME AND ADDRESS  Bureau of Reclamation Engineering and Research Center Denver, CO 80225				10. WORK UNIT NO.	
				11. CONTRACT OR GRANT NO.	
12. SPONSORING AGENCY NAME AND ADDRESS  Same				13. TYPE OF REPORT AND PERIOD COVERED	
				14. SPONSORING AGENCY CODE DIBR	
15. SUPPLEMENTARY NOTES  Microfiche and/or hard copy available at the E&R Center, Denver, Colorado  Editor: RNW(c)					
16. ABSTRACT  The use of desk-top microcomputers for the automatic acquisition of consolidation-test data and for data analyses is discussed. The various electrical sensing devices for measuring test parameters are briefly described. A program using several classical empirical procedures was written to analyze data. The Casagrande Logarithm of Time-fitting Method and the Cour Inflection Point Method for computing $C_v$ are used to analyze the time-dependent data. The Casagrande and Schmertmann construction techniques are also used to analyze the time-independent data. Additionally, the density, moisture content, and degree of specimen saturation are determined throughout the consolidation test.					
17. KEY WORDS AND DOCUMENT ANALYSIS a. DESCRIPTORS-- *microcomputers/ data acquisition/ *soil tests/ *consolidation/ consolidometer/ preconsolidation pressure/ settlement/ void ratio/ time-dependent analysis/ Casagrande Construction/ Casagrande's Logarithm of Time-fitting Method/ Schmertmann Procedures/ Cour Inflection Point Method/ time-consolidation curves/  b. IDENTIFIERS--  c. COSATI Field/Group 8M COWRR: 0813 SRIM:					
18. DISTRIBUTION STATEMENT				19. SECURITY CLASS (THIS REPORT) UNCLASSIFIED	
				20. SECURITY CLASS (THIS PAGE) UNCLASSIFIED	
				21. NO. OF PAGES 28	
				22. PRICE	

**GR-85-6**

**DESK-TOP COMPUTERS  
FOR CONSOLIDATION TESTING  
AND ANALYSIS OF SOILS**

by

**Kurt von Fay**

**Jack Byers**

**Betsy Kunzer**

Geotechnical Branch  
Division of Research and Laboratory Services  
Engineering and Research Center  
Denver, Colorado

June 1985



As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. Administration.

The research covered by this report was funded under the Bureau of Reclamation Program Related Engineering and Scientific Studies allocation No. DR-268, Soil Test Procedures.

The information contained in this report regarding commercial products or firms may not be used for advertising or promotional purposes and is not to be construed as an endorsement of any product or firm by the Bureau of Reclamation.

## CONTENTS

	Page
Introduction.....	1
Conclusions .....	1
Concept.....	2
Hardware .....	2
Software.....	5
Time-dependent analysis .....	8
Casagrande's Logarithm of Time-fitting Method .....	9
Inflection Method .....	10
Soil phase-relationship conditions.....	10
Printed output .....	11
Bibliography .....	12
Appendix – Examples of Computer Generated Output.....	13

## FIGURES

### Figure

1	Consolidation-test hardware configuration .....	4
2	Consolidation-test apparatus .....	5
3	The Casagrande Construction.....	7
4	The Schmertmann Procedure .....	8
5	Theoretical time-consolidation curves.....	9
6	The Casagrande Logarithm of Time-fitting Method.....	10
7	The Cour Inflection Point Method.....	11



## INTRODUCTION

The phenomenon of soil settlement has concerned civil engineers for many years. The Leaning Tower of Pisa is a classic example of what can happen when soil settlement characteristics are not determined correctly. Only parts of the settlement process were understood until 1925, when Karl Terzaghi [1]\* proposed a theory in *Erdbaumechanik*, which related pressure, volume change, and time. This theory described the process associated with compression of a mass of discrete, irregular particles into a denser material. This process became known as consolidation. To study consolidation characteristics, Terzaghi also developed a test that consisted of placing a cylindrical, saturated specimen in a ring (to prevent lateral displacements), loading the specimen, and letting the pore water drain through porous stones placed on the top and/or bottom. Terzaghi and others developed various analytical techniques whereby deformations of the sample were plotted against various time and load functions. With these data engineers are able to determine the settlement characteristics of a soil stratum and, hopefully, avoid a modern-day equivalent of the Leaning Tower of Pisa.

In the 1960's, with the advent of computer technology, more comprehensive and thorough consolidation analysis became possible. Since the early 1980's, advances in microcomputer technology have allowed specialized interactive systems to be developed with these computers. Tailoring automated microcomputer systems to specific data-acquisition requirements is now relatively easy, practical, and economical. Using these computers for various analytical techniques on an interactive basis is relatively simple and fast. Results from these analyses can be obtained almost immediately after the user initiates them, instead of the normal 1-day turnaround time associated with some larger computer systems.

This report discusses the program development, equipment interface, and use of a microcomputer for consolidation testing and analysis at the Bureau of Reclamation, Engineering and Research Center, Geotechnical Branch Laboratory.

## CONCLUSIONS

The principles of this data-acquisition and computer-analysis system can be applied to several materials tests and data analyses. The USBR (Bureau of Reclamation) has recently used this configuration in automating the triaxial and direct shear testing. The flexibility of the interactive program allows the user to obtain design and analysis information during and immediately after testing.

---

\* Numbers in brackets refer to entries in the bibliography.

The use of a microcomputer for data acquisition, and analysis of consolidation-test data has been reliable in providing excellent report-quality products with virtually no downtime.

## **CONCEPT**

In recent years, some of the most rapid advances in geotechnical laboratories have been in automatic data acquisition and analysis. The most common application is a single computer attached to one or two test units. Although this type of application has merit, significant increases in efficiency and productivity occur when several test units are monitored, the data are immediately analyzed, and test results are presented in the form of report-quality plots and data tables.

The concept of a single computer attached to several test units was used to develop consolidation-data acquisition and analysis programs. The USBR has 18 pneumatic consolidometers, each of which is in use approximately 60 percent of the time. The consolidating normal loads are applied manually. The data recording, storage, processing, and presentation are completely automated, using a combination of load cells and LVDT's (linear variable differential transformers), a data acquisition complex, microcomputer, thermal printer, and multipen plotter.

## **HARDWARE**

The core of the system is a microcomputer with 1 megabyte of RAM (random access memory), two built-in disk drives containing 256 kilobytes per disk, a 1-megabyte Winchester hard disk, and a 16-bit microprocessor. This computer stores all equipment-calibration curves, specimen data, and test data for each of the 18 systems, both in RAM and on disk. The result is extremely fast access for data calculations and graphs. The computer also has an internal clock and IEEE (Institute of Electrical and Electronic Engineers) parallel, interface bus. The data-acquisition complex, thermal printer, and a two-pen, 8-1/2- by 11-inch flat bed plotter all connect to the IEEE interface on the computer.

The computer is programmed in extended BASIC. Automatic LVDT height readings are recorded at programmed time intervals for each load of each consolidation test. Random height readings also can be taken and, if desired, stored as part of the test data. Each data record includes the system number of the test, LVDT height reading, normal load on the specimen, elapsed time in seconds from the moment the load was applied, number of readings from the beginning of the test, and date and time the reading was taken. The computer uses the stored specimen and test



data to calculate a number of test values and to generate various plots, which can be displayed on the CRT (cathode ray tube) or dumped to the printer or plotter. A schematic of the hardware configuration is shown on figure 1.

Before a material is tested, calibrated load cells are used to generate a calibration equation for each pressure gauge on a pneumatic consolidometer. Because the load cells require a 10-volt d-c power source, the computer is programed to switch the power source and the digital voltmeter to d.c. when a load-cell calibration is requested from the terminal. The computer is programed to switch back to a.c. at the end of the calibration. Pressure on the load cell alters the d-c signal sent from the load cell through the multiplexer to the digital voltmeter. The voltmeter interprets the changed signal as volts and sends the voltage reading to the computer.

The load cell is first subjected to known pressures. These pressures are entered in the computer from the terminal, and a pressure-voltage equation is generated and stored in the computer. The load cell is then placed in the consolidometer, and a number of gauge pressures are applied. Each gauge reading is entered into the computer from the terminal. The computer compares the voltage reading from the load cell with the stored pressure-voltage equation, derives the load on the load cell, and generates a gauge reading-load equation for that pressure gauge.

During a consolidation test, the required load is entered into the computer from the terminal. The computer calculates the necessary gauge reading-load equation and displays the appropriate gauge setting on the CRT. The computer then uses the manually entered load as the consolidation load for each LVDT reading taken during that load. Load cells are not used during a test because of the cost and because of signal amplification problems inherent in using a single, dual-range load cell for each consolidometer.

The consolidation test apparatus, shown in figure 2, is equipped with 2 LVDT's of 1 inch (25 mm) of travel to measure the height of the specimen to 0.0001 inch (0.0025 mm). Each consolidometer has an LVDT connected to a specific system channel in the data-acquisition unit. Because a large number of LVDT's are monitored at one time, the signal produced by the 2.5-kHz sine wave generator is boosted by an amplifier to ensure that 2.5 kHz goes to each of the 18 LVDT's. The LVDT barrel acts as an electromagnet, and the position of the core in the barrel alters the a-c signal. The altered signal is transmitted through the multiplex to the digital voltmeter, where the signal is interpreted as a voltage reading and monitored by the computer. The LVDT is calibrated, and the calibration equation is stored both in RAM and on disk.

