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SUBJECT: Research Report No. 468, "Computerized Analysis of Stress-Strain Consolidation Data," KYHPR-75-74; HPR-PL-1(12), Part II

The report enclosed completes a task or phase of work which may be appreciated by persons involved in consolidation testing of soils or, more specifically, analysis of the data from consolidation tests. The difficulty of determining the preconsolidated condition of a soil has been an enduring one. Any errors affect estimates of foundation settlement. The computer program is readily implementable, and the report may properly be called an "Implementation Package."

Respectfully submitted,

Jas. H. Havens
Director of Research

gd
Enclosure
cc's: Research Committee

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16. Abstract

A computerized, mathematical algorithm is described and presented for analyzing the semilogarithmic stress-strain (time-independent) properties of standard, controlled-gradient, and controlled-rate-of-strain consolidation tests. This algorithm is an automation of manual graphical procedures currently used in engineering practice to obtain stress-strain information necessary for use in time-independent settlement analysis. The Casagrande and Schmertmann constructions are analytically represented to determine the preconsolidation stress and the in situ, compressibility coefficients of compression and expansion. Values for each of these parameters range between a probable and minimum value. The point of maximum curvature is determined for the Casagrande construction by use of the mathematical definition of the radius of curvature or by the analytical representation of a newly proposed graphical approach. The location of the point of maximum curvature has been found to depend on the arithmetic scale factors used for the horizontal and vertical directions in the semilogarithmic representation of the consolidation curves. The mathematical algorithm is written in Fortran IV for use with the IBM 370/165 computer and the Calcomp 663 drum plotter. The computer program has proven effective in the reduction and analysis of stress-strain data from more than 40 controlled and 30 standard consolidation tests.

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Research Report
468

COMPUTERIZED ANALYSIS OF STRESS-STRAIN CONSOLIDATION DATA

Interim Report
KYHPR-75-74; HPR-PL-1(12), Part II

by

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Bureau of Highways
DEPARTMENT OF TRANSPORTATION
Commonwealth of Kentucky

in cooperation with
Federal Highway Administration
U. S. DEPARTMENT OF TRANSPORTATION

March 1977

INTRODUCTION

BACKGROUND

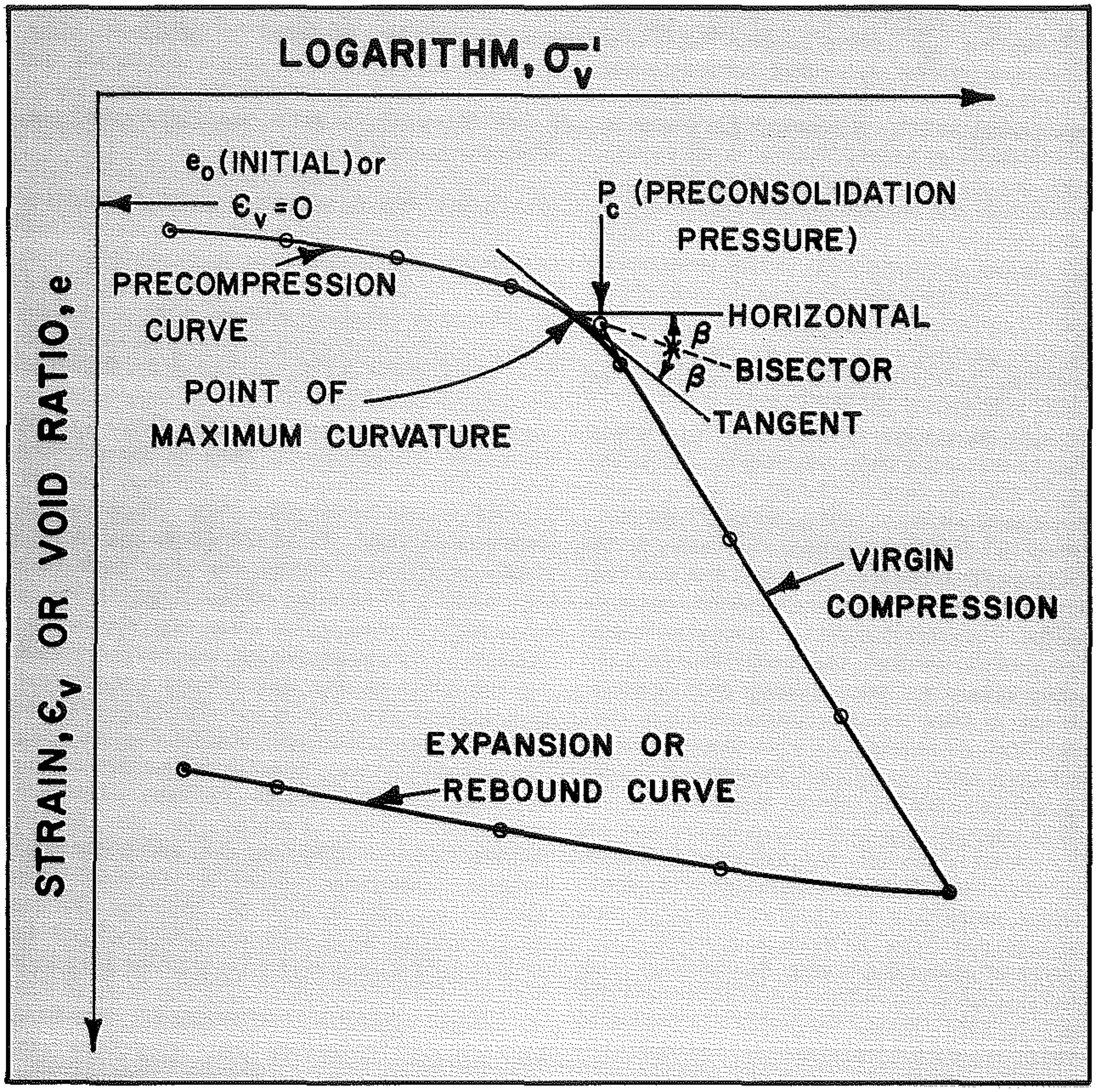
The problem of settlement has long been a concern to civil engineers. The Leaning Tower of Pisa remains a monumental reminder. Before Karl Terzaghi disclosed the mechanics of the settlement process in **Erabaumechanik** in 1925, only parts of the process had been understood -- no one had put it all together. Terzaghi described in an analytical fashion the process associated with the compression of a mass of discrete irregular particles into a denser material. This process became known as consolidation. The test developed by Terzaghi to study the characteristics of the consolidation process consisted of encasing a cylindrical specimen of particulate material in a ring to prevent lateral deformations, bounding the top and bottom of the specimen with porous stones to permit the escape of water from the soil specimen, and applying a vertical pressure to the sample. Deformations of the sample were measured and plotted as a function of stress. Because deformation is permitted only in the vertical direction, this test is commonly referred to today as the one-dimensional consolidation test. Test data have been studied using semilogarithmic graphical representations of the stress-deformation (time-independent) characteristics of the data. Such a representation yields the stress history and compressibility of the material. Knowledge of these material characteristics is of great practical value in the prediction of settlement associated with loadings where the effects of immediate settlement and lateral consolidation may be neglected.

The principle event in the stress history of a soil is that of the maximum, past, vertical pressure, the largest stress experienced by the material in its natural, subsurface environment. It is usually the result of loads imposed by past or present overlying materials and(or) the result of dessication. Today, the maximum, past, vertical pressure is referred to as the "preconsolidation stress." In 1936, Arthur Casagrande *(1)* devised an empirical, graphical procedure to determine the preconsolidation presssure from the semilogarithmic representation of time-independent, laboratory consolidation data. This method has come to be known as the "Casagrande construction." Figure 1 *(2)* illustrates the essential characteristics of this well known procedure.

Before 1955, the compressibility characteristics of particulate materials were expressed as the arithmetic slopes of the line representations of the semilogarithmic, laboratory consolidation curves. However, these lines did not account for the effects of disturbance on the consolidation curves. In 1955, Schmertmann *(3)* developed a procedure which accounted for the effect of sample distrubance and estimated in situ compressibility characteristics Figure 2 *(4)* shows the essential characteristics of the Schmertmann procedure.

Analyses of time-independent, one-dimensional consolidation data by empirical, graphical techniques such as the Casagrande and Schmertmann constructions have several drawbacks in their practical applications. Graphical procedures require a certain amount of time and effort from competent personnel oftentimes require subjective judgements which are somewhat susceptible to various graphical or computational errors. Results of a survey conducted by Sallfors *(5)* of 28 geotechnical engineers emphasized these difficulties. Figure 3 shows the scatter among engineers asked to determine the preconsolidation pressure of a given set of time-independent consolidation data. Values reported ranged from about 47 to 73 kilopascals. At the 80-percent confidence interval, the values ranged from approximately 55 to 65 kilopascals. Twenty of the 28 values fell in that range. The results show not only the difficulty in determining the preconsolidation pressure but also reflect the fact that different methods were used. Sallfors' survey, while not directly pertinent to the graphical procedures under discussion, again suggests there is a need for some means to alleviate the problems associated with the analysis of time independent consolidation data. According to the Geodex Information Source (1973), the only published attempt involving a computer analysis of time-independent consolidation data is that of Schiffman *(6)*. As documented in 1973, the program developed by Schiffman does not consider the graphical procedures discussed above and considers only data obtained from the standard, laboratory consolidation test. In essence, his program determines the coefficients for one-dimensional compression and expansion by calculating the arithmetic slope between consecutive data points on the void ratio-logarithm of effective-stress consolidation curves. The effect of specimen disturbance is not accounted for in the determination of the compression coefficients.

Figure 1. Casagrande Construction for the Determination of the Preconsolidation Pressure (after Ladd, 1968).



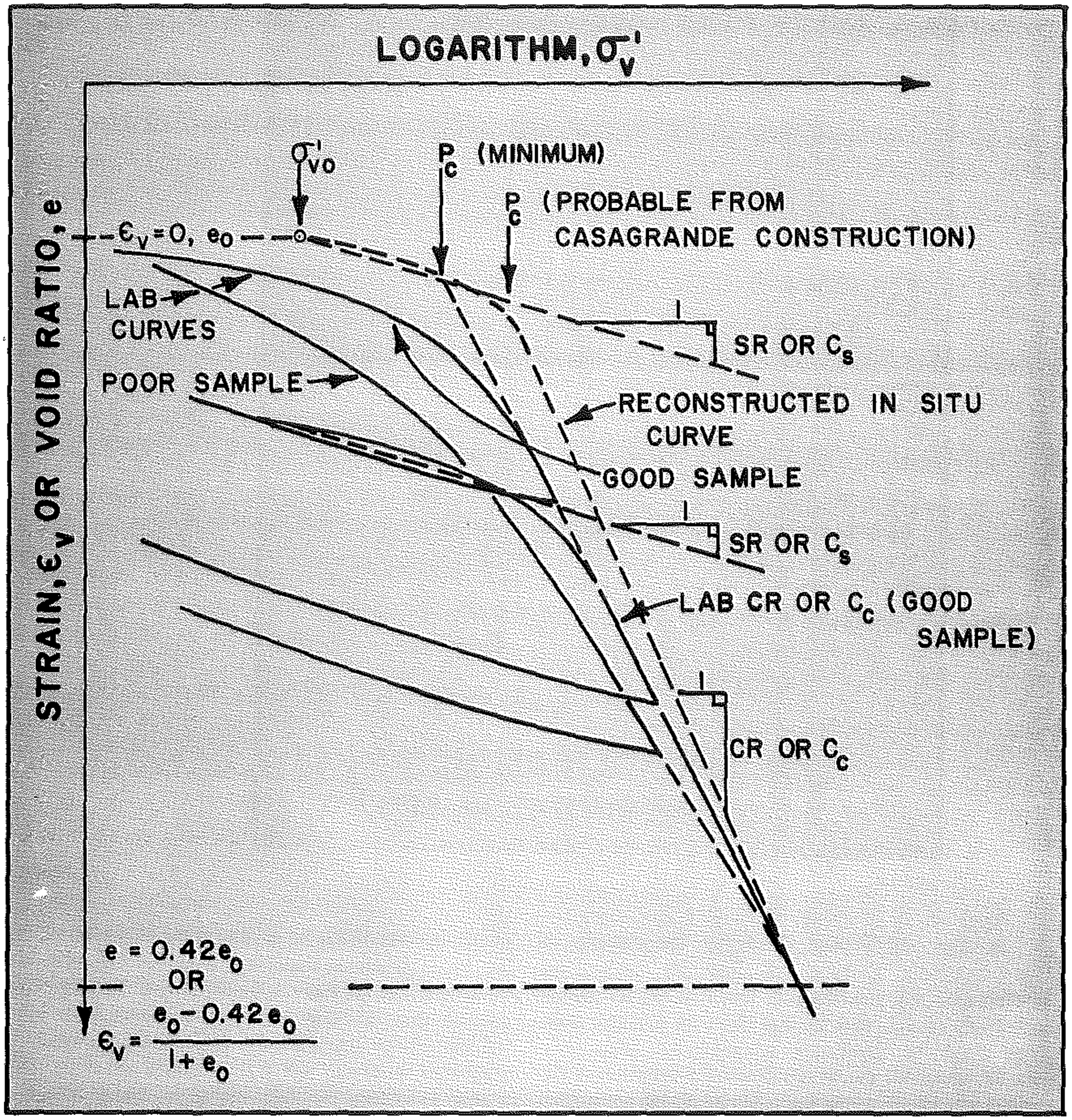
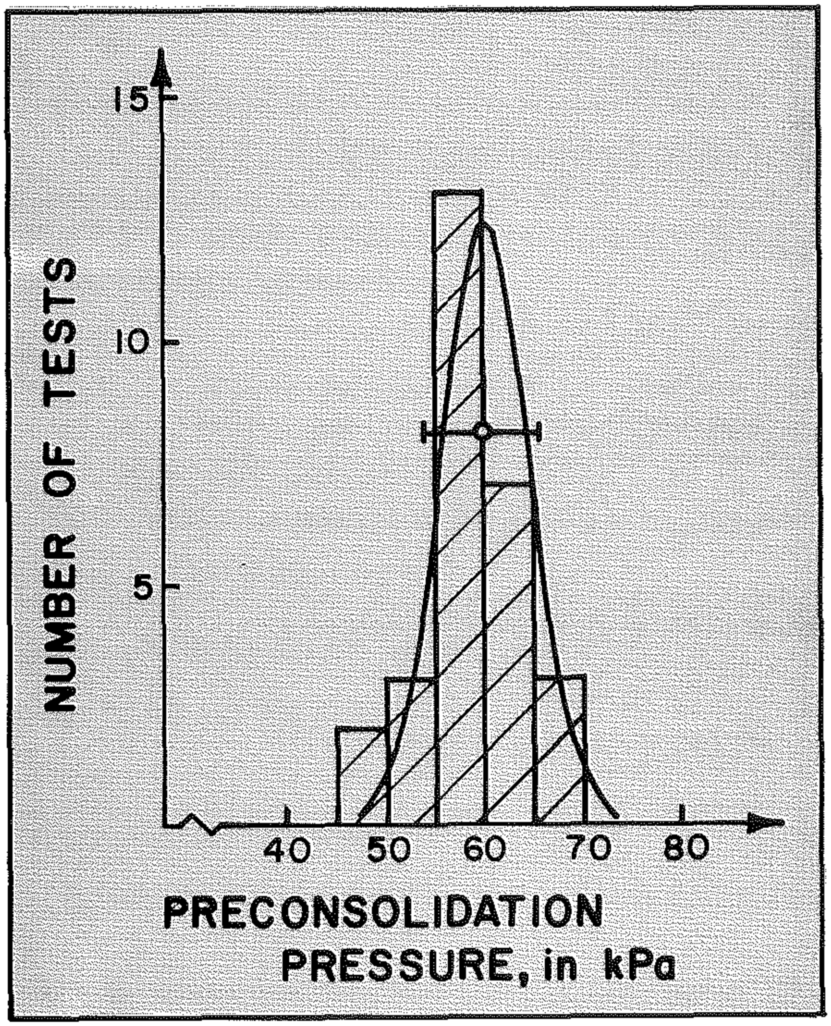


Figure 2. Reconstruction of in situ Compression Curves Using Schmertmann's Construction (after Ladd, 1968).

Figure 3. **Distribution of Evaluated Preconsolidation Pressures (80-percent confidence interval) (after Sallfors, 1975).**



In May 1975, the Kentucky Department of Transportation's Division of Research began the development of a computer program which would completely reduce, analyze, and plot data obtained from three types of laboratory consolidation tests. The material presented herein is a detailed description of the computer program which was achieved during an ensuing year of research and development. Included are coding instructions and examples of input and output. The computer program contains several innovative features which provide for the mathematical application of the Casagrande and Schmertmann constructions and the determination of the preconsolidation pressure and in situ coefficients of compressibility. The program also provides for complete reduction and plotting of the time-independent consolidation data obtained from three laboratory tests: standard, controlled-gradient, and controlled-rate-of-strain. A discussion of the latter two has been presented elsewhere *(7, 8, 9)*. The following discussion also includes a description of the algorithm used to study the time-independent consolidation data, the use of the algorithm for determining the point of maximum curvature and the preconsolidation pressure, a new procedure for determining maximum curvature and preconsolidation pressure, and the computer program capabilities and limitations. The computer program in APPENDIX A does not consider time-dependent (compression as a function of time) data obtained from the various consolidation tests. Future efforts will be devoted to plotting and analyzing time-dependent consolidation data and to determining coefficients of consolidation, C_v. This second phase will be in a future report.

ALGORITHM FOR TIME-INDEPENDENT, LABORATORY, CONSOLIDATION TEST DATA

The algorithm presented herein is a means of automating the current, manual, graphical procedures to analyze the time-independent, laboratory consolidation data. Four main points will be discussed in the description of this algorithm: the type of numerical analysis employed, the reasons for choosing this type of numerical analysis, a brief description of the analytical procedures, and a general description of how they are used to automate the Casagrande and Schmertmann graphical constructions with respect to the semilog, time-independent, one-dimensional consolidation data.

TYPE OF NUMERICAL ANALYSIS

The central element of the algorithm is the use of analytical curve-fitting procedures to represent the standard, graphical, semilog representation of test data. An ordinary least-squares polynomial *(10)* is used to represent the compression curve characteristics; a linear, least-squares representation is used for the rebound or expansion data. It is important to understand that these two functions are applied to the logarithms, base ten, of the abscissae. In other words, the raw data points which originally span logarithmic cycles are now reduced to a common, narrow, arithmetic range of values.

CRITERIA FOR SELECTION OF ORDINARY POLYNOMIAL

Three criteria were considered in selecting ordinary polynominals: functional shape, functional simplicity, and analytical accuracy. Any analytical function which is used for curve fitting must satisfy the all-important criteria of functional shape or form. Implied in this statement is the requirement that the function have the flexibility to accurately duplicate the wide range of shapes or forms to be expected from a given set of data. The ordinary polynomial satisfies all of these requirements amazingly well. Other types of functional fits have been investigated. Exponential and logarithmic functions are not satisfactory because their seemingly appropriate shapes are too extreme and inflexible to provide an accurate estimate of the point of maximum curvature and linear portion of virgin compression. In contrast, rational functions based on Chebyshev (Tchebycheff) polynomials are much better for fitting curves than exponential or logarithmic functions. However, these types of rational functions still have the general characteristic of being too inflexible to satisfactorily describe some of the finer, yet essential, shape characteristics. Example fits of the rational function to data are given in Figure 4. It is obvious from the figure that there are significant variations between rational functions of different orders. In contrast, the ordinary polynomials shown in Figure 5 do not vary significantly in their fit to the same data points shown in Figure 4. In view of this comparison, the shape of the ordinary polynominal has less dependence on the functional order used. This is very important from the standpoint of reducing the subjectivity involved in the choice of an appropriate order of the curve-fitting function.

The choice of any curve-fitting function should take into account the difficulty of manipulating the analytical expression. Differentiation and the use of related analytical expressions may become cumbersome for many types of functions. Exponential and logarithmic functions are especially cumbersome in a general operational sense because their related analytical operations are wholly dependent on the particular functional expression at hand. In other words, these types of functions are usually not derived from any particular recurrence relationship which can be used to obtain greater flexibility in functional shape. On the other hand, rational and polynomial functions do have desirable recurrence relationships. From the standpoint of mathematical manipulations, the ordinary polynomial is the most desirable of these functions because its recurrence relationships provide simpler analytical expressions. This fact is especially true from the standpoint of differentiation and generation of the functional expressions. The expressional forms of these two functions easily demonstrate this fact. The ordinary polynomial has the form

$$p(x) = c_1 + c_2x + c_3x^2 + \dots c_nx^{n-1}, \qquad 1$$

where p(x) is the given polynomial with terms having constant coefficients c for the abscissa terms x with integer powers n. The rational function using the ratio of two Chebyshev polynomials, $T_{n+1}(x)$ and $T_{m+1}(x)$, has the form

$$u(x)/v(x) = T_{n+1}(x)/T_{m+1}(x) = \sum_{n=1}^{n} (2x(T_n(x)) - T_{n-1}(x)) \Big/ \sum_{n=1}^{n} (2x(T_m(x)) - T_{m-1}(x))$$

where $T_0(x) = 1$, $T_1(x) = x$, $T_2(x) = 2x^2 - 1$, and n and m are the degrees of the Chebyshev polynomials in the numerator and denominator, respectively. Derivatives are easily obtained on the ordinary polynomial using the product rule of differentiation,

$$d(p(x))/dx = ncx^{(n-1)}, \quad 3$$

on the quantity

$$p(x)=cx^n. \quad 4$$

In contrast, derivatives of the rational function will involve a nontrivial consideration of its individual terms which have the somewhat peculiar recurrence relation shown in Equation 2. These derivatives are obtained using the quotient rule of differentiation,

$$d(u(x))/v(x))/dx = (v(du/dx) - u(dv/dx))/v^2, \quad 5$$

which in this case is nontrivial. In view of these differences in simplicity and the indications of fit found in Figures 4 and 5, the benefits gained using a rational function as opposed to an ordinary polynomial would be questionable at best.

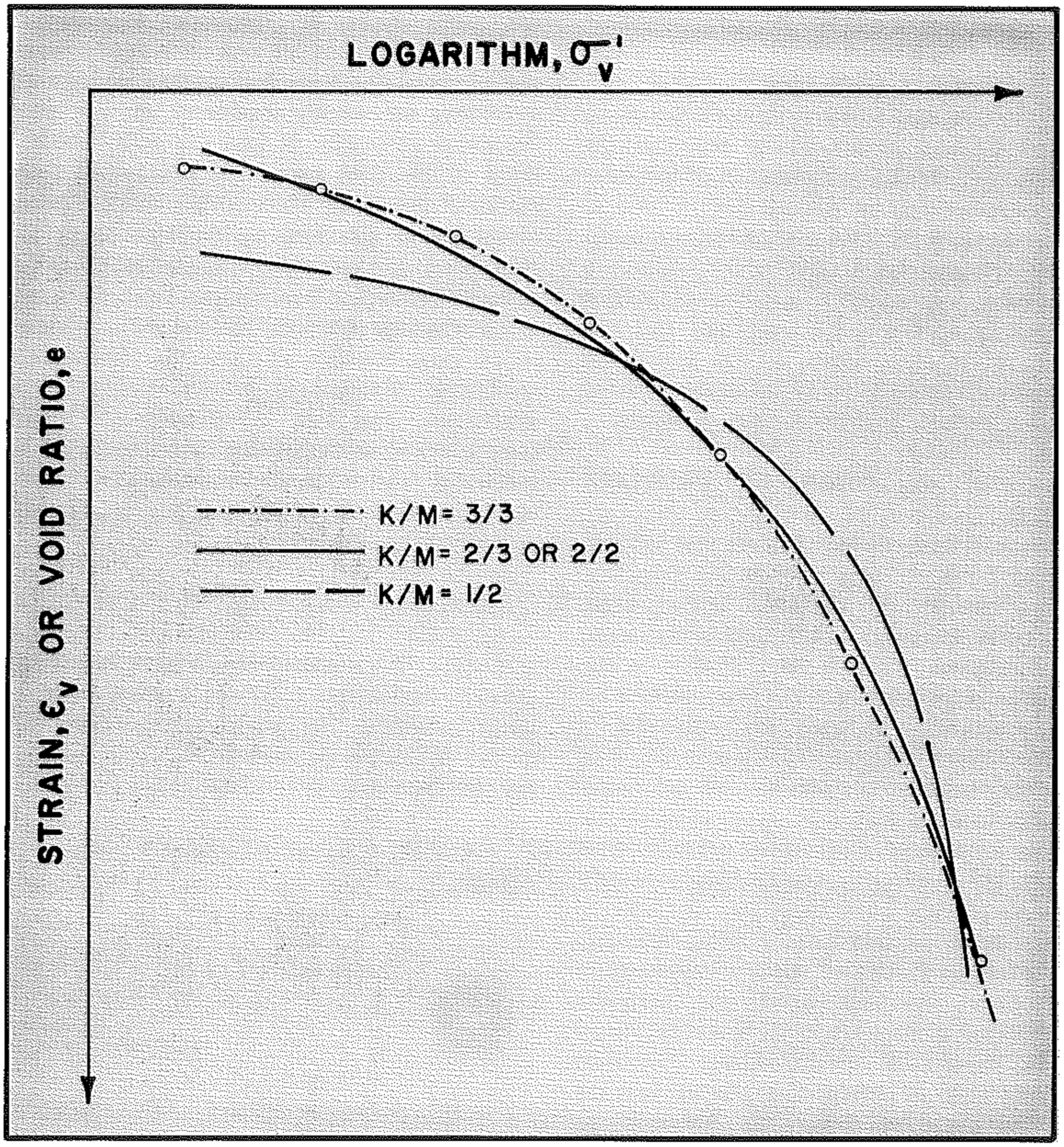
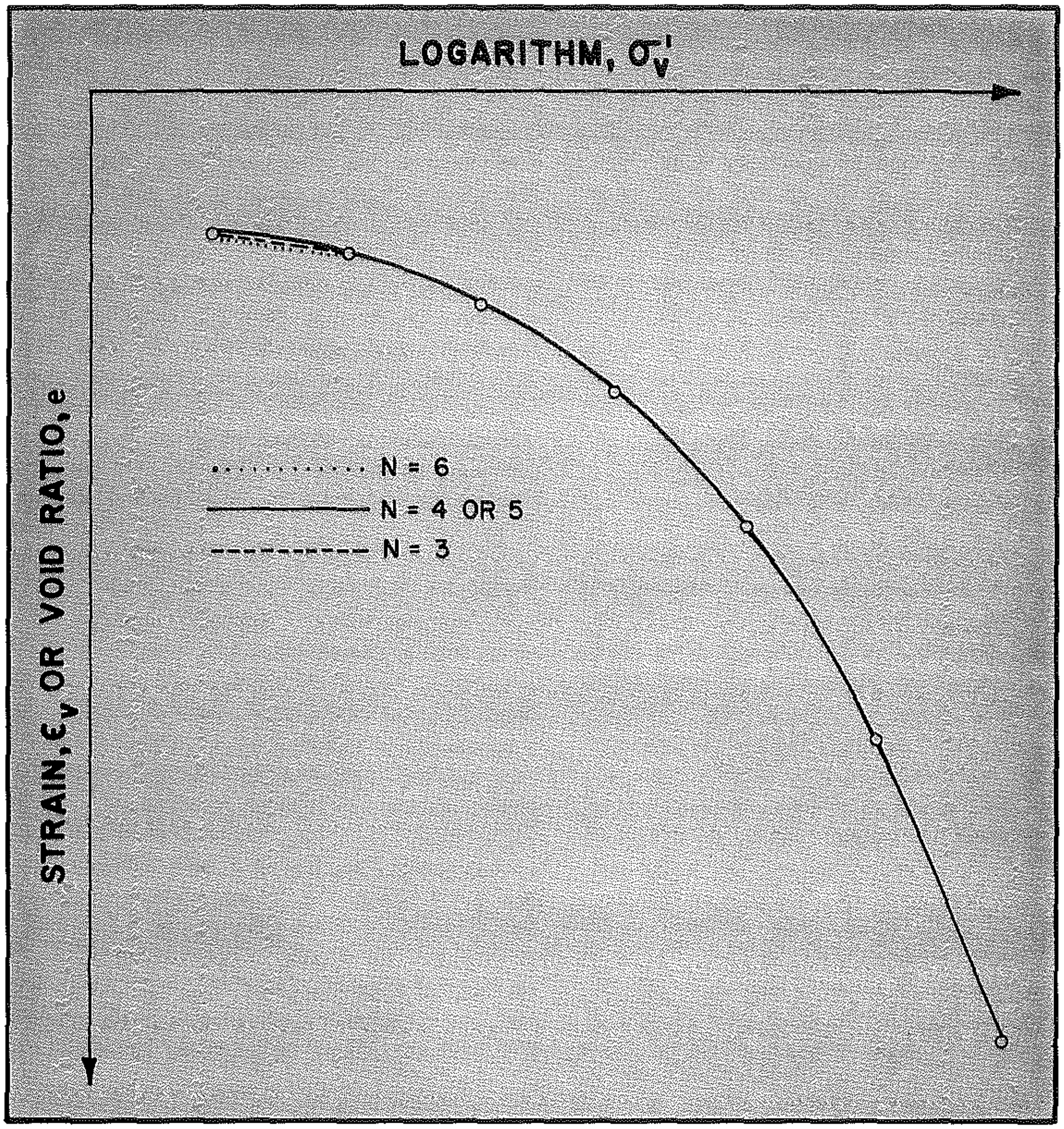


Figure 4. **Examples of Curve Fits by Rational Functions Having the Form u(x)/v(x), where u(x) and v(x) are Chebyshev Polynomials Having Orders k and m, respectively.**

Figure 5. **Examples of Curve Fits** by **Ordinary Polynomials p(x) Having Different Orders n.**



The final reason for choosing the ordinary polynomial as the curve-fitting function is the accuracy which can be obtained in the first and second derivatives of the analytical expression. This is due more to the functional characteristic than to a shape characteristic. As pointed out in the discussion of functional shape, the ordinary polynomial usually will provide a very good fit of the semilog representation of compression data. Consequently, differentiation based on the mathematical definitions of Equations 3 or 5 will yield accurate estimates of the first and second derivaties. When a finite difference approach is used as a check on the derivatives of the generated ordinary polynomial (Equation 3), the same results can be obtained if the increments are sufficiently small. The derivatives obtained by the two mathematical definitions will be legitimate if the polynomial curve provides a good representation of the data. In contrast, as the functional representation of the data becomes less accurate (as in the cases of rational functions and low degree polynomials), the legitimacy of the first- and higher-order derivatives becomes increasingly questionable.

ANALYTICAL PROCEDURES

This algorithm employs a variety of analytical procedures to represent the geometrical characteristics of the semilog, stress-deformation, consolidation curves. To begin with, the equation of the fitted ordinary polynomial is used to evaluate ordinate values at various abscissa locations on the curve. Slopes at these abscissa locations are determined using Equation 3. It should be noted that the rebound data are fitted only with a straight line. These analytically determined slopes are used with associated abscissa and ordinate values to produce equations of straight lines. Another geometrical quantity represented by analytical procedures is the radius of curvature. After the mathematical definition of Equation 3 is applied twice to evaluate the second derivative, the radius of curvature can be analytically determined at various abscissa locations through the use of the following mathematical definition:

$$R = (1 + (dy/dx)^2)^{3/2}/(d^2y/dx^2), \qquad 6$$

where R is the radius of curvature. The point of maximum curvature is given by the minimum value of the radius, 'R'. Another means of determining the point of maximum curvature is by approximating other geometrical characteristics of the curve. A combination of the procedures which set up equations of straight lines form the basis of this new method to determine the point of maximum curvature. A more complete discussion of this method follows in the section entitled "Graphical Method to Select Point of Maximum Curvature".

AUTOMATION OF THE CASAGRANDE AND SCHMERTMANN CONSTRUCTIONS

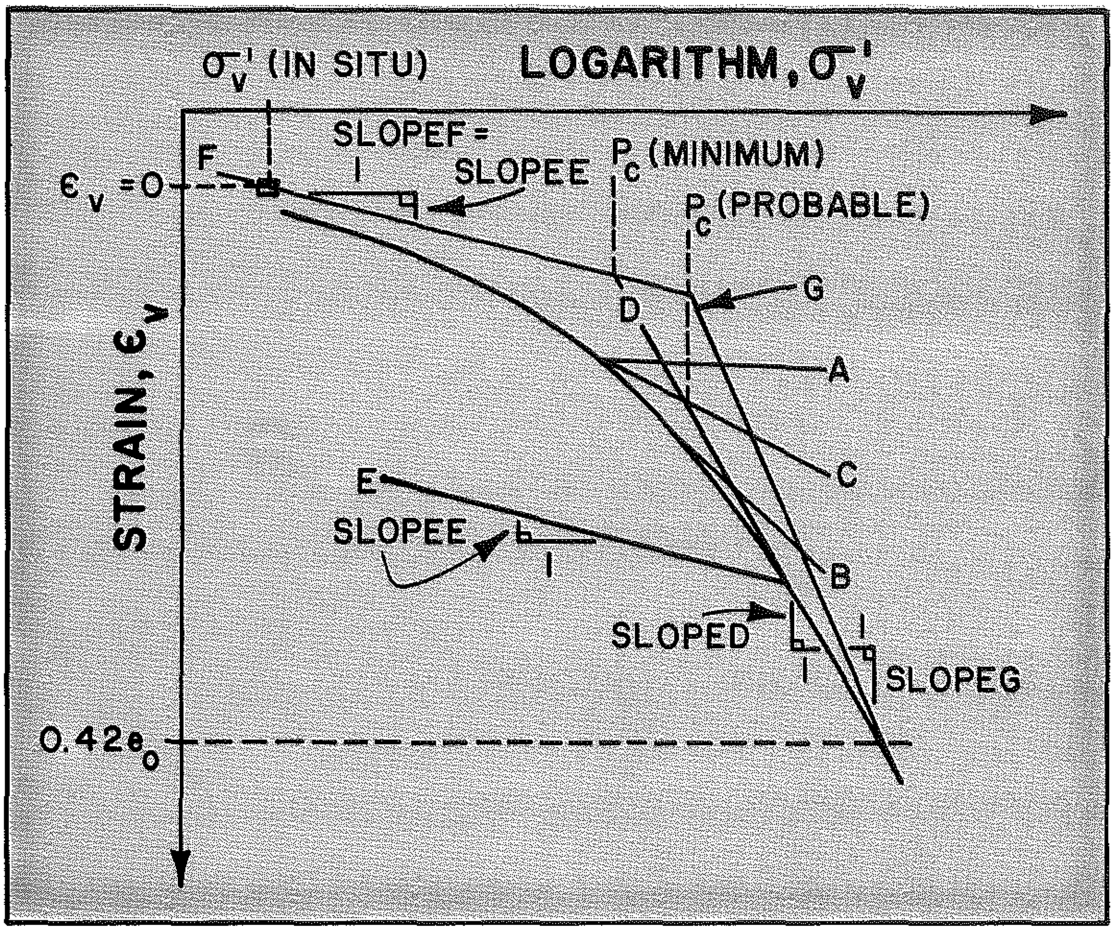
The analytical procedures described in the preceeding section form the basis for the mathematical representation of the two most widely used methods in the analysis of time-independent settlement. In review, the Casagrande construction is used by this algorithm to estimate the probable preconsolidation pressure, and the Schmertmann construction is employed to account for the effects of disturbance on the compressibility of the specimen. Steps in the two empirical constructions are described here to illustrate the various analytical procedures.

The first step in the Casagrande construction is the selection of the point of maximum curvature on the polynominal representation of the compression data. In the manual application of this step, a subjective decision is made on the basis of the appearance of the curve. In the analytical application of this step, the point of maximum curvature may be selected by one of two possible methods. One method employs the mathematical definition of the radius of curvature given in Equation 6 and is called the Analytical Method. The other is the newly developed Graphical Method, and the pictorial characteristics of the compression curve are used to choose the point of maximum curvature. This method is discussed further in the section entitled "Graphical Method to Select Point of Maximum Curvature". After the point of maximum curvature has been selected, lines horizontal and tangential to the fitted polynominal are mathematically determined at this point as shown by lines A and B, respectively, in Figure 6. The angle between these two lines is then bisected and mathematically represented by another line as shown by line C in Figure 6. The final step in the Casagrande construction comes in the selection of the line representation of the virgin compression curve. The polynomial representation of the compression curve is analyzed for a representative slope and suitable intercept, as shown by line D in Figure 6. The preconsolidation pressure, P_c(PROBABLE), is then determined at the intersection point of lines D and C, as shown in Figure 6, by taking the antilog of the abscissa at that point.

Following the Casagrande construction, the Schmertmann construction employs similar procedures to estimate the in situ compressibility characteristics implied by the geometrical nature of the consolidation curves. The mathematical steps exactly parallel those in the manual construction. In situ compressibility characteristics of the compression curve are approximated by two straight lines. First, the initial portion of the compression curve is represented by a line going through the in situ state of stress and strain having the slope of the rebound curve, line E in Figure 6. Finally, the in situ, virgin compression curve is represented by a line going from the end point of line F at the preconsolidation pressure to the point where the virgin curve, line D, intersects the ordinate value of strain at 42 percent of the initial void ratio. This is line G in Figure 6.

A minimum preconsolidation pressure, P_c(MINIMUM), is shown in Figure 6. This lower limit of preconsolidation pressure is determined in accordance with a procedure reviewed and modified by Schmertmann *(4)*. This minimum preconsolidation pressure is found simply by extending the virgin curve represented by line D in Figure 6 until it intersects either the $\epsilon_v = 0$ line or the in situ recompression curve represented by line F.

Figure 6. Combined Use of the Casagrande and Schmertmann Constructions.



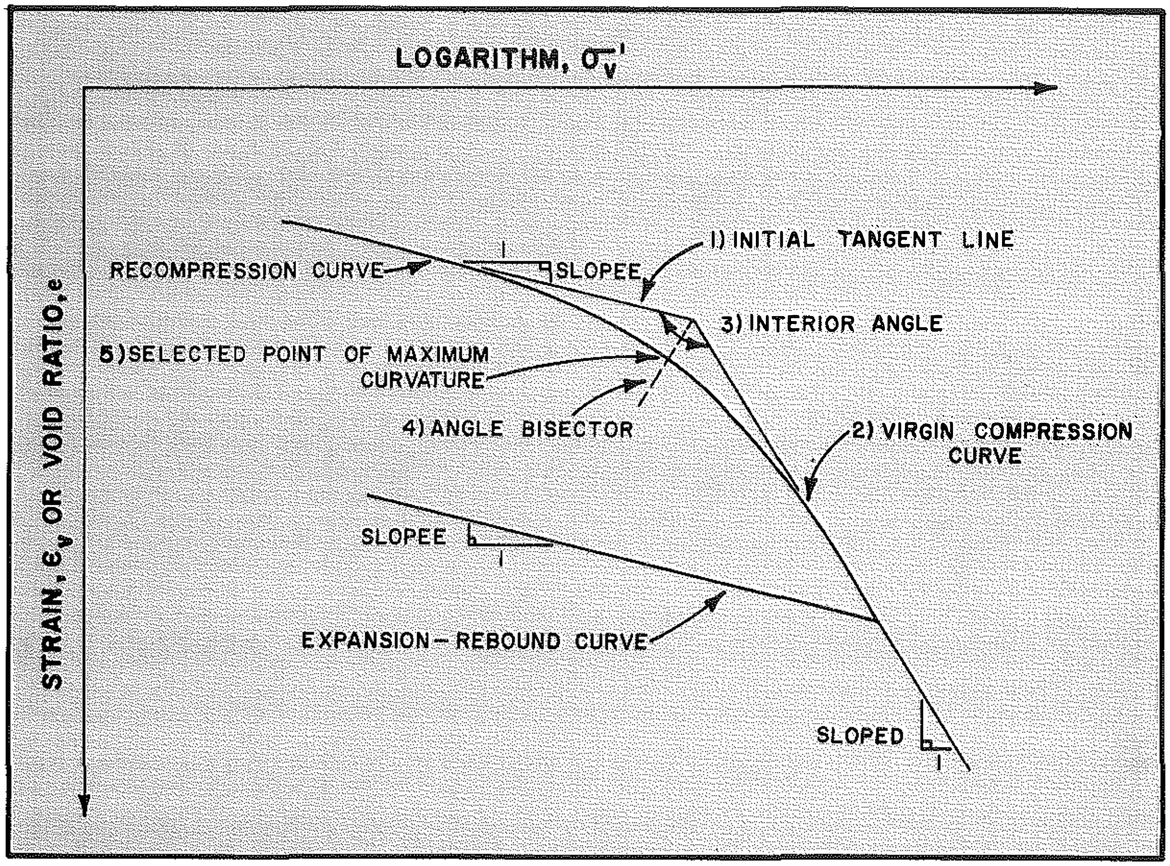
GRAPHICAL METHOD TO SELECT POINT OF MAXIMUM CURVATURE

Equation 6 can not be used successfully on curves having ill-defined curvature. The conceptual basis of this graphical method is the idealization of the recompression and virgin compression curves as straight line segments which have a transitional curve between them. Several assumptions are made. The first is that the recompression curve has the same slope as the rebound curve. Note that the Schmertmann construction employs a similar assumption. Second, the transitional curve between the two straight-line segments is to be smooth, evenly distributed, and have its point of maximum curvature at the center of its variance from the straight-line segments. An analogous situation can be found with the spiral highway curve and the principle, there, of gradual transition. Finally, the center point of the transitional curve is found by bisecting the interior angle formed by the intersection of the line representations of the recompression and virgin portions of the compression curves to obtain the point of maximum curvature as shown in Figure 7.

The implementation of this graphical method follows procedures outlined below. Consult Figure 7 for each of the following steps:

1. A line with the slope of the rebound curve is placed tangent to the recompression curve. If it is impossible to locate a tangent with this slope on the recompression curve, the line is arbitrarily drawn through the recompression curve at some point -- preferably the earliest possible point on the curve which is free from any irregular effects possibly produced during initial loading.
2. The virign compression curve is then represented by a line having the slope of its straight portion.
3. Extend the tangent of the recompression curve and the straight-line representation of the virgin compression curve until they intersect.
4. Bisect the interior angle formed by the intersection of these two lines.
5. Extend the angle bisector until it intersects the compression curve. This point of intersection is selected as the point of maximum curvature.

Figure 7. Graphical Procedure to Select Point of Maximum Curvature.



Most consolidation (compression) curves will not rigorously follow the assumption that their points of maximum curvature will be located at the center of their transitional curves. If the point of maximum curvature can be chosen accurately by visual inspection, it may be located slightly before or after the graphically selected point, and its location depends entirely on the characteristic shape of the time-independent compression curve. Nevertheless, this graphical approach is a more rational procedure to the determination of the point of maximum curvature on curves having ill-defined curvature than the traditional method of selecting this point by visual inspection. This method also provides more consistent results with curves having ill-defined curvature. In adddition, it is obvious from the nature of the Casagrande construction that the selection of the point of maximum curvature is less critical to the determined value of the preconsolidation stress than the selection of the virgin compression curve. And since this graphical approach determines the midpoint of the range of the possible points of maximum curvature, it is a reasonably good approximation to the midpoint of the range of possible values for the preconsolidation stress as determined by the Casagrande construction. Consequently, even though Casagrande does not use the construction which bears his name *(11)*, the graphical approach to the selection of the point of maximum curvature is in keeping with his statement that the preconsolidation pressure should always be considered in terms of a range of values *(12)*.

INFLUENCE OF POLYNOMIAL DEGREE ON ANALYSIS

The polynomial degree has been found to have a range of effects on three particular considerations: the shape of the fitted curve, the selected point of maximum curvature, and the values of the preconsolidation pressure and compression ratio. Similarly, since the effects of polynomial degree are largely dependent on the size of the data set being fitted, the three preceding points must be considered in terms of standard consolidation data versus controlled consolidation data.

EFFECT OF POLYNOMIAL DEGREE ON THE SHAPE OF FITTED POLYNOMIAL CURVE

For controlled test data, the polynominal degree has been found to have a small effect on the polynominal curve's shape for two reasons. First, the large number of data points involved in the controlled consolidation test usually gives a well-defined curve which can be easily duplicated by high-degree polynomials. Secondly, since the large number of data points allows the use of higher degree polynomials, the undulatory characteristics of low-degree polynomials cited by Hastings *(13)* are automatically avoided.

In contrast, consolidation curves derived from standard tests do not have the benefit of a large number of data points. The scarcity of data points introduces a reasonable amount of ambiguity into the shape of the curve. This ambiguity appears in the analysis of these standard compression curves irrespective of any curve-fitting process which is used, manual or analytical. Because of this ambiguity, a certain amount of variation in the shape of the compression curve results for polynomials of different degrees.

In addition, the small number of data points from the standard test limits the curve-fitting procedure to use of low-degree polynomials which have a certain undulatory characteristic. These shape characteristics of low-degree polynomials can sometimes introduce frustrating variations into the curve. These variations usually arise in cases where the curves assumes an almost horizontal character in the initial portion followed by a sharp angular break into the virgin compression portion. As Hastings *(13)* points out, the low-degree polynomials cannot turn sharply and go as straight as it is sometimes required by curves like the ones shown in Figure 8 *(14)*. Figure 9 shows the best possible, low-degree polynomial fit on Crawford's "End of Primary" curve of Figure 8. From this figure, one can get an idea of the shape limitations of low-degree polynomials.

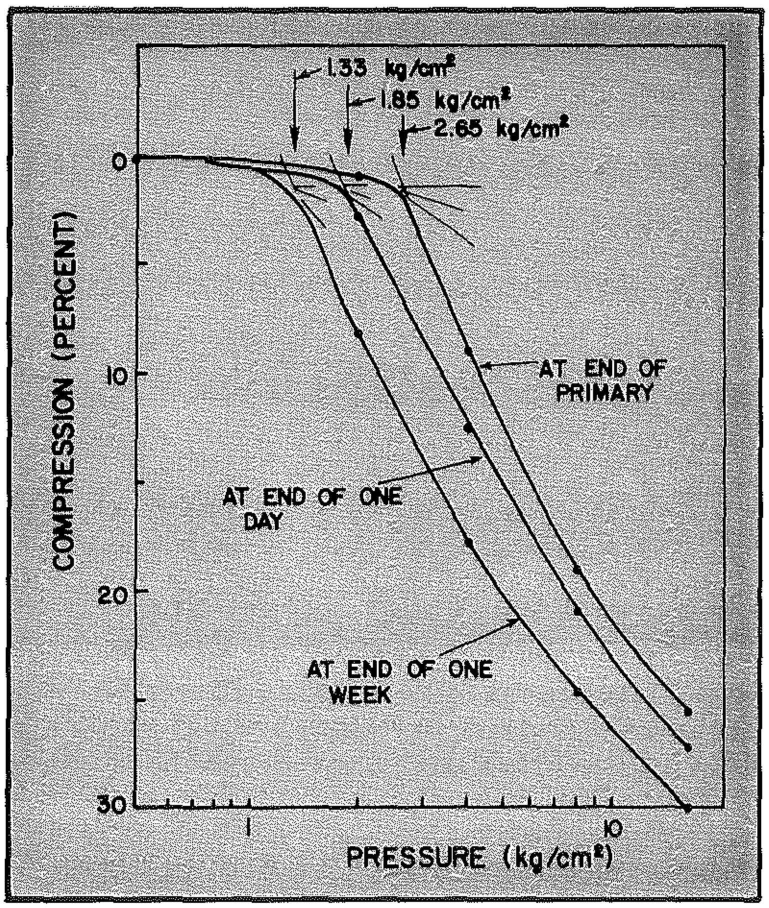
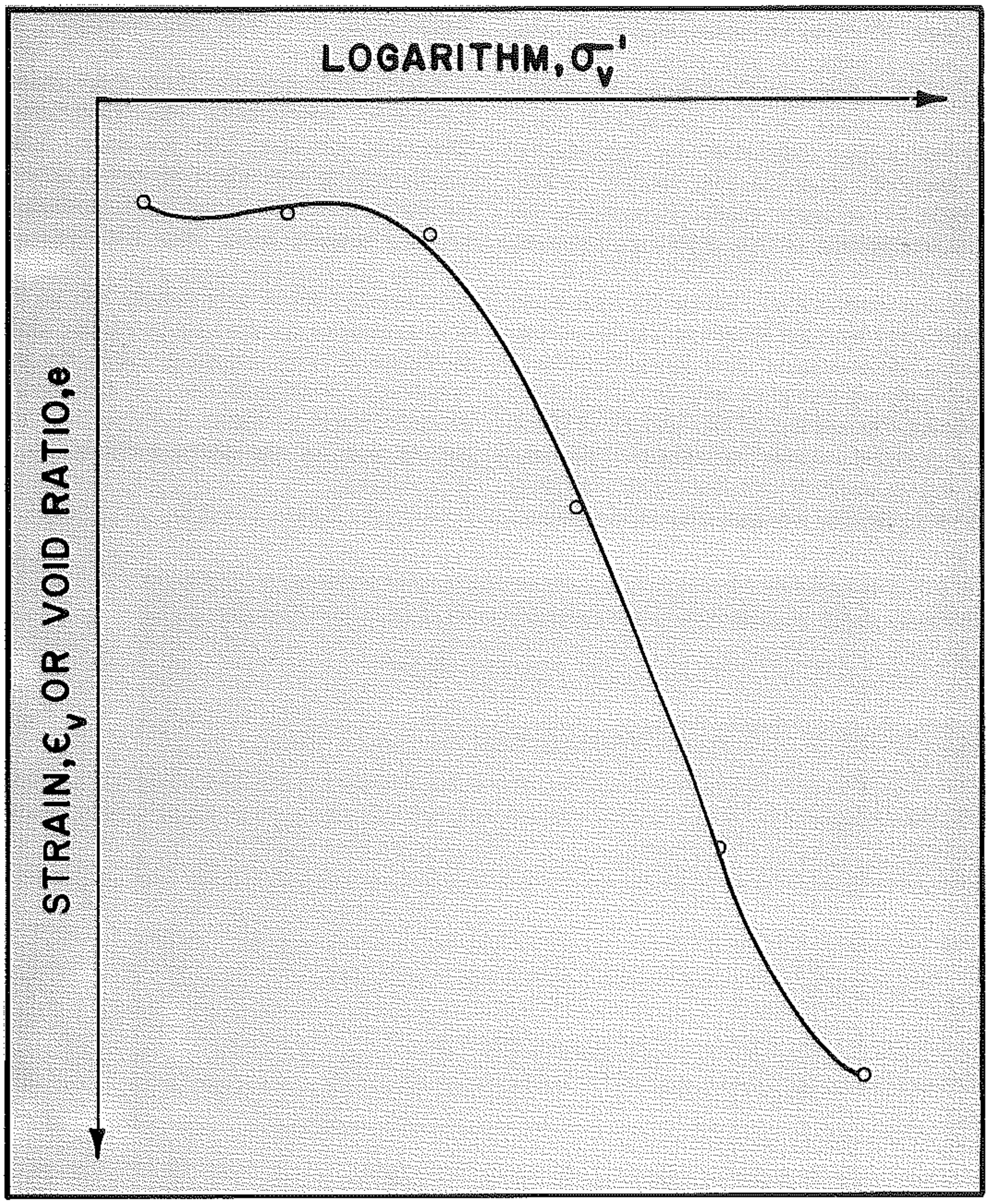


Figure 8. **Crawford's 1964 Illustration of the Influences of Secondary Compression on the Preconsolidation Pressure.**

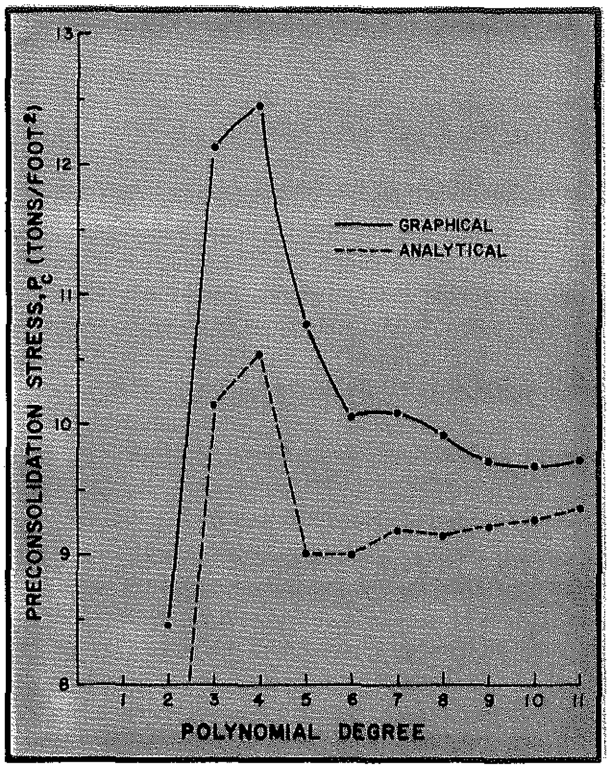
Figure 9. **Best Low-Degree Polynomial Fit on Crawford's "End of Primary Curve" in Figure 8.**



EFFECT OF POLYNOMIAL DEGREE ON THE SELECTION OF POINT OF MAXIMUM CURVATURE

The point of maximum curvature can be selected either by the Analytical or Graphical Methods discussed earlier in the section entitled "Algorithm for Time-Independent, Laboratory, Consolidation Test Data". As far as the controlled test data curves are concerned, both the Analytical and Graphical Methods give very consistent choices for the point of maximum curvature for polynomials of degree nine or greater when these two methods are considered separately. Figures 10 and 11, which will be discussed in greater detail later in this section, show that an acceptable consistency is obtained within each method to select a point of maximum curvature for polynomials of degree six or greater. Consistency occurs in each of these two methods after the sixth degree; there are two reasons: the shape of the well-defined compression curves are accurately duplicated with higher degree polynomials, and the undulatory characteristics more often found in low-degree polynomials are avoided, particularly in the initial portions of the compression curve and area of maximum curvature.

Figure 10. Preconsolidation Stress Plotted as a Function of Polynomial Degree of the Analytical and Graphical Methods to Select a Point of Maximum Curvature, Controlled-Gradient Test 13.



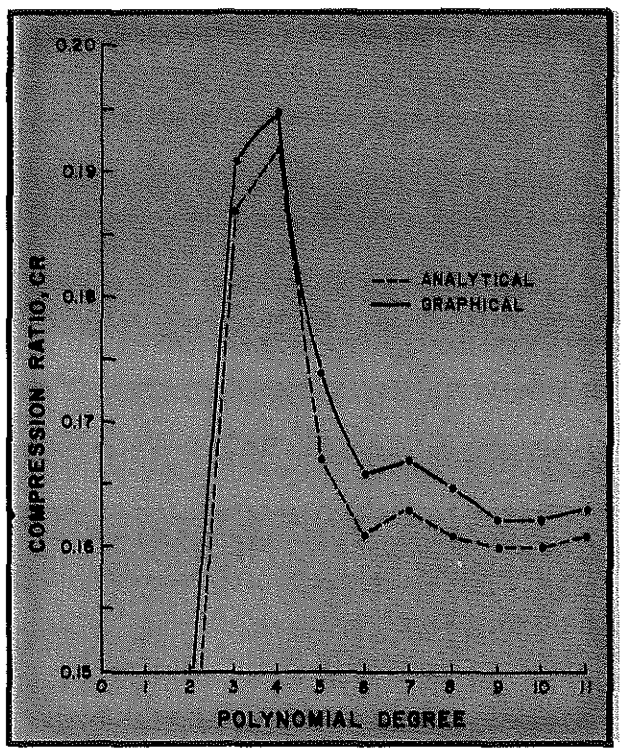


Figure 11. Compression Ratio Plotted as a Function of Polynomial Degree for the Analytical and Graphical Methods to Select a Point of Maximum Curvature, Controlled-Gradient Test 13.

In contrast, the effect of changing polynominal degree on the selection of the point of maximum curvature from polynomial fits of standard consolidation data is significantly greater. The number of data points involved restricts one to the use of low-degree polynomials on data groups that already admit a reasonable amount of ambiguity into their curve representations. Hence, given the undulatory characteristics of low-degree polynomials and the ambiguities inherent from few data points, selection of the point of maximum curvature can be affected in three ways: by localized undulations in the initial portion of the compression curve representations, by changes in the location of the point of maximum curvature with different polynomial degrees, and by special problems caused by a nonexistent or ambiguously defined point of maximum curvature. For the Analytical Method, the presence of localized irregularities in the initial portion of the polynomial representation of the compression curve can cause an erroneous point of maximum curvature to be chosen. Secondly, changes in the polynomial degree used in fitting a group of standard data can shift the point of maximum curvature from one location to another because of the ambiguities possible when fitting a few data points and the undulatory nature of low-degree polynomials. An example of the effects of the undulatory nature of low-degree polynomials on the selection of the point of maximum curvature can be realized through a comparison of the analyzed consolidation curves of Standard Test 24 in Figures 12a and 12b with Figure 12c. Thirdly, special problems occur when the Analytical Method is used on a polynomial representation of a set of consolidation data lacking a distinct and unique point of maximum curvature. In other words, the curve may lack a unique point of maximum curvature due to the nature of the data or because of the poor representation afforded by the low-degree polynomial. An excellent example of the nature of the data contributing to the ill-defined point of maximum curvature is shown in Figure 13 of Standard Test 12. Even though the third, fourth, fifth, and even sixth degree polynomials provide excellent representations of the data, the small differences in shape between these polynomials overshadow the ambiguous information furnished by the data points concerning the point of maximum curvature and give rise to significant differences in the location of the point of maximum curvature.

In contrast to the selection of the point of maximum curvature by the Analytical Method, the Graphical Method is influenced differently with varying amounts of significance for the three problems discussed above with respect to standard data. It may be helpful here for the reader to re-acquaint himself with the earlier description of the Graphical Method, with special attention to Figure 7, in the section entitled "Graphical Method to Determine Point of Maximum Curvature". As for the first problem, localized irregularities in the initial portion of the polynomial for the initial compression curve can disturb the Graphical Method by causing slight displacements or offsets up or down in the initial tangent line shown in Part 1 of Figure 7. An actual example of an upward displacement of this tangent line can be seen in the sixth degree polynomial fit on Standard Test 24 in Figure 19c. This upward displacement of the initial tangent line causes the angle bisector of Part 4 of Figure 7 to intersect the compression curve at a point further back up the curve. A downward displacement of the intitial tangent line will cause the point of maximum curvature to be located at a point further down on the compression curve. As for the second problem, the location chosen by the Graphical Method as the point of maximum curvature is largely unaffected by small changes in the shape of the fitted curve in the general area of the point of maximum curvature with changing polynomial degree. In other words, the point chosen remains essentially the same with changing polynomial degree. Basically, this fact comes about because the point selected by the Graphical Method is determined mostly by the interior angle formed by the intersection of the straight-line representations of the recompression and virgin compression curves shown in Figure 7. Hence, the Graphical Method is largely unaffected by changes in the characteristics of the fitted polynomial between the straight-line representations of the recompression and virgin compression curves.

Finally, the special problems encountered by the Analytical Method with an ill-defined point of maximum curvature are largely avoided by the use of the Graphical Method. When the data are responsible for these problems, as in the case in Figure 13 for Standard Test 12, the Graphical Method becomes more consistent and gives just as reasonable results by pictorially taking the midpoint of the range of possibilities for the point of maximum curvature, as shown in Figure 14.

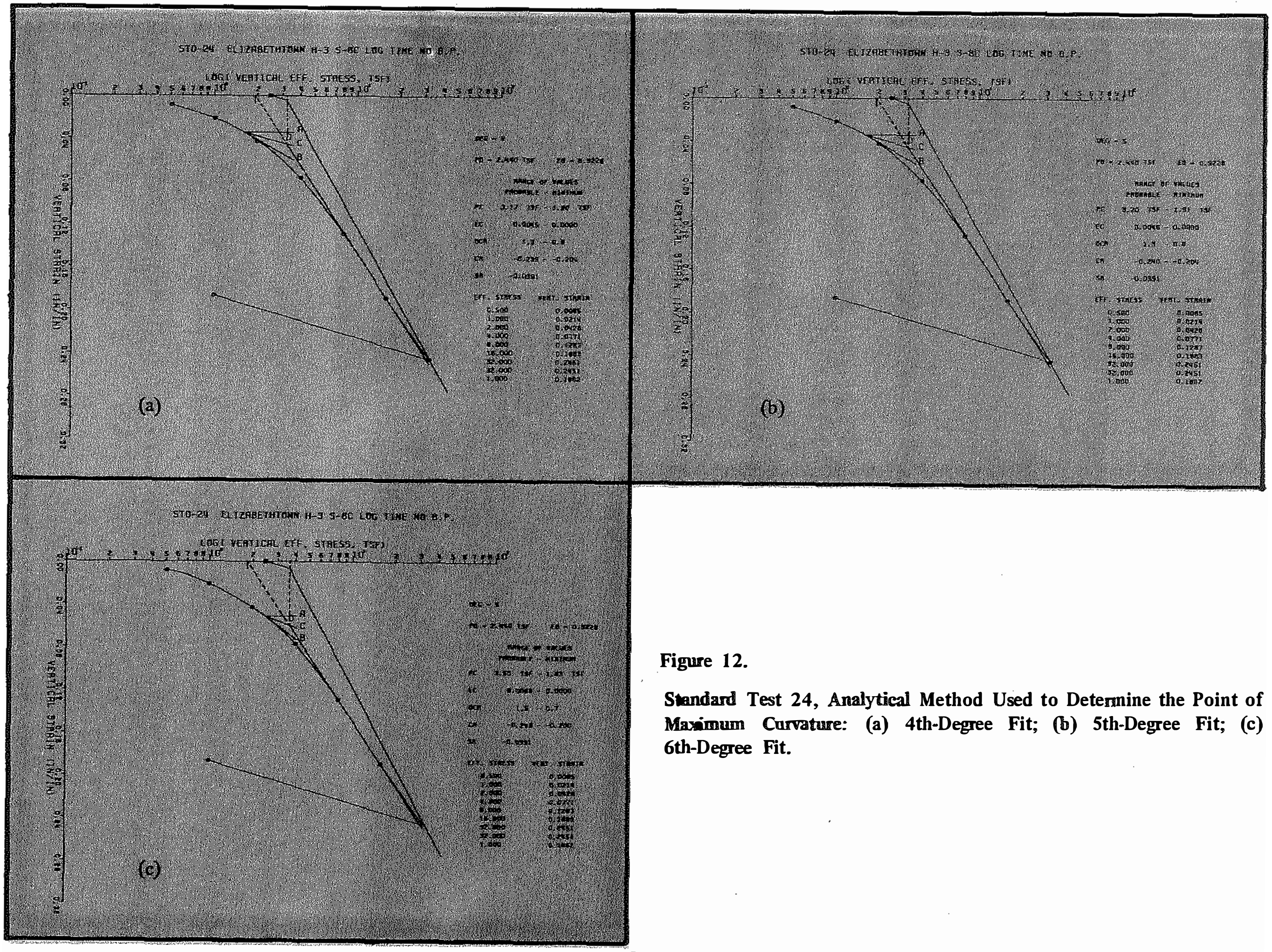


Figure 12.

Standard Test 24, Analytical Method Used to Determine the Point of Maximum Curvature: (a) 4th-Degree Fit; (b) 5th-Degree Fit; (c) 6th-Degree Fit.

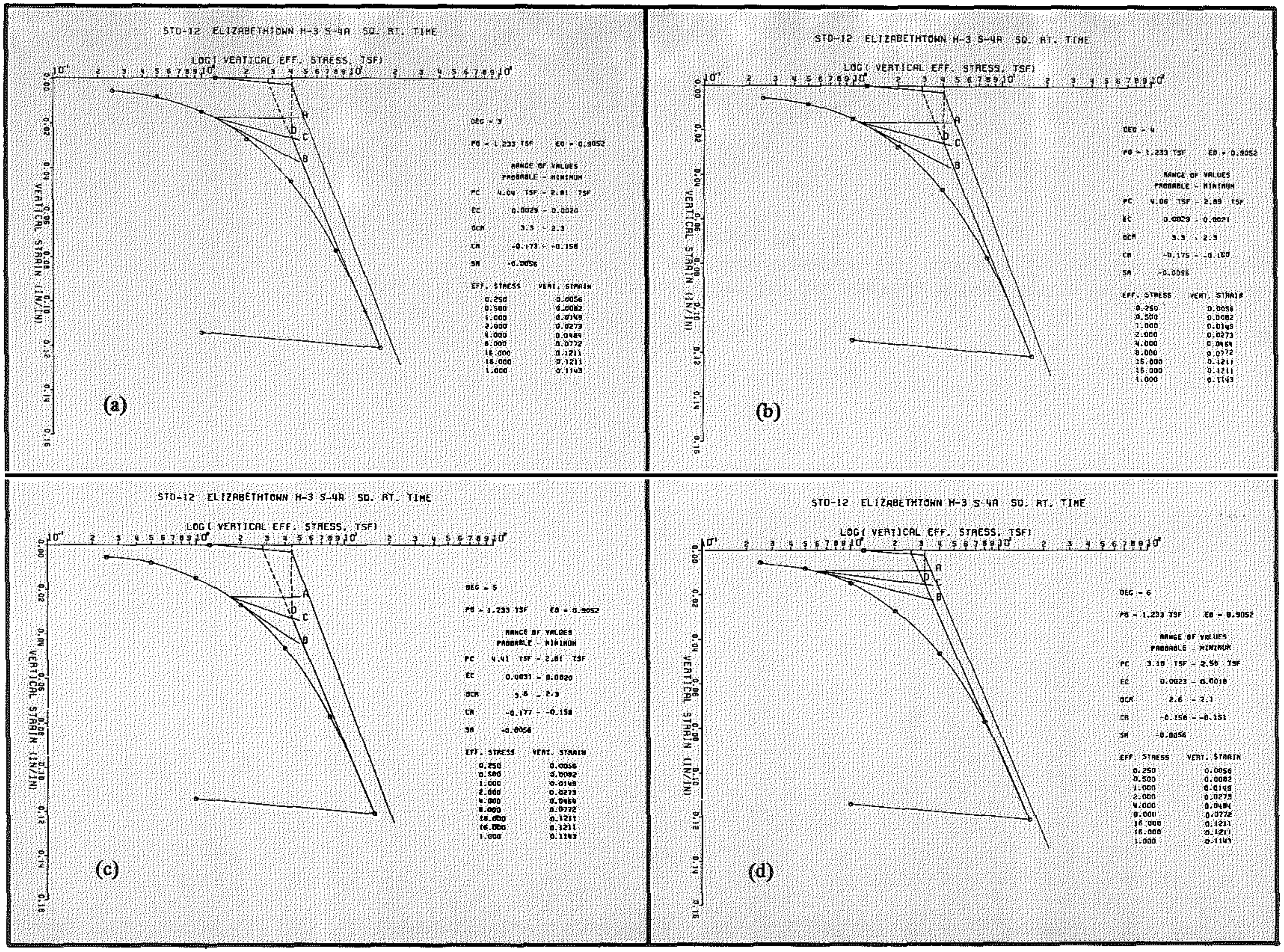


Figure 13. Standard Test 12, Analytical Method Used to Determine a Point of Maximum Curvature: (a) 3rd-Degree Fit; (b) 4th-Degree Fit; (c) 5th-Degree Fit; (d) 6th-Degree Fit.

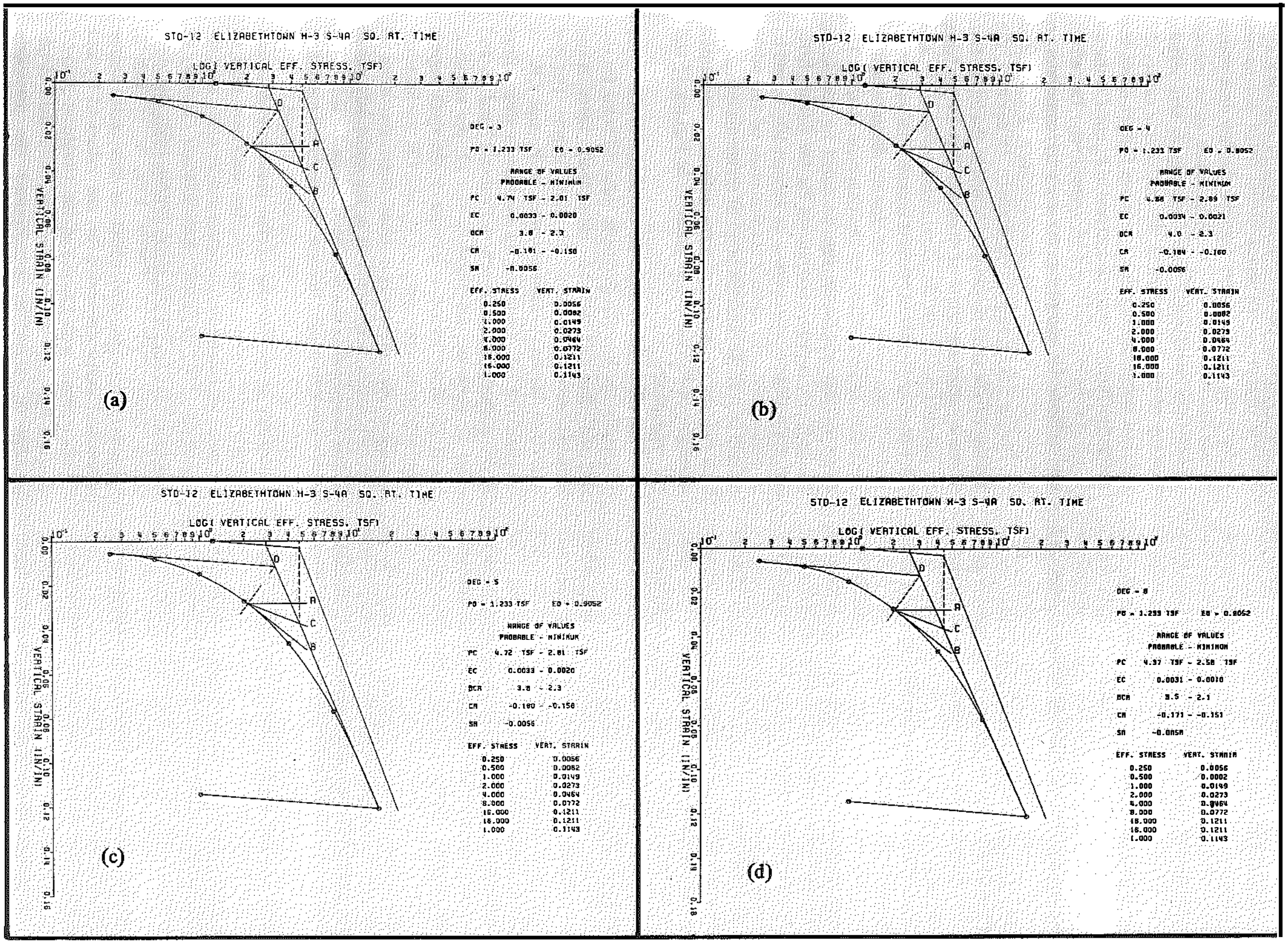


Figure 14. Standard Test 12, Graphical Method Used to Determine a Point of Maximum Curvature: (a) 3rd-Degree Fit; (b) 4th-Degree Fit; (c) 5th-Degree Fit; (d) 6th-Degree Fit.

INFLUENCE OF POLYNOMIAL DEGREE ON THE VALUES OF THE PRECONSOLIDATION STRESS AND COMPRESSION RATIO

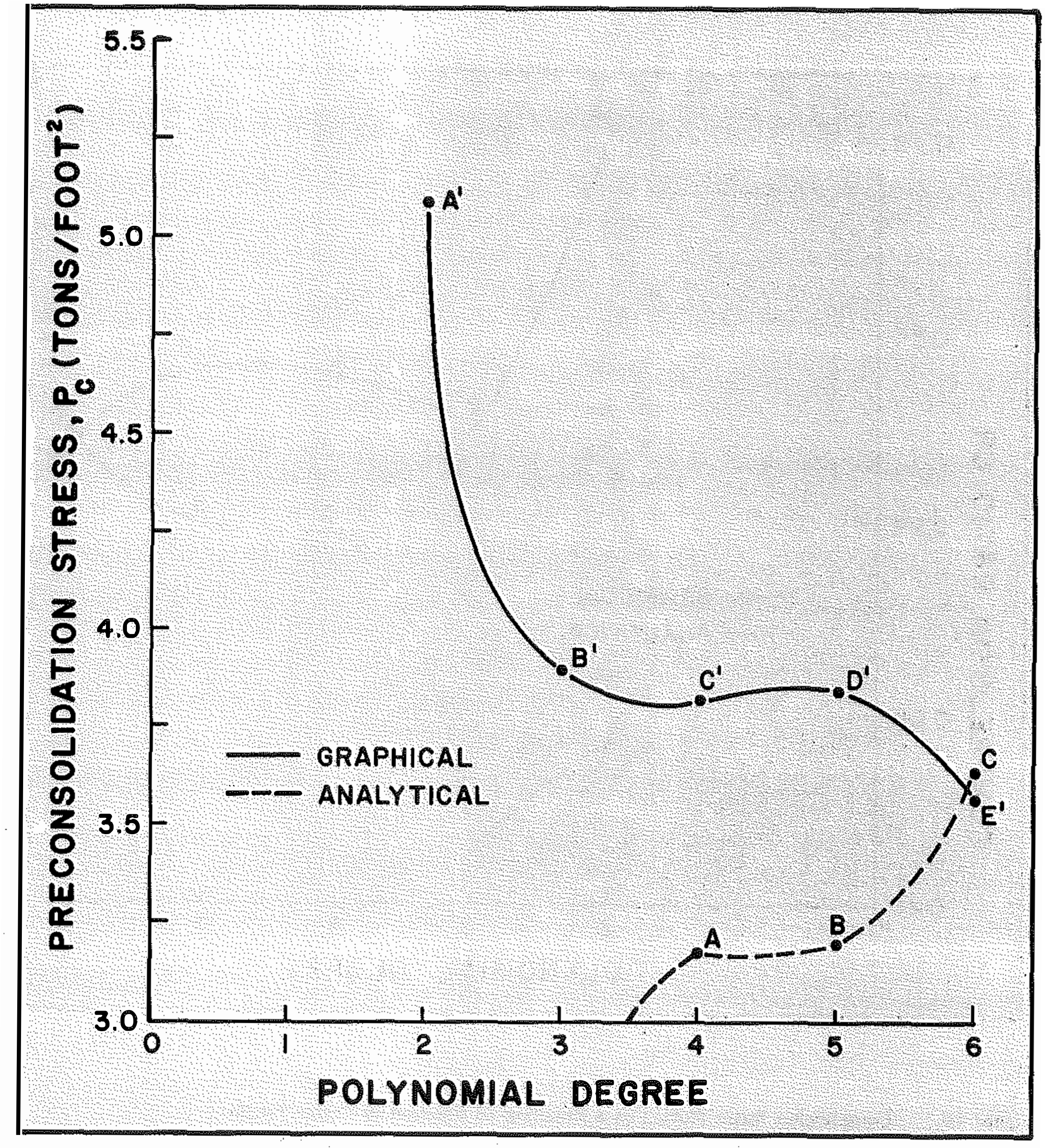
Variations caused by polynomial degree in the shape of the fitted curve and selected point of maximum curvature affect the values of preconsolidation stress, P_c, and the compression ratio, CR. Many observations to be made herein have already been mentioned. For controlled test data, the large number of data points allows the use of higher degree polynomials which give consistent results for the preconsolidation stress and compression ratio after the sixth degree. This consistency primarily reflects a lack of change in the shape of the fitted curve with increasing degree. Figures 10 and 11 demonstrate this point for the values of preconsolidation stress and compression ratio, respectively. The most representative values for these two parameters are usually obtained when the highest polynomial degree of 11 is used; but of course, the polynomial representation of a compression curve must be smooth and well defined by sufficient data points from a controlled consolidation test. The obvious trend of lower values for P_c and CR in Figures 10 and 11 for the Analytical Method is due only to the character of the data and its fitted polynomial but not because the Graphical Method always gives a trend of higher values for P_c and CR. In other words, for differently shaped compression curves, the Graphical Method could give a trend of lower values for P_c and CR.

In contrast, since the standard test data allow greater variation in the shape of the fitted polynomial and the selected point of maximum curvature with changing polynominal degree, the values of preconsolidation stress and compression ratio consequentially show less consistency with changing polynomial degree. However, fair consistency in the determination of P_c and CR is retained for certain polynomial degrees within each of the two methods to select a point of maximum curvature. In Figures 15 and 16 for Standard Test 24, good consistency is obtained by the fourth and fifth degree polynomials. In Figures 17 and 18 for Standard Test 12, satisfactory consistency is obtained in the third, fourth, and fifth degree polynomials. Note that in both sets of figures for Standard Tests 12 and 24, this consistency breaks down at the sixth degree. At the sixth degree, this breakdown in consistency can be expected since there is no least-squares smoothing afforded by the fitting polynomial when the polynomial degree is equal to the number of data points minus one.

Changes in the shape of the fitted polynomial with changing polynomial degree, particularly in the initial portion of compression data curve, are primarily responsible for the sudden changes in the determined values of P_c and CR. In Figures 15 and 16 for the use of the Analytical Method on the data of Standard Test 24, the change in the shape of the fitted polynomial at the sixth degree occurs because the few data points in the initial portion of the compression curve cannot prevent the polynomial from curving in this region. Curving of the polynomial in the initial data causes the point of maximum curvature to move further down the curve and thereby cause an increase in P_c and CR shown at point C in Figures 15 and 16, respectively. This effect can be seen by comparing the analyzed consolidation curves for the fourth, fifth, and sixth degree polynomials in Figures 12a, b, and c, respectively. In contrast, the curving of the sixth degree polynomial in the initial data of the compression curve of Standard Test 24 produces an opposite effect on the determined values of P_c and CR when the Graphical Method is used. This undulation in the fitted curve causes an upward displacement of the initial tangent found by the Graphical Method The effect of this undulation can be noted by comparing the analyzed consolidation curves for the fourth, fifth, and sixth degree polynomials in Figures 19a, b, and c. In Figure 19c the upward displacement of the initial tangent moves the selected point of maximum curvature back up the compression curve with a consequential reduction of P_c and CR at point E' in Figures 15 and 16, respectively.

The effect of changes in the shape of the fitted polynomial at the sixth degree is quite different for the data of Standard Test 12. Here again there is no least-squares smoothing at the sixth degree. For the Analytical Method's determination of P_c and CR for standard test 24, there was an increase in their values at the sixth degree, as shown in Figures 17 and 18 and point C. However, for Standard Test 12, the values of P_c and CR show instead a decrease at the sixth degree. This change in the values of P_c and CR for Standard Test 12 is also caused by a small shape aberration of the sixth degree polynomial fit in the initial data points of the compression curve. The decrease of the values of P_c and CR occurs because the point of maximum curvature is moved back up the curve instead of down the curve, as in the case of the previously discussed example of Standard Test 24. The backward shift of the point of maximum curvature can be easily seen by comparing the analyzed consolidation curves of Standard Test 12 for the third, fourth, fifth, and sixth degree polynomials in Figure 13 a, b, c, and d, respectively. As for the effect of this sixth degree polynomial shape aberration on the values of P_c and CR determined with the use of the Graphical Method to select the point of maximum curvature, there is not as large a change as accompanied the previously discussed example of Standard Test 24 of the preceeding discussion concerning the Analytical Method and

Figure 15. Preconsolidation Stress Plotted as a Function of Polynomial Degree for the Analytical and Graphical Methods to Select a Point of Maximum Curvature, Standard Test 24.



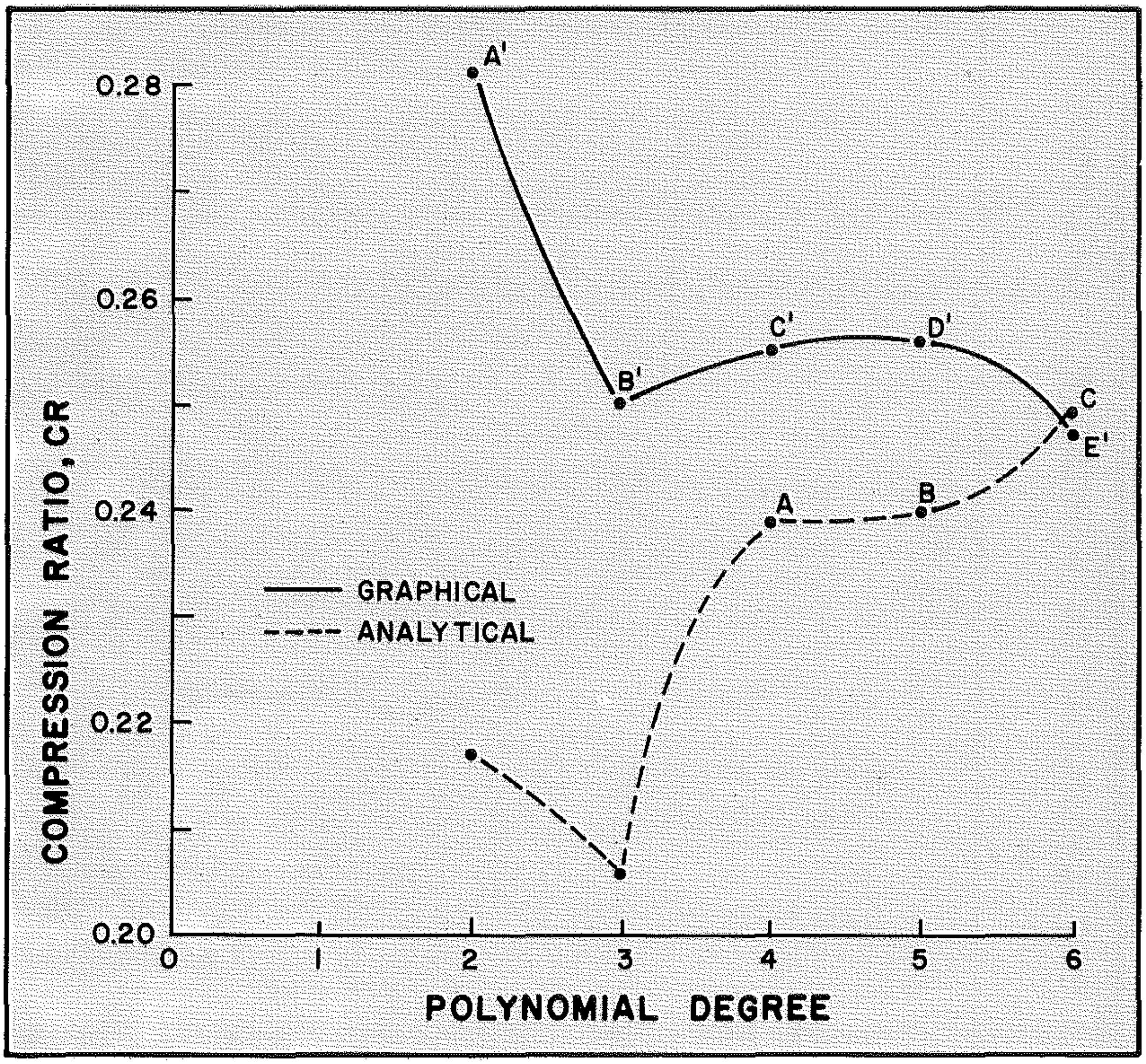
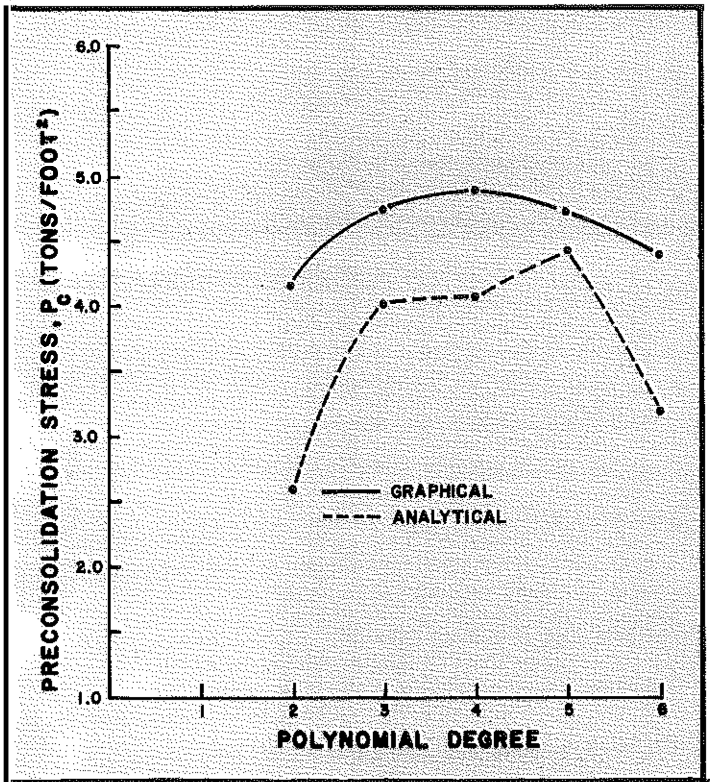


Figure 16. Compression Ratio Plotted as a Function of Polynomial Degree for the Analytical and Graphical Methods of Selecting a Point of Maximum Curvature, Standard Test 24.