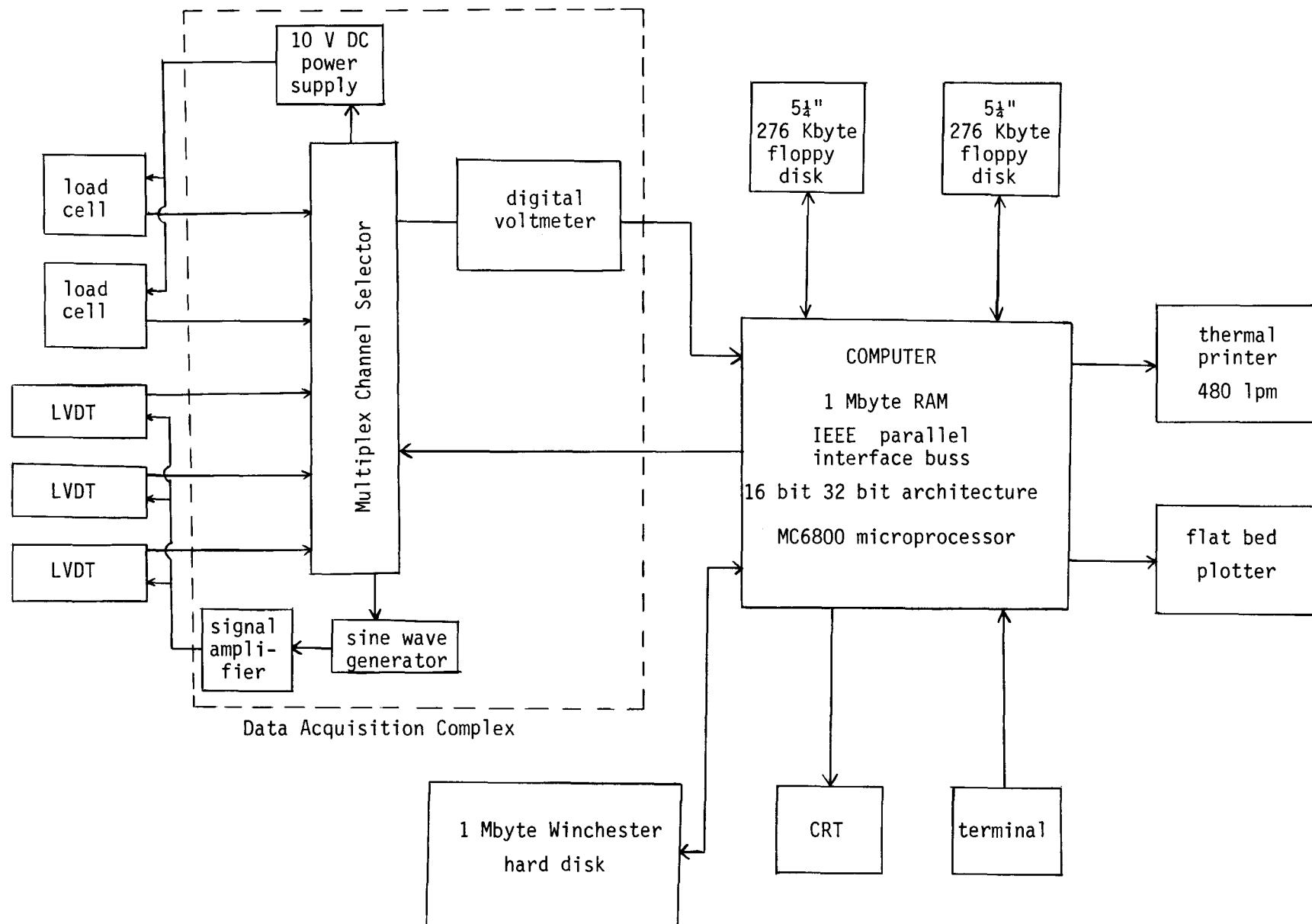


Figure 1. – Consolidation-test hardware configuration.

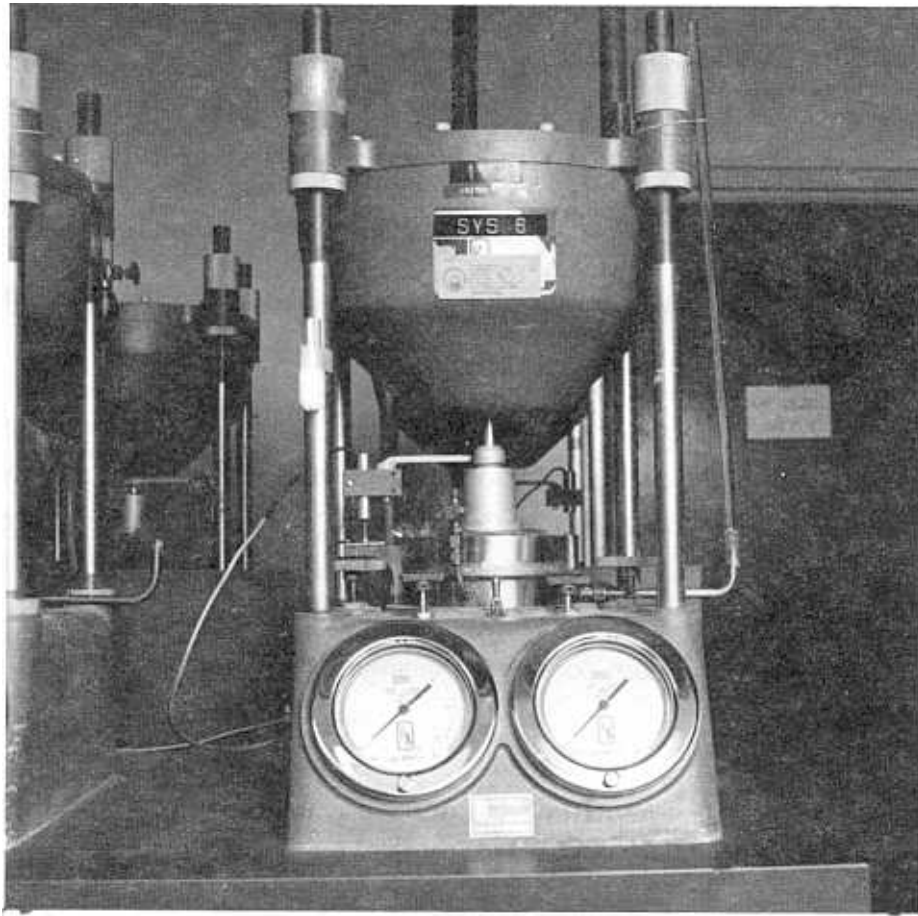


Figure 2. — Consolidation-test apparatus.

When the test is initiated, an LVDT reading is taken on a gauge block of known height. This reading is stored in the computer as part of the specimen data. The computer compares the first recorded LVDT specimen reading with the LVDT gauge-block reading and the given height of the gauge block. During the test, the amount an LVDT core moves is calculated by interpolating the voltage reading of the LVDT into the stored LVDT reference line. Then the computer calculates the height of the LVDT core within the barrel to the nearest 0.0001 inch. The computer stores as specimen data the height of the gauge block in inches, the LVDT reading on the gauge block, and the initial LVDT reading on the specimen. Each system is programed to record LVDT readings at set time intervals from the application of a load until a stop order is given through the terminal. The computer is programed so that the recording of LVDT readings takes priority over any other computer use.

## SOFTWARE

The program, "EngCon, Desk-Top Computer Analysis of Consolidation Data," calculates various phase-relationship conditions and time-dependent and time-independent parameters of a soil specimen tested according to the Incremental Stress, One-Dimensional Consolidation Soil Theory.

However, the methods and controlling theories concerning consolidation testing and data analysis were developed for certain specific conditions and simplifying assumptions: 1. The coefficient of compressibility is constant; 2. The coefficient of permeability is constant; 3. The specimen is saturated with an incompressible fluid; 4. The mineral grains are incompressible; and 5. The specimen is homogeneous throughout.

When these conditions are not met, sound engineering judgment is needed to use the computer-generated results correctly.

In 1936, Casagrande [2] developed an empirical, graphical technique to determine the preconsolidation pressure,  $P_c$ , from the semilogarithmic representation of specimen deformation versus effective stress. This method is known as the Casagrande Construction and is described below. Figure 3 illustrates the essential features of this construction.

1. Determine the point of maximum curvature (minimum radius),  $R$ , visually, graphically, or analytically (point 1 on fig. 3).

To determine this point graphically, extend the approximately straight portion of the top of the curve until it intersects the laboratory virgin compression line, described in step 5. Then bisect this angle. Point 1 represents the intersection of the curve and the angle bisect line. To determine the point analytically, the equation describing the curve must be known.  $R$  can be found using the relationship:

$$R = 1 + \frac{\left[ \left( \frac{dy}{dx} \right)^2 \right]^{3/2}}{\frac{d^2x}{dx^2}}$$

2. Draw a horizontal line from point 1.
3. Draw a line tangent to the curve at point 1.
4. Bisect the angle made in steps 2 and 3.
5. Extend the straight portion of the laboratory virgin compression curve (called the laboratory virgin compression line) to meet the bisector line obtained in step 4. The point of intersection is the most probable preconsolidation stress (point 2 on fig. 3).

The maximum possible preconsolidation stress is at point 3, where the laboratory virgin compression line leaves the curve. The minimum possible preconsolidation stress is at point 4, the intersection of the laboratory virgin compression line with a horizontal line drawn from  $e_0$ , the initial void ratio.

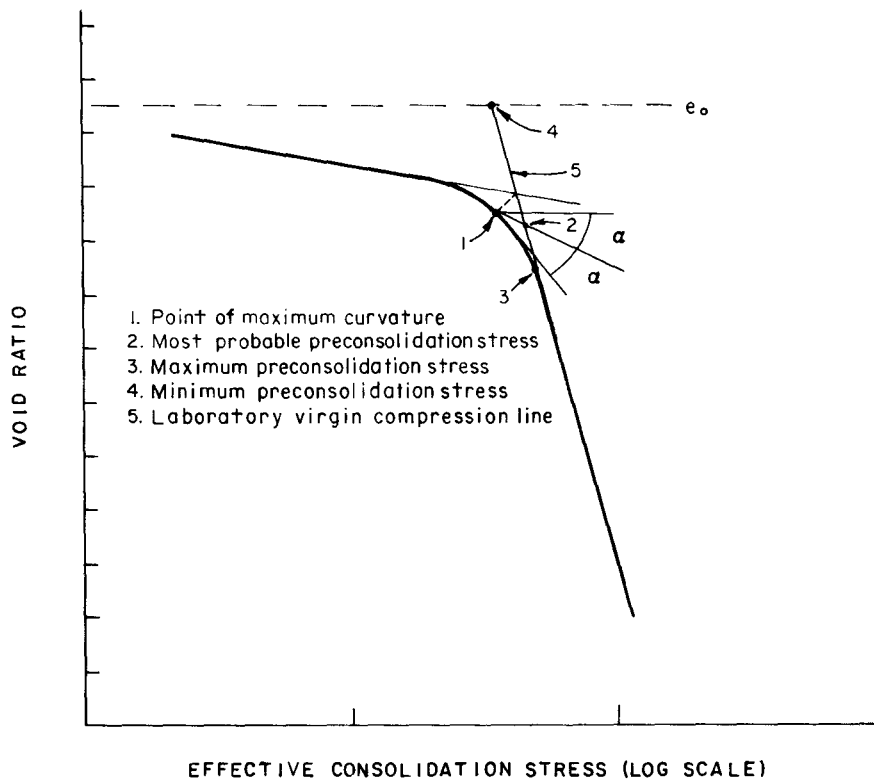
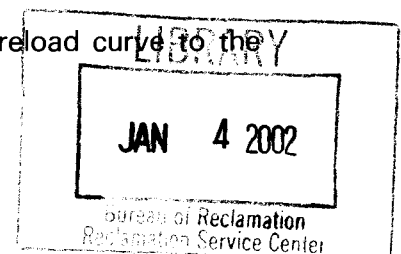


Figure 3. – The Casagrande Construction.