Figure 17. Preconsolidation Stress Plotted as a Function of Polynomnal Degree on Compression Data which Lack a Well-Defined Point of Maximum Curvature, Standard Test 12.



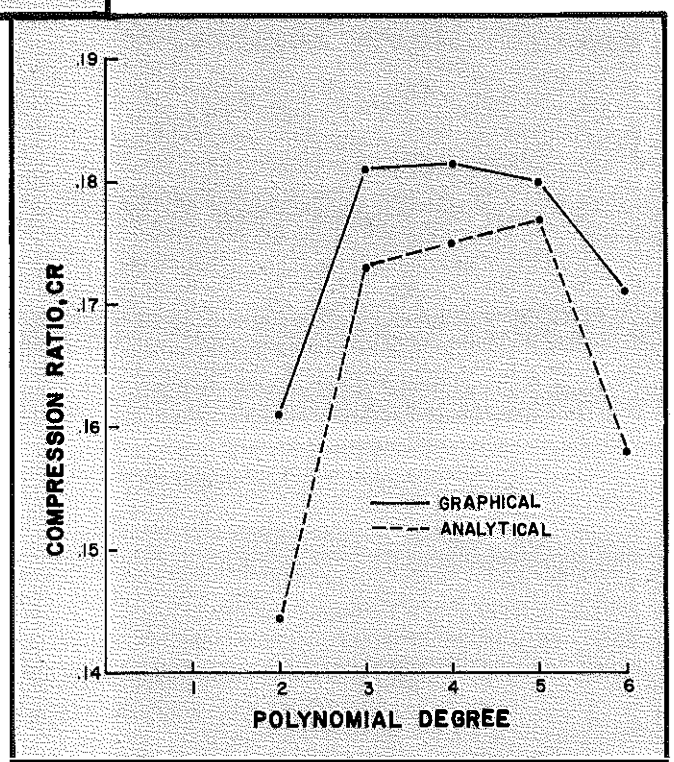


Figure 18. Compression Ratio Plotted as a Function of Polynomial Degree on Compression Data which Lack a Well-Defined Point of Maximum Curvature, Standard Test 12.

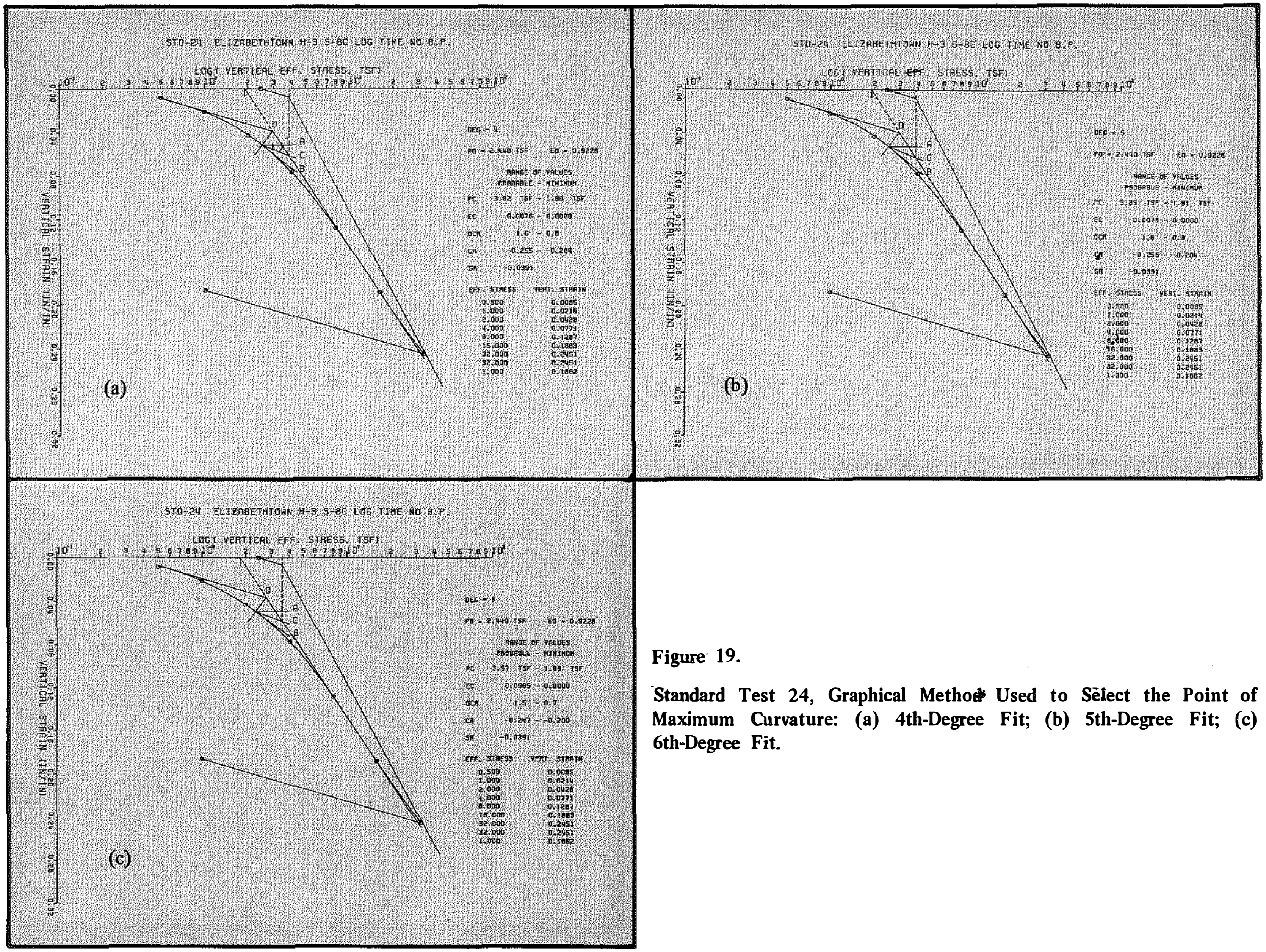


Figure 19.

Standard Test 24, Graphical Method Used to Select the Point of Maximum Curvature: (a) 4th-Degree Fit; (b) 5th-Degree Fit; (c) 6th-Degree Fit.

Standard Test 12. Hence, values of P_c and CR for the sixth degree Graphical Method's determination remain fairly consistent with respect to the other degrees as shown in Figures 17 and 18 for Standard Test 12. In spite of the excellent polynomial representations of the data furnished by all degrees of three or greater on the data of Standard Test 12, the scatter obtained in the values of P_c and CR when the Analytical Method is used illustrates the difficulties involved with selecting the point of maximum curvature on data which ambiguously define curvature. Whether the data from Standard Test 12 are accurate or not is not an issue here. Instead, the problem of selecting the point of maximum curvature on certain types of curves illustrates some basic limitations inherent in the use of empirical, graphical procedures to determine properties of stress-strain consolidation data. Sometimes, use of empirical, graphical procedures may raise some questions in their applicability to the analysis of certain types of data. With this in mind, the use of the Graphical Method as opposed to the Analytical Method to determine the point of maximum curvature on the data curves from Standard Test 12 gives just as reasonable choices for this geometrical quantity and, in addition, much more consistent values of P_c and CR. This can be seen by inspection of the analyzed consolidation curves for the third, fourth, fifth, and sixth degree polynomial fits in Figures 14a, b, c, and d, respectively.

SUMMARY

Changing the degree of the polynomial has a greater effect on the shapes of the curves fitted to standard data than on those fitted to controlled consolidation data. Usually, the best curve representation of the data will be obtained when the highest polynomial degree that provides some least-squares smoothing is used. However, there is one situation where any polynomial representation may not be adequate for either standard or controlled compression data curves. In Figure 8, there are curve shapes which are difficult to produce through the use of ordinary polynomials, particularly low-degree polynomials. This difficulty results because it is hard for polynomials to make sharp turns or to go straight horizontally for any great distance, especially when there are few data points to sufficiently constrain the polynomial fit as in the case of Figure 9. Secondly, changing polynomial degree does change the location for the point of maximum curvature. At low-degree polynomial fits, changes in the polynomial degree can adversely affect both the Analytical and Graphical Methods to select the point of maximum curvature because of possible undulations in the fitted curve in the initial portions of the data and region of maximum curvature. When the curvature of the fitted curve is ambiguously defined, despite an excellent polynomial representation of the data at most degrees, the Graphical Method to select the point of maximum curvature will be less susceptible to small variations in the fitted curve than the Analytical Method. And, considering the broad spectrum of shapes possible with most stress-strain consolidation data, the Graphical Method will give more consistent results with changing polynomial degree.

It is important to compare qualitatively the influences of polynomial degree with other external difficulties which can affect the analysis of consolidation test data irrespective of the procedures which are used. It will be shown herein that the variations incurred with different degree polynomials are usually less than the variations caused by effects external to the analysis of the data itself. For standard data, there are two significant sources of variations which can have a larger influence on the analysis than changing the polynomial degree. A very important factor is specimen disturbance, which can have a very appreciable influence on the values of P_c and CR and far outweigh any variations incurred by the curve-fitting functions. Also, such factors as load-increment ratio and load-increment duration can affect the determined values for P_c and(or) CR much more than changing polynomial degree, especially when data on highly sensitive clays are considered. (Crawford *(14)* showed in Figure 8 the extreme but valid case of a 50-percent reduction in the value for P_c for incremental loading programs of different durations.) In addition, Sallfors *(3)* pointed out that it is possible to represent the compression data with a number of different curves when there are only six or seven data points. This last type of variation accounts for most discrepancies between the values of P_c and CR for different degree polynomials. Hence, these variations in the shape of the fitted curve are just as much a result of the limitations imposed by standard consolidation tests as from the use of different polynomial degrees. For the controlled consolidation tests, this problem of choosing the appropriate curve representation of the compression data is greatly alleviated by the greater amount of data involved. However, this type of consolidation data can be influenced by some other factors external to the analysis. For instance, the effect of specimen disturbance is just as significant for the controlled consolidation tests as it is for the standard test. In addition, there are the special effects caused by pore pressure lag and strain rate which can change the nature of the compression curves and the determined values for P_c and CR. These special effects are generally far more significant than those incurred through the use of different polynomial degrees. In summary, variations incurred with the use of different degree polynomials are usually less than the inaccuracies incurred by such things as sample disturbance, few data points, loading procedures, and measurement of pore pressures.

THE COMPUTER PROGRAM

The computer program, CASAGR-O, analyzes the time-independent, one-dimensional strain consolidation data associated with consolidation tests. The program determines the preconsolidation stress and the in situ compressibility characteristics. The results derived from this program are used in the time-independent, one-dimensional strain analysis of settlement. The main characteristics of the program to be discussed herein include a description of its methods of solution, capabilities and limitations, data inputs, program options, program output, flow-chart outline, and sample runs.

METHOD OF SOLUTION

The computer program employs a numerical curve-fitting procedure with a least-squares ordinary polynomial to facilitate the analytical application of the Casagrande *(1)* and Schmertmann *(3)* constructions. Several procedures have been developed and incorporated into the program to carry out the analytical application of these constructions. The points to be discussed herein are the application of the curve-fitting procedure, a criterion for distinguishing between compression and rebound data, the selection of the point of maximum curvature, the selection of the virgin compression curve, and constants built into the program.

Application of the Curve-Fitting Procedure -- The compression and rebound curves are separated and fitted by two different polynomial functions. The compression data are fitted by a user-specified, least-squares polynomial. The rebound data are fitted by a least-squares straight line. These two functional representations provide the basis for the approach proposed in the section entitled "Algorithm to Study Time-Independent Laboratory Consolidation Test Data."

Criteria for Distinguishing between Compression and Rebound Data Curves – This criterion is predicated on the fact that compression data are read into the computer in an order such that the values of effective stress are increasing. Once this compression data have been read in, they are followed by the rebound data distinguished from compression data on the basis that there is a decrease in the value of effective stress. This criterion for distinguishing between compression and rebound data is applied differently to the data obtained from different types of consolidation tests. For standard consolidation test data, the computer program distinguishes between compression and rebound data when it encounters a data point having an effective stress less than the one previous to it. When this occurs, the computer program treats all subsequent data points as rebound data.

In contrast, controlled consolidation data are defined by a similar but less order-bound criterion. Compression data still must be entered first and in order of increasing effective stress. The difference is that small, local decreases in the values of effective stress in compression data will not cause the computer program to treat all subsequent data points as rebound data. As long as localized decreases are not greater than 0.7 tons per square foot (67 kPa), the computer program will continue to treat all subsequent data as compression data. When this amount of change occurs, all subsequent data points are treated as rebound points in the curve-fitting process. Finally, the data point which provokes this decrease in effective stress is dropped from the analysis entirely to avoid any effects it may have on the polynomial representation of the compression data.

Selection of the Point of Maximum Curvature -- The Casagrande point of maximum curvature is determined by the computer program by two methods, both of which have previously been described. The Analytical Method uses the mathematical definition of the radius of curvature given in Equation 6 to find the point of maximum curvature. The location of the point depends primarily on the arithmetic ratio of the scale factors. Hence, with a different ratio for the horizontal to vertical scale factors, the point of maximum curvature will be located at a different abscissa location on a given curve. The ratio of the horizontal to vertical scale factors must be multiplied times the first and second derivatives before Equation 6 can be used to select the point of maximum curvature based on the pictorial characteristics of the fitted curve. To find the point of maximum curvature, the Analytical Method tests for a minimum value for the radius of curvature within a 90-percent midportion of the search area as defined by the user-specified, abscissa search boundaries. If a discrete minimum value for the radius of curvature is not found within this 90-percent interval, the minimum value of the radius is not considered to be unique. In such a case, the computer program will default to select the point at which the second derivative is a maximum as the point of maximum curvature.

The second method to determine the point of maximum curvature is the Graphical Method. Procedures for this method have already been described in detail in the section entitled "A Graphical Method to Select Point of Maximum Curvature". The computer program uses the Graphical Method in several steps. First, the program searches between the user-specified boundaries for a point on the compression curve having the same slope as the line representation of the rebound curve. If this point is found, the line representation of the initial portion of the compression curve will be drawn through this point. If this point is not found, the computer program defaults and uses the first search boundary as the point through which to draw the line representation of the initial recompression curve. Note that this line will have the slope of the rebound curve line representation. Next, the pictorial appearance of the interior angle formed by the intersection of the line representations of the initial compression and virgin compression curves is bisected. Note that the pictorial appearance of this interior angle is directly related to the scale factors in the horizontal and vertical directions. Finally, having bisected this interior angle, the intersection of the angle bisector line with the compression curve is determined by comparing the incrementally generated ordinates of the angle bisector line and the polynomial representation of the compression curve. The ordinate values are computed at incrementally generated abscissae which are increasing in magnitude. When the ordinate of the angle bisector is greater than that of the compression polynomial, the point of intersection has been passed. The determination of the intersection point is refined by several iterations using the same procedure. This intersection is the graphically selected point of maximum curvature.

Selection of the Virgin Compression Curve -- The selection of an appropriate straight-line representation of the virgin compression curve uses the concept of percent difference. The percent-difference criterion is a procedure which is used to find that portion of the compression curve on which the slope is relatively constant. If the slope is relatively constant, the percent difference between slopes of consecutively generated search points will be very small and that portion of the curve will be nearly a straight line. In the use of this concept, the computer program incorporates the additional requirement that the straight-line representation of the virgin compression curve be selected at the point having the largest slope of those points whose slopes have passed the percent-differrence criterion. However, the percent-difference criterion will not always be satisfied. Hence, some kind of backup criterion is needed. The criterion to be outlined herein depends on the type of test data being analyzed. For controlled data, the computer program uses a simple default procedure when the percent-difference criterion is not satisfied. If the criterion is not satisfied for controlled data, the program selects the point at which the maximum slope occurs. This point and the slope of the curve at this point will be used to construct the straight-line representation of the virgin compression curve.

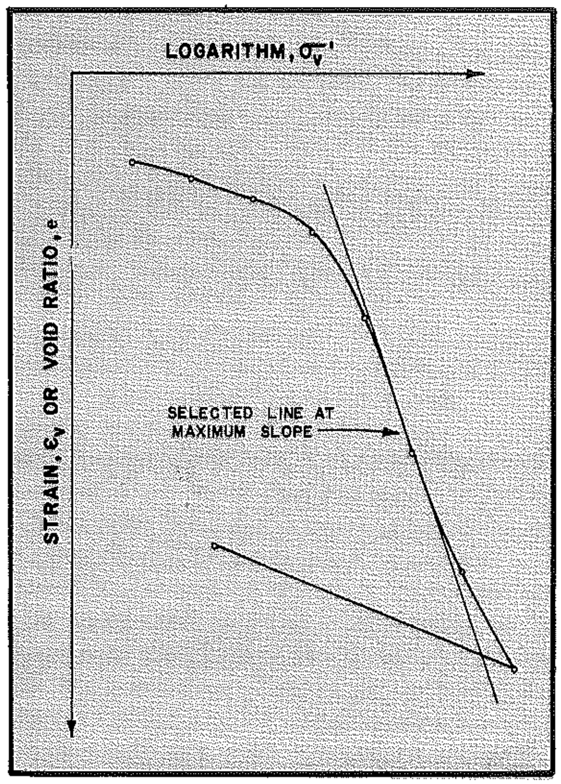
In the case of standard data when the percent-difference criterion is not satisfied, the procedures are slightly more complicated than those used on controlled data. When the percent-difference criterion is not satisfied on standard data, the representation of the virgin compression curve will be selected on the basis of the two procedures illustrated in Figures 20 and 21. In the case of a compression curve similar to the one in Figure 20, the line representation of the virgin compression curve will be selected at the point of maximum slope. In the case of a compression curve similar to the one in Figure 21, a much different procedure will be used because use of the tangent to the compression curve at its maximum slope would lead to a very unconservative estimate of the preconsolidation stress. Also, use of a line through the last two compression points as the representation of the virgin compression curve can be inappropriate because the next to last point may not be on the straight-line portion of the virgin compression range, as indicated by the trend of compression points in Figure 21. Hence, some median is needed between these two possible extremes. A way to obtain this median is simply to select a line having a slope averaged from the two extremes just discussed and going through the last compression curve point. This line is shown as a dashed line in Figure 21.

Constant Values Built Into Program -- Several constant values are built into the computer program for use in various steps of the analysis. There are constants for the Schmertmann construction and for matching of increasing dial readings with downward deflection (decreasing specimen length). For the Schmertmann construction, the computer program takes the intersection of the line representation of the in situ compression curve with the line representation of the laboratory virgin compression curve as occurring at 42 percent of the initial void ratio, as suggested by Schmertmann *(3)*.

Next, the program is set up to accept increasing dial readings of standard and controlled-rate-of-strain data as indicating downward deflection (decrease in specimen length). This has been accomplished by setting the variable name 'IDIAL' equal to '+1' during the data reduction for these two test types. Similarly, controlled-gradient data reduction is handled in much the same way with the exception that 'IDIAL' is set equal to '-1' when this type of data is being considered. The reason for this is that the dial gauge used for the controlled-gradient test apparatus has increasing dial readings indicating specimen lengthening:

SAMPLE HEIGHT = INI. HEIGHT - IDIAL*(DIAL RDG. - ZERO RDG.).

Figure 20. Standard Data for which the Line Representation of the Virgin Compression Curve Is Selected at Location of Maximum Slope.



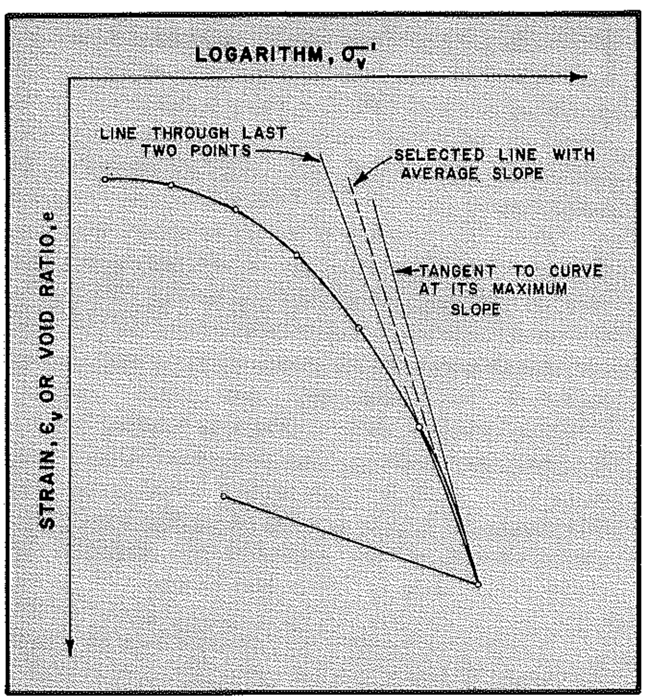


Figure 21. Standard Data for which the Line Representation of the Virgin Curve Is Selected by Averaging Slopes of Two Lines: One Tangent to the Curve at Its Maximum Slope and the Other Going through the Last Two Points.

By inspection of Equation 7, one can easily see that the use of this kind of procedure avoids the necessity of having different deformation equations for different types of dial gauges. The advantage of this scheme readily becomes apparent when dial gauge equipment varies within a laboratory for a given type of consolidation test. Finally, the user has the ability of overriding these built-in relationships through an option that changes the sign of the value for IDIAL in Equation 7.

PROGRAM CAPABILITIES

Ranges of Assigned Values - Quantities involved in the computer program which require certain. limitations on the range of input values fall into three basic categories: array storage space, effective stress values, and polynomial degree specification. First, the amount of array storage space limits the amount of data which can be considered at any given time. These arrays have been set up to handle a maximum of 300 compression data values and 100 rebound data values. Next, the effective stress values are limited to stresses greater than or equal to 0.1 ton per square foot (9.6 kPa). Any data having a value of effective stress less than 0.1 ton per square foot (9.6 kPa) will be changed to 0.1 ton per square foot (9.6 kPa). As for the polynomial degree specification, the program is limited in two ways, one internal and one external. Internally, the program can not handle any polynomial degree greater than 11. Externally, the user must make sure that the polynomial degree is not larger than the number of data points being fitted minus one. Otherwise, the user will receive an error message from the curve-fitting subroutine in the program.

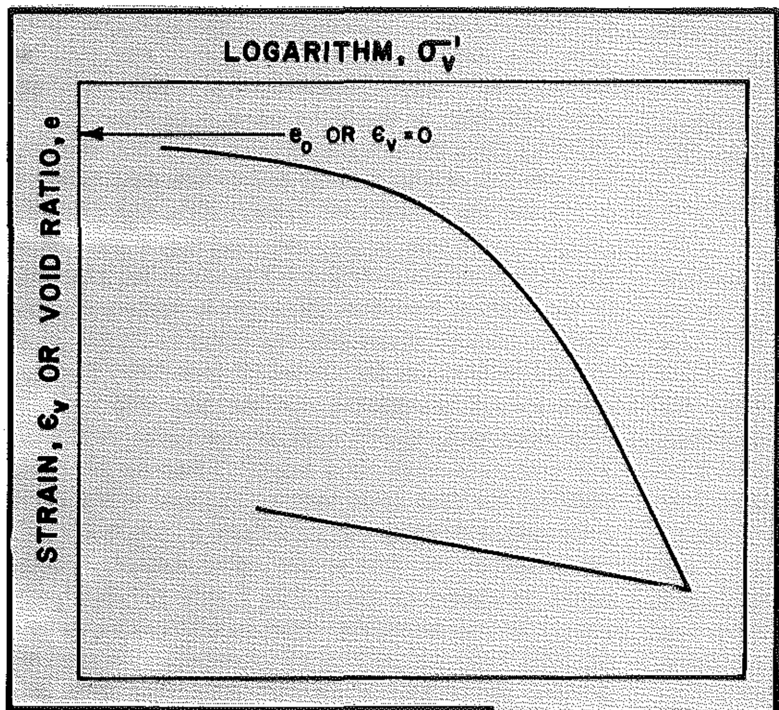
Limitations on the Formulation of a Test Problem - Two points must be made herein to define what constitutes a test problem. First, a given set of consolidation test data must have both compression and rebound data as shown in Figure 22. Otherwise, the program cannot analyze a data set which consists only of compression curve data as shown in Figure 23. Secondly, the program is set up to handle only one load cycle at a time. A load cycle consists of loading (compression) and unloading (rebound) as shown in Figure 22. The single load cycle illustrated in Figure 22 is considered by the computer program as one problem. Hence, the three load cycles displayed in Figure 24 will be considered as three separate problems by the computer program.

In considering the family of curves in Figure 24 as three separate problems, confusion will arise in the analysis if the initial void ratio, e_o, is not changed for load cycles two and three. First and foremost, the use of Schmertmann's construction in the later load cycles with the original initial void ratio will lead to unjustifiably large increases in the in situ compressibility, as shown by curve A in Figure 25. In addition, since the initial void ratio is not scaled by the computer in relation to the rest of the data before it is plotted, the output will become disturbed when the computer attempts to plot the determined position of the initial void ratio outside the limits of the plot page in the vertical direction. Hence, it is necessary in the analysis of load cycles two and three in Figure 24 to use different values for the initial void ratio. For load cycle two, it is suggested that the final void ratio for load cycle one, e_{f1}, be used as the initial void ratio. For load cycle three, it is suggested that the final void ratio for the load cycle two, e_{f2}, be used as the initial void ratio. Following this procedure, a more reasonable determination of the in situ compressibility can be made, as shown by curve B in Figure 25. The reader should be well aware that these problems concern both the void ratio and vertical strain deformation analyses. Results of each deformation analysis is intimately involved with the value of the initial void ratio. However, one should also realize that the vertical strain results lend readily to the comparison of the compressibility characteristics of soils having different initial void ratios. This enables a settlement analysis without knowledge of the in situ void ratios on layers of otherwise homogeneous materials which have the same compressibility characteristics.

DATA INPUTS

The data are input from punched cards using the format shown on the coding sheet forms in Figure 26a, b, and c in APPENDIX A. Detailed instructions are also contained in APPENDIX A along with a description of the job control cards.

Figure 22. Both Compression and Rebound Data necessary for Computer Program; Single Load Cycle Shown.



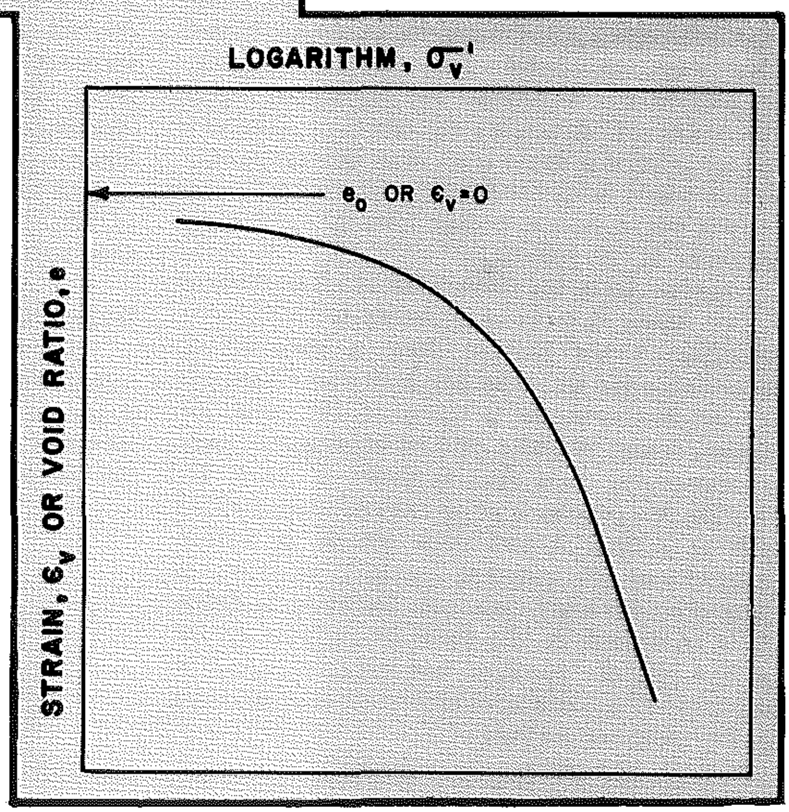
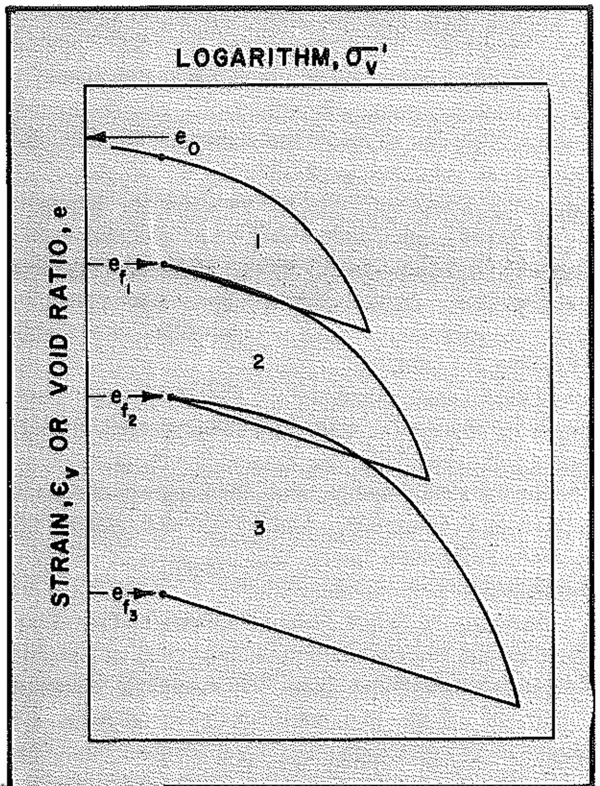


Figure 23. Compression Data only, Not Sufficient for Computer Program.

Figure 24. Three Load Cycles.



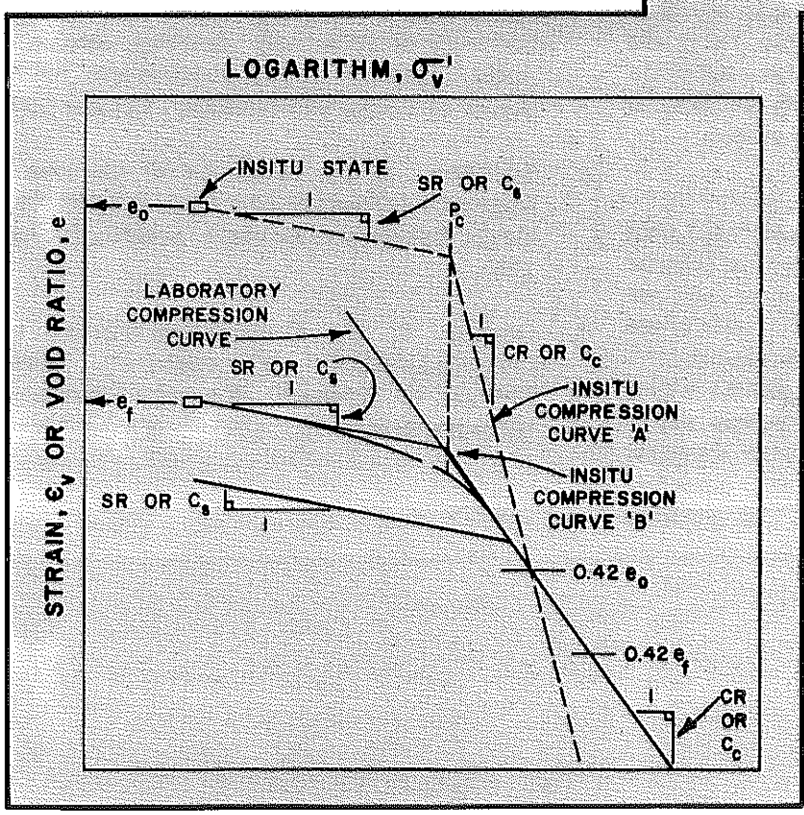


Figure 25. Use of e_o instead of e_f as the Initial Void Ratio on Later Load Cycles Leads to Unjustifiably Large Increases in Compressibility Coefficients. This Is Shown by a Comparison of In Situ Curves A and B.

PROGRAM OPTIONS

There are several run options available to the user of the computer program, CASAGR-0. All options are user specified. The user specifies the type of consolidation data being analyzed, the type of deformation analyses to be performed, and the method to select the point of maximum curvature. No debugging options are provided since the normal output of the program provides sufficient information for debugging.

Type of Consolidation Test -- The user may specify analysis on data from three different types of consolidation tests. These are the standard, controlled-gradient, and controlled-rate-of-strain consolidation tests.

Deformation Analyses -- The user may obtain results in terms of a void ratio and(or) vertical strain. Both yield essentially the same determination of the preconsolidation pressure. Also, the program enables the user to use deformation data from dial gauges with different calibration factors and directions of dial gauge movement.

Methods to Select Point of Maximum **Curvature** -- The user can choose either the Analytical or Graphical Method to select the point of maximum curvature. Details of these two methods have already been discussed. In review, the Graphical Method generally is less susceptible to anomalies caused by undulations in fitted compression curves and by irregularities in the data. The Analytical Method is better suited to consolidation curves which have relatively well-defined and undisturbed points of maximum curvature.

OUTPUT

Printed Output -- All input information and final results are printed to facilitate checking results. The user has the option of specifying whether or not the calculated radii from the analytical determination of the point of maximum curvature should be printed.

Plotted Output -- An example of plotted output is referred to in the discussion of the sample run in APPENDIX B. The plots produced by the computer program show data points, fitted curves, numerical results, and all the steps involved in the graphical analyses. The plot information is stored on 800-bytes-per-inch magnetic tape used in conjunction with the Calcomp 663 drum plotter.

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APPENDIX A

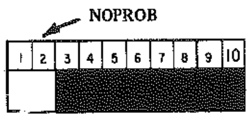
PROGRAM INPUT INSTRUCTIONS

CASAGR-0

TIME-INDEPENDENT CONSOLIDATION

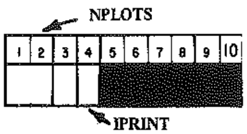
TEST DATA ANALYSIS

PROGRAM CODING SHEET



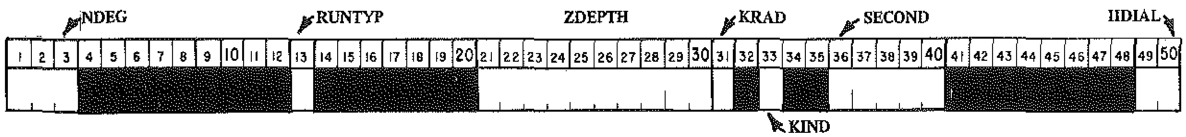
Number of problems, columns 1-2, right justified.

If NOPROB is greater than one, all of the remaining cards must be repeated for each problem.



For NPLOTS place a '1' in column 2.

IPRINT - output option for the Analytical method to determine the point of maximum curvature.
CODE '0' - Calculated radii printed out
'1' - Calculated radii not printed out



NDEG - Degree of polynomial used in curve fitting.

RUNTYP - Type of consolidation test
In COL. 13: CODE '0' - standard data
'1' - controlled gradient data
'2' - controlled rate of strain data

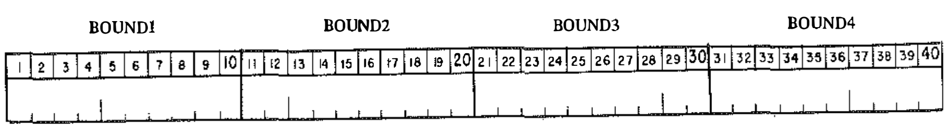
ZDEPTH Approximate field depth from which sample was recovered, in feet.

KRAD - Option for method to select point of maximum curvature.
In COL. 31 : a blank or '0' causes the Graphical method to be used.
: a '2' causes the Analytical method to be used.

KIND - Type of deformation analysis.
In COL. 33 : '0' is for both void ratio and strain analyses.
: '1' is for void ratio analysis only.
: '2' is for strain analysis only.

SECOND - Stress at start of secondary compression (controlled tests only).
If left blank, SECOND has default value of 31.2 Tsf.

IIDIAL - Option to override the assumed dial reading-versus-deflection relationship specified by computer program for each type of consolidation test.
In COLS. 50 : a blank or '0' changes none of the assumed relationships.
: '1' will specify that increasing dial readings indicate specimen shortening.
49-50 : '-1' will specify that increasing dial readings indicate specimen lengthening.



BOUND1, BOUND2 - search boundaries for selection of point of maximum curvature using Analytical or Graphical methods.

BOUND3, BOUND4 - search boundaries for selection of the line representation of the virgin compression curve.

CASAGR – O
LABORATORY CONSOLIDATION TEST DATA

SAMPLE AND TEST DESCRIPTION TO BE USED AS PLOT TITLE (BCD)

1 – 80

HOLE NO. (HOL) SAMPLE NO. (SAM) TEST NO. (TES) OPERATOR (OPR)

LOCATION (LOC) DATE (DAT) SAMPLE DESCRIPTON (DES)

1 – 57

SPECIMEN WEIGHTS DEFLECTION RDGS.

SP. GR. (SPG) | INI. WET (WTIW) | FIN. WET (WTFW) | FIN. DRY (WTFD) | INI. (DEFI) | FIN. (DEFF)

1 – 36

CALIBRATION FACTORS DIAM. SAMPLE

DEFLECTION (DCF) | LOAD (LCF) | PORE PRESS (PCF) | BLANK = default to 2.5" (DIA)

1 – 40

BACK PRESS. (BP) | ZERO READINGS DEFL. (DEFZ) | LOAD (WRZ) | P. P. (PPZ) | INI. SAMPLE HEIGHT (SAMPHI) BLANK= default to 1"

1 – 30

WATER CONTENT DATA	INITIAL		FINAL
Can No.			
Wt. can + wet soil			
Wt. can + dry soil			
Wt. of can			
Wt. of water			
Wt. dry soil			
Mois. cont.			

NOTE: P. P. ZERO READING should be taken after B. P. application.

(b)

Figure 26. (Continued)

CASAGR – O

LABORATORY CONSOLIDATION TEST DATA

(c)

CONTROLLED GRADIENT OR CONTROLLED RATE OF STRAIN CONSOLIDATION TEST DATA FORMAT

LABORATORY READINGS

TIME TR ( )	DEFL. DEFR ( )	P P PPR ( )	LOAD WRD ( )	
1 2 3 4	5 6 7 8 9	10 11 12 13	14 15 16 17	18 19
LAST CARD OF DATA BLANK				

TIME TR ( )	DEFL. DEFR ( )	P P PPR ( )	LOAD WRD ( )	
1 2 3 4	5 6 7 8 9	10 11 12 13	14 15 16 17	18 19
LAST CARD OF DATA BLANK				

STANDARD CONSOLIDATION TEST DATA FORMAT

EFF STRESS P ( ) (TSF)	DIAL RDG. E ( ) (IN)
1 2 3 4 5 6 7 8 9 10	11 12 13 14 15 16 17 18 19 20
LAST CARD OF DATA BLANK	

Figure 26. (Continued)

CASAGR-0

INPUT INSTRUCTIONS FOR TIME-INDEPENDENT LABORATORY CONSOLIDATION DATA ANALYSIS

COLUMNS	NAME	FORMAT	REMARKS
1. NUMBER OF PROBLEMS CARD			
1-2	NOPROB	I2	This card defines the number of problem sets to be solved. The number of problems equals the number of stress-strain axes which will be used in plotting the data. If card number two has NPLOTS equal to one, the number of problems will simply be the number of consolidation tests to be analyzed.
2. OUTPUT OPTION CARD			
1-2	NPLOTS	I2	For NPLOTS, place a '1' in column 2. This parameter is used only in program version CASAGR-I.
3-4	IPRINT	I2	Output option for the Analytical Method's determination of the point of maximum curvature (see CARD 3). A '0' or blank in columns 3-4 will cause the calculated radii of curvature at the generated incremental search abscissae to be printed out. A '1' in column four will eliminate this printed output.
3. DESCRIPTION OF ANALYSIS CARD			
1-3	NDEG	I3	These columns specify the degree of the ordinary, least-squares polynomial to be used in fitting the consolidation compression curve. The maximum possible degree is 11. Use the highest possible degree in most cases. For cases having few or scattered data points, a lower-degree polynomial must be used. A low polynomial degree of four or five generally provides a good fit. For data sets having less than 12 points, the maximum polynomial degree which can be used is equal to the number of data points minus 1. However, the best polynomial representation of the data will usually be obtained when the highest polynomial that provides some least-squares smoothing is used (number of data points minus 2). If this degree polynomial is found to provide an undulating representation of the data, the user can use a lower-degree polynomial in another computer run.
13	RUNTYP	I1	Place in column 13 a '0' for standard consolidation data reduction, '1' for controlled-gradient consolidation data reduction, or '2' for controlled-rate-of-strain consolidation data reduction.

Note: Repeat cards 2 through 10 for each additional problem.

21-30	ZDEPTH	F10.0	Place in columns 21-30 the approximate depth in decimal feet at which the sample was recovered in the field. This depth is used to calculate the approximate overburden pressure in tons per square foot from the wet unit weight of the laboratory test specimen. The calculation of this overburden pressure does not take into account the effects of the water table or layers of different materials. The user may compensate for these situations by using a depth which will produce the desired effective stress for a given wet unit weight of the specimen. The following relationship is used to calculate the overburden stress: Overburden stress = (DEPTH (ft)) * (1 ton/2000 lbf) * (Wet Unit weight (grams)) / (453.6 grams/lbf) * (1728 in^3/ft^3)/(lab sample volume (in^3)).
31	KRAD	I1	This parameter determines the method used to select the point of maximum curvature in Casagrande's construction. A '2' placed in column 31 causes the program to use the Analytical Method shown in Figure 27a. A blank in column 31 will cause the program to employ the Graphical Method to determine the point of maximum curvature as shown in Figure 27b. The Graphical Method is well suited to handling anomalies in data, ill-defined points of maximum curvature, and undulations in the fitted curve.
33	KIND	I1	Option for type of deformation analysis in terms of void ratio and(or) vertical strain. A '1' placed in column 33 specifies that the analysis be performed in terms of void ratio. A '2' placed in column 33 specifies that the analysis be performed in terms of vertical strain. If a '0' or a blank is in column 33, the deformation analysis is performed in terms of both void ratio and vertical strain.
36-40	SECOND	F5.0	This parameter is used to remove the secondary compression points shown in Figure 28. This is done specifying the stress in Tsf at which secondary compression begins in controlled consolidation tests. If columns 32-40 are left blank, the program will default to a value of 31.2 Tsf. Note that this parameter is not used in the analysis of the standard consolidation test data.
49-50	IIDIAL	I2	Option to override the assumed dial reading-versus-deflection relationships found in the computer program for each type of consolidation test. A '1' in column 50 will specify that increasing dial readings indicate specimen shortening. A '-1' in columns 49-50 will specify that increasing dial readings indicate specimen lengthening. If columns 49-50 are left blank or filled with zeros, the program will default to use the dial reading-versus-deflection relationships specified in

the program. The program assumes, unless the above override option is used, that increasing dial readings indicate specimen shortening for standard and controlled-rate-of-strain test data. For controlled-gradient test data, the program assumes that increasing dial readings indicate specimen lengthening.

4. SEARCH BOUNDARY CARD

1-10	BOUND1	F10.0	Stress search boundaries used for finding the point of maximum curvature by either the Analytical or Graphical Methods.
11-20	BOUND2	F10.0	

Stress search boundaries used for finding the point of maximum curvature by either the Analytical or Graphical Methods. These boundaries are especially useful in choosing the representative portions of the curve and avoiding the localized effects of poor data and undulations in the fitted curve. These kind of choices are not possible when the user lacks knowledge of data's appearance during the first computer run. In the first run of the data, the user can make rough estimates for these search boundaries. A list of suggested values for BOUND1 and BOUND2 is provided at the conclusion of these remarks. These values will usually provide acceptable results in the absence of disruptive anomalies in the data.

When these boundaries are used in conjunction with the Analytical Method shown in Figure 29, the user must have them span the expected range of locations for the point of maximum curvature. In contrast, these boundaries are used by the Graphical Method to locate a tangent to the consolidation compression curve having the same slope as the rebound curve shown in Figure 30.

BOUND1 is the most important search boundary for the graphical method. BOUND2 is of no consequence if it is located well into the steep portion of the compression curve. If a tangent to the consolidation compression curve cannot be found between BOUND1 and BOUND2, the line having the slope 'E' of the rebound curve is drawn through the compression curve at BOUND1 as shown in Figure 31.

SUGGESTED PRELIMINARY
VALUES FOR BOUND1 AND BOUND2

SPECIMEN CHARACTER	ANALYTICAL BOUND1 (tsf)	ANALYTICAL BOUND2 (tsf)	GRAPHICAL BOUND1 (tsf)	GRAPHICAL BOUND2 (tsf)
Very soft	0.5	4.0	0.5	16.0
Very stiff	0.5	8.0	0.5	16.0

21-30	BOUND3	F10.0	
31-40	BOUND4	F10.0	

These stress search boundaries are used to select the straight-line portion of the virgin compression curve shown in Figure 32. BOUND4 is the most important of these two search boundaries. BOUND4 usually is taken as the last or nearly last value of effective stress, but never greater than the last value of effective stress. BOUND3 is of no consequence if it is before the

			straight-line portion of the virgin compression curve. If the need arises, these search boundaries may be used to select a more representative portion of the virgin compression curve data.
5. PLOT TITLE CARD			
1-80	BCD	20A4	Alphanumeric information which will serve as the plot title and description of the test. The test description should include test type and series number, borehole location and number, sample number, and any other information pertinent to the data and testing procedures.
6. PRINTOUT DATA CARD			
1-16	LOC	4A4	General name of site from which sample was taken.
17-18	HOL	I2	Borehole number entered as a right justified integer.
19-21	SAM	A3	Alphanumeric identification of the sample.
22-25	TES	I4	Test number in a particular consolidation testing program.
26-29	OPR	A4	Initials of the consolidation test operator.
30-41	DAT	3A4	Alphanumeric identification of testing period.
42-57	DES	4A4	Alphanumeric information concerning material characteristics of sample.
7. INITIAL SOIL PROPERTIES CARD			
1-5	SPG	F5.2	Specific gravity of solids for the specimen.
6-12	WTIW	F7.2	Initial wet weight, in grams, of specimen.
13-19	WTFW	F7.2	Final wet weight, in grams, of specimen at end of test.
20-26	WTFD	F7.2	Final dry weight, in grams, of specimen after dessication.
27-31	DEFI	F5.2	Dial reading just before start of test.
32-36	DEFF	F5.2	Dial reading at conclusion of consolidation test.
8. CALIBRATION FACTORS AND SAMPLE DIAMETER CARD			
1-10	DCF	F10.0	Deflection calibration factor expressed with a decimal (inch/division).
11-20	LCF	F10.0	Load calibration factor expressed with a decimal (lbs/division).
21-30	PCF	F10.0	Pore-pressure calibration factor expressed with a decimal (psi/division).
31-40	DIA	F10.0	Diameter of sample in inches. If these columns are left blank, a default value of 2.5" is used.

9. ZERO INFORMATION CARD

1-5	BP	F5.1	Back pressure reading (psi).
6-10	DEFZ	F5.2	Dial reading taken when sample is at its initial height.
11-14	WRZ	F4.0	Load reading corresponding to zero applied load.
15-18	PPZ	F4.0	Pore-pressure reading taken after application of back pressure and before loading of specimen.
21-30	SAMPHI	F10.0	Height of sample in inches after placement in consolidation ring and placement of end platens, or previously measured height. If left blank, a default value of 1" is assumed.

10A. CONTROLLED-GRADIENT OR CONTROLLED-RATE-OF-STRAIN CONSOLIDATION DATA FORMAT

1-4	TR( )	F4.0	Time reading.
5-9	DEFR( )	F5.2	Defection reading; increasing for controlled-rate-of-strain and decreasing for controlled-gradient tests.
10-13	PPR( )	F4.0	Pore-pressure reading.
14-17	WRD( )	F4.0	Load reading.

(Add an additional card for each test reading)

NOTE: Consolidation compression points must be read in with the effective stress increasing. A drop in effective stress of greater than 0.7 tsf will cause the computer to treat all subsequent readings as rebound-expansion data.

10B. STANDARD CONSOLIDATION TEST DATA FORMAT

1-10	P( )	F10.0	Place in these first ten columns the effective stress in tons per square foot applied for a given load increment. Express the stress as a decimal number. Any stress less than 0.1 tsf will be automatically changed to 0.1 tsf.
11-20	E( )	F10.0	Dial reading at 100-percent primary consolidation for effective stress shown in columns 1-10. Dial readings should increase with increasing deflection and describe the change in inches in the specimen height. All dial readings must be expressed with a decimal.

(Add an additional card for each data point)

NOTE: Standard consolidation test data cards must start with compression data points and increasing effective stress. Rebound or expansion curve data cards follow the last compression data point in order of decreasing effective stress.

EFFECTIVE STRESS ORDER
(tsf)

0.25
0.50
1.0

32.0
1.0
0.5
0.25

11. END OF DATA SET CARD

1-80	BLANK	F10.0	This is the last card to be enclosed with each particular set of test data. The entire card is blank and signals to the program the end of the current set of test data.

JOB CONTROL CARDS

The following groups of job control cards apply when the University of Kentucky's IBM 370 at McVey Hall is used. These cards describe the JCL necessary for a source deck run, object deck run, source deck run with production of an object deck, and a source or object deck run in which the plot output is suppressed.

A standard JOB card which includes the waste paper option is the following:

```
//P74EGM      JOB(1009,51001,1,,,,,W), MCNULTY,MSGLEVEL=1, REGION=268K
```

FOR RUN WITH SOURCE DECK

```
//standard JOB card
//P74EGM EXEC FORTGCLP
//FORT.SYSIN DD *
                .
                .
                .
        FORTRAN SOURCE DECK
                .
                .
                .
/*
//GO.SYSIN DD *
                .
                .
                .
              DATA
                .
                .
                .
/*
```

FOR RUN WITH OBJECT DECK

```
//standard JOB card
//P74EGM EXEC FORTGLP
//LKED.SYSIN DD *
                .
                .
                .
        FORTRAN Object Deck
                .
                .
                .
/*
//GO.SYSIN DD *
                .
                .
                .
              DATA
                .
                .
                .
/*
```

To produce an object deck from a source deck run, change the second JCL card to the following:

```
//P74EGM EXEC FORTGCLP,PARM.FORT=DECK
```

To run either source or object deck versions of programs without production of plotted output, add the following card before the //GO.SYSIN DD * card:

```
//GO.PLOTTAPE DD DUMMY
```

NOTE: See Figure 33

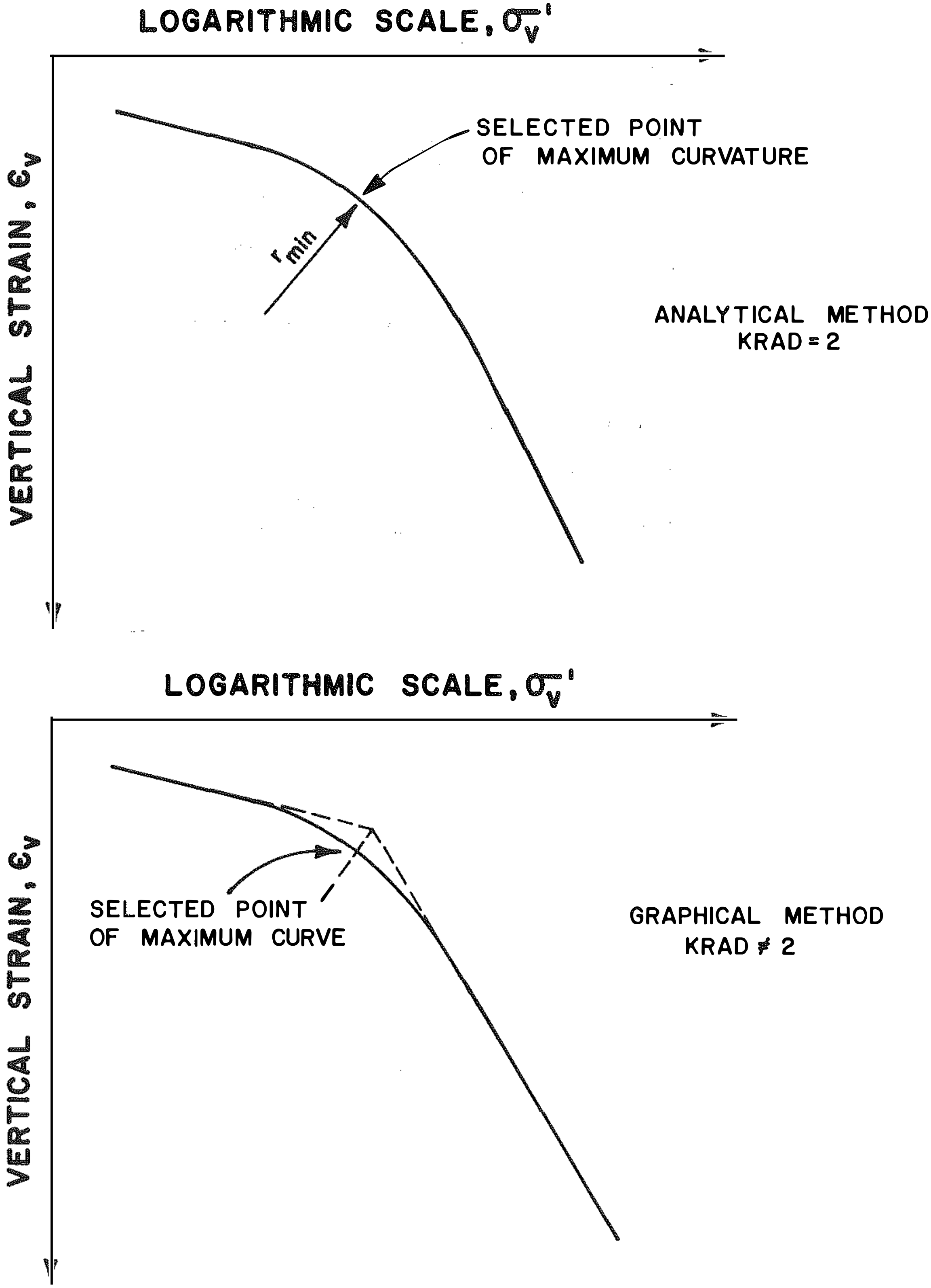
PLOT OUTPUT NOTATION

DEG	Degree of polynomial fit
PO	In situ vertical stress
EO	In situ void ratio or vertical strain
PC	Vertical presonsolication stress, P_c
EC	Vertical preconsolidation strain
OCR	Overconsolidation ratio
CC	Compression coefficient, C_c (void-ratio analysis)
CS	Expansion coefficient, C_s (void-ratio analysis)
CR	Compression coefficient for strain analysis, usually referred to as the compression ratio
SR	Expansion coefficient for strain analysis, usually referred to as the swell ratio

TEST DESIGNATIONS

STD	Standard consolidation
CG	Controlled-gradient consolidation
CRS	Controlled-rate-of-strain consolidation

Figure 27. Two Methods to Select the Point of Maximum Curvature.



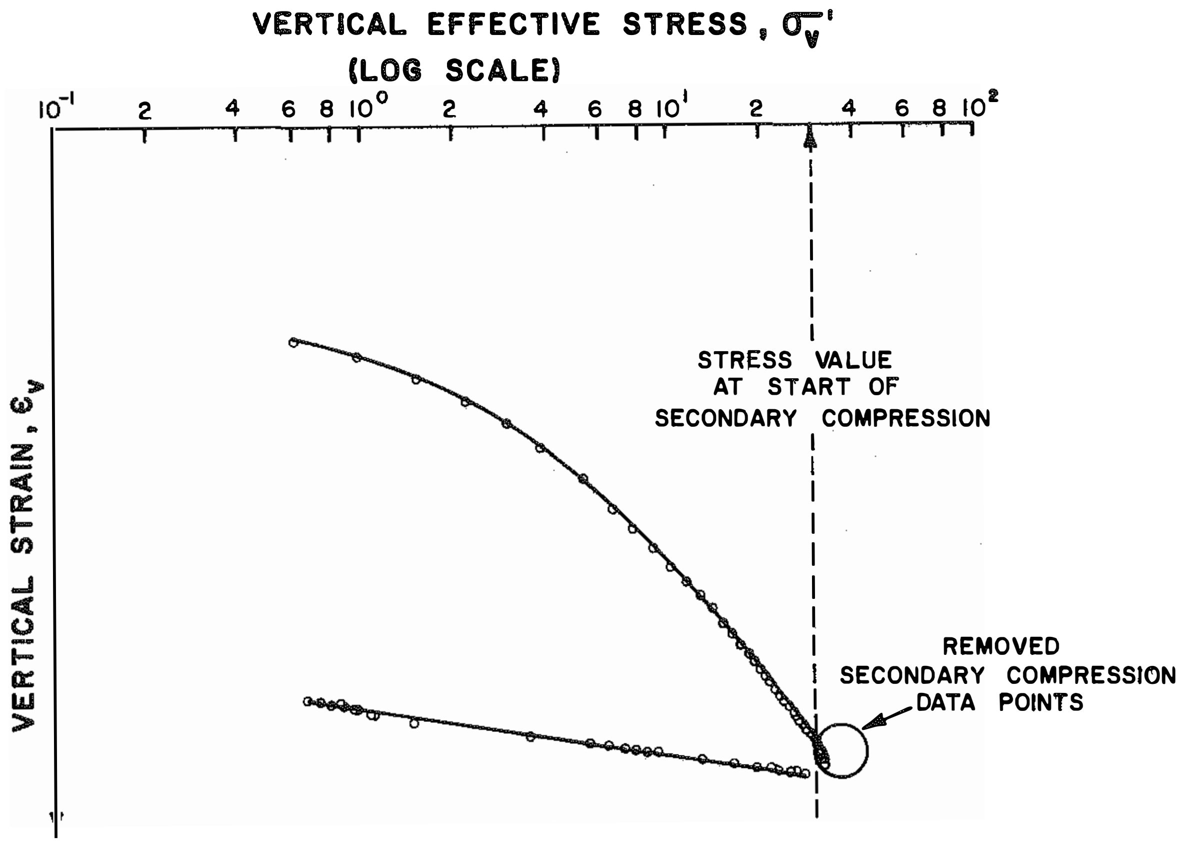


Figure 28. Procedure for Removing Secondary Compression Effects of Controlled Data on Curve-Fitting Process.

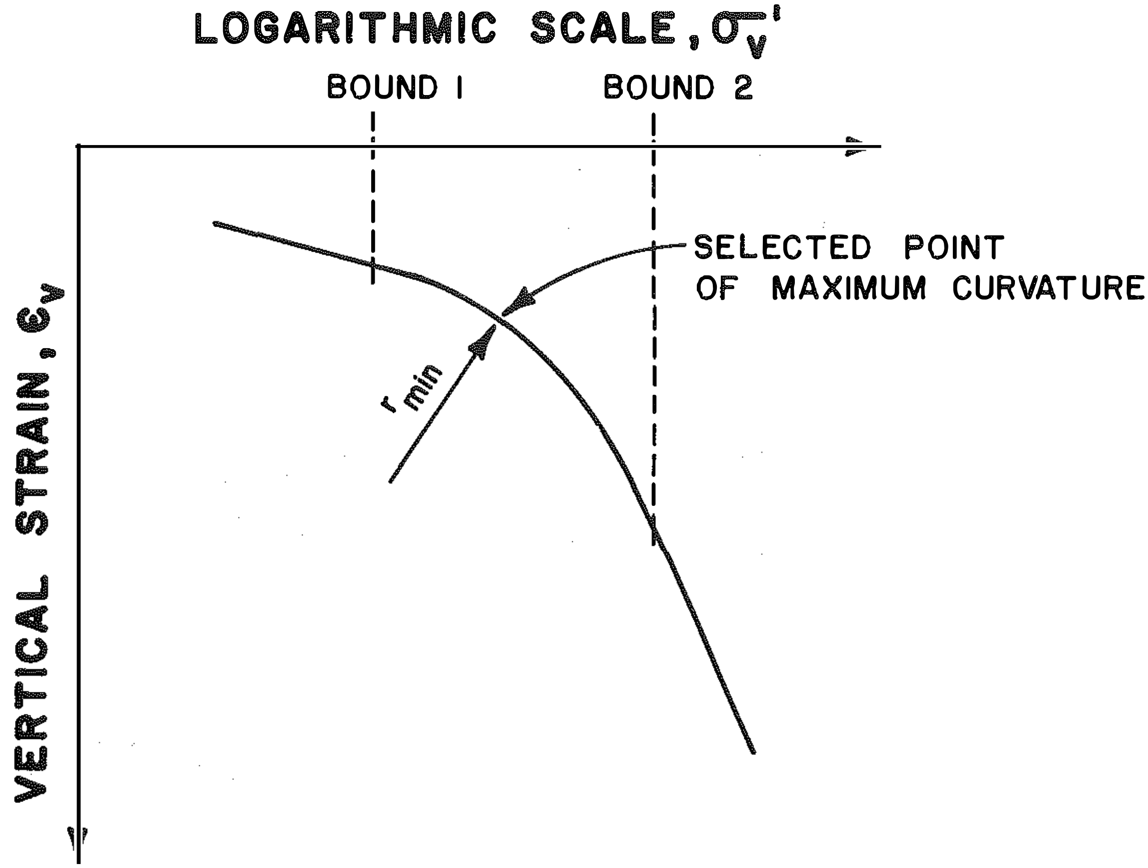


Figure 29. Search Boundaries for the Analytical Determination of the Point of Maximum Curvature.

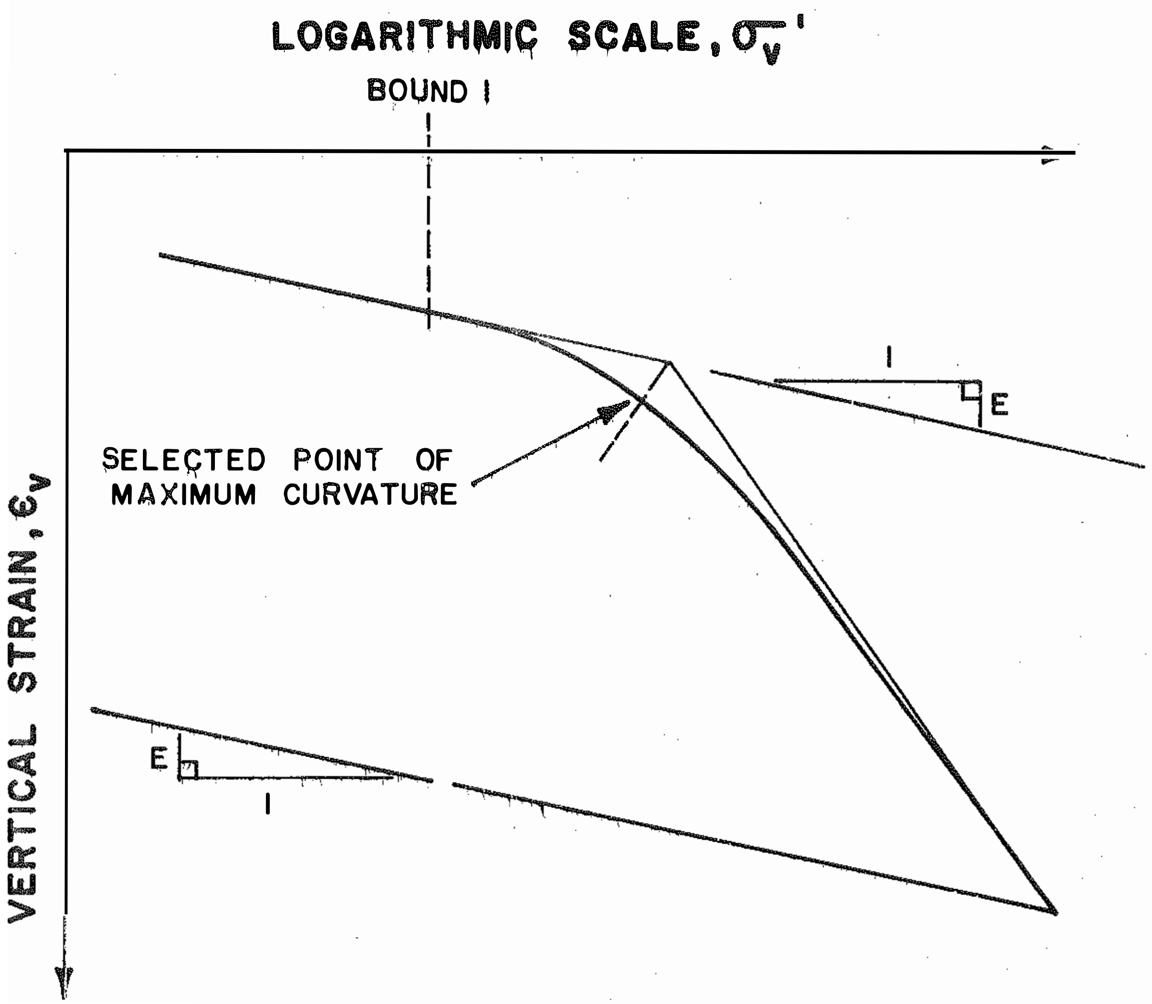
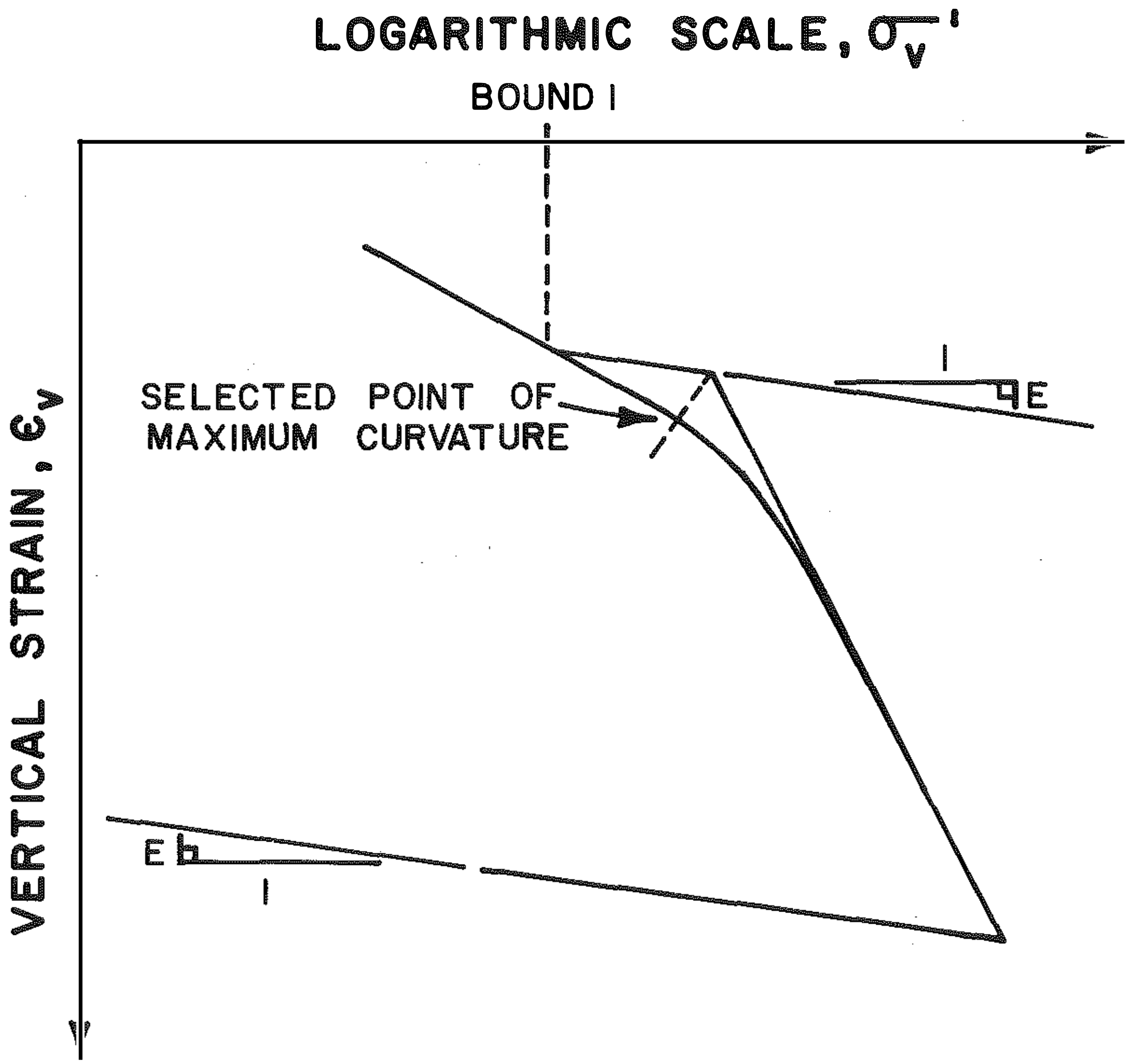


Figure 30. Search Boundaries for the Graphical Method to Select the Point of Maximum Curvature. BOUND2 Is Located in Straight Portion of Virgin Compression Curve.

Figure 31. Special-Case Use of BOUND1 by the Graphical Method as a default Location for the Initial Tangent Line when the Initial Portion of the Compression Curve Has a Slope Greater than E.



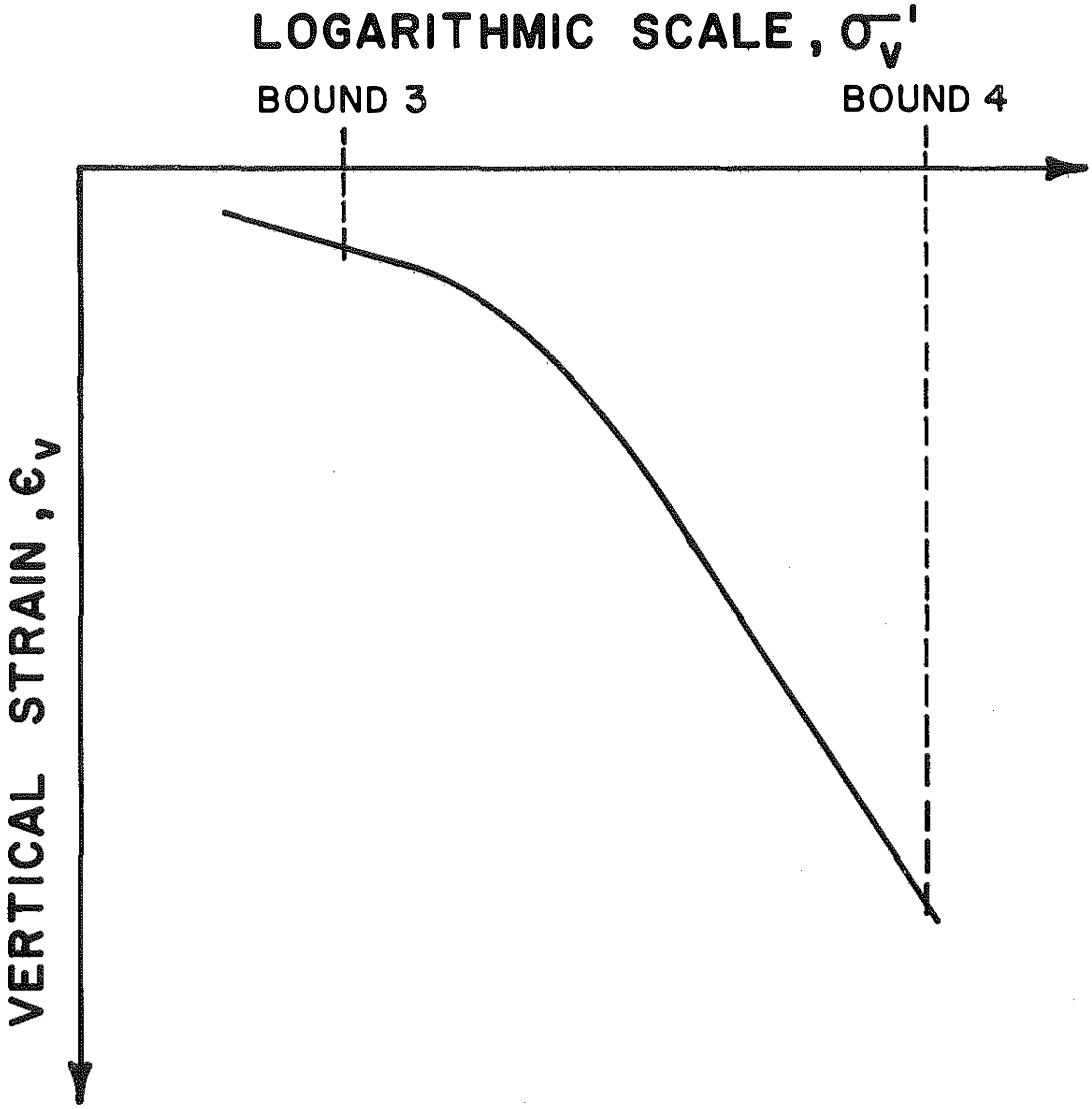
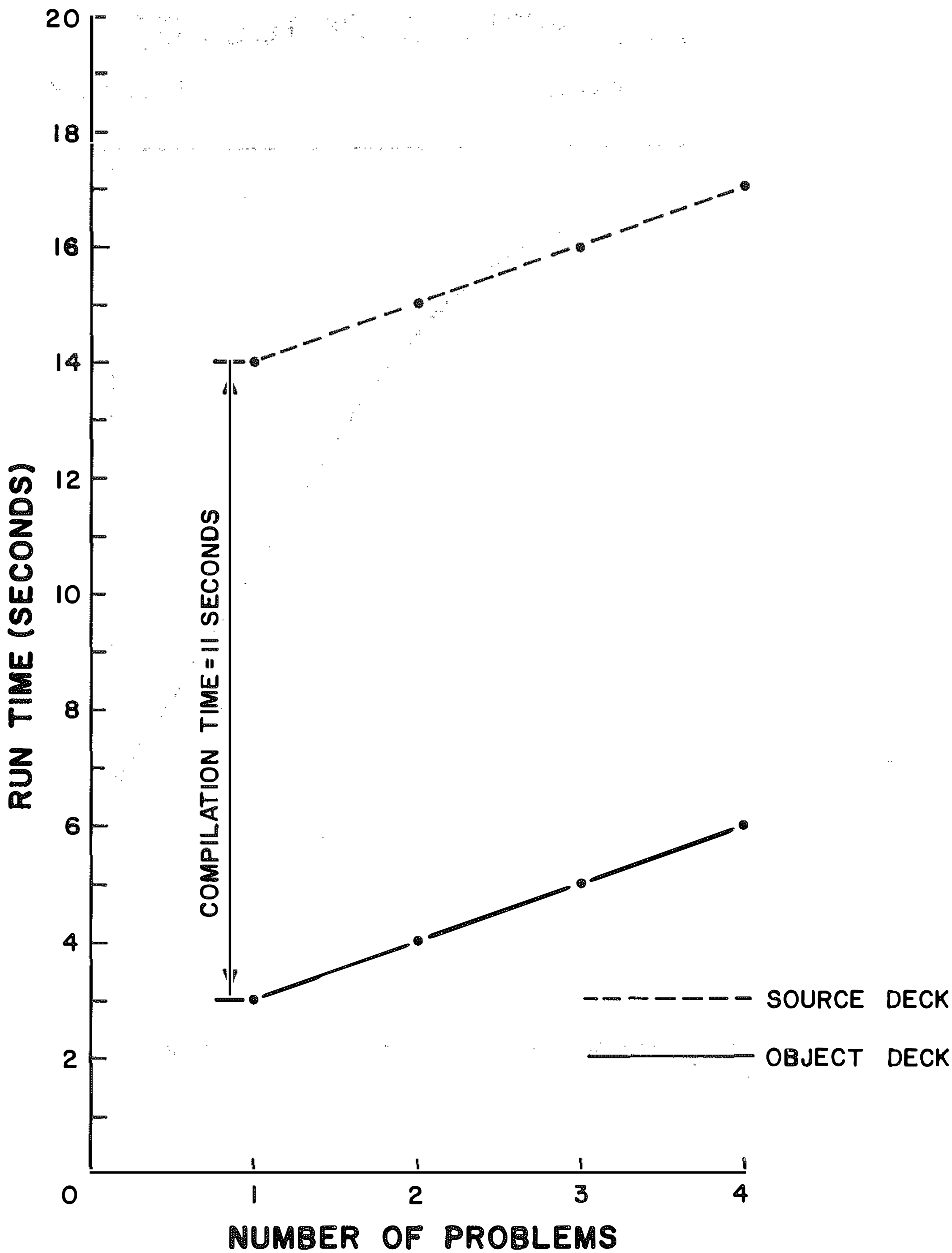


Figure 32. Use of Search Boundaries to Select Straight Portion of Virgin Compression Curve.

Figure 33. Approximate Computer Processing Time versus Number of Problems for Source and Object Deck Program Versions.



APPENDIX B

SAMPLE PROBLEM

CASAGR-0

TIME-INDEPENDENT CONSOLIDATION

TEST DATA ANALYSIS

PROGRAM CODING SHEET

NOPROB

1	2	3	4	5	6	7	8	9	10
0	1								

Number of problems, columns 1-2, right justified.

If NOPROB is greater than one, all of the remaining cards must be repeated for each problem.

NPLOTS

1	2	3	4	5	6	7	8	9	10
0	1		1						

IPRINT

For NPLOTS place a '1' in column 2.

IPRINT - output option for the Analytical method to determine the point of maximum curvature.
CODE '0' - Calculated radii printed out
'1' - Calculated radii not printed out

NDEG, RUNTYP, ZDEPTH, KRAD, KIND, SECOND, IIDIAL

NDEG	1-3	011
RUNTYP	13	1
ZDEPTH	21-30	11.0
KRAD	31	2
KIND	33	
SECOND	36-40	31.2
IIDIAL	49-50	

NDEG - Degree of polynomial used in curve fitting.

RUNTYP - Type of consolidation test
In COL. 13: CODE '0' - standard data
'1' - controlled gradient data
'2' - controlled rate of strain data

ZDEPTH Approximate field depth from which sample was recovered, in feet.

KRAD - Option for method to select point of maximum curvature.
In COL. 31 : a blank or '0' causes the Graphical method to be used.
: a '2' causes the Analytical method to be used.

KIND - Type of deformation analysis.
In COL. 33 : '0' is for both void ratio and strain analyses.
: '1' is for void ratio analysis only.
: '2' is for strain analysis only.

SECOND - Stress at start of secondary compression (controlled tests only).
If left blank, SECOND has default value of 31.2 Tsf.

IIDIAL - Option to override the assumed dial reading-versus-deflection relationship specified by computer program for each type of consolidation test.
In COLS. 50 : a blank or '0' changes none of the assumed relationships.
: '1' will specify that increasing dial readings indicate specimen shortening.
49-50 : '-1' will specify that increasing dial readings indicate specimen lengthening.

BOUND1	1-10	1.00
BOUND2	11-20	13.00
BOUND3	21-30	20.00
BOUND4	31-40	28.00

BOUND1, BOUND2 - search boundaries for selection of point of maximum curvature using Analytical or Graphical methods.

BOUND3, BOUND4 - search boundaries for selection of the line representation of the virgin compression curve.

CASAGR – O
LABORATORY CONSOLIDATION TEST DATA

SAMPLE AND TEST DESCRIPTION TO BE USED AS PLOT TITLE (BCD)

1–80
CG-13 ELIZABETHTOWN H-3 S-2B 2.5T PSI

LOCATION (LOC)	HOLE NO. (HOL)	SAMPLE NO. (SAM)	TEST NO. (TES)	OPERATOR (OPR)	DATE (DAT)	SAMPLE DESCRIPTON (DES)
ELIZABETHTOWN	3	2B	13	CTG	3/31-4/10-75	RED SANDY CLAY

SPECIMEN WEIGHTS / DEFLECTION RDGS.

SP. GR. (SPG)	INI. WET (WTIW)	FIN. WET (WTFW)	FIN. DRY (WTFD)	INI. (DEFI)	FIN. (DEFF)
2.70	156.65	152.55	123.60	13.61	10.99

CALIBRATION FACTORS

DEFLECTION (DCF)	LOAD (LCF)	PORE PRESS (PCF)	DIAM. SAMPLE BLANK = default to 2.5" (DIA)
0.03937	4.090	0.16667	

ZERO READINGS

BACK PRESS. (BP)	DEFL. (DEFZ)	LOAD (WRZ)	P. P. (PPZ)	INI. SAMPLE HEIGHT (SAMPHI) BLANK = default to 1"
10.0	13.0	899.	996.	

WATER CONTENT DATA	INITIAL		FINAL
Can No.			
Wt. can + wet soil			
Wt. can + dry soil			
Wt. of can			
Wt. of water			
Wt. dry soil			
Mois. cont.			

NOTE: P. P. ZERO READING should be taken after B. P. application.