The Casagrande Construction allows one to determine important soil deformation parameters, but fails to consider the effects of sample disturbance or to determine the slope of the field virgin compression line. In 1955, Schmertmann [3] developed a graphical method to analyze time-independent settlement data that accounts for the effect of sample disturbance and estimates the slope of the field virgin compression line. Figure 4 depicts the important elements of the Schmertmann Procedure and is used as follows:

*Note:* Figure 4 depicts an unload-reload segment in the compression curve, which is used to determine the recompression index,  $C_r$ . However, since USBR laboratories usually unload the specimen only once, the slope of the best-fit line of the unload data is used to approximate  $C_r$ .

1. Perform the Casagrande Construction and determine the preconsolidation stress.
2. Calculate the initial void ratio,  $e_o$ . Draw a horizontal line from  $e_o$  to the overburden stress; this defines point 1 on figure 4.
3. From point 1, draw a line parallel to the best-fit line of the unload-reload curve to the preconsolidation stress; this establishes point 2 on figure 4.



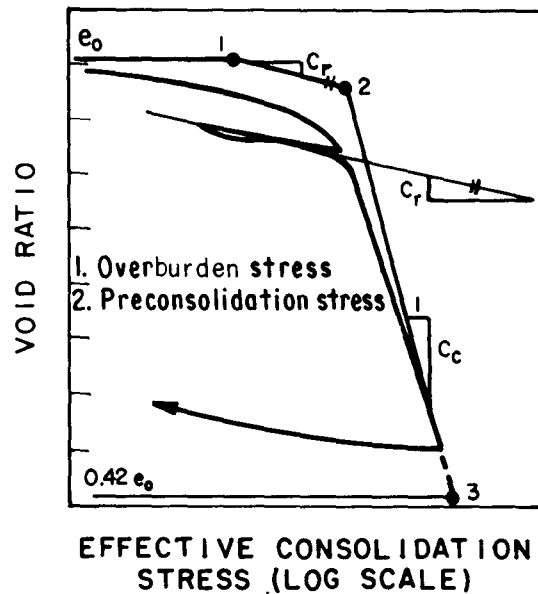


Figure 4. – The Schmertmann Procedure.

*Note:* If a soil is normally consolidated, the overburden stress equals the preconsolidation stress and points 1 and 2 will coincide.

4. From a point on the void ratio axis equal to  $0.42 e_0$ , draw a horizontal line. Where this line meets the extension of the laboratory virgin compression curve, another point (point 3) is established.
5. Connect points 2 and 3 with a straight line. The slope of this line defines the field virgin compression index  $C_c$ .

From the graphical representations created using the one-dimensional consolidation-test data, the program determines the laboratory virgin compression line, field virgin compression line, overconsolidation ratio, laboratory virgin compression index, field virgin compression line, preconsolidation stresses, the corresponding void ratios, compression ratio, and recompression index.

### Time-Dependent Analysis

This part of the program is based on Terzaghi's one-dimensional consolidation theory developed in 1925 [1] and is discussed in most soil mechanics texts. The program determines the coefficient of consolidation, the coefficient of permeability, and axial strain values at various average degrees of consolidation (percent consolidation) using two different curve-fitting techniques. These empirical procedures were developed to approximately fit the observed laboratory test data to the curves generated using Terzaghi's theory of consolidation. This is valid because actual curves

often have shapes similar to the theoretical percent consolidation  $U$  versus time factor  $T$  curves. Figure 5 shows the theoretical curves for two different functions of  $T$ .

### Casagrande's Logarithm of Time-Fitting Method

Casagrande [4] developed a logarithm of time-fitting method, called the graphic method on the computer-generated plots, in which deformation values (dial readings, axial strain, or void ratio) are plotted versus the logarithm of time (fig. 6). For this technique,  $R_{50}$  (time at 50 percent consolidation) and  $t_{50}$  (time at 50 percent consolidation) are determined from  $R_0$  and  $R_{100}$ , which are obtained using empirically derived methods.

An  $R_0$  is determined using the fact that  $T$  is proportional to  $U^2$  (time factor is proportional to the percent consolidation squared) up to about 60 percent consolidation on the theoretical  $U - \log T$  plot (fig. 5). Using this relationship, any two values for time in the ratio of 4 to 1 (i.e.,  $t_1$  and  $t_2$ , where  $t_2 = 4t_1$ ) are chosen, and their corresponding deformation values ( $R_1$  and  $R_2$ ) are determined. Next, the difference between these values is calculated ( $R_2 - R_1$ ) and subtracted from the first deformation value to yield  $R_0$  ( $R_0 = R_1 - (R_2 - R_1)$ ). This procedure is shown on figure 6.

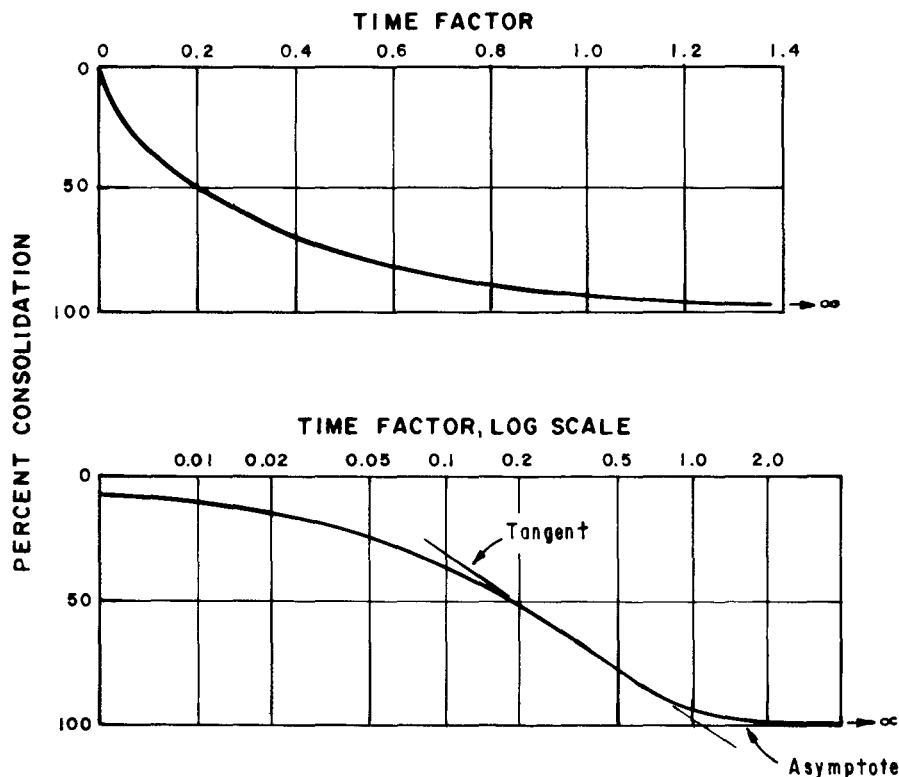


Figure 5. – Theoretical time-consolidation curves.

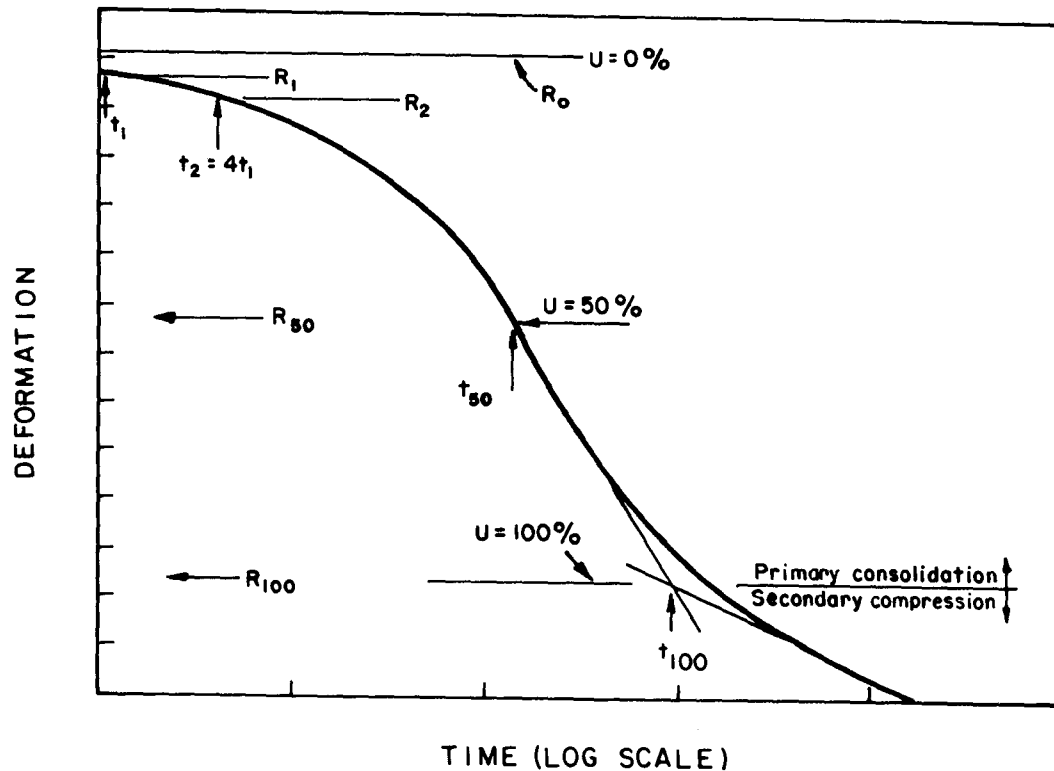


Figure 6. – The Casagrande Logarithm of Time-Fitting Method.

The  $R_{100}$  (deformation value at 100 percent consolidation) is defined as the intersection of the tangent to the straight-line portion of the curve and the tangent to the end of the curve on figure 6.

### Inflection Method

In 1971, Cour [5] developed another technique for finding the coefficient of consolidation. This technique is called the inflection method on the computer-generated plots. Cour used the inflection point of the deformation versus logarithm of time curve. He found that the inflection point of the theoretical  $U$  versus logarithm of  $T$  occurs at 70 percent consolidation and a time factor of 0.405 (fig. 7). From this,  $R_{70}$ , the coefficient of consolidation, and the coefficient of permeability can be determined.  $R_0$  is determined as before. Other deformation values corresponding to different average degrees of consolidation can be determined from  $R_0$  and  $R_{70}$  using linear relationships.