CASAGR – O
LABORATORY CONSOLIDATION TEST DATA

CONTROLLED GRADIENT OR CONTROLLED RATE OF STRAIN CONSOLIDATION TEST DATA FORMAT

STANDARD CONSOLIDATION TEST DATA FORMAT

LABORATORY READINGS

TIME TR ( ) (cols 1–4)	DEFL. DEFR ( ) (cols 5–9)	P. P. PPR ( ) (cols 10–13)	LOAD WRD ( ) (cols 14–17)
1	13.60	996	901
2	13.60	966	902
3	13.59	996	903
4	13.58	996	904
5	13.57	996	905
6	13.56	996	907
11	13.53	996	908
12	13.53	997	910
13	13.52	997	911
15	13.50	997	914
17	13.47	997	917
19	13.45	997	920
21	13.42	998	924
23	13.40	998	928
25	13.37	998	932
27	13.35	998	936
29	13.33	998	940
31	13.30	998	945
33	13.27	999	949
LAST CARD OF DATA BLANK			

TIME TR ( ) (cols 1–4)	DEFL. DEFR ( ) (cols 5–9)	P. P. PPR ( ) (cols 10–13)	LOAD WRD ( ) (cols 14–17)
35	13.25	999	954
37	13.22	999	958
40	13.18	1000	966
43	13.14	1002	975
50	13.02	1006	986
53	12.99	1007	1003
56	12.95	1008	1009
59	12.92	1010	1015
62	12.89	1011	1019
65	12.87	1010	1023
70	12.83	1011	1030
75	12.80	1012	1034
80	12.77	1012	1038
85	12.74	1012	1042
90	12.71	1012	1049
96	12.68	1014	1052
100	12.66	1014	1054
105	12.65	1013	1056
110	12.62	1013	1062
LAST CARD OF DATA BLANK			

EFF. STRESS P ( ) (TSF) (cols 1–10)	DIAL RDG. E ( ) (IN) (cols 11–20)
LAST CARD OF DATA BLANK	

CASAGR – 0
LABORATORY CONSOLIDATION TEST DATA

CONTROLLED GRADIENT OR CONTROLLED RATE OF STRAIN CONSOLIDATION TEST DATA FORMAT

STANDARD CONSOLIDATION TEST DATA FORMAT

LABORATORY READINGS

TIME TR ( )	DEFL. DEFR ( )	P. P. PPR ( )	LOAD WRD ( )
115	12.61	1013	1063
125	12.58	1012	1066
130	12.56	1012	1072
145	12.53	1011	1074
150	12.51	1011	1079
155	12.49	1011	1081
165	12.47	1011	1083
175	12.45	1011	1085
185	12.43	1011	1088
195	12.41	1010	1091
205	12.39	1010	1095
225	12.36	1010	1100
235	12.33	1010	1103
245	12.31	1010	1106
265	12.28	1010	1111
280	12.25	1010	1116
295	12.22	1010	1119
310	12.19	1010	1124
325	12.17	1010	1128
LAST CARD OF DATA BLANK			

TIME TR ( )	DEFL. DEFR ( )	P. P. PPR ( )	LOAD WRD ( )
340	12.15	1010	1131
355	12.12	1010	1135
370	12.10	1010	1139
390	12.07	1010	1143
410	12.04	1011	1148
430	12.01	1011	1152
445	11.99	1011	1156
460	11.97	1011	1159
471	11.96	1011	1161
508	11.91	1011	1169
546	11.87	1011	1178
584	11.82	1011	1186
621	11.78	1011	1193
659	11.73	1011	1200
697	11.70	1012	1207
734	11.66	1012	1214
772	11.63	1012	1220
810	11.60	1012	1226
848	11.56	1012	1231
LAST CARD OF DATA BLANK			

EFF. STRESS P ( ) (TSF)	DIAL RDG. E ( ) (IN)
LAST CARD OF DATA BLANK	

CASAGR – O
LABORATORY CONSOLIDATION TEST DATA

CONTROLLED GRADIENT OR CONTROLLED RATE OF STRAIN CONSOLIDATION TEST DATA FORMAT

LABORATORY READINGS

TIME TR ( )	DEFL. DEFR ( )	P. P. PPR ( )	LOAD WRD ( )
885	11.53	1012	1237
922	11.50	1012	1243
960	11.47	1012	1249
998	11.44	1012	1254
1035	11.41	1012	1259
1073	11.39	1012	1264
1111	11.37	1012	1269
1148	11.34	1012	1274
1186	11.32	1012	1280
1224	11.30	1012	1285
1262	11.28	1012	1290
1299	11.26	1012	1295
1337	11.23	1012	1301
1375	11.21	1013	1307
1400	11.20	1013	1309
1420	11.19	1013	1312
1440	11.18	1013	1315
1475	11.15	1013	1319
1490	11.15	1014	1321
LAST CARD OF DATA BLANK			

TIME TR ( )	DEFL. DEFR ( )	P. P. PPR ( )	LOAD WRD ( )
1500	11.14	1014	1322
1515	11.13	1014	1324
1535	11.12	1014	1327
1560	11.11	1014	1330
1585	11.09	1014	1334
1600	11.08	1014	1338
1630	11.07	1014	1340
1660	11.05	1014	1344
1685	11.04	1014	1347
1720	11.01	1016	1361
1730	11.00	1017	1362
1820	10.95	1016	1366
1870	10.92	1016	1380
1900	10.90	1016	1388
1937	10.88	1016	1390
1975	10.86	1016	1394
2013	10.84	1016	1401
2050	10.82	1016	1414
2088	10.79	1017	1420
LAST CARD OF DATA BLANK			

STANDARD CONSOLIDATION TEST DATA FORMAT

EFF. STRESS P ( ) (TSF)	DIAL RDG. E ( ) (IN)
LAST CARD OF DATA BLANK	

CASAGR – O
LABORATORY CONSOLIDATION TEST DATA

CONTROLLED GRADIENT OR CONTROLLED RATE OF STRAIN CONSOLIDATION TEST DATA FORMAT

STANDARD CONSOLIDATION TEST DATA FORMAT

LABORATORY READINGS

TIME TR ( ) (cols 1-4)	DEFL. DEFR ( ) (cols 5-9)	P. P. PPR ( ) (cols 10-13)	LOAD WRD ( ) (cols 14-17)	(cols 18-19)
2126	10.77	1017	1423	
2163	10.75	1017	1427	
2201	10.73	1016	1428	
2239	10.72	1015	1429	
2277	10.72	1014	1429	
2314	10.71	1013	1429	
2352	10.70	1011	1430	
2390	10.70	1009	1430	
2427	10.69	1008	1430	
2465	10.69	1007	1430	
2503	10.68	1006	1430	
2541	10.68	1005	1430	
2578	10.68	1004	1430	
2616	10.68	1003	1430	
2654	10.68	1002	1430	
2691	10.67	1002	1430	
2729	10.67	1002	1430	
2767	10.67	1001	1430	
2805	10.67	1001	1430	
LAST CARD OF DATA BLANK				

TIME TR ( ) (cols 1-4)	DEFL. DEFR ( ) (cols 5-9)	P. P. PPR ( ) (cols 10-13)	LOAD WRD ( ) (cols 14-17)	(cols 18-19)
2840	10.67	1001	1430	
2855	10.67	1001	1430	
2860	10.67	1001	1419	
2865	10.67	1001	1409	
2870	10.67	1000	1390	
2875	10.68	1000	1385	
2880	10.68	1000	1375	
2885	10.68	1000	1360	
2890	10.68	999	1348	
2895	10.69	999	1335	
2900	10.69	998	1323	
2905	10.70	998	1309	
2910	10.70	998	1293	
2915	10.70	997	1282	
2920	10.71	997	1271	
2925	10.71	996	1259	
2930	10.72	996	1246	
2935	10.72	995	1235	
2940	10.73	995	1220	
LAST CARD OF DATA BLANK				

EFF. STRESS P ( ) (TSF) (cols 1-10)	DIAL RDG. E ( ) (IN) (cols 11-20)
LAST CARD OF DATA BLANK	

CASAGR – O
LABORATORY CONSOLIDATION TEST DATA

CONTROLLED GRADIENT OR CONTROLLED RATE OF STRAIN CONSOLIDATION TEST DATA FORMAT

LABORATORY READINGS

TIME TR ( )	DEFL. DEFR ( )	P. P. PPR ( )	LOAD WRD ( )
2945	10.73	994	1208
2950	10.74	993	1195
2955	10.75	992	1183
2960	10.76	991	1168
2965	10.77	990	1155
2970	10.78	989	1144
2975	10.78	989	1133
2980	10.79	988	1118
2985	10.80	987	1113
2990	10.81	987	1107
2995	10.81	986	1102
3000	10.82	986	1096
3005	10.82	985	1089
3015	10.83	985	1083
3025	10.84	984	1078
3040	10.85	983	1070
3055	10.86	983	1063
3070	10.87	983	1056
3090	10.87	982	1050
LAST CARD OF DATA BLANK			

TIME TR ( )	DEFL. DEFR ( )	P. P. PPR ( )	LOAD WRD ( )
3105	10.88	982	1043
3125	10.89	982	1040
3140	10.89	982	1037
3155	10.90	982	1033
3170	10.90	982	1030
3190	10.91	982	1027
3205	10.91	982	1024
3220	10.92	982	1020
3235	10.92	982	1017
3255	10.93	982	1014
3270	10.93	982	1010
3285	10.94	982	1007
3325	10.95	981	1003
4440	10.99	993	995
LAST CARD OF DATA BLANK			

STANDARD CONSOLIDATION TEST DATA FORMAT

EFF. STRESS P ( ) (TSF)	DIAL RDG. E ( ) (IN)
LAST CARD OF DATA BLANK	

CONTROLLED GRADIENT CONSOLIDATION TEST
DATA REDUCTION

CG-13 ELIZABETHTOWN H-3 S-2B 2.5 PSI

TEST NO. 13	HOLE NO. 3
LOCATION ELIZABETHTOWN	SAMPLE NO. 2B
DATE 3/31-4/10/75	OPERATOR CTG
SOIL TYPE - RED SANDY CLAY	
BACK PRESSURE 10.00 PSI	

	INITIAL	FINAL
WATER CONTENT	26.7%	23.4%
VOID RATIO	0.80	0.62
DEG. OF SATURATION	90.4%	102.3%

DEGREE POLYNOMIAL =11

PT. OF MAX. CURVATURE SELECTED BY THE ANALYTICAL METHOD

SEARCH BOUNDARIES FOR PT. OF MAX. CURVATURE: 1.00 TSF 13.00 TSF

SEARCH BOUNDARIES FOR VIRGIN COMPRESSION CURVE: 10.00 TSF 28.00 TSF

DEPTH FOR INSITU STRESS CALCULATION: 11.00 FEET SECONDARY COMPRESSION AT 31.20 TSF

VOID RATIO ANALYSIS

INSITU VERTICAL STRESS = 0.653 TSF INITIAL VOID RATIO (EO) = 0.799

RANGES OF STRESS-VOID RATIO SETTLEMENT PARAMETERS

	PROBABLE	-	MINIMUM
VERTICAL PRECONSOLIDATION STRESS	9.545 TSF	-	8.112 TSF
PRECONSOLIDATION STATE'S VOID RATIO................	0.764	-	0.766
OVERCONSOLIDATION RATIO (OCR)	14.613	-	12.419
COMPRESSION INDEX (CC)	-0.291	-	-0.279
SWELL EXPANSION INDEX (CS)	-0.030		

STRAIN ANALYSIS

INSITU VERTICAL STRESS = 0.653 TSF   INITIAL VOID RATIO (EO) = 0.799

RANGES OF STRESS-STRAIN SETTLEMENT PARAMETERS

	PROBABLE	-	MINIMUM
VERTICAL PRECONSOLIDATION STRESS	9.441 TSF	-	8.112 TSF
PRECONSOLIDATION STATE'S VERTICAL STRAIN	0.019	-	0.018
OVERCONSOLIDATION RATIO (OCR)	14.454	-	12.419
COMPRESSION RATIO (CR)	-0.161	-	-0.155
SWELL RATIO (SR)	-0.017		

INPUT DATA

TIME	DEFL. RDG.	P.P. RDG.	LOAD RDG.
1.	13.60	996.	901.
3.	13.59	996.	903.
4.	13.58	996.	904.
5.	13.57	996.	905.
6.	13.56	996.	907.
11.	13.53	996.	908.
12.	13.53	997.	910.
13.	13.52	997.	911.
15.	13.50	997.	914.
17.	13.47	997.	917.
19.	13.45	997.	920.
21.	13.42	998.	924.
23.	13.40	998.	928.
25.	13.37	998.	932.
27.	13.35	998.	936.
29.	13.33	998.	940.
31.	13.30	998.	945.
33.	13.27	999.	949.
35.	13.25	999.	954.
37.	13.22	999.	958.
40.	13.18	1000.	966.
43.	13.14	1002.	975.
50.	13.02	1006.	996.
53.	12.99	1007.	1003.
56.	12.95	1008.	1009.
59.	12.92	1010.	1015.
62.	12.89	1011.	1019.
65.	12.87	1010.	1023.
70.	12.83	1011.	1030.
75.	12.80	1012.	1034.
80.	12.77	1012.	1038.
85.	12.74	1012.	1042.
90.	12.71	1012.	1049.
96.	12.68	1014.	1052.
100.	12.66	1014.	1054.
105.	12.65	1013.	1056.
110.	12.62	1013.	1062.
115.	12.61	1013.	1063.
125.	12.58	1012.	1066.
130.	12.56	1012.	1072.
145.	12.53	1011.	1074.
150.	12.51	1011.	1079.
155.	12.49	1011.	1081.
165.	12.47	1011.	1083.
175.	12.45	1011.	1085.
185.	12.43	1011.	1088.
195.	12.41	1010.	1091.
205.	12.39	1010.	1095.
225.	12.36	1010.	1100.
235.	12.33	1010.	1103.
245.	12.31	1010.	1106.
255.	12.28	1010.	1111.
280.	12.25	1010.	1116.
295.	12.22	1010.	1119.
310.	12.19	1010.	1124.
325.	12.17	1010.	1128.
340.	12.15	1010.	1131.
355.	12.12	1010.	1135.

370.	12.10	1010.	1139.
390.	12.07	1010.	1143.
410.	12.04	1011.	1148.
430.	12.01	1011.	1152.
445.	11.99	1011.	1156.
460.	11.97	1011.	1159.
471.	11.96	1011.	1161.
508.	11.91	1011.	1169.
546.	11.87	1011.	1178.
584.	11.82	1011.	1186.
621.	11.78	1011.	1193.
659.	11.73	1011.	1200.
697.	11.70	1012.	1207.
734.	11.66	1012.	1214.
772.	11.63	1012.	1220.
810.	11.60	1012.	1226.
848.	11.56	1012.	1231.
885.	11.53	1012.	1237.
922.	11.50	1012.	1243.
960.	11.47	1012.	1249.
998.	11.44	1012.	1254.
1035.	11.41	1012.	1259.
1073.	11.39	1012.	1264.
1111.	11.37	1012.	1269.
1148.	11.34	1012.	1274.
1186.	11.32	1012.	1280.
1224.	11.30	1012.	1285.
1262.	11.28	1012.	1290.
1299.	11.26	1012.	1295.
1337.	11.23	1012.	1301.
1375.	11.21	1013.	1307.
1400.	11.20	1013.	1309.
1420.	11.19	1013.	1312.
1440.	11.18	1013.	1315.
1475.	11.15	1014.	1319.
1490.	11.15	1014.	1321.
1500.	11.14	1014.	1322.
1515.	11.13	1014.	1324.
1535.	11.12	1014.	1327.
1560.	11.11	1014.	1330.
1585.	11.09	1014.	1334.
1610.	11.08	1014.	1338.
1630.	11.07	1014.	1340.
1660.	11.05	1014.	1344.
1685.	11.04	1014.	1347.
1720.	11.01	1016.	1361.
1730.	11.00	1017.	1363.
1820.	10.95	1016.	1366.
1870.	10.92	1016.	1380.
1900.	10.90	1016.	1388.
1937.	10.88	1016.	1390.
1975.	10.86	1016.	1394.
2013.	10.84	1016.	1401.
2050.	10.82	1016.	1414.
2088.	10.79	1017.	1420.
2088.	10.77	1017.	1423.
2088.	10.75	1017.	1427.
2088.	10.73	1016.	1428.
2088.	10.72	1015.	1429.
2088.	10.72	1014.	1429.
2088.	10.71	1013.	1429.
2088.	10.70	1011.	1430.
2088.	10.70	1009.	1430.

2088.	10.69	1008.	1430.
2088.	10.69	1007.	1430.
2088.	10.68	1006.	1430.
2088.	10.68	1005.	1430.
2088.	10.68	1004.	1430.
2088.	10.68	1003.	1430.
2088.	10.68	1002.	1430.
2088.	10.67	1002.	1430.
2088.	10.67	1002.	1430.
2088.	10.67	1001.	1430.
2088.	10.67	1001.	1430.
2088.	10.67	1001.	1430.
2088.	10.67	1001.	1430.
2860.	10.67	1001.	1419.
2865.	10.67	1001.	1409.
2875.	10.68	1000.	1385.
2880.	10.68	1000.	1375.
2885.	10.68	1000.	1360.
2890.	10.68	999.	1348.
2895.	10.69	999.	1335.
2900.	10.69	998.	1323.
2905.	10.70	998.	1309.
2910.	10.70	998.	1293.
2915.	10.70	997.	1282.
2920.	10.71	997.	1271.
2925.	10.71	996.	1259.
2930.	10.72	996.	1246.
2935.	10.72	995.	1235.
2940.	10.73	995.	1220.
2945.	10.73	994.	1208.
2950.	10.74	993.	1195.
2955.	10.75	992.	1183.
2960.	10.76	991.	1168.
2965.	10.77	990.	1155.
2970.	10.78	989.	1144.
2975.	10.78	989.	1133.
2980.	10.79	988.	1118.
2985.	10.80	987.	1113.
2990.	10.81	987.	1107.
2995.	10.81	986.	1102.
3000.	10.82	986.	1096.
3005.	10.82	985.	1089.
3015.	10.83	985.	1083.
3025.	10.84	984.	1078.
3040.	10.85	983.	1070.
3055.	10.86	983.	1063.
3070.	10.87	983.	1056.
3090.	10.87	982.	1050.
3105.	10.88	982.	1043.
3125.	10.89	982.	1040.
3140.	10.89	982.	1037.
3155.	10.90	982.	1033.
3170.	10.90	982.	1030.
3190.	10.91	982.	1027.
3205.	10.91	982.	1024.
3220.	10.92	982.	1020.
3235.	10.92	982.	1017.
3255.	10.93	982.	1014.
3270.	10.93	982.	1010.
3285.	10.94	982.	1007.
3325.	10.95	981.	1003.
4440.	10.99	993.	995.

EFF. VERT. STRESS (TSF)	VOID RATIO	VERT. STRAIN (IN/IN)	TIME(MIN)
0.11998	0.79869	0.00000	1.00000
0.23996	0.79800	0.00038	3.00000
0.29995	0.79731	0.00077	4.00000
0.35995	0.79662	0.00115	5.00000
0.47993	0.79592	0.00154	6.00000
0.53992	0.79385	0.00269	11.00000
0.65190	0.79385	0.00269	12.00000
0.71189	0.79316	0.00308	13.00000
0.89186	0.79177	0.00385	15.00000
1.07183	0.78970	0.00500	17.00000
1.25181	0.78831	0.00577	19.00000
1.48377	0.78624	0.00692	21.00000
1.72374	0.78485	0.00769	23.00000
1.96370	0.78278	0.00885	25.00000
2.20366	0.78140	0.00962	27.00000
2.44363	0.78001	0.01038	29.00000
2.74358	0.77794	0.01154	31.00000
2.97555	0.77586	0.01269	33.00000
3.27550	0.77448	0.01346	35.00000
3.51547	0.77240	0.01462	37.00000
3.98739	0.76964	0.01615	40.00000
4.51131	0.76687	0.01769	43.00000
5.73912	0.75857	0.02231	50.00000
6.15106	0.75649	0.02346	53.00000
6.50301	0.75372	0.02500	56.00000
6.84695	0.75165	0.02615	59.00000
7.07891	0.74957	0.02731	62.00000
7.32688	0.74819	0.02808	65.00000
7.73881	0.74542	0.02962	70.00000
7.97078	0.74335	0.03077	75.00000
8.21074	0.74127	0.03192	80.00000
8.45071	0.73920	0.03308	85.00000
8.87065	0.73712	0.03423	90.00000
9.03462	0.73505	0.03538	96.00000
9.15460	0.73366	0.03615	100.00000
9.28258	0.73297	0.03654	105.00000
9.64252	0.73089	0.03769	110.00000
9.70252	0.73020	0.03808	115.00000
9.89048	0.72813	0.03923	125.00000
10.25041	0.72674	0.04000	130.00000
10.37838	0.72467	0.04115	145.00000
10.67833	0.72328	0.04192	150.00000
10.79833	0.72190	0.04269	155.00000
10.91829	0.72052	0.04346	165.00000
11.03827	0.71913	0.04423	175.00000
11.21827	0.71775	0.04500	185.00000
11.40623	0.71637	0.04577	195.00000
11.64619	0.71498	0.04654	205.00000
11.94614	0.71291	0.04769	225.00000
12.12613	0.71083	0.04885	235.00000
12.30610	0.70945	0.04962	245.00000
12.60603	0.70737	0.05077	265.00000
12.90601	0.70530	0.05192	280.00000
13.08597	0.70322	0.05308	295.00000
13.38594	0.70115	0.05423	310.00000

13.62590	0.69976	0.05500	325.00000
13.80585	0.69838	0.05577	340.00000
14.04581	0.69630	0.05692	355.00000
14.28579	0.69492	0.05769	370.00000
14.52576	0.69284	0.05885	390.00000
14.81771	0.69077	0.06000	410.00000
15.05768	0.68869	0.06115	430.00000
15.29765	0.68731	0.06192	445.00000
15.47761	0.68593	0.06269	460.00000
15.59757	0.68524	0.06308	471.00000
16.07750	0.68178	0.06500	508.00000
16.61739	0.67901	0.06654	546.00000
17.09732	0.67555	0.06846	584.00000
17.51726	0.67278	0.07000	621.00000
17.93719	0.66932	0.07192	659.00000
18.34912	0.66725	0.07308	697.00000
18.76909	0.66448	0.07462	734.00000
19.12900	0.66241	0.07577	772.00000
19.48898	0.66033	0.07692	810.00000
19.78891	0.65756	0.07846	848.00000
20.14886	0.65549	0.07962	885.00000
20.50879	0.65341	0.08077	922.00000
20.86877	0.65134	0.08192	960.00000
21.16873	0.64926	0.08308	998.00000
21.46867	0.64719	0.08423	1035.00000
21.76860	0.64580	0.08500	1073.00000
22.06859	0.64442	0.08577	1111.00000
22.36850	0.64234	0.08692	1148.00000
22.72847	0.64096	0.08769	1186.00000
23.02844	0.63958	0.08846	1224.00000
23.32837	0.63819	0.08923	1262.00000
23.62833	0.63681	0.09000	1299.00000
23.98828	0.63473	0.09115	1337.00000
24.34024	0.63335	0.09192	1375.00000
24.46021	0.63266	0.09231	1400.00000
24.64021	0.63197	0.09269	1420.00000
24.82018	0.63127	0.09308	1440.00000
25.06010	0.62920	0.09423	1475.00000
25.17206	0.62920	0.09423	1490.00000
25.23206	0.62851	0.09462	1500.00000
25.35208	0.62782	0.09500	1515.00000
25.53203	0.62712	0.09538	1535.00000
25.71202	0.62643	0.09577	1560.00000
25.95197	0.62505	0.09654	1585.00000
26.19196	0.62436	0.09692	1610.00000
26.31192	0.62366	0.09731	1630.00000
26.55186	0.62228	0.09808	1660.00000
26.73187	0.62159	0.09846	1685.00000
27.55574	0.61951	0.09962	1720.00000
27.66774	0.61882	0.10000	1730.00000
27.85568	0.61536	0.10192	1820.00000
28.69559	0.61329	0.10308	1870.00000
29.17549	0.61190	0.10385	1900.00000
29.29547	0.61052	0.10462	1937.00000
29.53545	0.60914	0.10538	1975.00000
29.95537	0.60775	0.10615	2013.00000
30.73523	0.60637	0.10692	2050.00000
31.08717	0.60429	0.10808	2088.00000
31.08717	0.60429	0.10808	2088.00000
31.08717	0.60429	0.10808	2088.00000
31.08717	0.60429	0.10808	2088.00000
31.08717	0.60429	0.10808	2088.00000
31.08717	0.60429	0.10808	2088.00000

31.08717	0.60429	0.10808	2088.00000
31.08717	0.60429	0.10808	2088.00000
31.08717	0.60429	0.10808	2088.00000
31.08717	0.60429	0.10808	2088.00000
31.08717	0.60429	0.10808	2088.00000
31.08717	0.60429	0.10808	2088.00000
31.08717	0.60429	0.10808	2088.00000
31.08717	0.60429	0.10808	2088.00000
31.08717	0.60429	0.10808	2088.00000
31.08717	0.60429	0.10808	2088.00000
31.08717	0.60429	0.10808	2088.00000
31.08717	0.60429	0.10808	2088.00000
31.08717	0.60429	0.10808	2088.00000
31.08717	0.60429	0.10808	2088.00000
31.08717	0.60429	0.10808	2088.00000
31.08717	0.60429	0.10808	2088.00000
31.15517	0.59599	0.11269	2860.00000
30.55528	0.59599	0.11269	2865.00000
29.12352	0.59668	0.11231	2875.00000
28.52357	0.59668	0.11231	2880.00000
27.62372	0.59668	0.11231	2885.00000
26.91187	0.59668	0.11231	2890.00000
26.13197	0.59738	0.11192	2895.00000
25.42009	0.59738	0.11192	2900.00000
24.58022	0.59807	0.11154	2905.00000
23.62033	0.59807	0.11154	2910.00000
22.96844	0.59807	0.11154	2915.00000
22.30856	0.59876	0.11115	2920.00000
21.59666	0.59876	0.11115	2925.00000
20.81679	0.59945	0.11077	2930.00000
20.16489	0.59945	0.11077	2935.00000
19.26503	0.60014	0.11038	2940.00000
18.55313	0.60014	0.11038	2945.00000
17.78127	0.60084	0.11000	2950.00000
17.06937	0.60153	0.10962	2955.00000
16.17751	0.60222	0.10923	2960.00000
15.40566	0.60291	0.10885	2965.00000
14.75375	0.60360	0.10846	2970.00000
14.09385	0.60360	0.10846	2975.00000
13.20197	0.60429	0.10808	2980.00000
12.91004	0.60499	0.10769	2985.00000
12.55007	0.60568	0.10731	2990.00000
12.25814	0.60568	0.10731	2995.00000
11.89818	0.60637	0.10692	3000.00000
11.48624	0.60637	0.10692	3005.00000
11.12629	0.60706	0.10654	3015.00000
10.83434	0.60775	0.10615	3025.00000
10.36241	0.60845	0.10577	3040.00000
9.94252	0.60914	0.10538	3055.00000
9.52258	0.60983	0.10500	3070.00000
9.17064	0.60983	0.10500	3090.00000
8.75070	0.61052	0.10462	3105.00000
8.57072	0.61121	0.10423	3125.00000
8.39075	0.61121	0.10423	3140.00000
8.15078	0.61190	0.10385	3155.00000
7.97081	0.61190	0.10385	3170.00000
7.79085	0.61260	0.10346	3190.00000
7.61087	0.61260	0.10346	3205.00000
7.37091	0.61329	0.10308	3220.00000
7.19093	0.61329	0.10308	3235.00000
7.01096	0.61398	0.10269	3255.00000
6.77100	0.61398	0.10269	3270.00000
6.59103	0.61467	0.10231	3285.00000
6.35906	0.61536	0.10192	3325.00000
5.78313	0.61813	0.10038	4440.00000

ADDITIONAL INPUT DATA

CALIBRATION FACTORS:
DEFLECTION = C.03937 LOAD = 4.09000 PRESSURE = 0.16667

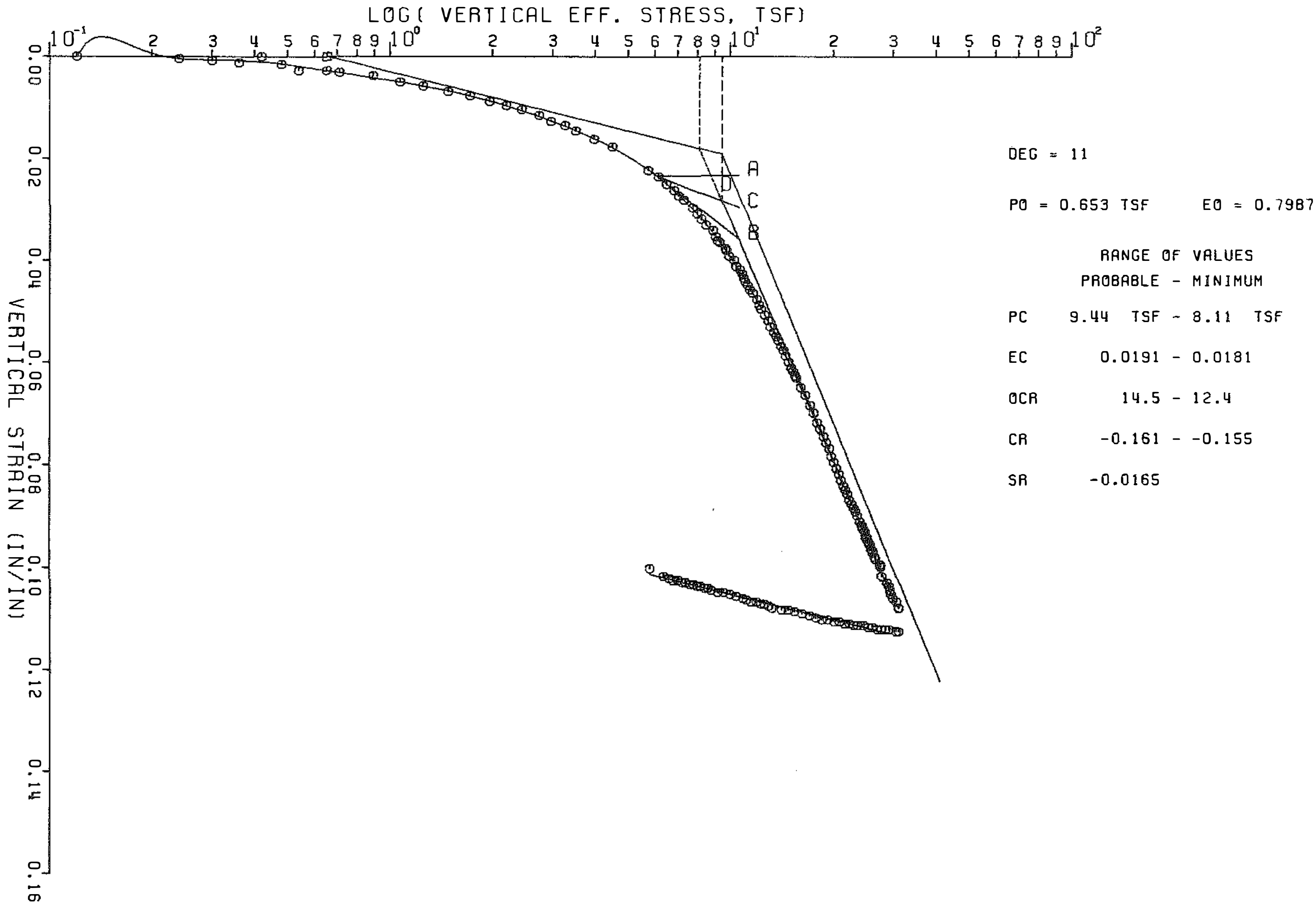
EQUIPMENT ZERO READINGS:
DEFLECTION = 13.000 LOAD = 899.000 PORE PRESSURE =996.0000

DIAMETER OF SPECIMEN = 2.500 INCHES INITIAL HEIGHT OF SAMPLE = 1.000 INCHES

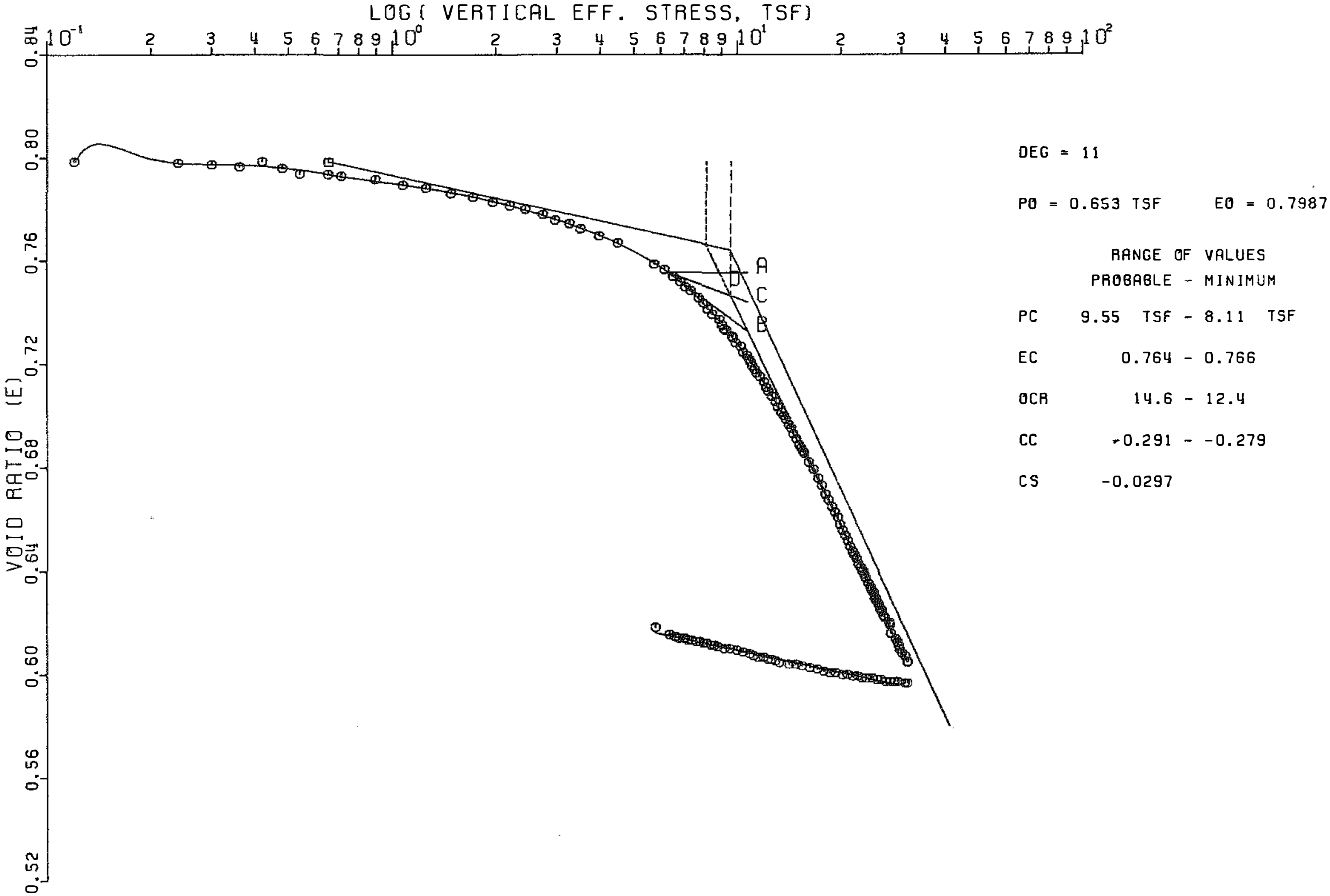
```
CORE USAGE        OBJECT CODE=   59952 BYTES,ARRAY AREA=  116648 BYTES,TOTAL AREA AVAILABLE=  190464  BYTES
DIAGNOSTICS        NUMBER OF ERRORS=       0, NUMBER OF WARNINGS=       0, NUMBER OF EXTENSIONS=       0
COMPILE TIME=     1.50 SEC,EXECUTION TIME=     4.12 SEC,      8.35.03    FRIDAY       18 MAR 77    WATFIV - JAN 1976 V1L5

        $STOP
```

CG-13 ELIZABETHTOWN H-3 S-2B 2.5 PSI



CG-13 ELIZABETHTOWN H-3 S-2B 2.5 PSI



APPENDIX C

COMPUTER SYSTEM DESCRIPTION

COMPUTER SYSTEM DESCRIPTION

Computer	
Manufacturer	IBM
Model number	System/370 Model 165 II
Word length	Single Precision - 4 bytes, 32 bits
	Double Precision - 8 bytes, 64 bits
Core access speed	700 nano seconds
Virtual storage	16 mega bytes (maximum)
Peripheral Equipment	
Line printers	IBM/3211 Chain Printers
	IBM/2821-5 I/0 Control Unit
Card readers	IBM/3505 Card Reader
Card punch	IBM/029 Card Key Punch
Magnetic tape drives	IBM Tape Unit 2401 processes tapes at 75 inches/second
	Uses 800 bytes per inch density magnetic tape
	Processes 60,000 bytes/second
	Uses either 9 or 7 track tapes
Plotters	Calcomp 663 Digital Incremental Drum Plotter

Source Program's Storage Requirements

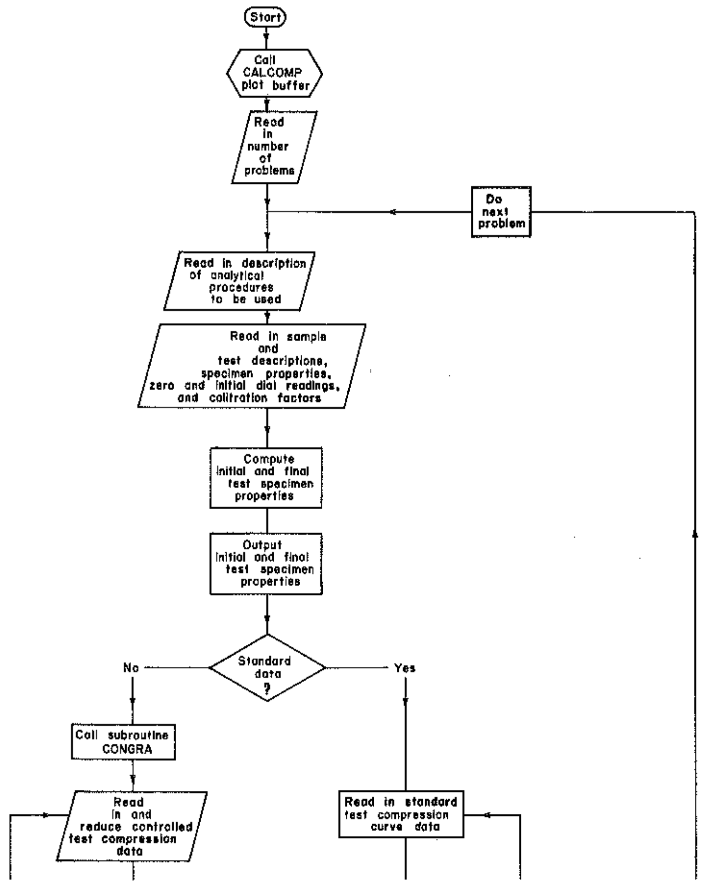
Total storage requirements of program around 268^k

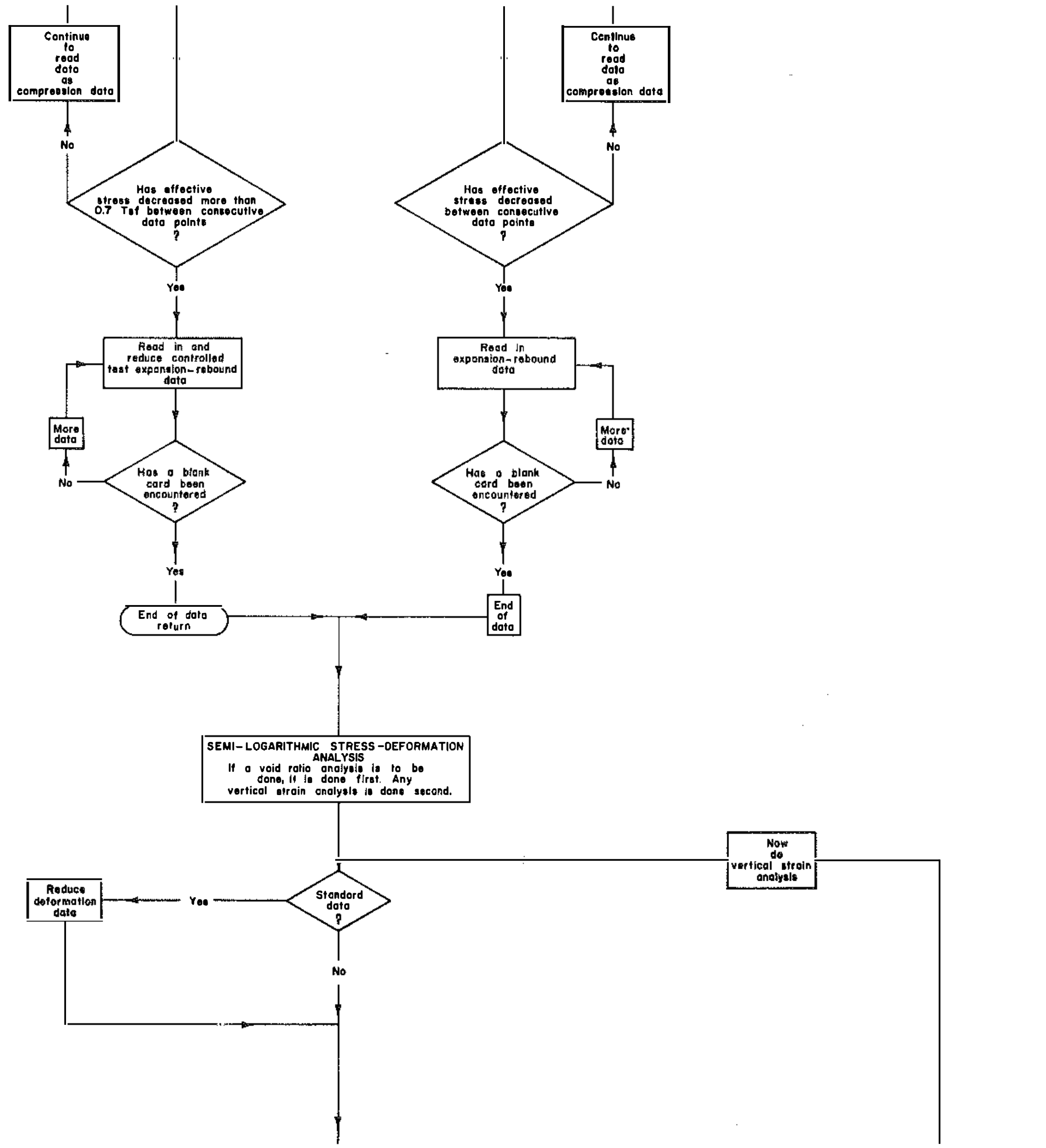
MAIN	42556
ANARAD	44760
GRARAD	4490
CASPLT	15308
CONSGRA	5858
FLSQFY	958
FGEFYT	1904
FCODA	928

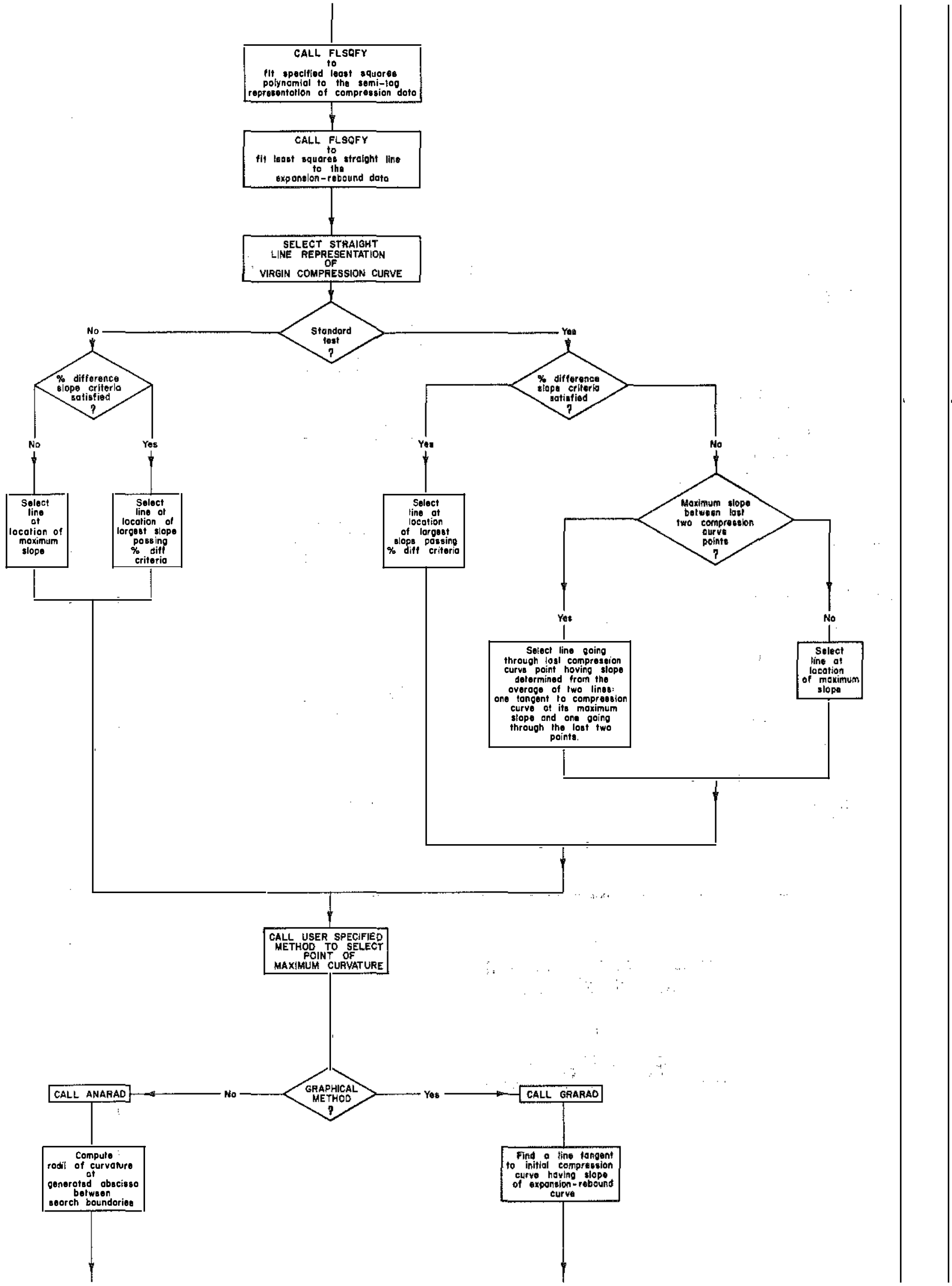
Plot buffer - up to 74^k

APPENDIX D

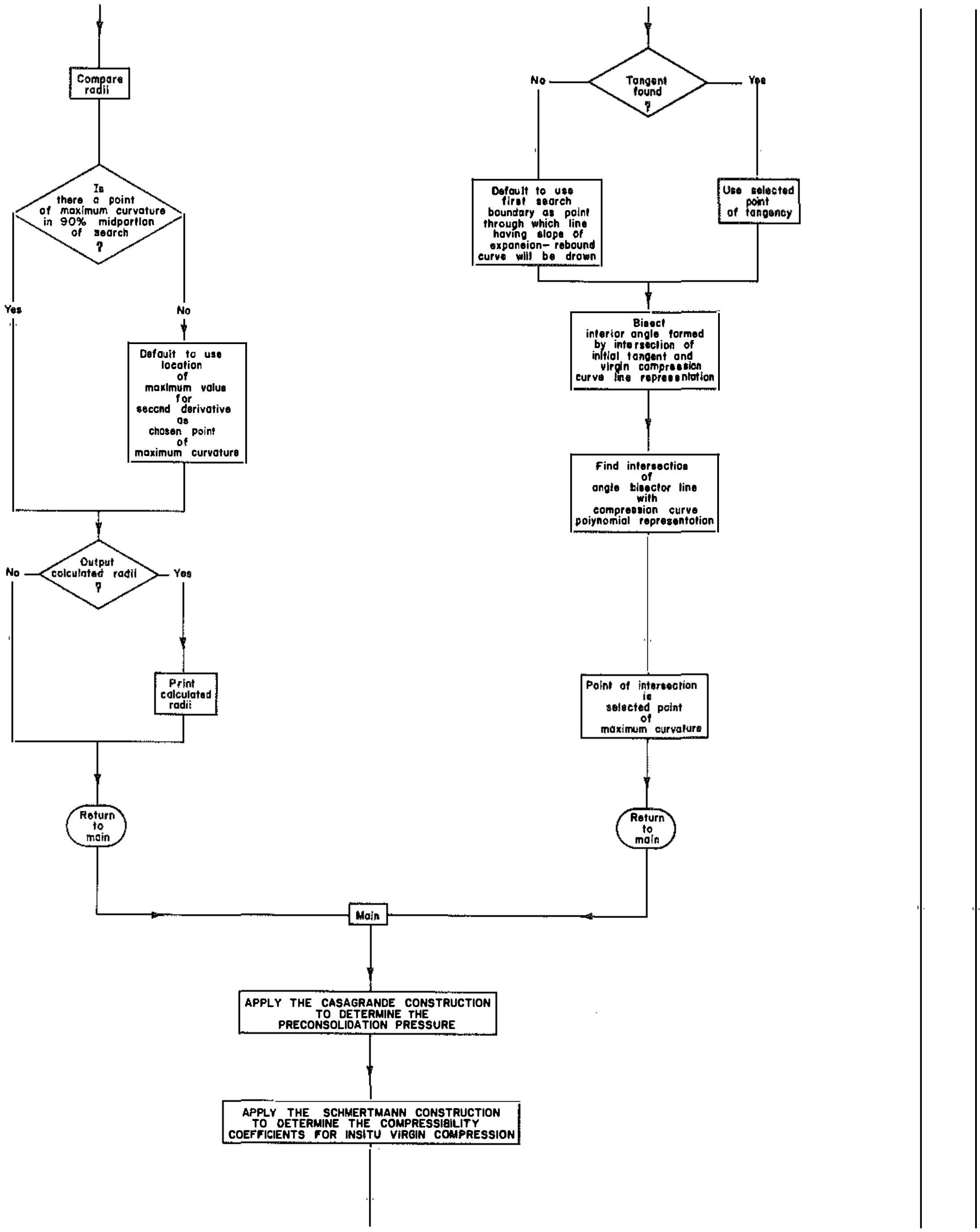
FLOW CHART

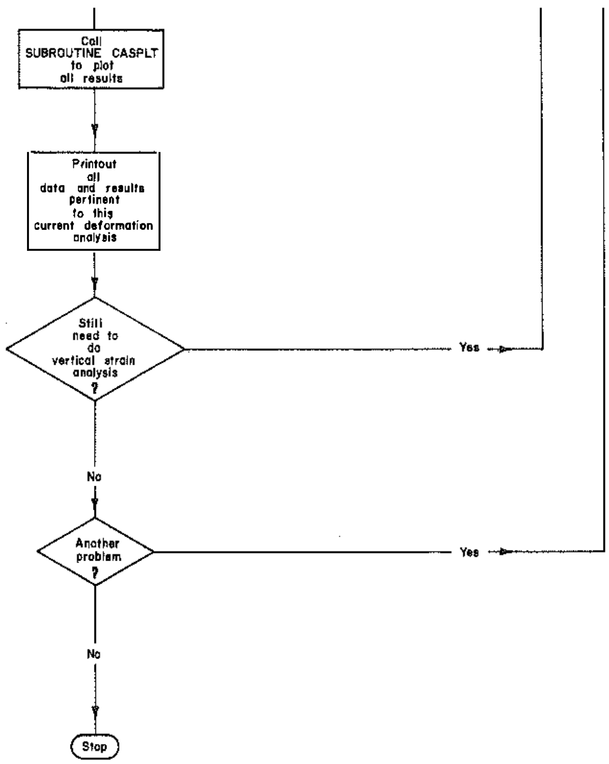

Start
Call CALCOMP plot buffer
Read in number of problems
Do next problem
Read in description of analytical procedures to be used
Read in sample and test descriptions, specimen properties, zero and initial dial readings, and calibration factors
Compute initial and final test specimen properties
Output initial and final test specimen properties
Standard data ?
No
Yes
Call subroutine CONGRA
Read in and reduce controlled test compression data
Read in standard test compression curve data


Continue to read data as compression data
No
Has effective stress decreased more than 0.7 Tsf between consecutive data points ?
Yes
Read in and reduce controlled test expansion-rebound data
More data
No
Has a blank card been encountered ?
Yes
End of data return
Continue to read data as compression data
No
Has effective stress decreased between consecutive data points ?
Yes
Read in expansion-rebound data
More data
No
Has a blank card been encountered ?
Yes
End of data
SEMI-LOGARITHMIC STRESS-DEFORMATION ANALYSIS
If a void ratio analysis is to be done, it is done first. Any vertical strain analysis is done second.
Now do vertical strain analysis
Reduce deformation data
Yes
Standard data ?
No



CALL FLSQFY to fit specified least squares polynomial to the semi-log representation of compression data
CALL FLSQFY to fit least squares straight line to the expansion-rebound data
SELECT STRAIGHT LINE REPRESENTATION OF VIRGIN COMPRESSION CURVE
Standard test ?
No
Yes
% difference slope criteria satisfied ?
No
Yes
Select line at location of maximum slope
Select line at location of largest slope passing % diff criteria
% difference slope criteria satisfied ?
Yes
No
Select line at location of largest slope passing % diff criteria
Maximum slope between last two compression curve points ?
Yes
No
Select line going through last compression curve point having slope determined from the average of two lines: one tangent to compression curve at its maximum slope and one going through the last two points.
Select line at location of maximum slope
CALL USER SPECIFIED METHOD TO SELECT POINT OF MAXIMUM CURVATURE
GRAPHICAL METHOD ?
No
Yes
CALL ANARAD
CALL GRARAD
Compute radii of curvature at generated abscissa between search boundaries
Find a line tangent to initial compression curve having slope of expansion-rebound curve


Compare radii
Is there a point of maximum curvature in 90% midportion of search ?
Yes
No
Default to use location of maximum value for second derivative as chosen point of maximum curvature
Output calculated radii ?
No
Yes
Print calculated radii
Return to main
Tangent found ?
No
Yes
Default to use first search boundary as point through which line having slope of expansion– rebound curve will be drawn
Use selected point of tangency
Bisect interior angle formed by intersection of initial tangent and virgin compression curve line representation
Find intersection of angle bisector line with compression curve polynomial representation
Point of intersection is selected point of maximum curvature
Return to main
Main
APPLY THE CASAGRANDE CONSTRUCTION TO DETERMINE THE PRECONSOLIDATION PRESSURE
APPLY THE SCHMERTMANN CONSTRUCTION TO DETERMINE THE COMPRESSIBILITY COEFFICIENTS FOR INSITU VIRGIN COMPRESSION


Call
SUBROUTINE CASPLT
to plot
all results
Printout
all
data and results
pertinent
to this
current deformation
analysis
Still
need to
do
vertical strain
analysis
?
Yes
No
Another
problem
?
Yes
No
Stop