### Soil Phase-Relationship Conditions

The program "EngCon" computes the percent vertical strain from seating load conditions (initial conditions) as a function of vertical deformation reading changes monitored by an LVDT. From



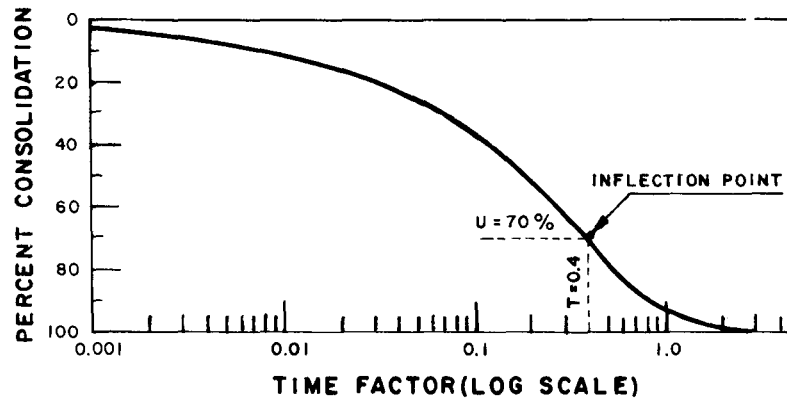


Figure 7. – The Cour Inflection Point Method.

these computed values, the soil phase-relationship conditions at the end of each consolidation load are determined: specimen height, void ratio, dry density (unit weight), moisture content, degree of saturation, and axial strain.

The program calculates the initial conditions needed for analysis from the initial (seating-load) height readings, specimen size, specific gravity, and weight. It then calculates the appropriate strain values and void-ratio values. These values are used where needed by different analysis techniques. Because the specimen diameter is constant, air, water, and soil volumes are determined in terms of their height.

### Printed Output

First, a formatted copy of the data file is printed. This includes general specimen identification and placement conditions as well as a computer listing of all test measurements. The appendix is a typical example of this computer-printed data.

Because of the flexibility of this program, several different output options are available, depending on the analysis procedure used. Point-to-point plots of axial strain versus logarithm of time, axial strain versus load, and void ratio versus logarithm of load are available. In addition, the void ratio and axial strain versus square root of time consolidation plot can be obtained for each load. A table is printed showing the loads and the corresponding values of height, void ratio, dry density (unit weight), moisture content, degree of saturation, and axial strain. The values used in the table correspond to the last LVDT reading taken for a specific load. In conjunction with the table described, the following is printed also: the values for percent rebound, dry weight determined from the initial moisture, dry weight determined from the final weights, and moisture content determined from the final weight and initial moisture. A separate table of values also is printed, showing the

dry density (unit weight), the moisture content and degree of saturation corresponding to the initial load, and the maximum load.

A curve-fitted void ratio versus logarithm of pressure plot can be generated. This plot shows results of the Casagrande and Schmertmann construction techniques using analytical and graphical analysis methods or a manual analysis method, depending upon which was chosen. Among the results shown are the minimum, most probable, and maximum preconsolidation stress; laboratory virgin compression line; field virgin compression line; point(s) of maximum curvature; rebound line; and  $e_0$ . Also available is a table showing the results from the analysis of the time-independent data. This table has values for the various preconsolidation stresses, void ratios at the different preconsolidation stresses, overconsolidation ratio, compression index, rebound index, and field compression index.

Curve-fitted axial strain versus logarithm of time plots for specific loads can also be generated. The plots show the results of the Casagrande Logarithm of Time-fitting Method (called the graphic method on the plot) and the Cour Inflection Point Method for determining  $c_v$  (called the inflection method on the plot). Shown on the plot are the coefficient of consolidation, coefficient of permeability, and the strain values at 0, 50, 70, and 100 percent consolidation.

## BIBLIOGRAPHY

- [1] Terzaghi, Karl, *Erdbaumechanik auf Bodenphysikalischer Grundlage*, Franz Deuticke, Leipzig und Wein, p. 399, 1925.
- [2] Casagrande, Arthur, "The Determination of the Preconsolidation Load and its Practical Significance," *Proceedings, First International Conference on Soil Mechanics and Foundation Engineering*, vol. 3, pp. 60-64, 1936.
- [3] Schmertmann, John H., "The Undisturbed Consolidation Behavior of Clay," *Transactions, American Society of Civil Engineers*, vol. 120, paper No. 2775, pp. 1201-1233, 1955.
- [4] Casagrande, Arthur, "Notes on Soil Mechanics – First Semester," Harvard University (unpublished), p. 129, 1938.
- [5] Cour, Francis R., "Inflection Point Method for Computing  $C_v$ ," *Journal of the Soil Mechanics and Foundations Division, American Society of Civil Engineers*, vol. 97, No. SM5, pp. 827-831, 1971.

## **APPENDIX**

### **EXAMPLES OF COMPUTER-GENERATED OUTPUT**



SAMPLE NUM EXAMPLE	SPEC NO. 51	DRILL HOLE DH-282	DEPTH 1.5-5.0	CLASS SYM CL	SPEC GRAV 2.69	SPEC TYPE 1
DATE PLACE 3-02-84	LOAD NO. 7	CONT. NO. 298	CONT. HT. 1.25	CONT. DIA. 4.25	P.I. % 20	L.L. % 32
WET SPEC+C 1825.3	CONT+PLATE 1213.8	DIAL BLOCK .2595	DIAL SPEC .2517	DATE REMOV 3-29-84	C WATER CO RP# 11	C WT TRIM CL-230
S.L. %		C IN WATER CL-241	IN WATER % 13.2	F WATER % 15.9	HO .8639	HI 1.2578
	F WAT+CONT 817.4	F DRY SP+C 732.9	F C FOR SP 200.3	F DRY W+C 208.9	F C FOR WS 207.3	ADD WATER# 2
	EFF OVER B 45	FEATURE	CONT			

LVDT ins	LOAD lb/in2	TIME secs	SYS/LINE	DATE	TIME
.2517	1.0	4	10 1	3 2	12:58:50
.2518	3.0	4	10 2	3 2	13:04:12
.2518	3.0	10	10 3	3 2	13:04:19
.2518	3.0	20	10 4	3 2	13:04:30
.2518	3.0	40	10 5	3 2	13:04:50
.2518	3.0	80	10 6	3 2	13:05:31
.2518	3.0	200	10 7	3 2	13:07:31
.2519	6.0	4	10 8	3 2	13:10:40
.2519	6.0	10	10 9	3 2	13:10:46
.2519	6.0	20	10 10	3 2	13:10:56
.2519	6.0	40	10 11	3 2	13:11:18
.2519	6.0	80	10 12	3 2	13:11:58
.2519	6.0	200	10 13	3 2	13:13:52
.2520	12.5	4	10 14	3 2	11:18:21
.2520	12.5	10	10 15	3 2	11:18:27
.2520	12.5	20	10 16	3 2	11:18:38
.2521	12.5	40	10 17	3 2	11:18:58
.2522	12.5	80	10 18	3 2	11:19:39
.2528	12.5	200	10 19	3 2	11:21:39
.2532	12.5	400	10 20	3 2	11:25:19
.2533	12.5	800	10 21	3 2	11:32:19
.2534	12.5	2000	10 22	3 2	11:52:19
.2536	12.5	4000	10 23	3 2	12:25:49
.2538	12.5	8000	10 24	3 2	13:32:49
.2539	12.5	20000	10 25	3 2	16:52:49
.2550	12.5	71038	10 26	3 3	07:02:15
.2588	25.0	4	10 27	3 6	07:26:08
.2595	25.0	10	10 28	3 6	07:26:14
.2600	25.0	20	10 29	3 6	07:26:25
.2605	25.0	40	10 30	3 6	07:26:46
.2609	25.0	80	10 31	3 6	07:27:26
.2616	25.0	200	10 32	3 6	07:29:26
.2622	25.0	400	10 33	3 6	07:34:11
.2628	25.0	800	10 34	3 6	07:45:37
.2633	25.0	2000	10 35	3 6	08:05:42
.2637	25.0	4000	10 36	3 6	08:39:12
.2642	25.0	8000	10 37	3 6	09:46:12
.2644	25.0	20000	10 38	3 6	13:06:42
.2645	25.0	85942	10 39	3 7	07:18:26
.2705	50.0	4	10 40	3 7	08:08:28
.2718	50.0	10	10 41	3 7	08:08:34
.2728	50.0	20	10 42	3 7	08:08:44
.2737	50.0	40	10 43	3 7	08:09:05
.2746	50.0	80	10 44	3 7	08:09:45
.2758	50.0	200	10 45	3 7	08:11:45
.2769	50.0	400	10 46	3 7	08:16:40
.2776	50.0	800	10 47	3 7	08:23:23
.2786	50.0	2000	10 48	3 7	08:43:46
.2795	50.0	4000	10 49	3 7	09:17:12

.2795	50.0	8000	10	50	3	7	10:24:12
.2804	50.0	20000	10	51	3	7	13:44:17
.2808	50.0	85929	10	52	3	8	08:00:33
.2808	100.0	4	10	53	3	8	09:16:04
.2896	100.0	10	10	54	3	8	09:16:11
.2916	100.0	20	10	55	3	8	09:16:21
.2930	100.0	40	10	56	3	8	09:16:42
.2942	100.0	80	10	57	3	8	09:17:23
.2956	100.0	200	10	58	3	8	09:19:23
.2981	100.0	400	10	59	3	8	09:28:54
.2989	100.0	800	10	60	3	8	09:35:38
.3002	100.0	2000	10	61	3	8	09:55:38
.3015	100.0	4000	10	62	3	8	10:29:08
.3026	100.0	8000	10	63	3	8	11:36:08
.3027	100.0	13573	10	64	3	8	13:02:13
.3027	100.0	13606	10	65	3	8	13:02:46
.3032	100.0	20000	10	66	3	8	14:56:08
.3041	100.0	77178	10	67	3	9	06:42:18
.3042	200.0	4	10	68	3	9	08:44:50
.3129	200.0	10	10	69	3	9	08:44:57
.3149	200.0	20	10	70	3	9	08:45:08
.3162	200.0	40	10	71	3	9	08:45:28
.3174	200.0	80	10	72	3	9	08:46:09
.3192	200.0	200	10	73	3	9	08:48:09
.3242	200.0	400	10	74	3	9	09:04:18
.3260	200.0	800	10	75	3	9	09:16:27
.3280	200.0	2000	10	76	3	9	09:36:46
.3298	200.0	4000	10	77	3	9	10:10:47
.3317	200.0	8000	10	78	3	9	11:17:35
.3336	200.0	20000	10	79	3	9	14:37:49
.3346	200.0	86400	10	80	3	10	09:04:47
.3350	200.0	172800	10	81	3	11	09:05:15
.3351	200.0	252245	10	82	3	12	06:48:51
.3382	400.0	4	10	83	3	12	08:10:53
.3416	400.0	10	10	84	3	12	08:10:59
.3426	400.0	20	10	85	3	12	08:11:10
.3434	400.0	40	10	86	3	12	08:11:31
.3442	400.0	80	10	87	3	12	08:12:11
.3458	400.0	200	10	88	3	12	08:14:11
.3485	400.0	400	10	89	3	12	08:20:15
.3506	400.0	800	10	90	3	12	08:27:23
.3550	400.0	2000	10	91	3	12	08:50:22
.3592	400.0	4000	10	92	3	12	09:24:09
.3628	400.0	8000	10	93	3	12	10:31:09
.3654	400.0	20000	10	94	3	12	13:51:22
.3663	400.0	80971	10	95	3	13	06:40:20
.3664	600.0	4	10	96	3	13	07:37:17
.3702	600.0	10	10	97	3	13	07:37:24
.3706	600.0	20	10	98	3	13	07:37:34
.3709	600.0	40	10	99	3	13	07:37:55
.3714	600.0	80	10	100	3	13	07:38:36
.3721	600.0	200	10	101	3	13	07:40:36
.3734	600.0	400	10	102	3	13	07:46:07
.3748	600.0	800	10	103	3	13	07:54:22
.3770	600.0	2000	10	104	3	13	08:14:33
.3792	600.0	4000	10	105	3	13	08:48:18
.3813	600.0	8000	10	106	3	13	09:55:06
.3835	600.0	20000	10	107	3	13	13:15:34
.3854	600.0	83658	10	108	3	14	06:51:31
.3853	400.0	4	10	109	3	14	07:55:06
.3852	400.0	10	10	110	3	14	07:55:13
.3851	400.0	20	10	111	3	14	07:55:23
.3850	400.0	40	10	112	3	14	07:55:44
.3848	400.0	80	10	113	3	14	07:56:25
.3845	400.0	200	10	114	3	14	07:58:25
.3842	400.0	400	10	115	3	14	08:01:56

.3840	400.0	800	10	116	3 14 08:11:22
.3838	400.0	2000	10	117	3 14 08:31:50
.3836	400.0	4000	10	118	3 14 09:05:20
.3834	400.0	8000	10	119	3 14 10:12:20
.3833	400.0	20000	10	120	3 14 13:32:27
.3832	400.0	82752	10	121	3 15 06:54:14
.3830	100.0	4	10	122	3 15 07:44:31
.3822	100.0	10	10	123	3 15 07:44:37
.3813	100.0	20	10	124	3 15 07:44:47
.3809	100.0	40	10	125	3 15 07:45:08
.3796	100.0	80	10	126	3 15 07:45:48
.3794	100.0	200	10	127	3 15 07:47:48
.3792	100.0	400	10	128	3 15 07:54:41
.3791	100.0	800	10	129	3 15 08:02:29
.3789	100.0	2000	10	130	3 15 08:22:40
.3787	100.0	4000	10	131	3 15 08:56:10
.3785	100.0	8000	10	132	3 15 10:03:10
.3720	100.0	20000	10	133	3 15 13:23:10
.3713	100.0	84095	10	134	3 16 07:06:02
.3753	50.0	4	10	135	3 16 07:34:04
.3734	50.0	10	10	136	3 16 07:34:10
.3724	50.0	20	10	137	3 16 07:34:21
.3714	50.0	40	10	138	3 16 07:34:42
.3704	50.0	80	10	139	3 16 07:35:22
.3698	50.0	200	10	140	3 16 07:37:22
.3695	50.0	400	10	141	3 16 07:42:04
.3694	50.0	800	10	142	3 16 07:51:21
.3693	50.0	2000	10	143	3 16 08:11:38
.3690	50.0	4000	10	144	3 16 08:45:08
.3687	50.0	8000	10	145	3 16 09:52:07
.3683	50.0	20000	10	146	3 16 13:12:07
.3682	50.0	86400	10	147	3 17 07:39:06
.3680	50.0	94383	10	148	3 17 09:47:03
.3676	50.0	172800	10	149	3 18 07:39:23
.3675	50.0	256581	10	150	3 19 06:50:21
.3672	12.5	4	10	151	3 19 07:36:05
.3670	12.5	10	10	152	3 19 07:36:11
.3666	12.5	20	10	153	3 19 07:36:21
.3663	12.5	40	10	154	3 19 07:36:42
.3658	12.5	80	10	155	3 19 07:37:22
.3650	12.5	200	10	156	3 19 07:39:22
.3644	12.5	400	10	157	3 19 07:43:52
.3637	12.5	800	10	158	3 19 07:50:51
.3625	12.5	2000	10	159	3 19 08:10:51
.3620	12.5	4000	10	160	3 19 08:44:21
.3617	12.5	8000	10	161	3 19 09:51:21
.3610	12.5	20000	10	162	3 19 13:11:21
.3604	12.5	83413	10	163	3 20 06:46:14
.3570	12.5	86400	10	164	3 20 07:38:23
.3567	12.5	169040	10	165	3 21 06:33:21
.3563	1.0	4	10	166	3 21 07:00:39
.3560	1.0	10	10	167	3 21 07:00:45
.3558	1.0	20	10	168	3 21 07:00:55
.3555	1.0	40	10	169	3 21 07:01:16
.3552	1.0	80	10	170	3 21 07:01:56
.3546	1.0	200	10	171	3 21 07:03:56
.3538	1.0	400	10	172	3 21 07:08:30
.3530	1.0	800	10	173	3 21 07:15:21
.3511	1.0	2000	10	174	3 21 07:35:21
.3488	1.0	4000	10	175	3 21 08:08:50
.3480	1.0	8000	10	176	3 21 09:15:45
.3469	1.0	20000	10	177	3 21 12:35:44
.3441	1.0	86400	10	178	3 22 07:02:43
.3430	1.0	109757	10	179	3 22 13:29:52
.3408	1.0	172800	10	180	3 23 07:03:08

5 Dec 1984

15:20:52

LOAD lbf/in2	HEIGHT ins	VOID RATIO	DRY UNIT WT lbf/ft3	MOISTURE CONTENT %	DEGREE OF SATURATION %	AXIAL STRAIN %
1.00	1.2578	.4559	115.33	13.20	77.88	0.00
3.00	1.2577	.4558	115.34	16.95	100.01	.01WETTED
6.00	1.2576	.4557	115.35	16.94	100.01	.02
12.50	1.2545	.4521	115.64	16.81	100.01	.26
25.00	1.2450	.4411	116.52	16.40	100.01	1.02
50.00	1.2287	.4223	118.06	15.70	100.01	2.31
100.00	1.2054	.3953	120.35	14.70	100.01	4.17
200.00	1.1744	.3594	123.52	13.36	100.01	6.63
400.00	1.1432	.3233	126.89	12.02	100.01	9.11
600.00	1.1241	.3012	129.05	11.20	100.01	10.63
400.00	1.1263	.3037	128.80	11.29	100.01	10.45
100.00	1.1382	.3175	127.45	11.80	100.01	9.51
50.00	1.1420	.3219	127.03	11.97	100.01	9.21
12.50	1.1528	.3344	125.84	12.43	100.01	8.35
1.00	1.1702	.3545	123.97	13.18	100.01	6.96

REBOUND 34.48 %

DRY MASS(FROM INITIAL MOISTURE) = 540.2 gms

DRY MASS(FROM FINAL MASS) = 534.2 gms

FINAL MOISTURE CONTENT(FROM FINAL MASS AND INITIAL MOISTURE) = 15.3 %

	INITIAL	MAX LOAD
DRY UNIT WEIGHT(lbf/ft3)	115.332	129.050
MOISTURE CONTENT	13.200 %	11.198 %
DEGREE OF SATURATION	77.879 %	100.012 %

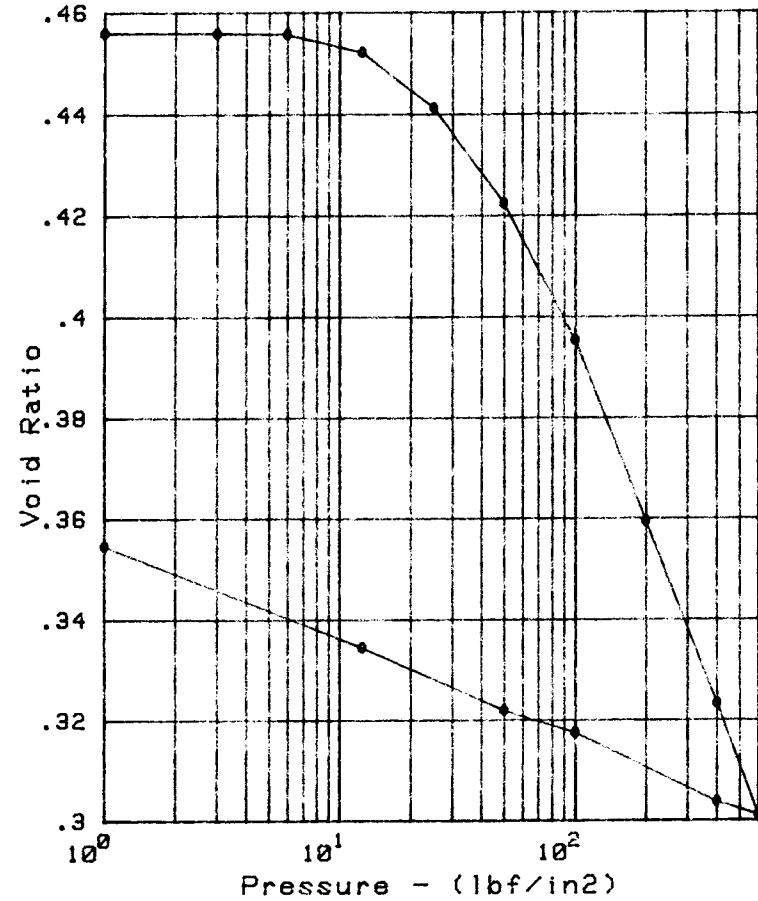
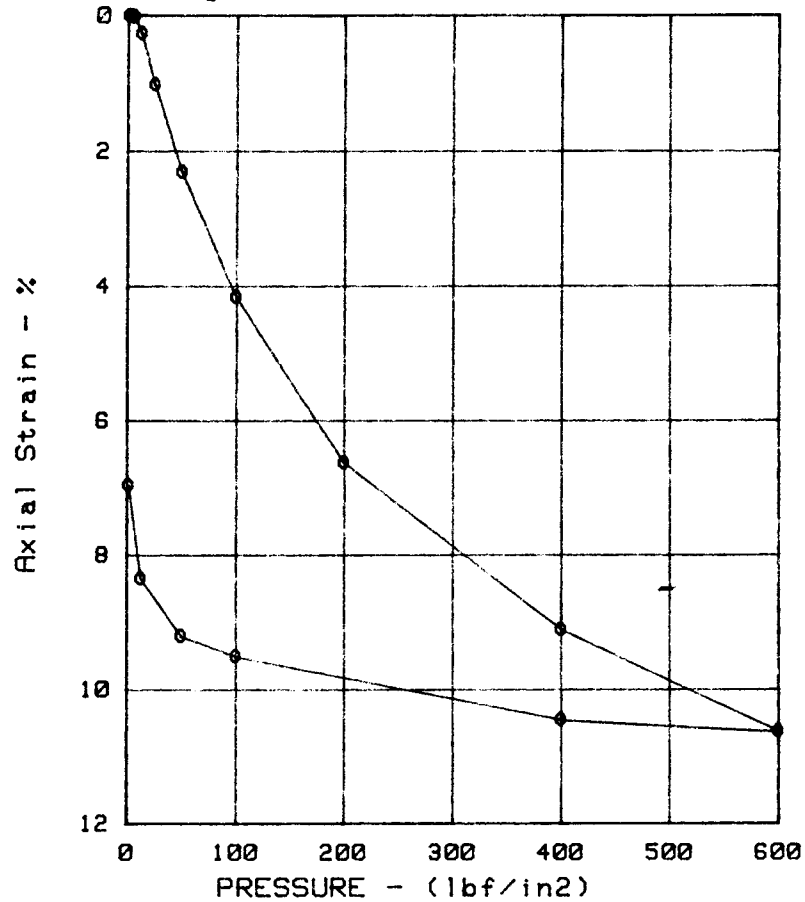
.3400	1.0	431050	10	181	3 26 07:00:54
.3393	1.0	517450	10	182	3 28 06:48:23