APPENDIX E

CASAGR-O COMPUTER PROGRAM

```
C           ********************************************
C           *                                          *
C           *                                          *
C           *              CASAGR - 0                  *
C           *                                          *
C           *                                          *
C           *         1ST VERSION, MAY 1976            *
C           *                                          *
C           *        UPDATES, VERSIONS: NONE           *
C           *                                          *
C           *                                          *
C           ********************************************
C           *                                          *
C           *                                          *
C           *         COMPUTER APPLICATION             *
C           *                                          *
C           *                OF THE                    *
C           *                                          *
C           *      CASAGRANDE AND SCHMERTMANN          *
C           *                                          *
C           *            CONSTRUCTIONS                 *
C           *                                          *
C           *                                          *
C           *                  BY                      *
C           *                                          *
C           *                                          *
C           *        EDMUND GREGORY MCNULTY            *
C           *                                          *
C           *                                          *
C           ********************************************
C           *                                          *
C           *      THIS COMPUTER PROGRAM EMPLOYS A     *
C           *   MATHEMATICAL ALGORITHM TO ANALYZE      *
C           *   THE SEMI-LOGARITHMIC REPRESENTATION    *
C           *   OF THE TIME INDEPENDENT STRESS-        *
C           *   DEFORMATION CURVES FOR THE CON-        *
C           *   VENTIONAL, CONTROLLED GRADIENT,        *
C           *   AND CONTROLLED RATE OF STRAIN CON-     *
C           *   SOLIDATION TESTS.  THE CASAGRANDE      *
C           *   AND SCHMERTMANN CONSTRUCTIONS ARE      *
C           *   EMPLOYED TO DETERMINE THE PRECON-      *
C           *   SOLIDATION PRESSURE AND THE COEFFI-    *
C           *   CIENTS OF COMPRESSIBILITY FOR THE      *
C           *   COMPRESSION AND EXPANSION-REBOUND      *
C           *   DATA CURVES.                           *
C           *                                          *
C           ********************************************
C           *                                          *
C           *                                          *
```

```
C            *                                                       *
C            *                                                       *
C   ****************************************************************
C
C       THIS PROGRAM IS WRITTEN IN FORTRAN IV AND PRODUCES PLOT-
C  TED OUTPUT USING THE IBM 370/165 II AND CALCOMP 663 DRUM PLOTTER.
C  THIS PROGRAM WAS DEVELOPED BY
C
C              THE KENTUCKY DEPARTMENT OF TRANSPORTATION
C
C
C                         BUREAU OF HIGHWAYS
C
C                        DIVISION OF RESEARCH
C                           SOILS SECTION
C                        533 S. LIMESTONE ST.
C                        LEXINGTON, KENTUCKY
C                               40508
C                       PH. 606 254-4475 EXT 28
C
C
C   ****************************************************************
C
C
C     AVAILABILITY OF THE PROGRAM'S CARD DECK AND/OR LISTING WILL
C  BE CONSIDERED ON THE MERITS OF EACH INDIVIDUAL INQUIRY.  THE USER
C  IS TOTALLY RESPONSIBLE FOR THE RESULTS DERIVED FROM THIS
C  PROGRAM'S USE.
C
C     THIS PROGRAM HAS THE CAPABILITY OF EMPLOYING A VOID RATIO
C  AND/OR VERTICAL STRAIN DEFORMATION ANALYSIS.  ALSO, THE PROGRAM
C  PROVIDES FOR THE SPECIFICATION OF CALIBRAION FACTORS COMMONLY USED
C  AND A MEANS OF MATCHING A DIAL GAUGE'S INCREASING DIAL READINGS
C  WITH INCREASING DOWNWARD DEFLECTION.
C
C     THE PROGRAM ALSO DETERMINES THE INITIAL AND FINAL TEST
C  PROPERTIES OF THE CONSOLIDATION TEST SPECIMEN.
C
C     THE METHOD OF ANALYSIS IS BASED ON A LEAST SQUARES CURVE
C  FITTING SCHEME BY ORDINARY POLYNOMIALS.  THE COMPRESSION CURVE
C  DATA IS FITTED WITH A USER SPECIFIED POLYNOMIAL OF UP TO THE
C  ELEVENTH DEGREE.  THE EXPANSION-REBOUND CURVE DATA IS FITTED
C  WITH A LEAST SQUARES STRAIGHT LINE.  USING THE MATHEMATICAL
C  CHARACTERISTICS OF THESE TWO FUNCTIONS, THE CASAGRANDE AND
C  SCHMERTMANN CONSTRUCTIONS ARE EMPLOYED.
C
C     THE POINT OF MAXIMUM CURVATURE FOR CASAGRANDE'S CONSTRUCTION
C  MAY BE DETERMINED BY TWO COMPLETELY DIFFERENT METHODS.  THE
C  ANALYTICAL METHOD USES THE MATHEMATICAL DEFINITION OF THE RADIUS
C  OF CURVATURE TO SELECT THE POINT OF MAXIMUM CURVATURE.  THE
C  GRAPHICAL METHOD IS A NEWLY PROPOSED METHOD WHICH USES THE
C  GEOMETRICAL CHARACTERISTICS OF THE CONSOLIDATION CURVES TO
C  SELECT THE POINT OF MAXIMUM CURVATURE.
C
C     DATA POINTS, FITTED CURVES, AND THE INTERMEDIATE
C  CONSTRUCTIONS INVOLVED IN THE CASAGRANDE AND SCHMERTMANN
C  PROCEDURES ARE SHOWN IN THE PLOTTED OUTPUT ALONG WITH THE
C  FINAL RESULTS.
C
C
```

```
C    ******************************************************************
C
C      THE PROGRAM USES THE FOLLOWING SUBROUTINES AND COMPUTER
C   SUPPLIED BUFFERS:
C
C          1.  MAIN PROGRAM
C
C          2.  SUBROUTINE CONGRA - INPUT AND REDUCTION OF
C                                  CONTROLLED CONSOLIDATION
C                                  DATA.
C
C          3.  SUBROUTINE FLSQFY - LEAST SQUARES CURVE
C                                  FITTING BY ORDINARY
C                                  POLYNOMIALS.
C
C          4.  SUBROUTINE GRARAD - GRAPHICAL METHOD TO
C                                  DETERMINE POINT OF MAX
C                                  CURVATURE.
C
C          5.  SUBROUTINE ANARAD - ANALYTICAL METHOD TO
C                                  DETERMINE POINT OF MAX
C                                  CURVATURE.
C
C          6.  SUBROUTINE CASPLT - PLOTTING OF RESULTS
C
C          7.  SUBROUTINE PLOTS  - SETS UP PLOT LIBRARY
C                                  BUFFER FOR IBM 370/165 II
C                                  COMPUTER.
C
C          8.  PLOT LIBRARY SUBROUTINES:  AXIS
C                                         DASHLN
C                                         LINE
C                                         LOGAXS
C                                         NUMBER
C                                         PLOT
C                                         SCALE
C                                         SYMBOL
C
C          9.  LIBRARY FUNCTIONS: ABS
C                                 ATAN
C                                 ASIN
C                                 DSQRT
C                                 SIN
C                                 TAN
C
C    ******************************************************************
C
C      POSSIBLE DIFFICULTIES WITH RESULTS:
C
C      1)  IF UNDULATIONS PRESENT IN FITTED CURVE;
C
C         POSSIBLE CAUSES:  - LOW DEGREE POLYNOMIAL LIMITATION DUE
C                             TO FEW DATA POINTS.  IF THIS IS
C                             THE CASE, THE ONLY POSSIBLE COURSE
C                             OF ACTION IS TO TRY A LOWER
C                             DEGREE POLYNOMIAL.
C
C                             HARD TO FIT DATA, EITHER SCATTERED
C                             DATA OR SHAPE CHARACTERISTICS OF DATA
C                             TOO EXTREME TO BE FITTED BY A POLYNOMIAL.
```

```
C
C                             - TOO LOW A DEGREE POLYNOMIAL, USE HIGHEST
C                               POSSIBLE DEGREE.
C
C      2)  IF POINT OF MAXIMUM CURVATURE DOES NOT EXIST WHEN ANALYTICAL
C          METHOD IS USED;
C
C         POSSIBLE CAUSES:    - SEARCH BOUNDARIES NEED TO BE CHANGED.
C
C                             - POINT OF MAX CURVATURE NOT WELL ENOUGH
C                               DEFINED TO BE ANALYTICALLY DETERMINED.
C
C                             - SIMPLY DOES NOT EXIST.
C                               POSSIBLE SOLUTION IS TO USE GRAPHICAL
C                               METHOD.
C
C   ******************************************************************
C
C
C
C *********************************************************************
C
C                          VARIABLE DEFINITIONS
C
C *********************************************************************
C
C A
C     HORIZONTAL PEN POSITION AT WHICH LETTER 'A' IS PLOTTED.  THIS
C     VARIABLE IS COMPUTED IN SUBROUTINE CASPLT.
C
C ALPHA( )
C     SCRATCH ARRAY FOR SUBROUTINE FLSQFY.
C
C AR
C     AREA OF TEST SPECIMEN IN INCHES.
C
C AY
C     SEE CEPTA.
C
C B
C     HORIZONTAL PEN POSITION AT WHICH LETTER 'B' IS PLOTTED.
C
C B( )
C     INCREMENTAL ABSCISSAE GENERATED ON THE FITTED POLYNOMIAL IN
C     SEARCHING FOR THE VIRGIN COMPRESSION CURVE.
C
C BCD 20A4
C     PLOT TITLE AND COMPUTER PRINTOUT HEADING.
C
C BETA( )
C     SCRATCH ARRAY FOR SUBROUTINE FLSQFY.
C
C BISECT( )
C     STORAGE LOCATION OF GENERATED INCREMENTAL ORDINATES USED IN
C     PLOTTING THE LINE REPRESENTING THE ANGLE BISECTOR USED IN THE
C     GRAPHICAL METHOD TO SELECT THE POINT OF MAXIMUM CURVATURE.
C
C BIG
C     THE SELECTED SLOPE FOR THE LINE REPRESENTATION OF THE VIRGIN COM-
C     PRESSION CURVE.
```

```
C
C BOUND
C     TEMPORARY STORAGE LOCATION FOR BOUND1 IN SUBROUTINE GRARAD.
C
C BOUND1, B1
C BOUND2, B2
C BOUND3, B3
C BOUND4, B4
C BOUND5, B5
C BOUND6, B6
C     BOUNDARIES 1 AND 2 ARE ABSCISSA SEARCH BOUNDARIES FOR POINT OF
C     MAXIMUM CURVATURE.  BOUNDARIES 3 AND 4 ARE ABSCISSA SEARCH BOUND-
C     ARIES FOR THE SELECTION OF LINE REPRESENTATION OF THE VIRGIN COM-
C     PRESSION CURVE.  BOUNDARIES 5 AND 6 ARE GENERALLY USED AS
C     TEMPORARY STORAGE LOCATIONS FOR BOUND1 AND BOUND2 IN SUBROUTINE
C     ANARAD.
C
C BOVER( )
C     STORAGE VARIABLE FOR THE LOGARITHM, BASE TEN, OF THE OVERBURDEN
C     PRESSURE AND THE ARGUMENTS NEEDED IN PLOTTING THE OVERBURDEN
C     PRESSURE.
C
C BP
C     BACK PRESSURE.
C
C BY
C     VERTICAL INTERCEPT AT THE ZERO ABSCISSA OF LINE 'B'.
C
C B1 = B( )
C B2 = B( )**2
C B3 = B( )**3
C B4 = B( )**4
C B5 = B( )**5
C B6 = B( )**6
C B7 = B( )**7
C B8 = B( )**8
C B9 = B( )**9
C B10 = B( )**10
C     VARIABLES USED TO SET UP THE TERMS OF THE SPECIFIED POLYNOMIAL FOR
C     PAIRING WITH THEIR RESPECTIVE COEFFICIENTS.  THE RESULTANT
C     EQUATION IS USED TO COMPUTE THE SLOPE AT EACH OF THE GENERATED
C     ABSCISSA.
C
C C( )
C     COEFFICIENT VARIABLE USED FOR SETTING UP ALL POLYNOMIAL EQUATIONS.
C
C CC( )
C     COEFFICIENT ARRAY USED FOR STORING THE COEFFICIENTS OF THE COM-
C     PRESSION DATA'S FITTED POLYNOMIAL.
C
C CC1
C     COMPRESSION INDEX AS DETERMINED BY SCHMERTMANN'S CONSTRUCTION.
C
C CEPTA
C CEPTB
C CEPTBI
C CEPTC
C CEPTD
C CEPTE
C CEPTF
```

```
C CEPTG
C CEPTAN
C      VERTICAL INTERCEPTS AT THE ZERO ABSCISSA FOR LINES A, B, BISCECT,
C      C, D, E, F, G, AND TANGEN RESPECTIVELY.
C
C CHECK
C      USED TO CHECK IF PERCENT DIFFERENCE CRITERIA FOR SLOPE CONSTANCY
C      HAS BEEN SATISFIED.  IF CHECK IS NOT SET EQUAL TO ONE, THE PERCENT
C      DIFFERENCE CRITERIA HAS NOT BEEN SATISFIED AND THE MAXIMUM SLOPE
C      FOUND IS USED.
C
C CR
C      COMPRESSION RATIO.
C
C CRMIN
C      MINIMUM VALUE OF COMPRESSION RATIO OR COMPRESSION INDEX ( I.E.
C      THE SLOPE OF LABORATORY VIRGIN CURVE, LINED).
C
C CS
C      SWELL-EXPANSION-REBOUND COEFFICIENT.
C
C CSEVT( )
C      DUMMY VARIABLE USED PRIMARILY FOR STORAGE OF VOID RATIOS OF COM-
C      PRESSION CURVE DATA POINTS PRIOR TO OUTPUT.
C
C CSEVTE( )
C      DUMMY VARIABLE USED PRIMARILY FOR STORAGE OF VOID RATIOS OF
C      REBOUND-EXPANSION DATA POINTS PRIOR TO OUTPUT.
C
C CURVE( )
C      COMPUTED ORDINATES AT THE GENERATED ABSCISSA LOCATIONS ALONG THE
C      COMPRESSION CURVE'S FITTED POLYNOMIAL.
C
C CURVFT( )
C      COMPUTED ORDINATES OF THE FITTED POLYNOMIAL WHICH ARE USED FOR
C      PLOTTING PURPOSES.
C
C CX
C      HORIZONTAL PEN POSITION AT WHICH THE LETTER 'C' IS PLOTTED.  THIS
C      VARIABLE IS COMPUTED IN SUBROUTINE CASPLT.
C
C CY
C      VERTICAL INTERCEPT OF LINE 'C' AT THE ZERO ABSCISSA.
C
C D
C      HORIZONTAL PEN POSITION AT WHICH THE LETTER 'D' IS PLOTTED.  THIS
C      VARIABLE IS COMPUTED IN SUBROUTINE CASPLT.
C
C DASH( )
C      GENERATED ABSCISSA VALUES WHICH WILL BE USED IN PLOTTING DASHED
C      LINES.
C
C DASHY( )
C      GENERATED ORDINATE VALUES WHICH WILL BE USED IN PLOTTING DASHED
C      LINES.
C
C DAT( ) 3A4
C      TEST DATE.
C
C DATA( )
```

```
C     PRINCIPLE SCRATCH ARRAY USED FOR PLOTTING PURPOSES.
C
C DCF
C     DEFLECTION CALIBRATION FACTOR.
C
C DEFF
C     FINAL DEFLECTION READING TAKEN AT END OF TEST.
C
C DEFI
C     INITIAL DEFLECTION READING TAKEN JUST BEFORE START OF TEST.
C
C DEFR( )
C     DEFLECTION READING ARRAY OF COMPRESSION DATA FROM CONTROLLED CON-
C     SOLIDATION TESTS.
C
C DEFRE( )
C     DEFLECTION READING ARRAY OF EXPANSION-REBOUND DATA FROM CONTROLLED
C     CONSOLIDATION TESTS.
C
C DEFZ
C     DIAL READING TAKEN WHEN SAMPLE IS AT ITS INITIAL HEIGHT.
C
C DELLOG
C     PORTION OF LOG CYCLE PER INCH OF PLOT PAPER.  IN PLOTTING SUB-
C     PROGRAM CASPLT, DELLOG IS SET EQUAL TO 0.300 FOR THREE LOG CYCLES
C     OVER TEN INCHES OF PAPER.
C
C DELTA
C     INCREMENT TO BE USED IN GENERATION OF EVENLY SPACED VALUES OF A
C     GIVEN PARAMETER.
C
C DES 4A4
C     SAMPLE DESCRIPTION.
C
C DFLI( )
C     CALCULATED DEFLECTION IN INCHES FOR CONTROLLED CONSOLIDATION TEST
C     COMPRESSION DATA.
C
C DFLIE( )
C     CALCULATED DEFLECTION IN INCHES FOR CONTROLLED CONSOLIDATION TEST
C     EXPANSION-REBOUND DATA.
C
C DIA
C     DIAMETER OF CONSOLIDATION TEST SPECIMEN IN INCHES.
C
C DIFF
C     PERCENT DIFFERENCE BETWEEN CONSECUTIVE SLOPES ON THE COMPRESSION
C     DATA'S POLYNOMIAL REPRESENTATION.
C
C DIFF, DIFFI
C     DIFFERENCE IN EFFECTIVE STRESS BETWEEN CONSECUTIVE CONTROLLED
C     CONSOLIDATION TEST COMPRESSION DATA POINTS.
C
C DY
C     SEE CEPTD
C
C E( )
C     VARIABLE WHICH STORES DIAL READINGS, VOID RATIOS, AND VERTICAL
C     STRAIN OF COMPRESSION DATA POINTS AT VARIOUS TIMES DURING THE
C     PROGRAM'S EXECUTION.
```

```
C
C EC
C     VOID RATIO OR VERTICAL STRAIN AT THE PRECONSOLIDATION STATE AS
C     IDEALIZED BY THE SCHMERTMANN CONSTRUCTION.
C
C ECMIN
C     ORDINATE VALUE OF VOID RATIO OR VERTICAL STRAIN AT THE
C     MINIMUM PRECONSOLIDATION STATE.
C
C EE( )
C     VARIABLE WHICH STORES DIAL READINGS, VOID RATIOS, AND VERTICAL
C     STRAIN OF EXPANSION-REBOUND DATA POINTS AT VARIOUS TIMES DURING
C     PROGRAM'S EXECUTION.
C
C EEO
C     VOID RATIO FOR FIRST DATA POINT ON STANDARD TEST'S EXPANSION-
C     REBOUND CURVE.
C
C EF
C     FINAL VOID RATIO.
C
C EI
C     INITIAL VOID RATIO.
C
C EO
C     INITIAL VOID RATIO.
C
C FACTOR
C     THE CORRECTION NEEDED TO TAKE INTO ACCOUNT THE SCALE FACTORS THAT
C     MODIFY THE APPEARANCE OF ANGLES ON THE PLOT OUTPUT.
C
C FIRLOG
C     THE INITIAL STARTING EXPONENT OF TEN FROM WHICH THE LOG AXIS WILL
C     BE DRAWN IN PLOTTING SUBPROGRAM CASPLT.  (I.E., FIRLOG IS EQUAL
C     TO -1.0)
C
C FY
C     VERTICAL INTERCEPT OF LINE 'F' AT THE ZERO ABSCISSA.
C
C GY
C     VERTICAL INTERCEPT OF LINE 'G' AT THE ZERO ABSCISSA.
C
C H( )
C     HEIGHT OF SPECIMEN FOR CONTROLLED COMPRESSION DATA.  STORAGE
C     VARIABLE FOR INPUT DIAL READINGS FOR STANDARD TEST COMPRESSION
C     DATA.
C
C HE( )
C     HEIGHT OF SPECIMEN FOR CONTROLLED EXPANSION-REBOUND DATA.  STORAGE
C     VARIABLE FOR INPUT DIAL READINGS OF STANDARD TEST EXPANSION-
C     REBOUND DATA.
C
C HI
C     INITIAL HEIGHT OF SPECIMEN AT START OF TEST.
C
C HOL I2
C     BORE HOLE NUMBER.
C
C HS
C     HEIGHT OF SOLIDS.
```

```
C
C HV
C      INITIAL HEIGHT OF VOIDS.
C
C I
C      DO LCOP PARAMETER.
C
C IBIG
C      ARRAY LOCATION FOR THE ABSCISSA VALUE CORRESPONDING TO THE
C      LOCATION OF THE LARGEST RADIUS OF CURVATURE.
C
C ICHECK
C      THIS VARIABLE IS SET EQUAL TO ONE IN SUBROUTINE ANARAD WHEN A
C      DISCRETE LOCALIZED POINT OF MAXIMUM CURVATURE HAS BEEN FOUND.  IF
C      A DISCRETE PCINT OF MAXIMUM CURVATURE HAS NCT BEEN FOUND, ICHECK
C      HAS A VALUE CF ZERO AND THIS CAUSES A DEFAULT TC SELECT THE
C      POINT WHERE THE SECOND DERIVATIVE IS A MAXIMUM.
C
C IDERV2
C      ARRAY LOCATICN FOR THE ABSCISSA VALUE WITH THE LARGEST VALUE OF
C      THE SECOND DERIVATIVE.
C
C IDIAL
C      VARIABLE TO SPECIFY WHETHER DIAL READINGS INCREASE CR DECREASE
C      WITH INCREASING DOWNWARD DEFLECTION.  IDIAL EQUALS +1 FCR DIAL
C      READINGS WHICH INCREASE WITH INCREASING DOWNWARD DEFLECTION.
C      IDIAL EQUALS -1 FOR DIAL READINGS WHICH DECREASE WITH INCREASING
C      DOWNWARD DEFLECTION.
C
C IIDIAL
C      OPTION VARIABLE WHICH CAN BE USED TC OVERRIDE PROGRAM'S
C      BUILT IN VALUES FOR IDIAL.
C
C IMIN
C      ARRAY LOCATICN FOR THE ABSCISSA VALUE OF THE POINT CF MAXIMUM
C      CURVATURE.
C
C IN
C      COMPUTER INPUT UTILITY DEVICE NUMBER FOR READ STATEMENTS.
C
C INUM
C      DUMMY ARGUMENT IN SUBROUTINE GRARAD THAT ASSIGN CORRECT ARRAY
C      LOCATION FOR THE GRAPHICALLY SELECTED PCINT OF MAXIMUM CURVATURE.
C
C IOUT
C      COMPUTER OUTPUT UTILITY DEVICE NUMBER FCR WRITE STATEMENTS.
C
C IPRINT
C      OPTION PARAMETER FOR REDUCING THE AMOUNT OF OUTPUT PRODUCED IN
C      SELECTING THE POINT OF MAXIMUM CURVATURE BY THE ANALYTICAL METHOD.
C
C ISTR
C      DO LOOP PARAMETER WHICH IS MANIPULATED TO GIVE EITHER A VOID RATIO
C      OR VERTICAL STRAIN ANALYSIS.  IF KIND EQUALS 1, ISTR EQUALS 1.
C      IF KIND EQUALS 2, ISTR EQUALS 2.
C
C IVOID
C      DO LCOP PARAMETER WHICH IS MANIPULATED TO GIVE EITHER A VOID RATIO
C      OR VERTICAL STRAIN ANALYSIS.  IF KIND EQUALS 1, IVOID DQUALS 1.
C      IF KIND EQUALS 2, IVCID EQUALS 2.
```

```
C
C J
C      DO LOOP PARAMETER.
C
C JPRINT
C      OPTION PARAMETER FOR OUTPUT WHICH IS PRESENTLY NOT USED.
C
C KIND
C      OPTION VARIABLE FOR SPECIFYING EITHER VOID RATIO OR VERTICAL
C      STRAIN ANALYSIS.
C
C KK
C      DO LOOP PARAMETER FOR DISTINGUISHING BETWEEN VOID RATIO AND
C      VERTICAL STRAIN MODES OF ANALYSIS.
C
C KRAD
C      OPTION PARAMETER FOR SELECTION OF DESIRED METHOD TO SELECT POINT
C      OF MAXIMUM CURVATURE.  IF KRAD IS NOT EQUAL TO '2', PROGRAM
C      DEFAULTS TO USE THE GRAPHICAL METHOD TO SELECT THE POINT OF
C      MAXIMUM CURVATURE.
C
C KSLOPE
C      PARAMETER USED IN TELLING THE PROGRAM HOW THE VIRGIN CURVE LINE
C      REPRESENTATION WAS SELECTED FOR STANDARD CONSOLIDATION DATA.
C      IF KSLOPE IS NOT EQUAL TO '0', THE LINE WAS SELECTED ON THE BASIS
C      OF AN AVERAGE SLOPE BETWEEN THE TANGENT OF MAXIMUM SLOPE AND A
C      LINE GOING THROUGH THE LAST TWO COMPRESSION DATA POINTS.
C
C L
C      DUMMY PARAMETER PRESENTLY NOT USED.
C
C LCF REAL
C      LENGTH CALIBRATION FACTOR.
C
C LINEA( ) REAL
C LINEB( ) REAL
C LINEC( ) REAL
C LINED( ) REAL
C LINEE( ) REAL
C LINEF( ) REAL
C LINEG( ) REAL
C      REAL VARIABLES WHICH ARE USED IN SUBROUTINE CASPLT TO STORE THE
C      INCREMENTALLY GENERATED ORDINATES VALUES USED IN PLOTTING LINES A,
C      B, C, ...G.
C      LINEA - HORIZONTAL LINE THROUGH POINT OF MAXIMUM CURVATURE.
C      LINEB - TANGENT TO COMPRESSION CURVE AT POINT OF MAXIMUM
C      CURVATURE.
C      LINEC - LINE BISECTING ANGLE BETWEEN LINES 'A' AND 'B'.
C      LINED - LINE REPRESENTATION OF VIRGIN COMPRESSION CURVE.
C      LINEE - LINE REPRESENTATION OF EXPANSION-REBOUND CURVE.
C      LINEF - LINE IN SCHMERTMANN'S CONSTRUCTION USED TO REPRESENT
C      INITIAL COMPRESSION CURVE.  IT HAS THE SLOPE OF LINEE AND GOES
C      THROUGH THE POINT HAVING ITS ABSCISSA AT THE INSITU VERTICAL
C      STRESS AND ORDINATE AT THE INITIAL VOID RATIO OR VERTICAL STRAIN.
C      LINEG - LINE DERIVED FROM SCHMERTMANN'S CONSTRUCTION AS REP-
C      RESENTATION OF THE INSITU VIRGIN COMPRESSION CURVE.
C
C LL
C      DO LOOP PARAMETER USED IN DOING THE SPECIFIED NUMBER OR PROBLEMS.
C
```

```
C LOC( ) 4A4
C      GENERAL LOCATION OR NAME OF SITE FROM WHICH SAMPLE WAS TAKEN.
C
C MDC
C      WATFIVE PARAMETER THAT REPRESENTS THE COMPRESSION CURVE'S NUMBER
C      OF DATA POINTS, PLUS THE DEGREE OF POLYNOMIAL, AND PLUS ONE.
C
C MDE
C      SAME AS MDC, BUT FOR EXPANSION-REBOUND CURVE DATA.
C
C NC
C      NUMBER OF COMPRESSION CURVE DATA POINTS.
C
C NDC
C      WATFIVE PARAMETER WHICH SPECIFIES THE NUMBER OF POLYNOMIAL CO-
C      EFFICIENTS NEEDED FOR THE POLYNOMIAL FITTED THROUGH THE COM-
C      PRESSION CURVE DATA.
C
C NDE
C      SAME AS NDC BUT FOR EXPANSION-REBOUND CURVE DATA.
C
C NDEG
C      DEGREE POLYNOMIAL FOR COMPRESSION CURVE.
C
C NDEGE
C      EQUALS ONE AND IS DEGREE POLYNOMIAL FOR EXPANSION-REBOUND CURVE
C      DATA.
C
C NE
C      NUMBER OF EXPANSION-REBOUND DATA POINTS.
C
C NOPROB
C      THE NUMBER OF PROBLEM SETS TO BE SOLVED.  IN PROGRAM VERSION
C      CASAGR-I, THIS QUANTITY IS SYNOMOUS WITH THE NUMBER OF STRESS-
C      STRAIN AXES WHICH WILL BE USED IN THE PLOTTING OF THE DATA.
C
C NPLOTS
C      IN PROGRAM VERSION CASAGR-O, NPLOTS IS A DUMMY INPUT PLACE HOLDER.
C      IN THE PROGRAM VERSION CASAGR-I, THIS QUANTITY IS THE NUMBER OF
C      PLOTS TO APPEAR ON ONE SET OF STRESS-STRAIN AXES.
C
C NUMPTC
C      NUMBER OF COMPRESSION CURVE DATA POINTS.
C
C NUMPTE
C      NUMBER OF EXPANSION-REBOUND CURVE DATA POINTS.
C
C ORCMIN
C      MINIMUM POSSIBLE OVERCONSOLIDATION RATIO.
C
C OPR( ) A4
C      INITIALS OF TEST OPERATOR.
C
C ORDINA
C      VARIABLE USED IN PLOTTING SUBROUTINE CASPLT TO CHANGE LINES WHILE
C      THE REDUCED STANDARD TEST DATA IS BEING PLOTTED IN TABULAR FORM.
C
C P( )
C      EFFECTIVE STRESS OF COMPRESSION DATA POINTS.
C
```

```
C PC
C     PRECONSOLIDATION PRESSURE.
C
C PCF
C     PRESSURE CALIBRATION FACTOR (PSI/DIV).
C
C PDUMMY( )
C     DUMMY VARIABLE FOR PLOTTING THE TABLE OF EFFECTIVE STRESS VALUES.
C
C PE( )
C     EFFECTIVE STRESS OF EXPANSION-REBOUND DATA POINTS.
C
C PI
C     3.141592
C
C PINSTU
C     OVERBURDEN PRESSURE.
C
C PO( ), POVE, POVER
C     (SEE PINSTU)
C
C PPP( )
C     PORE PRESSURE IN PSI FOR COMPRESSION DATA.
C
C PPPE( )
C     PORE PRESSURE IN PSI FOR EXPANSION-REBOUND DATA.
C
C PPR( )
C     PORE PRESSURE READING FOR COMPRESSION DATA.
C
C PPRE( )
C     PORE PRESSURE READING FOR EXPANSION-REBOUND DATA.
C
C PPT( )
C     PORE PRESSURE IN TSF FOR COMPRESSION DATA.
C
C PPTE( )
C     PORE PRESSURE IN TSF FOR EXPANSION-REBOUND DATA.
C
C PPZ
C     PORE PRESSURE READING TAKEN AFTER BACK PRESSURE APPLICATION AND
C     BEFORE LOADING OF SPECIMEN.
C
C PRECON
C     PRECONSOLIDATION PRESSURE.
C
C PREMIN
C     MINIMUM POSSIBLE PREOCONSOLIDATION STRESS DETERMINED BY EXTENDING
C     THE LABORATORY VIRGIN SLOPE UNTIL IT INTERSECTS EITHER THE INITIAL
C     THE INITIAL VOID RATIO OR ZERO STRAIN LINE OR LINEAR
C     REPRESENTATION OF RECOMPRESSION CURVE (LINE F).
C
C RAD( )
C     CALCULATED RADIUS OF CURVATURE.
C
C RADMIN
C     MINIMUM RADIUS OF CURVATURE.
C
C RADMX
C     ABSCISSA AT POINT OF THE MINIMUM RADIUS OF CURVATURE (I.E., POINT
```

```
C     OF MAXIMUM CURVATURE).
C
C RUNTYP INTEGER
C     TYPE OF CONSOLIDATION DATA:
C     CODE 0: - STANDARD
C     CODE 1: - CONTROLLED GRADIENT
C     CODE 2: - CONTROLLED RATE OF STRAIN
C
C S( )
C     SCRATCH ARRAY FOR SUBROUTINE FLSQFY.
C
C SAM A3
C     IDENTIFICATION OF SAMPLE.
C
C SAMPHI
C     INITIAL HEIGHT OF SAMPLE IN INCHES.
C
C SB
C     SEE SLOPEB
C
C SC
C     SEE SLOPEC
C
C SD
C     SEE SLOPED
C
C SE
C     SEE SLOPEE
C
C SECOND
C     STRESS IN TSF AT WHICH SECONDARY COMPRESSION BEGINS IN CONTROLLED
C     CONSOLIDATION TEST DATA.
C
C SEVT( )
C     VERTICAL EFFECTIVE STRESS FOR COMPRESSION DATA POINTS.
C
C SEVTE( )
C     VERTICAL EFFECTIVE STRESS FOR EXPANSION-REBOUND DATA POINTS.
C
C SF
C     SEE SLOPEF
C
C SFAC INTEGER
C     ARRAY LOCATION OF THE COMPRESSION DATA'S SCALE FACTORS.
C     SFAC = NUMPTC + 2
C
C SFACUR INTEGER
C     ARRAY LOCATION FOR THE SCALE FACTOR FOR VARIABLES WHICH ARE USED
C     IN PLOTTING THE FITTED POLYNOMIAL CURVE SFACUR = 101 + 2.
C
C SFAE INTEGER
C     ARRAY LOCATION FOR THE EXPANSION-REBOUND DATA'S SCALE FACTORS.
C     SAFE = NUMPTE + 2
C
C SG
C     SEE SLOPEG
C
C SGMSQ( )
C     SCRATCH ARRAY USED BY SUBROUTINE FLSQFY.
C
```

```
C SI
C      INITIAL DEGREE OF SATURATION.
C
C SLOPBI
C      SLOPE OF ANGLE BISECTOR LINE USED BY THE GRAPHICAL METHOD TO
C      DETERMINE POINT OF MAXIMUM CURVATURE.
C
C SLOPE
C      SLOPE OF LINE GOING THROUGH LAST TWO POINTS OF THE STANDARD TEST'S
C      CONSOLIDATION COMPRESSION CURVE.
C
C SLOPE1( )
C      FIRST DERIVATIVE OR SLOPE AT GENERATED ABSCISSA VALUES ALONG THE
C      COMPRESSION DATA'S FITTED POLYNOMIAL CURVE.
C
C SLOPE2( )
C      SECOND DERIVATIVE AT GENERATED ABSCISSA VALUES ALONG THE COM-
C      PRESSION DATA'S FITTED POLYNOMIAL CURVE.
C
C SLOPEB
C      SLOPE OF LINEB.
C
C SLOPEC
C      SLOPE OF LINEC.
C
C SLOPED
C      SLOPE OF LINED.
C
C SLOPEE
C      SLOPE OF LINEE.
C
C SLOPEF
C      SLOPE OF LINEF.
C
C SLOPEG
C      SLOPE OF LINEG.
C
C SLOPEM
C      AVERAGE OF TWO LINES, ONE TANGENT TO THE CURVE AT ITS MAXIMUM
C      SLOPE AND THE OTHER GOING THROUGH THE STANDARD COMPRESSION
C      CURVE'S LAST TWO DATA POINTS.
C
C SPG
C      SPECIFIC GRAVITY OF SOLIDS.
C
C SR
C      SWELL RATIO.
C
C STARE INTEGER
C      ARRAY LOCATION OF THE STARTING VALUE THAT WILL BE USED IN PLOTTING
C      THE ABSCISSA AND ORDINATE POSITIONS OF THE EXPANSION-REBOUND
C      CURVE'S DATA POINTS.
C      STARE = NUMPTE + 1
C
C START INTEGER
C      ARRAY LOCATION OF THE STARTING VALUE THAT WILL BE USED IN PLOTTING
C      THE ABSCISSA AND ORDINATE POSITIONS OF THE COMPRESSION CURVE'S
C      DATA POINTS.
C      START = NUMPTC + 1
C
```

```
C STARX INTEGER
C     ARRAY LOCATION OF THE STARTING VALUE THAT WILL BE USED IN PLOTTING
C     THE ABSCISSA AND ORDINATE POSITIONS OF THE GENERATED SEGMENTS OF
C     THE POLYNOMIAL CURVE.
C     STARX = 101 + 1
C
C STR( )
C     VERTICAL STRAIN ARRAY FOR COMPRESSION DATA POINTS.
C
C STRE( )
C     VERTICAL STRAIN ARRAY OF THE EXPANSION-REBOUND DATA POINTS.
C
C STVT( )
C     TOTAL VERTICAL STRESS ARRAY FOR COMPRESSION DATA POINTS.
C
C STVTE( )
C     TOTAL VERTICAL STRESS ARRAY FOR EXPANSION-REBOUND DATA POINTS.
C
C T( )
C     TIME AT WHICH COMPRESSION DATA POINT WAS ACQUIRED DURING CON-
C     TROLLED CONSOLIDATION TEST.
C
C TANGEN( )
C     STORAGE LOCATION OF THE GENERATED INCREMENTAL ORDINATES USED IN
C     PLOTTING THE LINE TANGENT TO THE COMPRESSION CURVE AT THE POINT
C     (XTAN, YTAN).
C
C TE( )
C     TIME AT WHICH EXPANSION-REBOUND DATA POINT WAS ACQUIRED DURING
C     CONSOLIDATION TEST.
C
C TES A3
C     TEST NUMBER IN A PARTICULAR CONSOLIDATION TESTING PROGRAM.
C
C TR( )
C     TIME READING AT WHICH A COMPRESSION DATA POINT WAS ACQUIRED DURING
C     A CONTROLLED CONSOLIDATION TEST.
C
C TRE( )
C     TIME READING AT WHICH AN EXPANSION-REBOUND DATA POINT WAS ACQUIRED
C     DURING A CONTROLLED CONSOLIDATION TEST.
C
C VOIDC
C     THE VOID RATIO AT THE PRECONSOLIDATION STATE AS IDEALIZED BY
C     SCHMERTMANN'S CONSTRUCTION.
C
C VOIDEO( )
C     INITIAL VOID RATIO VARIABLE USED FOR PLOTTING.
C
C W( )
C     ARRAY IN WHICH THE WEIGHTS OF INDIVIDUAL DATA POINTS ARE PLACED
C     FOR SUBSEQUENT USE BY SUBROUTINE FLSQFY.  ALL DATA POINTS ARE MADE
C     TO HAVE EQUAL WEIGHTS (I.E., W( ) = 1.0).
C
C WF
C     FINAL WATER CONTENT.
C
C WI
C     INITIAL WATER CONTENT.
C
```

```
C WRD( )
C     LOAD READING FOR CONTROLLED TEST COMPRESSION DATA.
C
C WRDE( )
C     LOAD READING FOR CONTROLLED TEST EXPANSION-REBOUND DATA.
C
C WRZ
C     LOAD READING CORRESPONDING TO ZERO APPLIED LOAD.
C
C WTFD
C     FINAL DRY WEIGHT OF CONSOLIDATION SPECIMEN.
C
C WTFW
C     FINAL WET WEIGHT OF CONSOLIDATION SPECIMEN.
C
C WTIW
C     INITIAL WET WEIGHT OF CONSOLIDATION SPECIMEN.
C
C X( , )
C     ARRAY VARIABLE IN WHICH THE INCREMENTALLY GENERATED ABSCISSA
C     VALUES ARE STORED.
C
C XANGLE
C     ABSCISSA OF THE POINT OF INTERSECTION BETWEEN THE GRAPHICAL
C     METHOD'S INITIAL TANGENT LINE AND THE VIRGIN COMPRESSION LINE.
C
C XB
C     ABSCISSA THROUGH WHICH THE LINE REPRESENTION OF VIRGIN CURVE WILL
C     BE DRAWN (I.E., LINED).
C
C XBIG
C     SAME AS XB.
C
C XB1 = XB
C XB2 = XB*XB
C XB3 = XB**3
C XB4 = XB**4
C XB5 = XB**5
C XB6 = XB**6
C XB7 = XB**7
C XB8 = XB**8
C XB9 = XB**9
C XB10 = XB**10
C XB11 = XB**11
C     THESE VARIABLES SET UP POLYNOMIAL TERMS FROM THE ABSCISSA VALUE
C     OF A POINT ON REPRESENTATIVE PORTION OF VIRGIN COMPRESSION CURVE.
C     THESE TERMS WILL BE PAIRED WITH APPROPRIATE COEFFICIENTS TO
C     COMPUTE AN ORDINATIE VALUE AT A POINT ON THE REPRESENTATIVE
C     PORTION OF VIRGIN COMPRESSION CURVE.
C
C XS
C     ABSCISSA OF THE POINT OF MAXIMUM CURVATURE.
C
C XS1 = XS
C XS2 = XS**2
C XS3 = XS**3
C XS4 = XS**4
C XS5 = XS**5
C XS6 = XS**6
C XS7 = XS**7
```

```
C XS8 = XS**8
C XS9 = XS**9
C XS10 = XS**10
C XS11 = XS**11
C     THESE VARIABLES SET UP THE POLYNOMIAL TERMS FROM THE ABSCISSA
C     VALUE OF THE POINT OF MAXIMUM CURVATURE.  THESE TERMS WILL BE
C     PAIRED WITH THE APPROPRIATE COEFFICIENTS TO COMPUTE THE ORDINATE
C     OF THE SELECTED POINT OF MAXIMUM CURVATURE.
C
C XSLP2
C     SAME AS XS.
C
C XTAN
C     ABSCISSA OF THE POINT OF TANGENCY ON THE INITIAL PORTION OF THE
C     COMPRESSION CURVE AND IS DETERMINED BY SUBROUTINE GRARAD.
C
C XVIRGI
C     ABSCISSA OF THE POINT OF INTERSECTION BETWEEN LINE 'D' AND THE
C     ORDINATE VALUE OF 0.42 * EO.
C
C X1( , ) = X( , )
C X2( , ) = X( , )**2
C X3( , ) = X( , )**3
C X4( , ) = X( , )**4
C X5( , ) = X( , )**5
C X6( , ) = X( , )**6
C X7( , ) = X( , )**7
C X8( , ) = X( , )**8
C X9( , ) = X( , )**9
C X10( , ) = X( , )**10
C X11( , ) = X( , )**11
C     THESE VARIABLES SET UP THE POLYNOMIAL TERMS FROM THEIR INCREMENTAL
C     ABSCISSAE SO THAT THEY MAY BE PAIRED WITH THEIR RESPECTIVE CO-
C     EFFICIENTS.
C
C Y( , )
C     DUMMY SCRATCH ARRAY.
C
C YLINE( )
C     INCREMENTALLY GENERATED ORDINATE VALUES OF THE ANGLE BISECTOR
C     LINE USED IN SUBROUTINE GRARAD.
C
C YSLP2
C     ORDINATE OF THE POINT OF MAXIMUM CURVATURE.
C
C YTAN
C     ORDINATE OF THE POINT OF TANGENCY ON THE INITIAL PORTION OF THE
C     COMPRESSION CURVE AND IS DETERMINED BY SUBROUTINE GRARAD.
C
C YVIRGI
C     EQUALS 0.42 * EO.
C
C ZDEPTH
C     APPROXIMATE FIELD DEPTH AT WHICH SAMPLE WAS RECOVERED.
C
C ZERO
C     DIAL READING CORRESPONDING TO FIRST DATA POINT ON THE EXPANSION-
C     REBOUND CURVE.
C
C ******************************************************************
```

```
C
C
      COMMON /BLOK1/ P(303),E(303),PE(103),EE(103),CC(103)
      DOUBLE PRECISION CC
      COMMON /BLOK2/ CEPTA,SLOPEB,CEPTB,SLOPEC,CEPTC,SLOPED,CEPTD,
     1SLOPEE,CEPTE,SLOPEF,CEPTF,SLOPEG,CEPTG,BOUND1,BOUND2,BOUND3,BOUND4
     2,BOUND5,BOUND6,NUMPTC,NUMPTE,PINSTU,XSLP2,PC,EC,EO,CCR,CC1,CS,CR,
     3SR,NDEG,IN,ICUT,IDIAL
      COMMON /BLOK3/ POVE,PRECON,PREMIN,VOIDC,ECMIN,OCRMIN,CRMIN
      COMMON /BLOK4/ TR(303),TRE(103),DEFR(303),DEFRE(103),PPR(303),
     1PPRE(103),WRD(303),WRDE(103),L,STVT(303),
     2STVIE(103),PPP(303),PPPE(103),PPT(303),PPTE(103),
     3CSEVT(303),CSEVTE(103),DFLI(303),DFLIE(103),STR(303),
     4STRE(103),H(303),HE(103),DCF,LCF,PCF
      COMMON /BLOK5/ LOC(4),HOL,SAM,TES,OPR(1),DAT(3),DES(4),BCD(20),
     1KK,RUNTYP
      COMMON /BLOK6/ SPG,WTIW,WTFW,WTFD,DEFI,DEFF,BP,DEFZ,WRZ,PPZ,HS,HI,
     1HV,SI,EI,EF,SF,WI,WF,SECOND,AR
      COMMON /BLOK8/ RAD(103),RADMIN,RADMX,IMIN,IPRINT,JPRINT,KIND
      COMMON /BLOK9/ X(103, 4),SLOPE1(103),SLOPE2(103)
      COMMON  X1(103, 4),X2(103, 4),X3(103, 4),X4(103, 4),X5(103, 4),
     1X6(103, 4),X7(103, 4),X8(103, 4),X9(103, 4),X10(103, 4),X11(103, 4
     2)
      DOUBLE PRECISION W(303),C(12),ALPHA(314),BETA(314),S(314),
     1SGMSQ(314),PR(314),PO(314),B(314),Y(103, 4)
      REAL LCF
      INTEGER RUNTYP,TES,HOL
      INTEGER START,SFAC
      DIMENSION DATA(1024)
      CALL PLOTS (DATA,4096)
      CALL PLOT (0.0,-11.,-3)
      CALL PLOT (0.0,1.0,-3)
C
C     INPUT AND OUTPUT UTILITY DEVICE CODE NUMBERS.
C
      IN=5
      IOUT=6
C
      KK=1
C     NOPROB - NUMBER OF PROBLEMS TO BE ANALYZED
      READ (IN,1000) NOPROB
 1000 FORMAT(2I2)
      DO 400 LL=1,NOPROB
C     NPLOTS IS EQUAL TO ONE ALWAYS FOR THIS PROGRAM VERSION.
C     IPRINT - OUTPUT OPTION FOR CALCULATED RADII FROM SUB ANARAD.
      READ (IN,1000) NPLOTS,IPRINT
      IF (NPLOTS.EQ.0) NPLOTS=1
C
C     READ DATA FOR COMPRESSION CURVES.
C     NDEG = POLYNOMIAL DEGREE
C     RUNTYP = TYPE OF CONSOLIDATION TEST DATA
C     ZDEPTH = DEPTH FOR CALCULATION OF INSITU STRESS BASED ON SPECIMEN
C              WET UNIT WEIGHT.
C   INSERT FOLLOWING IN COL. 31 FOR RADIUS METHOD
C      GRAPHICAL RADIUS METHOD - SET KRAD=0
C     ANALYTICAL RADIUS METHOD - SET KRAD=2
C
C     KIND - OPTION VARIABE FOR SPECIFYING EITHER A VOID RATIO OR
C             VERTICAL STRAIN ANALYSIS.  PLACE IN COL.33 ONE OF THE
C             FOLLOWING VALUES FOR ' KIND '.
```

```
C            KIND=C, DOES BOTH VOID RATIO AND VERTICAL STRAIN ANALYSES.
C            KIND=1, ONLY VOID RATIO ANALYSIS PERFORMED.
C            KIND=2, ONLY VERTICAL STRAIN ANALYSIS PERFORMED.
C
C     SECOND - PRESSURE AT WHICH SECONDARY COMPRESSION OCCURS.
C
C
C     IIDIAL - OPTION VARIABLE TO OVERRIDE PROGRAM'S BUILT-IN VALUES
C              FOR IDIAL. IIDIAL MUST BE MADE EQUAL TO EITHER '+1' OR
C              '-1' TO OVERRIDE BUILT-IN VALUES OF IDIAL.  SEE
C              DESCRIPTION OF IDIAL BELOW.
C
      READ(IN,1010) NDEG,RUNTYP,ZDEPTH,KRAD,KIND,SECOND,IIDIAL
 1010 FORMAT(2(I3,7X),F10.0,I1,1X,I1,2X,F5.0,8X,I2)
      IF (SECOND.LT.0.001) SECOND=31.2
C
C
C     IDIAL IS USED TO MATCH DIAL GAUGE READINGS WITH DEFLECTION.
C     NOTE: INCREASING DEFLECTION IS SPECIMEN SHORTENING.
C     IDIAL IS EQUAL TO +1 WHEN DIAL READINGS INCREASE WITH DEFLECTION.
C     IDIAL IS EQUAL TO -1 WHEN DIAL READINGS DECREASE WITH DEFLECTION.
C     IF THE RELATIONSHIP BETWEEN DIAL READING AND DEFLECTION IS CHANGED
C     FOR A PARTICULAR TEST TYPE, THE TEST'S RESPECTIVE ARGUMENT FOR
C     IDIAL WILL BE SET EQUAL TO THE VALUE OF IIDIAL.
C
C     STD. DIAL RDGS. INCREASING WITH INCREASING DEFLECTION (DEFI-DEFZ).
      IF (RUNTYP.EQ.0) IDIAL = +1
C
C **  CONTROL. GRAD. DIAL RDGS. DECREASING W/ INCR. DEFL. (DEFZ-DEFI).
      IF (RUNTYP.EQ.1) IDIAL = -1
C
C     CONTROL. RATE OF STRAIN RDGS. INCR. W/ INCR. DEFL. (DEFI-DEFZ).
      IF (RUNTYP.EQ.2) IDIAL = +1
C
C
C     CHECKING IF PROGRAM IS TO OVERRIDE BUILT-IN VALUE OF IDIAL.
      IF (IIDIAL.NE.0) IDIAL=IIDIAL
C
C
C
C     READ IN SEARCH BOUNDARIES FOR SELECTION OF POINT OF MAXIMUM
C     CURVATURE AND LINE REPRESENTATION OF VIRGIN COMPRESSION CURVE.
C
      READ(IN,1020) BOUND1,BOUND2,BOUND3,BOUND4
 1020 FORMAT(4F10.0)
C
C     THE FOLLOWING ARGUMENTS ARE THE DIAMETER AND AREA OF THE SAMPLE
C     BEING SPEICIFIED IN INCHES AND INCHES SQUARED.
      DIA=2.50
      AR=4.9087
C
C
C     READ PLOT TITLE
C
      READ (IN,1030) BCD
 1030 FORMAT (20A4)
C
C
C     READ LOCATION, HOLE, SAMPLE, TEST, OPERATOR, DATE AND SAMPLE
C     DESCRIPTION.
```

```
C
      READ (IN,1040) LOC,HOL,SAM,TES,OPR,DAT,DES
 1040 FORMAT (4A4,I2,A3,I4,A4,3A4,4A4)
C
C
C     READ SPECIFIC GRAVITY, INITIAL WET WEIGHT, FINAL WET WEIGHT,
C     FINAL DRY WEIGHT, INITIAL DEFLECTION, AND FINAL DEFLECTION.
C
      READ (IN,1050) SPG,WTIW,WTFW,WTFO,OEFI,DEFF
 1050 FORMAT (F5.2,3F7.2,2F5.2)
C
C
C     DEFL. CAL. FACTOR - DCF (INCH/DIV)
C     LOAD CAL. FACTOR - LCF (LBS/DIV)
C     PRESSURE CAL. FACTOR - PCF (PSI/DIV)
C     DIA - DIAMETER OF SOIL SAMPLE (INCHES)
C     READ IN CALIBRATION FACTORS FOR DEFLECTION, LOAD, PRESSURE,
C     AND DIAMETER OF SOIL SPECIMEN IF IT IS NOT EQUAL TO 2.5".
C
      READ (IN,1060) DCF,LCF,PCF,DIA
 1060 FORMAT (4F10.2)
C
      IF (DIA.LT.0.001) DIA=2.5
      AR=(355./113.)*(DIA/2.0)**2
C
C
C     READ BACK PRESSURE, ZERO DEFLECTION, ZERO LOAD, ZERO PORE, AND
C     INITIAL HEIGHT OF SAMPLE IF NOT EQUAL TO ONE INCH.
C
      READ (IN,1070) BP,DEFZ,WRZ,PPZ,SAMPHI
 1070 FORMAT (F5.1,F5.2,2F4.0,2X,F10.0)
C
      IF (SAMPHI.LT.0.001)   SAMPHI=1.000
C
C     COMPUTE INITIAL AND FINAL SOIL PROPERTIES
C
      HS=WTFO/(SPG*AR*16.3871)
      HI=SAMPHI-IDIAL*((DEFI-DEFZ)*DCF)
      HV=HI-HS
      SI=(WTIW-WTFD)*100./(HV*AR*16.3871)
      EI=HV/HS
      EO=EI
      EF=(HV-IDIAL*(DEFF-DEFI)*DCF)/HS
      SF=(WTFW-WTFD)*100./((HV-IDIAL*(DEFF-DEFI)*DCF)*AR*16.3871)
      WI=(WTIW-WTFD)/WTFD*100
      WF=(WTFW-WTFD)/WTFD*100
      PINSTU=(WTIW*1728*ZDEPTH)/(AR*HI*453.6*2000.0)
C
C
C     CONTROLLED TEST DATA INPUT AND REDUCTION.
C     *********************
      IF (RUNTYP.EQ.1) CALL CONGRA
      IF (RUNTYP.EQ.2) CALL CONGRA
C     *********************
C
      IF (RUNTYP.EQ.1) GO TO 50
      IF (RUNTYP.EQ.2) GO TO 50
C
C     ************************
C     STANDARD TEST DATA INPUT
```

```
C       ************************
C       STANDARD TEST DIAL READINGS ARE BEING PLACED IN PROPER ARRAY
C       LOCATIONS.
        DO 10 I =1,20
C
C       COMPRESSION CURVE DIAL READINGS.
        READ (IN,1020) P(I),E(I)
        STR(I)=E(I)
        H(I)=E(I)
        IF (I.EQ.1) GO TO 10
C
C       HAS EFFECTIVE STRESS DECREASED BETWEEN CONSECUTIVE DATA POINTS?
C       IF SO, CONSIDER ALL SUBSEQUENT DATA AS EXPANSION-REBOUND DATA.
        IF (P(I).LT.P(I-1)) GO TO 20
   10   CONTINUE
   20   CONTINUE
C
        NUMPTC=I-1
        DO 30 I=3,20
C
C       READ IN REBOUND-EXPANSION DATA
C       DIAL READINGS ARE BEING PLACED IN PROPER ARRAY LOCATIONS.
C
        READ (IN,1020) PE(I),EE(I)
        STRE(I)=EE(I)
        HE(I)=EE(I)
        PE(1)=P(NUMPTC)
        EE(1)=E(NUMPTC)
        STRE(1)=E(NUMPTC)
        HE(1)=E(NUMPTC)
        ZERO=EE(1)
        PE(2)=P(NUMPTC+1)
        EE(2)=E(NUMPTC+1)
        STRE(2)=E(NUMPTC+1)
        HE(2)=E(NUMPTC+1)
        IF (PE(I).LT.0.001) GOTO 40
   30   CONTINUE
   40   CONTINUE
        NUMPTE=I-1
C
   50   CONTINUE
        IF (RUNTYP.EQ.0) WRITE (IOUT,1080)
        IF (RUNTYP.EQ.1) WRITE (IOUT,1090)
        IF (RUNTYP.EQ.2) WRITE (IOUT,1100)
        WRITE(IOUT,1210) BCD
        WRITE (IOUT,1110) TES,HOL,LOC,SAM,DAT,OPR
        WRITE (IOUT,1120) DES,BP
        WRITE (IOUT,1130) WI,WF,EI,EF,SI,SF
C
        IF(BOUND1.EQ.0.0) BOUND1=0.1
        IF(BOUND2.EQ.0.0) BOUND2=0.1
        IF(BOUND3.EQ.0.0) BOUND3=0.1
        IF(BOUND4.EQ.0.0) BOUND4=0.1
        IF(PINSTU.EQ.0.0) PINSTU=0.1
        BOUND1=ALOG10(BOUND1)
        BOUND2=ALOG10(BOUND2)
        BOUND3=ALOG10(BOUND3)
        BOUND4=ALOG10(BOUND4)
        PINSTU=ALOG10(PINSTU)
        IF (RUNTYP.EQ.0) SECOND = 99999
```

```
      B1=10.**BOUND1
      B2=10.**BOUND2
      B3=10.**BOUND3
      B4=10.**BOUND4
      IF (KRAD.EQ.2) WRITE(IOUT,1140) NDEG,B1,B2,B3,B4,ZDEPTH,SECOND
      IF (KRAD.NE.2) WRITE(IOUT,1150) NDEG,B1,B2,B3,B4,ZDEPTH,SECOND
C
      DO 60 I=1,NUMPTC
      W(I)=1.0
   60 CONTINUE
C
C
C
C
C     **************************************************
C     *  SEMI-LOGARITHMIC STRESS DEFORMATION ANALYSIS  *
C     **************************************************
C
C     VOID RATIO AND STRAIN ANALYSIS OF CONSOLIDATION DATA TO BE
C     PERFORMED IF SPECIFIED PREVIOUSLY BY USER.
      IVOID=1
      ISTR=2
C
      IF (KIND.EQ.1) IVOID=1
      IF (KIND.EQ.1) ISTR=1
      IF (KIND.EQ.2) IVOID=2
      IF (KIND.EQ.2) ISTR=2
      DO 390 KK = IVOID,ISTR
C
C     REDUCE DEFORMATION DATA.
C
C     COMPRESSION DATA POINTS.
      DO 100 I=1,NUMPTC
      IF (RUNTYP.EQ.1) GO TO 80
      IF (RUNTYP.EQ.2) GO TO 80
      IF (KK.EQ.2) GO TO 70
      E(I)=EO - IDIAL*(E(I)-DEFI)/HS
   70 CONTINUE
      IF (KK.EQ.1) GO TO 80
C     CONVENTIONAL DEFLECTION READINGS ARE INCREASING.
      E(I)=IDIAL*(STR(I)-DEFI)*DCF/HI
C
C     PURPOSES.
C     VALUES OF VERTICAL STRAIN ARE MADE NEGATIVE FOR CURVE FITTING
      E(I)=-E(I)
      GO TO 90
   80 CONTINUE
      IF (KK.EQ.1) GO TO 90
C     VALUES OF VERTICAL STRAIN ARE MADE NEGATIVE FOR CURVE FITTING
C     PURPOSES.
      E(I) = -STR(I)
   90 CONTINUE
      IF (KK.EQ.1) CSEVT(I)=E(I)
      IF (P(I).LE.0.1) P(I)=0.1
      P(I)=ALOG10(P(I))
  100 CONTINUE
C
C
C     NOW CALLING FLSQFY FOR NUMERICAL
C     ANALYSIS BY LEAST SQUARES CURVE
```

```
C     FITTING TO OBTAIN POLYNOMIAL COEFFICIENTS.
C
C     MUST INITIALIZE VALUES FOR COEFFICEINTS
C     TO AVOID UNDEFINED VARIALBE ERROR UV-0
C     UPON RETURN FORM SUBROUNTINE FLSQFY.
C
      DO 110 I=1,12
      C(I)=0.0
  110 CONTINUE
C
      NDC=NDEG+1
      MDC=NDEG+NUMPTC+1
C
C
C     FIT SPECIFIED LEAST SQUARES POLYNOMIAL TO SEMI-LOG REPRESENTATION
C     OF COMPRESSION DATA.
C
      CALL FLSQFY(NDEG,NUMPTC,P,E,W,C,ALPHA,BETA,S,SGMSQ,PR,PC,NDC,MDC)
C
C
      DO 120 I=1,12
      CC(I)=C(I)
  120 CONTINUE
C
C
C     REBOUND-EXPANSION DATA POINTS.
C
C     FIND THE SLOPE OF THE SWELL-RECOMPRESSION CURVE
C     AND CALL IT SLOPEE.
C
      DO 130 I=1,NUMPTE
      W(I)=1.0
  130 CONTINUE
C
C
      DO 170 I=1,NUMPTE
      IF (RUNTYP.EQ.1) GO TO 150
      IF (RUNTYP.EQ.2) GO TO 150
      IF (KK.EQ.2) GO TO 140
      EEO=E(NUMPTC)
      EE(I)=EEO -IDIAL*( EE(I)-ZERO )/HS
      CSEVTE(I) = EE(I)
      GOTO 160
  140 CONTINUE
      EE(I)=IDIAL*(STRE(I)-DEFI)*DCF/HI
      EE(I)=-EE(I)
      GO TO 160
  150 CONTINUE
      IF (KK.EQ.1) CSEVTE(I)=EE(I)
      IF (KK.EQ.2) EE(I)=-STRE(I)
  160 CONTINUE
      IF (PE(I).LE.0.1) PE(I) = 0.1
      PE(I) = ALOG10(PE(I))
  170 CONTINUE
C
C
C     CALLING FLSQFY TO OBTAIN LINEAR COEFFICEINTS.
C
      NDEGE=1
      NDE=2
```

```
      MOE=NUMPTE+2
C
C     FIT LEAST SQUARES STRAIGHT LINE TO EXPANSION REBOUND DATA.
C
      CALL FLSQFY(NDEGE,NUMPTE,PE,EE,W,C,ALPHA,BETA,S,SGMSQ,PR,PO,NDE,MD
     1E)
C
C     LINEE=C(1)+C(2)*XP
C
      SLOPEE=C(2)
      CEPTE=C(1)
C
C     FIND SLOPE OF VIRGIN COMPRESSION CURVE.
C
C
C
C     ******************************************************************
C     * SELECT STRAIGHT LINE REPRESENTATION OF VIRGIN COMPRESSION CURVE*
C     ******************************************************************
C
      CHECK=0.0
      XBIG=0.0
      BIG=0.0
      DELTA=(BOUND4-BOUND3)/100.
      B(1)=BOUND3
      DO 200 J=1,101
C
      B1=B(J)
      B2=B(J)*B(J)
      B3=B(J)*B(J)*B(J)
      B4=B(J)*B(J)*B(J)*B(J)
      B5=B(J)*B(J)*B(J)*B(J)*B(J)
      B6=B(J)*B(J)*B(J)*B(J)*B(J)*B(J)
      B7=B(J)*B(J)*B(J)*B(J)*B(J)*B(J)*B(J)
      B8=B(J)*B(J)*B(J)*B(J)*B(J)*B(J)*B(J)*B(J)
      B9=B(J)*B(J)*B(J)*B(J)*B(J)*B(J)*B(J)*B(J)*B(J)
      B10=B(J)*B(J)*B(J)*B(J)*B(J)*B(J)*B(J)*B(J)*B(J)*B(J)
C
C
C
      SLOPE1(J)=CC(2)+2*C(3)*B1   +3*C(4)*B2      +4*C(5)*B3   +
     15*C(6)*B4      +6*C(7)*B5      +7*C(8)*B6      +8*C(9)*B7   +
     29*C(10)*B8      +10*C(11)*B9      +11*C(12)*B10
C
      IF (J.EQ.1) GO TO 190
      DIFF=ABS((SLOPE1(J)-SLOPE1(J-1))/SLOPE1(J))
      IF(DIFF.LE.0.00019) CHECK=1.0
      IF (DIFF.LE.0.00019) GO TO 180
      IF ((RUNTYP.EQ.2).AND.(DIFF.LE.0.0025)) CHECK = 1
      IF ((RUNTYP.EQ.2).AND.(DIFF.LE.0.0025)) GO TO 180
      GO TO 190
  180 IF(ABS(SLOPE1(J)).GT.ABS(BIG)) XBIG=B(J)
      IF(ABS(SLOPE1(J)).GT.ABS(BIG)) BIG=SLOPE1(J)
  190 CONTINUE
C
      B(J+1)=B(J)+DELTA
  200 CONTINUE
      IF(CHECK.GT.0.50) GO TO 230
C
      DO 220 I=1,101
```

```
      IF (ABS(SLOPE1(I)).GE.ABS(BIG)) GO TO 210
      GOTO 220
  210 BIG=-ABS(SLOPE1(I))
      XBIG=B(I)
  220 CONTINUE
      GO TO 240
  230 CONTINUE
  240 CONTINUE
      XB=XBIG
C
      XB1=XB
      XB2=XB*XB
      XB3=XB*XB*XB
      XB4=XB*XB*XB*XB
      XB5=XB*XB*XB*XB*XB
      XB6=XB*XB*XB*XB*XB*XB
      XB7=XB*XB*XB*XB*XB*XB*XB
      XB8=XB*XB*XB*XB*XB*XB*XB*XB
      XB9=XB*XB*XB*XB*XB*XB*XB*XB*XB
      XB10=XB*XB*XB*XB*XB*XB*XB*XB*XB*XB
      XB11=XB*XB*XB*XB*XB*XB*XB*XB*XB*XB*XB
C
C     CALCULATE A LINE 'O' REPRESENTING THE
C     STRAIGHT PORTION OF VIRGIN COMPRESSION CURVE.
C
C
C
C
      YBIG=CC(1)+CC(2)*XB1+ C(3)*XB2    +C(4)*XB3    +C(5)*XB4    +
     1C(6)*XB5    +C(7)*XB6    +C(8)*XB7    +C(9)*XB8    +
     2C(10)*XB9    +C(11)*XB10   +C(12)*XB11
C
C
C     FOR STANDARD TEST DATA ONLY!!!!!
C     IF MAXIMUM SLOPE TANGENT IS BETWEEN LAST TWO COMPRESSION CURVE
C     POINTS AND HAS A GREATER SLOPE THAN A LINE GOING THROUGH LAST TWO
C     COMPRESSION CURVE POINTS, TAKE THE AVERAGE SLOPE OF THE TWO
C     AND DRAW THE LINE THROUGH THE LAST COMPRESSION CURVE POINT.
C
      KSLOPE=0
      IF (RUNTYP.NE.0) GO TO 250
      IF (YBIG.GT.E(NUMPTC-1)) GO TO 250
      SLOPE=(E(NUMPTC)-E(NUMPTC-1))/(P(NUMPTC)-P(NUMPTC-1))
      IF (ABS(SLOPE).LT.ABS(BIG)) SLOPEM=SLOPE-ABS(SLOPE-BIG)/2
      IF (ABS(SLOPE).LT.ABS(BIG)) KSLOPE = 999
  250 CONTINUE
      SLOPED=BIG
      IF (KSLOPE.EQ.999) SLOPED=SLOPEM
      IF (KSLOPE.EQ.999) YBIG=E(NUMPTC)
      IF (KSLOPE.EQ.999) XBIG=P(NUMPTC)
      CEPTD=YBIG-SLOPED*(XBIG)
C
C     LINED=SLOPED*X+ CEPTD
C
C
C     ***************************************************************
C     * CALL USER SPECIFIED METHOD TO SELECT POINT OF MAXIMUM CURVATURE*
C     ***************************************************************
C
C     TESTING NOW FOR POINT OF MAXIMUM
```

```
C     CURVATURE BETWEEN X VALUES OF BOUND1 AND BOUND2.
C
C     ********************
C
      IF (KRAD.EQ.2) CALL ANARAD
      IF (KRAD.NE.2) CALL GRARAD
C
C     ********************
C
      XS=RADMX
      XSLP2=RADMX
      X22=RADMX
C
C     DETERMINE ORDINATE VALUE AT POINT OF MAXIMUM CURVATURE.
      XS1=XS
      XS2=XS*XS
      XS3=XS*XS*XS
      XS4=XS*XS*XS*XS
      XS5=XS*XS*XS*XS*XS
        XS6=XS*XS*XS*XS*XS*XS
      XS7=XS*XS*XS*XS*XS*XS*XS
      XS8=XS*XS*XS*XS*XS*XS*XS*XS
      XS9=XS*XS*XS*XS*XS*XS*XS*XS*XS
      XS10=XS*XS*XS*XS*XS*XS*XS*XS*XS*XS
      XS11=XS*XS*XS*XS*XS*XS*XS*XS*XS*XS*XS
C
C
C
C
      YSLP2=CC(1)+CC(2)*XS1    +C(3)*XS2      +C(4)*XS3      +C(5)*XS4
     1+C(6)*XS5      +C(7)*XS6      +C(8)*XS7      +C(9)*XS8
     2+C(10)*XS9      +C(11)*XS10      +C(12)*XS11
C
C
C
C     * * * * * * * * * * * * * * * * * * * * * * *
C     *                                           *
C     *         CASAGRANDE'S CONSTRUCTION         *
C     *                                           *
C     * * * * * * * * * * * * * * * * * * * * * * *
C
C     CALCULATE A HORIZONTAL LINE CALLED 'A' THROUGH
C     (XSLP2,YSLP2), POINT OF MAX CURVATURE.
      CEPTA=YSLP2
C
C     LINEA=YSLP2
C
C     CALCULATE A LINE TANGENT TO CURVE AT
C     (XSLP2,YSLP2),POINT OF MAX CURVATURE,
C     AND CALL IT LINE 'B'.
C
C
C
C
C
      SLOPEB=CC(2)+2*C(3)*XS1+3*C(4)*XS2     +4*C(5)*XS3+ 5*C(6)*XS4 +
     16*C(7)*XS5   +7*C(8)*XS6   +8*C(9)*XS7 +9*C(10)*XS8     +
     110*C(11)*XS9   +11*C(12)*XS10
C
      CEPTB=YSLP2-SLOPEB*(XSLP2)
```

```
C
C      LINEB=SLOPEB*XP+CEPTB
C
C      BISECT DIFFERENCES IN SLOPE BETWEEN
C      LINE 'A' AND LINE 'B' AND CALCULATE
C      LINE 'C' THROUGH POINT OF MAX CURVATURE.
C
       SLOPEC=SLOPEB/2
       CEPTC=YSLP2-SLOPEC*(XSLP2)
C
C      LINEC=SLOPEC*XP+CEPTC
C
C      FIND INTERSECTION  OF LINES 'D' AND 'C' TO GET
C      THE VALUE FOR PRECONSOLIDATION PRESSURE.
C
       PC=(CEPTC-CEPTD)/(SLOPED-SLOPEC)
C
C
C      * * * * * * * * * * * * * * * * * * * * * * *
C      *                                           *
C      *          SCHMERTMANN'S CONSTRUCTION       *
C      *                                           *
C      * * * * * * * * * * * * * * * * * * * * * * *
C
C      COMPUTE A LINE 'F' THAT HAS A SLOPE OF
C      'SLOPEE' AND GOES THROUGH INTIAL PRESSURE
C      AND INITIAL VOID RATIO OR ZERO PERCENT STRAIN.
C
       IF (KK.EQ.2) GO TO 260
       CEPTF=EO-SLOPEE*(PINSTU)
       GO TO 270
  260  CEPTF = -SLOPEE*PINSTU
  270  CONTINUE
       SLOPEF=SLOPEE
C
C      LINEF=SLOPEE*XP+CEPTF
C
C      COMPUTE PRECONSOLIDATION VOID RATIO OR PRECONSOLIDATION VERTICAL
C      STRAIN TO DEFINE INSITU PRECONSOLIDATION STATE.
C
       EC=SLOPEE*PC+CEPTF
C
C      NOW COMPUTE A LINE 'G' THAT WILL REPRESENT
C      TRUE VIRGIN COMPRESSION LINE.
C
       YVIRGI=0.42*EO
       IF (KK.EQ.1) GO TO 280
       YVIRGI=-(EO-0.42*EO)/(1+EO)
  280  CONTINUE
       XVIRGI=(YVIRGI-CEPTD)/SLOPED
       SLOPEG=(YVIRGI -EC)/(XVIRGI -PC)
C
C
       CEPTG=EC-SLOPEG*PC
C
C      LINEG=SLOPEG*XP+CEPTG
C
C
C      OUTPUT OVER CONSOLIDATION RATIO AND PRECONSOLIDATION VERTICAL
C      EFFECTIVE PRESSURE WITH EITHER THE VOID RATIO OR VALUE OF STRAIN.
```

```
C
      POVE=10.**PINSTU
      PRECON=10.0**PC
      CC1=SLOPEG
      CS=SLOPEE
      VOIDC=EC
      OCR=PRECON/POVE
      IF (KK.EQ.1) CR = CC1
      IF (KK.EQ.1) SR = CS
      IF (KK.EQ.1) CRMIN=SLOPED
      PCMIN=(CEPTD-CEPTF)/(SLOPEF-SLOPED)
      ECMIN=SLOPEE*PCMIN+CEPTF
      IF (KK.EQ.1.AND.ECMIN.GT.EO) PCMIN=(CEPTD-EC)/(-SLOPEO)
      IF (KK.EQ.1.AND.ECMIN.GT.EO) ECMIN=EO
      IF (KK.EQ.2.AND.ECMIN.GT.0) PCMIN=-CEPTD/SLOPED
      IF (KK.EQ.2.AND.ECMIN.GT.0) ECMIN=0.0
      PREMIN=10.**PCMIN
      OCRMIN=PREMIN/POVE
      IF (KK.EQ.2) CR = CC1
      IF (KK.EQ.2) SR = CS
      IF (KK.EQ.2) CRMIN=SLOPED
C
C
C     CALL PLOTTING SUBROUTINE CASPLT
C
C     *********************
C
      CALL CASPLT
C
C     *********************
C
      PINSTU=10**PINSTU
      DO 290 I=1,NUMPTC
      P(I)=10.0**P(I)
  290 CONTINUE
      DO 300 I=1,NUMPTE
      PE(I)=10.0**PE(I)
  300 CONTINUE
C
 1080 FORMAT ('1',//14X,'STANDARD CONSOLIDATION TEST'/20X,       'DATA RE
     1DUCTION'//)
 1090 FORMAT ('1',//14X,'CONTROLLED GRADIENT CONSOLIDATION TEST'/25X,  '
     1DATA REDUCTION'//)
 1100 FORMAT ('1',//14X,'CONTROLLED RATE OF STRAIN CONSOLIDATION TEST'
     1/28X,'DATA REDUCTION'//)
 1110 FORMAT (1H0,9X,'TEST NO.',I4,19X,'HOLE NO. ',I2/1H0,9X,'LOCATION '
     1,4A4,6X,'SAMPLE NO. ',A3/1H0,9X,'DATE ',3A4,14X,'OPERATOR ',A4)
 1120 FORMAT (1H0,9X,'SOIL TYPE - ',4A4/1H0,9X,'BACK PRESSURE ',F6.2,1X,
     1'PSI'///,1H0,34X,'INITIAL',9X,'FINAL')
 1130 FORMAT (1H0,9X,'WATER CONTENT',14X,F4.1,'%',10X,F4.1,'%'/1H0,9X,'V
     1OID RATIO',17X,F4.2,11X,F4.2/1H0,9X,'DEG. OF SATURATION',8X,F5.1,'
     2%',9X,F5.1,'%')
 1140 FORMAT(1H0///25X,'DEGREE POLYNOMIAL =',I2/1H0,5X,
     1'PT. OF MAX. CURVATURE SELECTED BY THE ANALYTICAL METHOD'/1H0,
     25X,'SEARCH BOUNDARIES FOR PT. OF MAX. CURVATURE:',
     A2X,F5.2,' TSF',2X,F5.2,' TSF'
     3/1H0,5X,'SEARCH BOUNDARIES FOR VIRGIN COMPRESSION CURVE:',F6.2,' T
     4SF',2X,F5.2,' TSF'/1H0,5X,'DEPTH FOR INSITU STRESS CALCULATION:',
     52X,F5.2,' FEET',4X,'SECONDARY COMPRESSION AT',1X,
     6F5.2,' TSF')
```

```
1150 FORMAT(1HO///25X,'DEGREE POLYNOMIAL =',I2/1HO,5X,
    1'PT. OF MAX. CURVATURE SELECTED BY THE GRAPHICAL METHOD'/1HO,
    25X,'SEARCH BOUNDARIES FOR INITIAL TANGENT:',2X,F5.2,' TSF',2X,F5.2
    3,' TSF'/1HO,5X,'SEARCH BOUNDARIES FOR VIRGIN COMPRESSION CURVE:',
    A2X,F5.2,' TSF',2X,F5.2
    4,' TSF'/1HO,5X,'DEPTH FOR INSITU STRESS CALCULATION:',
    52X,F5.2,' FEET',4X,'SECONDARY COMPRESSION AT',1X,
    6F5.2,' TSF')
     IF (KIND.NE.2.AND.KK.EQ.1.AND.KRAD.NE.2)  WRITE(IOUT,1180)
     IF (KIND.EQ.2.AND.KK.EQ.2.AND.KRAD.NE.2) WRITE(IOUT,1180)
     IF (KK.EQ.1) WRITE(IOUT,1190)
     IF (KK.EQ.2) WRITE (IOUT,1200)
     IF(KK.EQ.1) WRITE(IOUT,1220) PINSTU,EO,PRECCN,PREMIN,VOIDC,ECMIN,
    1CCR,OCRMIN,CR,CRMIN,SR
     IF (KK.EQ.2) VOIDC=-VOIDC
     IF (KK.EQ.2) ECMIN = -ECMIN
     IF (KK.EQ.2) WRITE(IOUT,1230) PINSTU,EO,PRECCN,PREMIN,VOIDC,ECMIN,
    1CCR,OCRMIN,CR,CRMIN,SR
     IF (KK.EQ.2) VOIDC=-VOIDC
     IF (KK.EQ.2) ECMIN = -ECMIN
     IF (RUNTYP.EQ.0) GO TO 340
     IF ((KK.EQ.1).AND.(KIND.EQ.0)) GO TO 330
     WRITE (IOUT,1160)
1160 FORMAT (1H1,29X,'INPUT DATA'//1HO,9X,'TIME',3X,'DEFL. RDG.',9X,'P.
    1P. RDG.',4X,'LOAD RDG.'/1H )
     DO 310 I=1,NUMPTC
     WRITE (IOUT,1170) TR(I),DEFR(I),PPR(I),WRD(I)
1170 FORMAT (1H ,9X,F5.0,5X,F6.2,10X,F5.0,10X,F5.0)
 310 CONTINUE
     DO 320 I=1,NUMPTE
     WRITE (IOUT,1170) TRE(I),DEFRE(I),PPRE(I),WRDE(I)
 320 CONTINUE
     WRITE(IOUT,1180)
1180 FORMAT('1')
 330 CONTINUE
1190 FORMAT (1X//1X, '          ***************************************
    1**************              '/ 1X,'          *
    2                            *           '/ 1X,'           *
    3    VOID RATIO ANALYSIS                  *                    '/
    41X,'          *
    5 *              '/ 1X,'          ***************************************
    6*****************            ' /)
1200 FORMAT (1X//1X, '          ***************************************
    1**************              '/ 1X,'          *
    2                            *           '/ 1X,'           *
    3      STRAIN    ANALYSIS                 *                    '/
    41X,'          *
    5 *              '/ 1X,'          ***************************************
    6*****************            '/)
 340 CONTINUE
1210 FORMAT (16X,20A4/)
1220 FORMAT(1HO/1X ,'INSITU VERTICAL STRESS =',F6.3,' TSF',9X,
    1'INITIAL VOID RATIO (EO) =',F6.3//1HO,10X,'RANGES OF STRESS-',
    2'VOID RATIO SETTLEMENT PARAMETERS'/1HO,50X,'PROBABLE    -    ',
    3'MINIMUM'/1HO,'VERTICAL PRECONSCLIDATION STRESS ..............',
    4F8.3,' TSF   -',F8.3,' TSF'/1HO,    35HPRECONSOLIDATION STATE'S VOID
    5 RATIO      ,16('.'),    F8.3,2X,'-',F8.3/1HO,'OVERCONSOLIDATION',
    6' RATIO (OCR) ',21('.'),F8.3,2X,'-',F8.3/1HO,'COMPRESSION ',
    7'INDEX (CC) ',28('.')                ,F8.3,2X,'-',F8.3/1HO,'SWELL
    8EXPANSION INDEX (CS) ',24('.') ,F8.3,2X//)
```