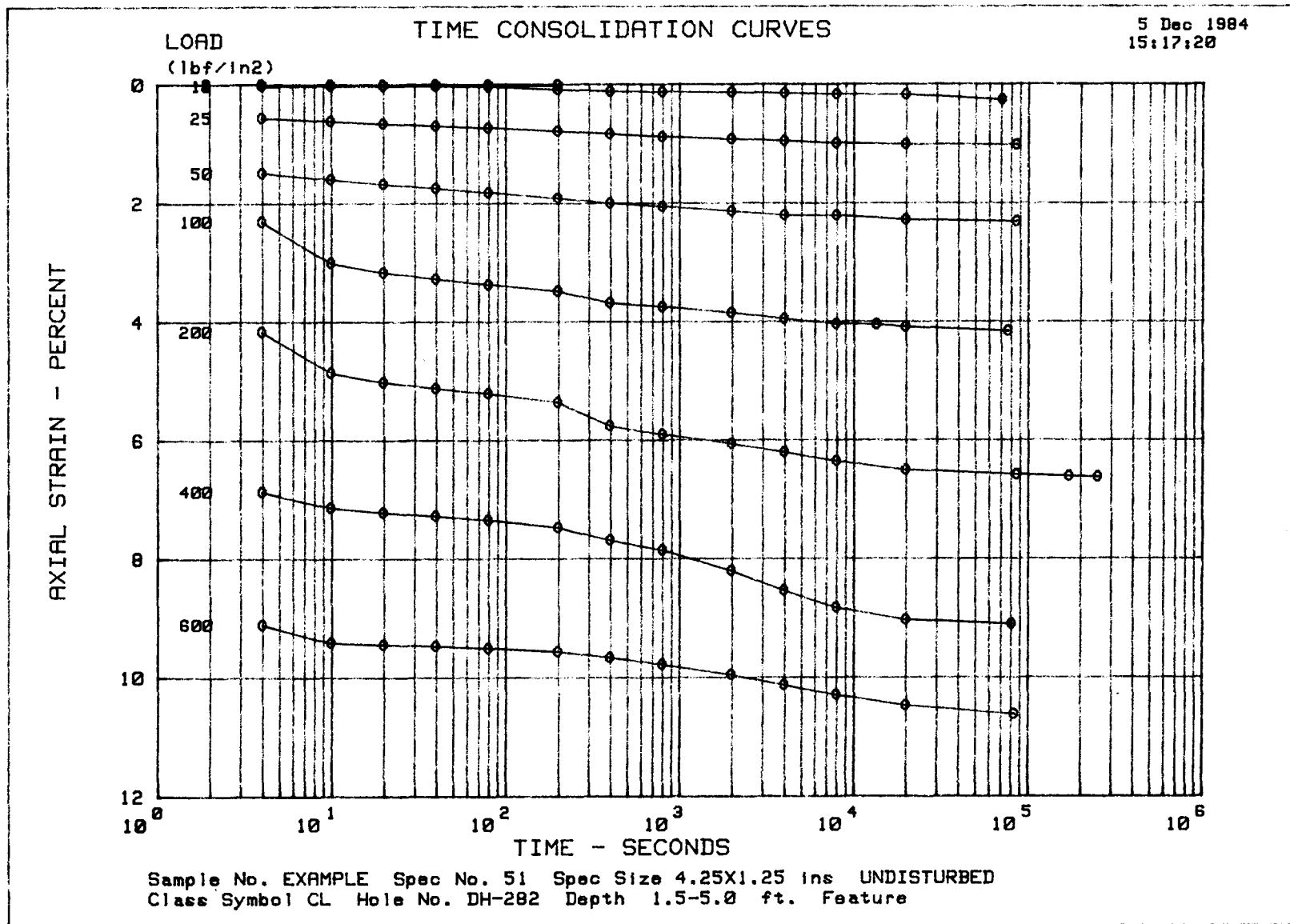
## ONE - DIMENSIONAL CONSOLIDATION

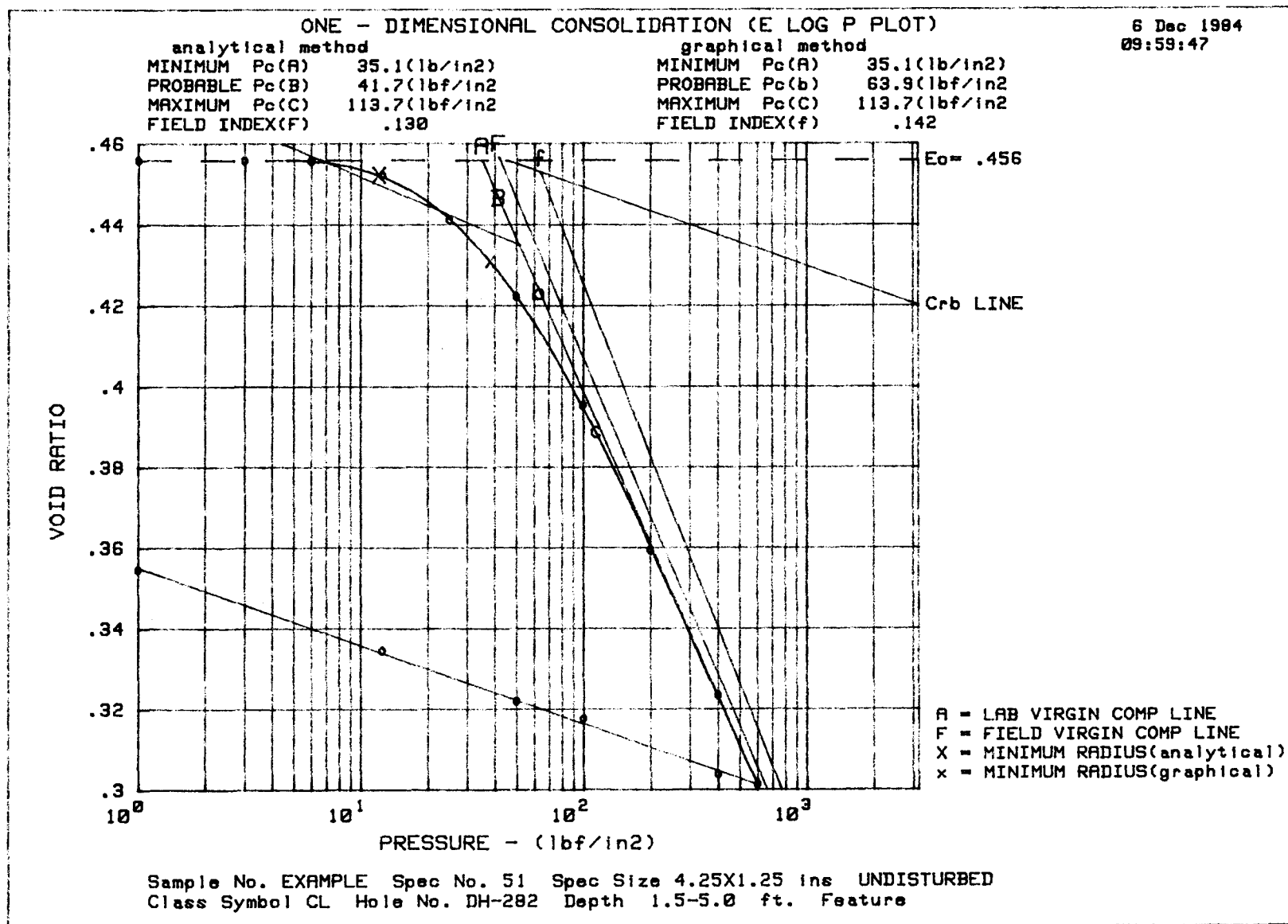
5 Dec 1984  
15:18:36

	INITIAL	MAX LOAD
Void Ratio	.456	.301
Dry Unit Wt - lbf/ft <sup>3</sup>	115.3	129.0
Moisture Content	13.2%	11.2%
Degree of Saturation	77.9%	100.0%



Sample No. EXAMPLE Spec No. 51 Spec Size 4.25X1.25 ins UNDISTURBED  
 Class Symbol CL Hole No. DH-282 Depth 1.5-5.0 ft. Feature





6 Dec 1984

10:01:20

RESULTS(E LOG P)

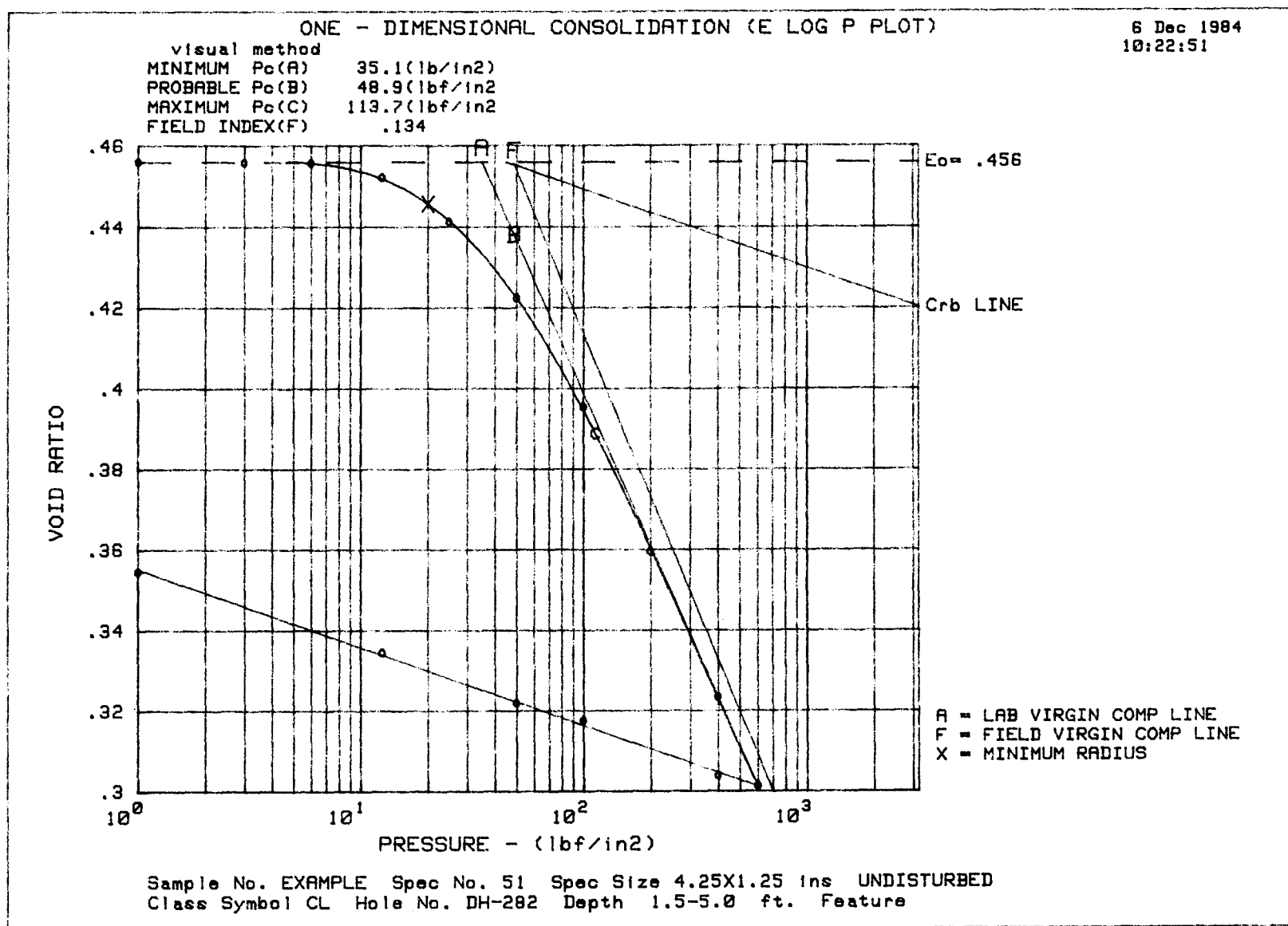
SAMPLE NO. EXAMPLE

ANALYTICAL METHOD

	MINIMUM	PROBABLE	MAXIMUM
PRECONSOLIDATION STRESS(lbf/in2)	35.1	41.7	113.7
VOID RATIO AT PRECONSOLIDATION	.456	.447	.389
OVERCONSOLIDATION RATIO	.780	.927	2.527
LAB COMPRESSION INDEX =	.126		
COMPRESSION RATIO =	.086		
REBOUND INDEX =	.019		
FIELD COMPRESSION INDEX =	.130		

GRAPHICAL METHOD

	MINIMUM	PROBABLE	MAXIMUM
PRECONSOLIDATION STRESS(lbf/in2)	35.1	63.9	113.7
VOID RATIO AT PRECONSOLIDATION	.456	.423	.389
OVERCONSOLIDATION RATIO	.780	1.419	2.527
LAB COMPRESSION INDEX =	.126		
COMPRESSION RATIO =	.086		
REBOUND INDEX =	.019		
FIELD COMPRESSION INDEX =	.142		



6 Dec 1984

10:25:39

RESULTS(E LOG P)

SAMPLE NO. EXAMPLE

VISUAL METHOD

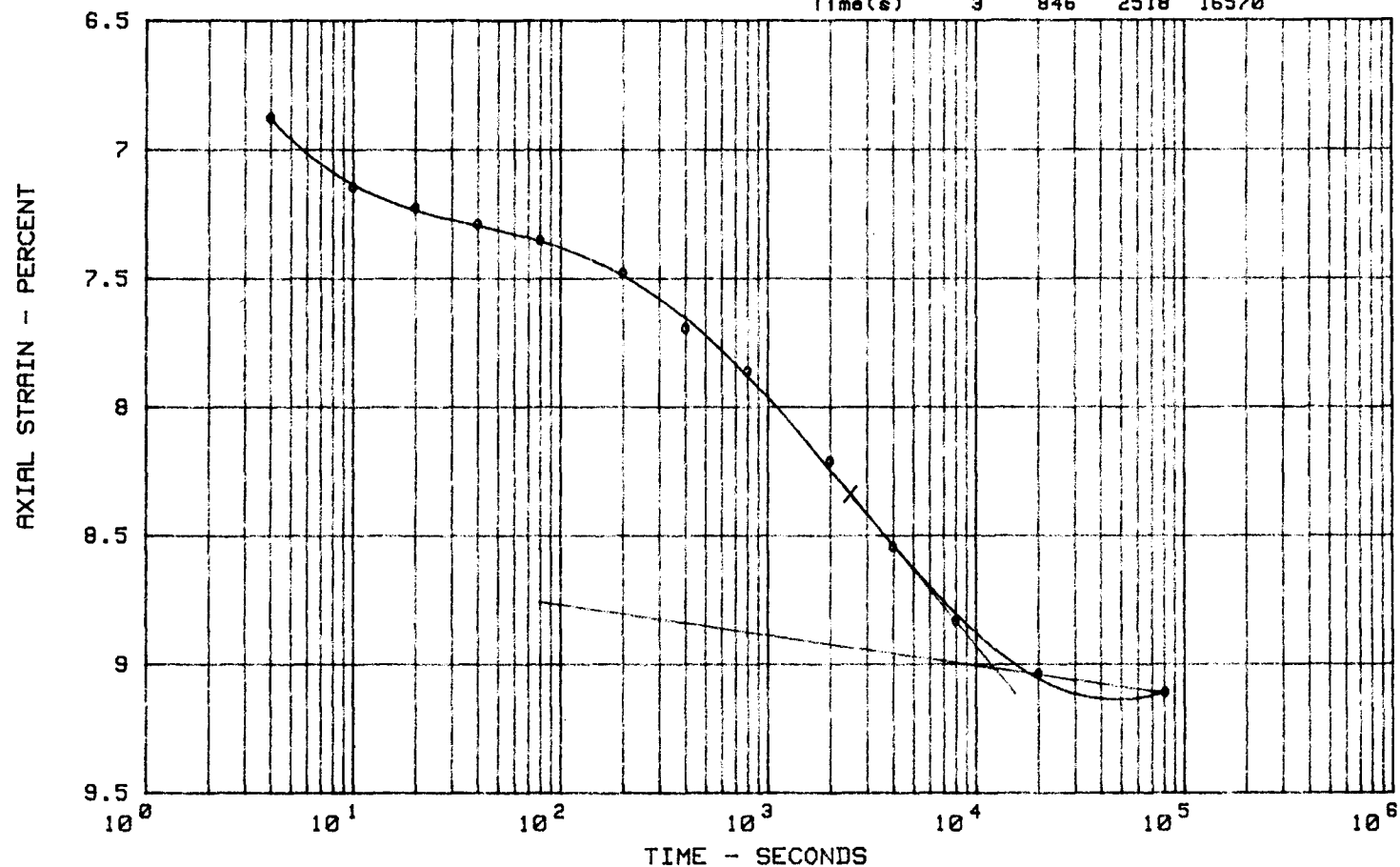
	MINIMUM	PROBABLE	MAXIMUM
PRECONSOLIDATION STRESS(lbf/in2)	35.1	48.9	113.7
VOID RATIO AT PRECONSOLIDATION	.456	.438	.389
OVERCONSOLIDATION RATIO	.780	1.086	2.527
LAB COMPRESSION INDEX =	.126		
COMPRESSION RATIO =	.086		
REBOUND INDEX =	.019		
FIELD COMPRESSION INDEX =	.134		

Load = 400 lbf/in<sup>2</sup>

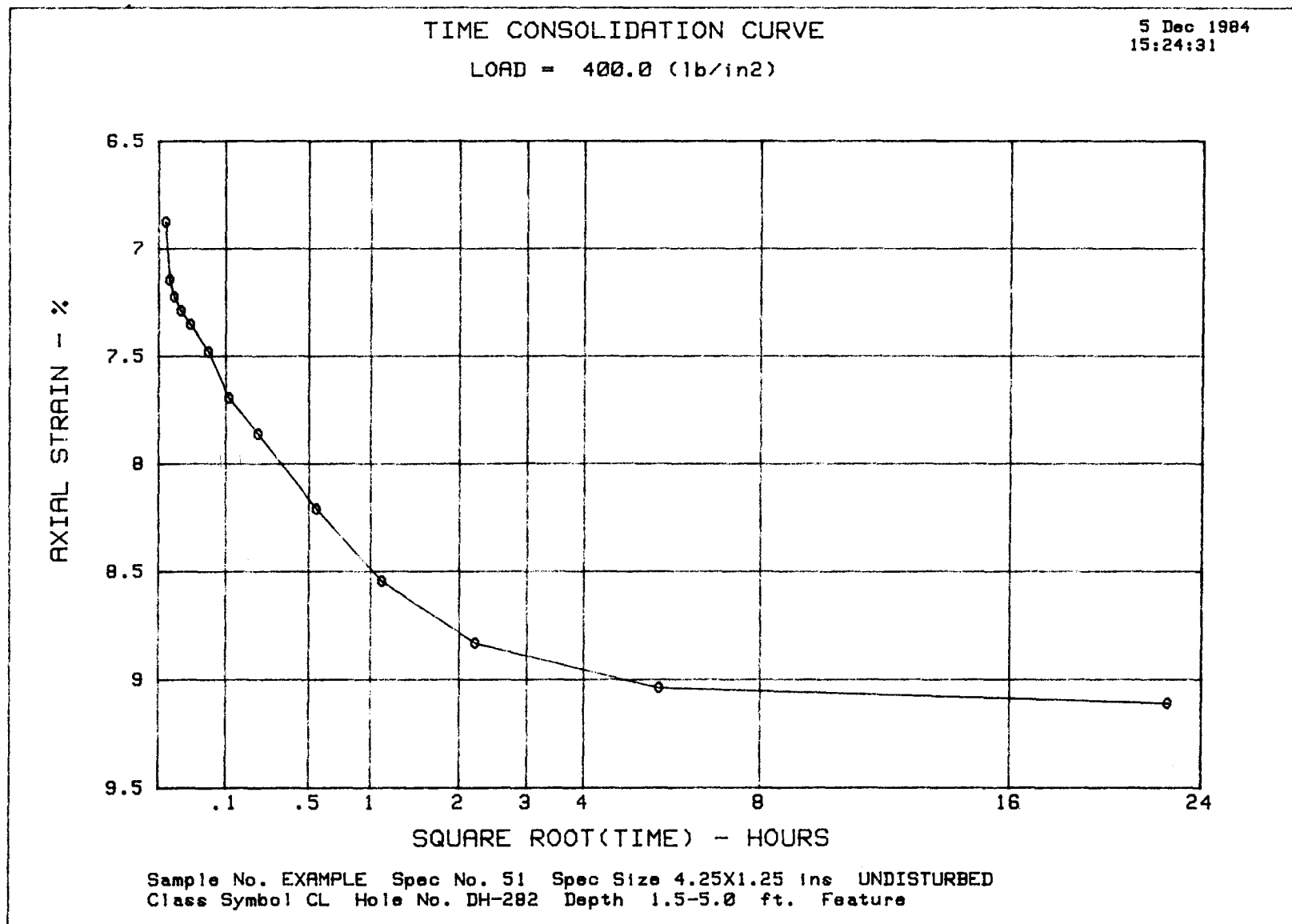
## TIME CONSOLIDATION CURVES

8 Dec 1984  
10:29:04

Method	Coef of Consol	Coef of Perm	U%	0%	50%	70%	100%
Graphic	.00050(cm <sup>2</sup> /sec)	9.537E-10(cm/sec)	Strain	6.8	7.9	8.3	9.0
			Time(s)	3	846	2781	12233
Inflection	.00034(cm <sup>2</sup> /sec)	6.523E-10(cm/sec)	Strain	6.8	7.9	8.3	9.0
			Time(s)	3	846	2518	16570



Sample No. EXAMPLE Spec No. 51 Spec Size 4.25X1.25 ins UNDISTURBED  
 Class Symbol CL Hole No. DH-282 Depth 1.5-5.0 ft. Feature

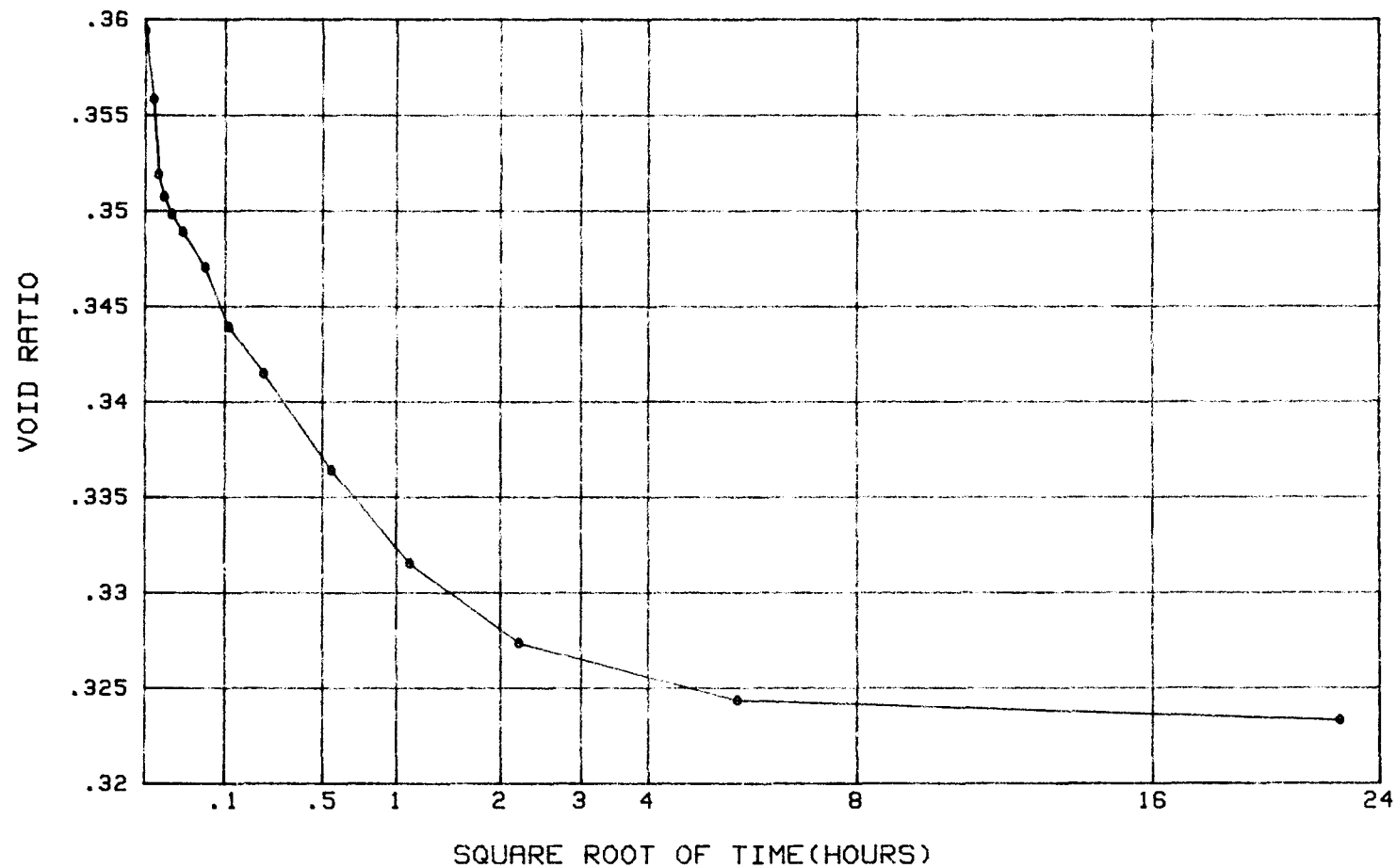




# DEFORMATION VS SQUARE ROOT OF TIME

6 Dec 1984  
10:11:55

LOAD = 400.0



Sample No. EXAMPLE Spec No. 51 Spec Size 4.25X1.25 ins UNDISTURBED  
Class Symbol CL Hole No. DH-282 Depth 1.5-5.0 ft. Feature

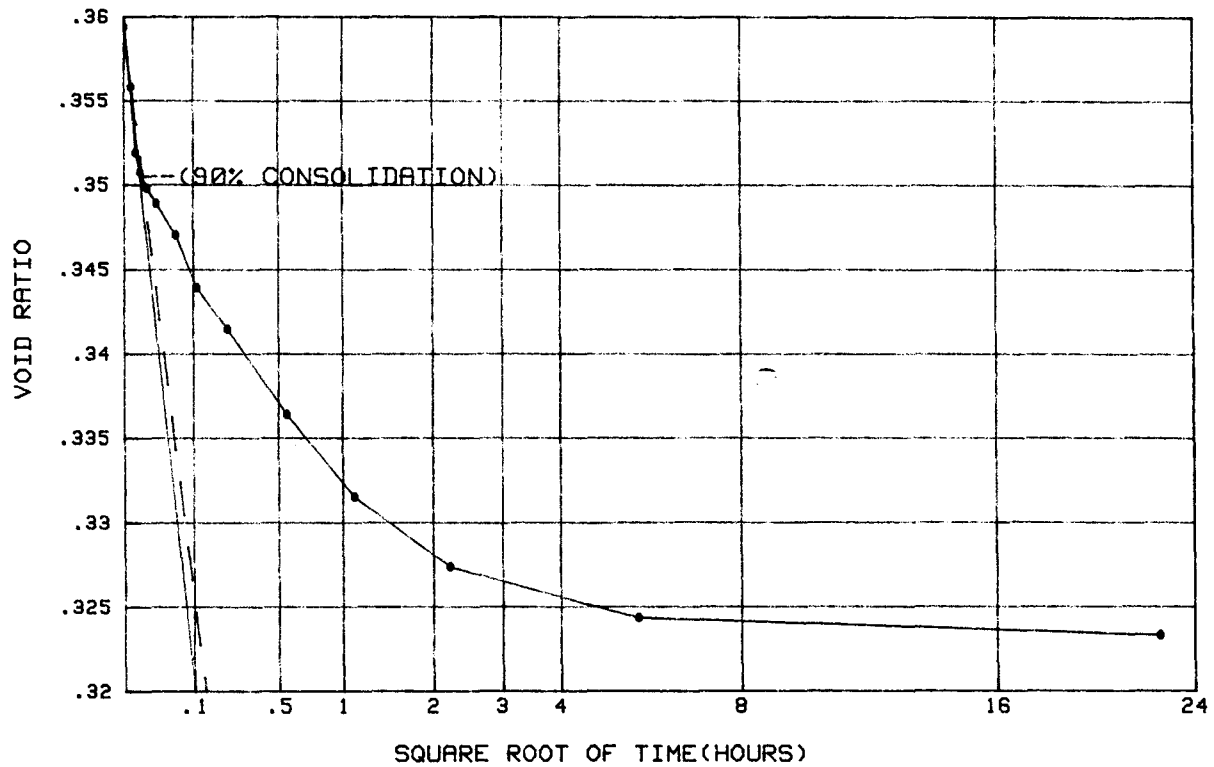
# DEFORMATION VS SQUARE ROOT OF TIME

LOAD = 400.0 lb/in<sup>2</sup>

CV = .0114

100% CONSOLIDATION = .3495

6 Dec 1984  
10:14:38



Sample No. EXAMPLE Spec No. 51 Spec Size 4.25X1.25 ins UNDISTURBED  
Class Symbol CL Hole No. DH-282 Depth 1.5-5.0 ft. Feature

### **Mission of the Bureau of Reclamation**

*The Bureau of Reclamation of the U.S. Department of the Interior is responsible for the development and conservation of the Nation's water resources in the Western United States.*

*The Bureau's original purpose "to provide for the reclamation of arid and semiarid lands in the West" today covers a wide range of interrelated functions. These include providing municipal and industrial water supplies; hydroelectric power generation; irrigation water for agriculture; water quality improvement; flood control; river navigation; river regulation and control; fish and wildlife enhancement; outdoor recreation; and research on water-related design, construction, materials, atmospheric management, and wind and solar power.*

*Bureau programs most frequently are the result of close cooperation with the U.S. Congress, other Federal agencies, States, local governments, academic institutions, water-user organizations, and other concerned groups.*

A free pamphlet is available from the Bureau entitled "Publications for Sale." It describes some of the technical publications currently available, their cost, and how to order them. The pamphlet can be obtained upon request from the Bureau of Reclamation, Attn D-922, P O Box 25007, Denver Federal Center, Denver CO 80225-0007.