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1230 FORMAT(1HO,/1X ,'INSITU VERTICAL STRESS =',F6.3,' TSF',9X,
    1'INITIAL VOID RATIO (EO) =',F6.3//1HO,13X,'RANGES OF STRESS-STRAIN
    2 SETTLEMENT PARAMETERS'/1HO,50X,'PROBABLE    -    MINIMUM'/1HO,
    3'VERTICAL PRECONSOLIDATION STRESS .............',F8.3,' TSF  -',
    4F8.3,' TSF'/1HO,41HPRECONSOLIDATION STATE'S VERTICAL STRAIN  ,10('
    5.'),F8.3,2X,'-',F8.3/1HO,'OVERCONSOLIDATION RATIO (OCR) ',21('.'),
    6               F8.3,2X,'-',F8.3/1HO,'COMPRESSION RATIO (CR) ',
    728('.'),F8.3,2X,'-',F8.3/1HO,'SWELL RATIO (SR) ',
    834('.'),F8.3,2X ///)
     IF ((KIND.EQ.0).AND.(KK.EQ.1)) GO TO 380
     IF (KIND.EQ.0.AND.RUNTYP.EQ.0.AND.KRAD.EQ.2) GO TO 350
     IF (KIND.EQ.0.AND.RUNTYP.EQ.0) WRITE(IOUT,1180)
 350 CONTINUE
     IF ((KK.EQ.2).AND.(RUNTYP.NE.0)) WRITE (IOUT,1250)
     IF ((KK.EQ.2).AND.(RUNTYP.EQ.0)) WRITE (IOUT,1240)
     IF ((KK.EQ.1).AND.(RUNTYP.NE.0).AND.(KIND.NE.0)) WRITE(IOUT,1250)
     IF ((KK.EQ.1).AND.(RUNTYP.EQ.0).AND.(KIND.NE.0)) WRITE(IOUT,1240)
1240 FORMAT (8X,'EFF. VERT. ',9X,'VOID RATIO',9X,'VERT. STRAIN'/
    11HO,8X,'STRESS',34X,'(IN/IN)',13X,'DIAL RDG.'/1HO,8X,'(TSF)'//)
1250 FORMAT (8X,'EFF. VERT. ',9X,'VOID RATIO',9X,'VERT. STRAIN'/
    11HO,8X,'STRESS',34X,'(IN/IN)',13X,'TIME(MIN)'/1HO,8X,'(TSF)'//)
     DO 360 I=1,NUMPTC
     IF (NUMPTC.GT.10) E(I)=-E(I)
     IF((KIND.EQ.1).AND.(RUNTYP.EQ.0))WRITE(IOUT,1270)P(I),CSEVT(I),H(I
    1)
     IF((KIND.EQ.1).AND.(RUNTYP.NE.0))WRITE(IOUT,1270)P(I),CSEVT(I),TR(
    1I)
     IF((KIND.EQ.2).AND.(RUNTYP.EQ.0))WRITE(IOUT,1280)P(I),E(I),H(I)
     IF((KIND.EQ.2).AND.(RUNTYP.NE.0))WRITE(IOUT,1280)P(I),E(I),TR(I)
     IF (KIND.NE.0) GO TO 360
     IF (RUNTYP.EQ.0) WRITE (IOUT,1260) P(I),CSEVT(I),E(I),H(I)
     IF (RUNTYP.NE.0) WRITE (IOUT,1260) P(I),CSEVT(I),E(I),TR(I)
1260 FORMAT (1H ,5X,6(F10.5,10X))
1270 FORMAT (1H ,5X,2(F10.5,10X),20X,F10.5)
1280 FORMAT (1H ,5X,F10.5,30X,2(F10.5,10X))
 360 CONTINUE
     DO 370 I=1,NUMPTE
     IF (NUMPTC.GT.10) EE(I)=-EE(I)
     IF((KIND.EQ.1).AND.(RUNTYP.EQ.0))WRITE(IOUT,1270)PE(I),CSEVTE(I),
    1 HE(I)
     IF((KIND.EQ.1).AND.(RUNTYP.NE.0))WRITE(IOUT,1270)PE(I),CSEVTE(I),
    1 TRE(I)
     IF((KIND.EQ.2).AND.(RUNTYP.EQ.0))WRITE(IOUT,1280)PE(I),EE(I),HE(I)
     IF((KIND.EQ.2).AND.(RUNTYP.NE.0))WRITE(IOUT,1280)PE(I),EE(I),
    1 TRE(I)
     IF (KIND.NE.0) GO TO 370
     IF (RUNTYP.EQ.0) WRITE (IOUT,1260) PE(I),CSEVTE(I),EE(I),HE(I)
     IF (RUNTYP.NE.0) WRITE (IOUT,1260) PE(I),CSEVTE(I),EE(I),TRE(I)
 370 CONTINUE
 380 CONTINUE
C
C     IF THE PT. OF MAX. CURVATURE HAS GREATER ABSCISSA VALUE THAN THE
C     PRECONSOLIDATION STRESS BY CASAGRANDE'S CONSTRUCTION, THE PROCEDUR
C     HAS FAILED.
C
     IF (PC.LT.XSLP2)  WRITE (IOUT,1290)
1290 FORMAT(1X///1X,'**** ATTENTION ****  ANALYTICAL PROCEDURE WITH
    1CASAGRANDE CONSTR. HAS FAILED.  CHECK DATA AND ASSUMPTIONS!!! ** A
    2 **'///)
     PINSTU=ALOG10(PINSTU)
```

```
  390 CONTINUE
      WRITE (IOUT,1300) DCF,LCF,PCF
 1300 FORMAT(1H0,5X,'ADDITIONAL INPUT DATA'//6X,'CALIBRATION FACTORS:'/
     16X,'DEFLECTION =',F8.5,5X,'LOAD =',F8.5,5X,'PRESSURE =',F8.5)
      WRITE (IOUT,1310) DEFZ,WRZ,PPZ
 1310 FORMAT(1H0,5X,'EQUIPMENT ZERO READINGS:'/6X,'DEFLECTION =',
     1F8.3,5X,'LOAD =',F8.3,5X,'PORE PRESSURE =',F8.4)
      WRITE (IOUT,1320) DIA,SAMPHI
 1320 FORMAT(1H0,5X,'DIAMETER OF SPECIMEN =',F6.3,' INCHES',5X,
     1'INITIAL HEIGHT OF SAMPLE =',F6.3,' INCHES')
  400 CONTINUE
      WRITE (IOUT,1180)
      CALL PLOT (15.0,0.0,-3)
      CALL PLOT(0.0,0.0,999)
      STOP
      END
      SUBROUTINE CONGRA
C
C     THIS SUBROUTINE READS AND REDUCES THE TEST DATA FOR THE CONTROLLED
C     GRADIENT AND RATE OF STRAIN CONSOLIDATION TESTS.
C
      COMMON /BLOK1/ SEVT(303),E(303),SEVTE(103),EE(103),C(103)
      DOUBLE PRECISION C
      COMMON /BLOK2/ CEPTA ,SLOPEB,CEPTB,SLOPEC,CEPTC,SLOPED,CEPTD,
     1SLOPEE,CEPTE,SLOPEF,CEPTF,SLOPEG,CEPTG,BOUND1,BOUND2,BOUND3,BOUND4
     2,BOUND5,BOUND6,NUMPTC,NUMPTE,PINSTU,XSLP2,PC,EC,EO,CCR,CC1,CS,CR,
     3SR,NDEG,IN,IOUT,IDIAL
      COMMON /BLOK4/ TR(303),TRE(103),DEFR(303),DEFRE(103),PPR(303),
     1PPRE(103),WRD(303),WRDE(103),L,STVT(303),
     2STVTE(103),PPP(303),PPPE(103),PPT(303),PPTE(103),
     3CSEVT(303),CSEVTE(103),DFLI(303),DFLIE(103),STR(303),
     4STRE(103),H(303),HE(103),DCF,LCF,PCF
      COMMON /BLOK5/ LOC(4),HOL,SAM,TES,OPR(1),DAT(3),DES(4),BCO(20),
     1KK,RUNTYP
      COMMON /BLOK6/ SPG,WTIW,WTFW,WTFD,DEFI,DEFF,BP,DEFZ,WRZ,PPZ,HS,HI,
     1HV,SI,EI,EF,SF,WI,WF,SECOND,AR
      DIMENSION  T(503),TE(503)
      REAL LCF
      INTEGER RUNTYP
C
C     READ IN CONTROLLED TEST COMPRESSION DATA -- TIME, DEFLECTION,
C     PORE PRESSURE, AND LOAD.
C
C
      DO 30 I=1,300
      READ (IN,1000) TR(I),DEFR(I),PPR(I),WRD(I),L
 1000 FORMAT (F4.0,F5.2,2F4.0,I2)
C
C     COMPUTE ALL OUTPUT
C
      T(I)=TR(I)-TR(1)+1.0
      STVT(I)=((WRD(I)-WRZ)*LCF*144.0)/(2000.0*AR)
      PPP(I)=((PPR(I)-PPZ)*PCF)
      PPT(I)=PPP(I)*0.072
      SEVT(I)=STVT(I)-(0.66667*PPT(I))
      CSEVT(I)=SEVT(I)
      DFLI(I)=IDIAL*(DEFR(I)-DEFI)*DCF
      STR(I)=DFLI(I)/HI
      H(I)=HI-DFLI(I)
      E(I)=(HV-DFLI(I))/HS
```

```
      IF (SEVT(I).GT.SECOND) TR(I)=TR(I-1)
      IF (SEVT(I).GE.SECOND) STR(I)=STR(I-1)
      IF (SEVT(I).GE.SECOND) E(I)=E(I-1)
      IF (SEVT(I).GE.SECOND) SEVT(I) = SEVT(I-1)
      IF (KK.EQ.1) CSEVT(I)=E(I)
C     MUST DETERMINE WHEN EXPANSION  POINTS START.
      IF(I.EQ.1) GOTO 20
C
C     HAS EFFECTIVE STRESS DECREASED MORE THAN 0.7 TSF BETWEEN
C     CONSECUTIVE DATA POINTS?  IF SO, CONSIDER ALL SUBSEQUENT
C     DATA AS EXPANSION-REBOUND DATA.
      IF(SEVT(1).GT.1.0) GO TO 10
      DIFF=SEVT(I)-SEVT(I-1)
      IF(I.EQ.2) GO TO  10
      DIFF1=SEVT(I-1)-SEVT(I-2)
   10 CONTINUE
      IF (SEVT(I).LT.(SEVT(I-1)-0.7)) GO TO 40
      IF (SEVT(I).LT.0.1) SEVT(I)=0.1
C     CONTINUE TO READ COMPRESSION DATA.
   20 CONTINUE
   30 CONTINUE
C
   40 CONTINUE
C
C *** IGNORING LAST POINT (SECONDARY COMPRESSION PROBABLY) TO AVOID
C *** FITTED CURVE BENDING BACK TRYING TO FIT IT.
      NUMPTC=I-1
C *** THIS POINT HAS NOW BEEN MADE INVISIBLE TO ANALYSIS.
C
C
C     READ IN CONTROLLED TEST EXPANSION-REBOUND DATA -- TIME,DEFLECTION,
C     PORE PRESSURE, AND LOAD.
C
      DO 50 I=1,103
      READ (IN,1000) TRE(I),DEFRE(I),PPRE(I),WRDE(I),L
C
C     HAS A BLANK CARD BEEN ENCOUNTERED?  IF NOT, CONTINUE TO LOOK FOR
C     MORE DATA.
      IF(TRE(I).EQ.0) GOTO 60
      TE(I)=TRE(I)-TRE(1)+1.0
      TE(I)=TRE(I)-TR(1)+1.0
      TRE(I)=TE(I)
      STVTE(I)=((WRDE(I)-WRZ)*LCF*144.0)/(2000.0*AR)
      PPPE(I)=((PPRE(I)-PPZ)*PCF)
      PPTE(I)=PPPE(I)*0.072
      NUMPTE=I
      SEVTE(I)=STVTE(I)-(0.66667*PPTE(I))
      CSEVTE(I)=SEVTE(I)
      DFLIE(I)=IDIAL*(DEFRE(I)-DEFI)*DCF
      STRE(I)=DFLIE(I)/HI
      HE(I)=HI-DFLIE(I)
      EE(I)=(HV-DFLIE(I))/HS
      IF (KK.EQ.1) CSEVTE(I)=EE(I)
   50 CONTINUE
   60 CONTINUE
      RETURN
      END
C
C
C     *******************
```

```
C       * GRAPHICAL METHOD *
C       ********************
C
        SUBROUTINE GRARAD
C
C       THIS VERSION EMPLOYS MCNULTY'S CONSTRUCTION TO DETERMINE
C       THE POINT OF MAXIMUM CURVATURE.
        COMMON /BLOK1/ P(303),E(303),PE(103),EE(103),C(103)
        DOUBLE PRECISION C
        COMMON /BLOK2/ CEPTA ,SLOPEB,CEPTB,SLOPEC,CEPTC,SLOPED,CEPTD,
       1SLOPEE,CEPTE,SLOPEF,CEPTF,SLOPEG,CEPTG,BOUND1,BOUND2,BOUND3,BOUND4
       2,BOUND5,BOUND6,NUMPTC,NUMPTE,PINSTU,XSLP2,PC,EC,EO,CCR,CC1,CS,CR,
       3SR,NDEG,IN,ICUT,IDIAL
        COMMON /BLOK5/ LOC(4),HOL,SAM,TES,OPR(1),DAT(3),DES(4),BCD(20),
       1KK,RUNTYP
        COMMON /BLOK8/ RAD(103),RADMIN,RADMX,IMIN,IPRINT,JPRINT,KIND
        COMMON /BLOK9/ X(103, 4),SLOPE1(103),SLOPE2(103)
        COMMON     X1(103, 4),X2(103, 4),X3(103, 4),X4(103, 4),X5(103, 4),
       1X6(103, 4),X7(103, 4),X8(103, 4),X9(103, 4),X10(103, 4),X11(103, 4
       2)
        COMMON /BISEC/ XTAN,YTAN,CEPTAN,XANGLE,SLOPBI,CEPTBI
        INTEGER RUNTYP
        INTEGER START,SFAC
        DIMENSION CURVE(101),YLINE(101)
C
C       BOUND IS USED AS TEMPORARY STORAGE LOCATION FOR BOUND1.
        BOUND=BOUND1
        BOUND5=BOUND2
C
C       BOUND6 IS SET EQUAL TO 0.0 SO THAT PLOTTING SUBROUTINE CASPLT WILL
C       USE APPROPRIATE STATMENTS WHICH WILL PLOT MCNULTY'S CONTRUCTION.
        BOUND6=0.0
C
        IMIN=7
        RADMIN=100.
        RADMX=0.0
C
C       FIND A LINE TANGENT TO INITIAL COMPRESSION CURVE HAVING SLOPE OF
C       EXPANSION-REBOUND CURVE.
        DO 30 J=1,3
        DELTA=ABS(BOUND2-BOUND1)/100.0
        RADMIN=100.0
        DO 10 I=1,101
        X(1,J)=BOUND1
C
        X1(I,J)=X(I,J)*1.0
        X2(I,J)=X(I,J)*X(I,J)
        X3(I,J)=X(I,J)*X(I,J)*X(I,J)
        X4(I,J)=X(I,J)*X(I,J)*X(I,J)*X(I,J)
        X5(I,J)=X(I,J)*X(I,J)*X(I,J)*X(I,J)*X(I,J)
        X6(I,J)=X(I,J)*X(I,J)*X(I,J)*X(I,J)*X(I,J)*X(I,J)
        X7(I,J)=X(I,J)*X(I,J)*X(I,J)*X(I,J)*X(I,J)*X(I,J)*X(I,J)
        X8(I,J)=X(I,J)*X(I,J)*X(I,J)*X(I,J)*X(I,J)*X(I,J)*X(I,J)*X(I,J)
        X9(I,J)=X(I,J)*X(I,J)*X(I,J)*X(I,J)*X(I,J)*X(I,J)*X(I,J)*X(I,J)
       1*X(I,J)
        X10(I,J)=X(I,J)*X(I,J)*X(I,J)*X(I,J)*X(I,J)*X(I,J)*X(I,J)*X(I,J)
C
C
C
        SLOPE1(I)=C(2)+2*C(3)*X1(I,J) + 3*C(4)*X2(I,J) +   4*C(5)*X3(I,J)+
```

```
     K5*C(6)*X4(I,J)+  6*C(7)*X5(I,J)+ 7*C(8)*X6(I,J)+8*C(9)*X7(I,J)+
     K9*C(10)*X8(I,J)+  10*C(11)*X9(I,J) +11*C(12)*X10(I,J)
C
C
C      TRYING TO FIND TANGENT TO CURVE WITH SLOPE OF REBOUND-EXPANSION
C      CURVE.
       IF (SLOPE1(I).LT.SLOPEE) GO TO 20
C
    10 X(I+1,J)=X(I,J)+DELTA
    20 CONTINUE
       IF (I.EQ.1) GO TO 40
       BOUND2=X(I,J)
       BOUND1=X(I-1,J)
    30 CONTINUE
C
       J=3
       XB=X(I,J)
    40 CONTINUE
C
C      IF A TANGENT TO INITIAL COMPRESSION CURVE IS NOT FOUND, DEFAULT
C      TO USE FIRST SEARCH BOUNDARY (BOUND1) AS ABSCISSA VALUE ON
C      COMPRESSION CURVE THROUGH WHICH LINE HAVING THE SLOPE WILL BE
C      DRAWN.
       IF (I.EQ.1 )  XB=BOUND
C      **********************
C
       XTAN=XB
       XB1=XB
       XB2=XB*XB
       XB3=XB*XB*XB
       XB4=XB*XB*XB*XB
       XB5=XB*XB*XB*XB*XB
       XB6=XB*XB*XB*XB*XB*XB
       XB7=XB*XB*XB*XB*XB*XB*XB
       XB8=XB*XB*XB*XB*XB*XB*XB*XB
       XB9=XB*XB*XB*XB*XB*XB*XB*XB*XB
       XB10=XB*XB*XB*XB*XB*XB*XB*XB*XB*XB
       XB11=XB*XB*XB*XB*XB*XB*XB*XB*XB*XB*XB
C
C
C
       YTAN=C(1)+C(2)*XB1+ C(3)*XB2     +C(4)*XB3     +C(5)*XB4     +
     1C(6)*XB5     +C(7)*XB6     +C(8)*XB7     +C(9)*XB8     +
     2C(10)*XB9     +C(11)*XB10    +C(12)*XB11
C
       CEPTAN=YTAN-SLOPEE*XB
C      TANGENT LINE HAS BEEN DEFINED.
C      FIND INTERSECTION WITH LINE 'D' (VIRGIN COMPRESSION LINE).
C
       XANGLE=(CEPTAN-CEPTD)/(SLOPED-SLOPEE)
       YANGLE=SLOPEE*XANGLE+CEPTAN
       PI=355./113.
       SFAC=NUMPTC+2
       IF (KK.EQ.1) E(SFAC)=0.04
       IF (KK.EQ.2) E(SFAC)=0.02
       DELTA=E(1)-E(NUMPTC)
       IF (KK.EQ.1.AND.ABS(DELTA).GT.0.32) E(SFAC)=0.08
       IF (KK.EQ.2.AND.ABS(DELTA).GT.0.16) E(SFAC)=0.04
       CALL SCALE (E,9.0,NUMPTC,1)
       P(SFAC)=0.3000
       FACTOR=P(SFAC)/E(SFAC)
```

```
C
C     BISECT PICTORIAL REPRESENTATION OF INTERIOR ANGLE FORMED
C     BY INTERSECTION OF INITIAL TANGENT AND VIRGIN COMPRESSION
C     CURVE LINE REPRESENTATION.
      SLOPBI=TAN(PI-ABS(ATAN(SLOPED*FACTOR))-ABS(ABS(ATAN(SLOPEE*
     1FACTOR))-ABS(ATAN(SLOPED*FACTOR))+PI))/2.0)
C
      SLOPBI=SLOPBI/FACTOR
      CEPTBI=YANGLE-SLOPBI*XANGLE
C     LINE OF ANGLE BISECTOR HAS BEEN DEFINED.
      BOUND1=BOUND
      BOUND2=P(NUMPTC)
C
C     FIND INTERSECTION OF ANGLE BISECTOR LINE WITH COMPRESSION CURVE'S
C     POLYNOMIAL REPRESENTATION.
      DO 70 J=1,3
      DELTA=ABS(BOUND2-BOUND1)/100.0
      DO 50 I=1,101
      X(1,J)=BOUND1
      X1(I,J)=X(I,J)*1.0
      X2(I,J)=X(I,J)*X(I,J)
      X3(I,J)=X(I,J)*X(I,J)*X(I,J)
      X4(I,J)=X(I,J)*X(I,J)*X(I,J)*X(I,J)
      X5(I,J)=X(I,J)*X(I,J)*X(I,J)*X(I,J)*X(I,J)
      X6(I,J)=X(I,J)*X(I,J)*X(I,J)*X(I,J)*X(I,J)*X(I,J)
      X7(I,J)=X(I,J)*X(I,J)*X(I,J)*X(I,J)*X(I,J)*X(I,J)*X(I,J)
      X8(I,J)=X(I,J)*X(I,J)*X(I,J)*X(I,J)*X(I,J)*X(I,J)*X(I,J)*X(I,J)
      X9(I,J)=X(I,J)*X(I,J)*X(I,J)*X(I,J)*X(I,J)*X(I,J)*X(I,J)*X(I,J)
     1*X(I,J)
      X10(I,J)=X(I,J)*X(I,J)*X(I,J)*X(I,J)*X(I,J)*X(I,J)*X(I,J)*X(I,J)
     1*X(I,J)*X(I,J)
      X11(I,J)=X(I,J)*X(I,J)*X(I,J)*X(I,J)*X(I,J)*X(I,J)*X(I,J)*X(I,J)
     1*X(I,J)*X(I,J)*X(I,J)
C
C
C
      CURVE(I)=C(1)+   C(2)*X1(I,J)+   C(3)*X2(I,J)+   C(4)*X3(I,J)+
     1C(5)*X4(I,J)+   C(6)*X5(I,J)+   C(7)*X6(I,J)+   C(8)*X7(I,J)+
     2C(9)*X8(I,J)+   C(10)*X9(I,J)+   C(11)*X10(I,J)+   C(12)*X11(I,J)
C
      YLINE(I)=SLOPBI*X(I,J)+CEPTBI
C
      INUM=J
C
C     FINDING THE INTERSECTION OF ANGLE BISECTOR WITH COMPRESSION CURVE
C     BY COMPARING ORDINATES OF COMPRESSION CURVE'S POLYNOMIAL AND
C     ANGLE BISECTOR LINE WITH INCREASING ABSCISSA VALUES.  INTERSECTION
C     IS FOUND WHEN THE ORDINATE VALUE OF THE ANGLE BISECTOR LINE IS
C     GREATER THAN THE CORRESPONDING ORDINATE VALUE OF THE COMPRESSION
C     CURVE POLYNOMIAL.
C     POINT OF INTERSECTION IS GRAPHICALLY SELECTED POINT OF MAXIMUM
C     CURVATURE.
C
      IF (YLINE(I).GT.CURVE(I)) GO TO 60
C
      X(I+1,J)=X(I,J)+DELTA
   50 CONTINUE
   60 CONTINUE
      IF (I.LE.1) GO TO 70
      BOUND2=X(I,J)
```

```
      BOUND1=X(I-1,J)                                                   GRAR1850
   70 CONTINUE                                                          GRAR1860
      IF (I.NE.1) J=3                                                   GRAR1870
      IF ((INUM.EQ.1).AND.(I.LE.1)) J=1                                 GRAR1880
      IF ((INUM.EQ.2).AND.(I.LE.1)) J=2                                 GRAR1890
      IF ((INUM.EQ.3).AND.(I.LE.1)) J=3                                 GRAR1900
      BOUND1=BOUND                                                      GRAR1910
      BOUND2=BOUND5                                                     GRAR1920
C                                                                       GRAR1930
C     THE GRAPHICALLY SELECTED POINT OF MAX. CURVATURE.                 GRAR1940
      RADMX=X(I,J)                                                      GRAR1950
C                                                                       GRAR1960
      RETURN                                                            GRAR1970
      END                                                               GRAR1980
      SUBROUTINE ANARAD                                                 ANAR0001
C                                                                       ANAR0010
C                                                                       ANAR0020
C     ********************                                              ANAR0030
C     * ANALYTICAL METHOD *                                             ANAR0040
C     ********************                                              ANAR0050
C                                                                       ANAR0060
C                                                                       ANAR0061
C     THIS VERSION EMPLOYS THE MATHEMATICAL DEFINITION OF THE           ANAR0062
C     RADIUS OF CURVATURE IN SEARCHING FOR THE POINT OF MAXIMUM         ANAR0063
C     CURVATURE.                                                        ANAR0064
C                                                                       ANAR0070
C     THE PICTORIAL LOCATION OF THE POINT OF MAXIMUM CURVATURE DEPENDS  ANAR0080
C     PRIMARILY ON THE ARITHMETIC RATIO OF THE SCALE FACTORS USED IN    ANAR0090
C     THE HORIZONTAL AND VERTICAL DIRECTIONS.  HENCE, WITH A DIFFERENT  ANAR0100
C     RATIO FOR THE HORIZONTAL TO VERTICAL SCALE FACTORS, THE POINT OF  ANAR0110
C     MAXIMUM CURVATURE WILL BE LOCATED AT A DIFFERENT ABSCISSA LOCATIONANAR0120
C     ON A GIVEN CURVE.  THE RATIO OF THE HORIZONTAL TO VERTICAL SCALE  ANAR0130
C     FACTORS MUST BE MULTIPLIED TIMES THE FIRST AND SECOND DERIVATIVES ANAR0140
C     BEFORE THE MATHEMATICAL DEFINITION OF THE POINT OF MAXIMUM CUR-   ANAR0150
C     VATURE CAN BE USED TO SELECT THE POINT OF MAXIMUM CURVATURE BASED ANAR0160
C     ON THE PICTORIAL CHARACTERISTICS OF THE FITTED CURVE.             ANAR0170
C                                                                       ANAR0180
      REAL*8 DSQRT                                                      ANAR0190
      COMMON /BLOK1/ P(303),E(303),PE(103),EE(103),CC(103)              ANAR0200
      DOUBLE PRECISION CC                                               ANAR0210
      COMMON /BLOK2/ CEPTA,SLOPEB,CEPTB,SLOPEC,CEPTC,SLOPED,CEPTD,      ANAR0220
     1SLOPEE,CEPTE,SLOPEF,CEPTF,SLOPEG,CEPTG,BOUND1,BOUND2,BOUND3,BOUND4ANAR0230
     2,BOUND5,BOUND6,NUMPTC,NUMPTE,PINSTU,XSLP2,PC,EC,EO,CCR,CC1,CS,CR, ANAR0240
     3SR,NDEG,IN,ICUT,IDIAL                                             ANAR0250
      COMMON /BLOK5/ LOC(4),HOL,SAM,TES,OPR(1),DAT(3),DES(4),BCD(20),   ANAR0260
     1KK,RUNTYP                                                         ANAR0270
      COMMON /BLOK8/ RAD(103),RADMIN,RADMX,IMIN,IPRINT,JPRINT,KIND      ANAR0280
      DOUBLE PRECISION C(12),X(103, 4),SLOPE1(103)                      ANAR0290
      DIMENSION SLOPE2(103)                                             ANAR0300
      DOUBLE PRECISION  X1(103, 4),X2(103, 4),X3(103, 4),X4(103, 4),    ANAR0310
     1X5(103,4),X6(103, 4),X7(103, 4),X8(103, 4),X9(103, 4),X10(103, 4),ANAR0320
     KX11(103,4)                                                        ANAR0330
      DO 10 I = 1,12                                                    ANAR0340
      C(I)=0.0                                                          ANAR0350
      C(I)=CC(I)                                                        ANAR0360
   10 CONTINUE                                                          ANAR0370
C                                                                       ANAR0380
      BOUND5=BOUND1                                                     ANAR0390
      BOUND6=BOUND2                                                     ANAR0400
C                                                                       ANAR0410
```

```
      DERIV2=0.0
      IMIN=7
      IDERV2=7
      RADBIG=0.0
      ICHECK=0
      J=1
      IF (KK.EQ.1) E(NUMPTC+2)=0.04
      IF (KK.EQ.2) E(NUMPTC+2)=0.02
      DELTA=E(1)-E(NUMPTC)
      IF (KK.EQ.1.AND.ABS(DELTA).GT.0.32) E(NUMPTC+2)=0.08
      IF (KK.EQ.2.AND.ABS(DELTA).GT.0.16) E(NUMPTC+2)=0.04
      CALL SCALE(E,8.0,NUMPTC,1)
      FACTOR=0.3000/E(NUMPTC+2)
C
C     COMPUTE RADII OF CURVATURE AT GENERATED ABSCISSA BETWEEN SEARCH
C     BOUNDARIES.
      DO 40 J=1,2
      IF (IPRINT.EQ.0) WRITE(IOUT,1030)
      IF ((IPRINT.EQ.1).AND.(J.EQ.2)) WRITE(IOUT,1030)
      DELTA=ABS(BOUND2-BOUND1)/100.0
      RADMIN=100.0
      DO 30 I =1,101
      X(1,J)=BOUND1
C
      X1(I,J)=X(I,J)*1.0
      X2(I,J)=X(I,J)*X(I,J)
      X3(I,J)=X(I,J)*X(I,J)*X(I,J)
      X4(I,J)=X(I,J)*X(I,J)*X(I,J)*X(I,J)
      X5(I,J)=X(I,J)*X(I,J)*X(I,J)*X(I,J)*X(I,J)
      X6(I,J)=X(I,J)*X(I,J)*X(I,J)*X(I,J)*X(I,J)*X(I,J)
      X7(I,J)=X(I,J)*X(I,J)*X(I,J)*X(I,J)*X(I,J)*X(I,J)*X(I,J)
      X8(I,J)=X(I,J)*X(I,J)*X(I,J)*X(I,J)*X(I,J)*X(I,J)*X(I,J)*X(I,J)
      X9(I,J)=X(I,J)*X(I,J)*X(I,J)*X(I,J)*X(I,J)*X(I,J)*X(I,J)*X(I,J)
     1*X(I,J)
      X10(I,J)=X(I,J)*X(I,J)*X(I,J)*X(I,J)*X(I,J)*X(I,J)*X(I,J)*X(I,J)
     1*X(I,J)*X(I,J)
C
C
C
      SLOPE1(I)=C(2)+2.*C(3)*X1(I,J)+3.*C(4)*X2(I,J) + 4.*C(5)*X3(I,J)+
     K5.*C(6)*X4(I,J)+6.*C(7)*X5(I,J)+7.*C(8)*X6(I,J)+8.*C(9)*X7(I,J)+
     K9*C(10)*X8(I,J)+  10*C(11)*X9(I,J) +11*C(12)*X10(I,J)
C
C
C
      SLOPE2(I)=2*C(3)+6*C(4)*X1(I,J)+12*C(5)*X2(I,J)+20*C(6)*X3(I,J)
     1+30*C(7)*X4(I,J)+42*C(8)*X5(I,J)+56*C(9)*X6(I,J)
     2+72*C(10)*X7(I,J)+90*C(11)*X8(I,J)+110*C(12)*X9(I,J)
C
      SLOPE1(I)=SLOPE1(I)*FACTOR
      SLOPE2(I)=SLOPE2(I)*FACTOR
C     THIS NEXT EQUATION IS USED TO CALCULATE
C     THE MINIMUM RADIUS OF CURVATURE.
C     THESE RADII ARE THEN COMPARED TO OBTAIN THE
C     SMALLEST ONE PRESENT.
C
      RAD(I)=DSQRT((1+SLOPE1(I)*SLOPE1(I))*(1+SLOPE1(I)*SLOPE1(I))*(1+
     1SLOPE1(I)*SLOPE1(I)))/SLOPE2(I)
      IF (IPRINT.EQ.0) WRITE(IOUT,1000) I,X(I,J),RAD(I),SLOPE2(I)
 1000 FORMAT (1X,I3,2X,'X =',G15.5,5X,'RAD =',G15.5,5X,'SLOPE2 =',F10.5)
```

```
C
      IF(ABS(RAD(I)).GE.ABS(RADBIG)) RADBIG=RAD(I)
      IF(ABS(RAD(I)).GE.ABS(RADBIG)) IBIG=I
      IF(ABS(RAD(I)).GE.ABS(RADBIG))  XBIG=X(I,J)
      IF(ABS(SLOPE2(I)).GT.ABS(DERIV2)) IDERV2=1
      IF(ABS(SLOPE2(I)).GT.ABS(DERIV2)) DERIV2=SLOPE2(I)
      IF (I.EQ.1) GO TO 30
      IF (ABS(RAD(I)) .GT.ABS(RAD(I-1)))   GO TO 20
      GO TO 30
   20 CONTINUE
      IF (I.EQ.2) GO TO 30
      IF (ABS(RADMIN).LE.ABS(RAD(I-1))) GO TO 30
      IF (ABS(RAD(I-2)).LE.ABS(RAD(I-1))) GO TO 30
      ICHECK=1
      IMIN=I-1
      IF(IMIN.LE.5) GO TO 30
      IF(IMIN.GE.96 ) GO TO 30
      RADMIN=RAD(I-1)
      RADMX=X(I-1,J)
   30 X(I+1,J)=X(I,J)+DELTA
      IF (IMIN.EQ.7) GO TO 40
      IF (IMIN.EQ.1) GO TO 40
      IF (IMIN.EQ.101) GO TO 40
      BOUND1=X(IMIN-1,J)
      BOUND2=X(IMIN+1,J)
   40 CONTINUE
      J=2
C
C     IS THERE A DISCRETE POINT OF MAXIMUM CURVATURE IN 90( MIOPORTION
C     OF SEARCH BOUNDARIES?  IF THERE IS NOT, DEFAULT TO USE LOCATION
C     OF THE MAXIMUM VALUE FOR THE SECOND DERIVATIVE AS CHOSEN POINT
C     OF MAXIMUM CURVATURE.
      IF (ICHECK.EQ.0) IMIN=IDERV2
      IF (ICHECK.EQ.0) RADMX=X(IMIN,J)
      IF(IMIN.LE.6) RAOMX=X(IDERV2,J)
      IF(IMIN.GE.94) RADMX=X(IDERV2,J)
      IF(IPRINT.EQ.0) WRITE(IOUT,1010) X(IMIN,J),IMIN,DERIV2,IDERV2
 1010 FORMAT(5X,'XMIN =',F10.5,5X,'IMIN =',I3,9X,'DERIV2 =',F10.5,5X,
     K'IDERV2 =',I3)
      IF(ICHECK.EQ.0) WRITE(IOUT,1020)
      IF(IMIN.LE.6) WRITE(IOUT,1020)
      IF(IMIN.GE.94)WRITE(IOUT,1020)
 1020 FORMAT('0',5X,'**WARNING**: PT. MAX. CURVATURE NOT WITHIN 90( '
     1,'MIDPORTION OF BOUND1 AND BOUND2.'/1H0,5X,'LOCATION OF MAXIMUM '
     2,'SECOND DERIVATIVE TAKEN AS DEFAULT FOR PT. OF MAX. CURVATURE'//)
      IF(ICHECK.EQ.0) WRITE(IOUT,1030)
      IF(ICHECK.NE.0.AND.IPRINT.EQ.0) WRITE(IOUT,1030)
 1030 FORMAT ('1')
      BOUND1=BOUND5
      BOUND2=BOUND6
C
C     BOUND6 IS SET EQUAL TO 999 SO THAT PLOTTING SUBROUTINE
C     CASPLT WILL SKIP ARGUMENTS RELATING TO THE GRAPHICAL
C     METHOD.
      BOUND6=999.0
C
      RETURN
      END
C
C     ***********************************************************
```

```
C      * LEAST SQUARES ORDINARY POLYNOMIAL CURVE FITTING SUBROUTINE.*
C      ****************************************************************
C
C
C                                 NUMALIB
C
C                        UNIVERSITY OF KENTUCKY
C
C                            COMPUTER CENTER
C
C                               MCVEY HALL
C                         LEXINGTON, KENTUCKY
C
C
      SUBROUTINE FLSQFY(N,M,X,Y,W,C,ALPHA,BETA,S,SGMSQ,PR,PO,N1,MN1)
      IMPLICIT REAL*8 (A-H,O-W,Z)
      DIMENSION C(N1),ALPHA(MN1),BETA(MN1),S(MN1),SGMSQ(MN1),PR(MN1),PO(
     $MN1),W(M),X(M),Y(M)
      GAMDA=1.
      NO=0
      CALL FGEFYT(N,NO,X,Y,W,BETA,S,SGMSQ,ALPHA,PR,PO,M,MN1)
      CALL FCODA(N,C,PO,PR,ALPHA,BETA,GAMDA,S,N+1)
      RETURN
      END
      SUBROUTINE FCODA(N,C,PM,PR,ALPHA,BETA,GAMDA,S,NN)
      IMPLICIT REAL*8 (A-H,O-W,Z)
      DIMENSION C(NN),ALPHA(NN),BETA(NN),PM(NN),PR(NN),S(NN)
      N1=N+1
      DO 10 IB=1,N1
      C(IB)=0.
      PM(IB)=0.
   10 PR(IB)=0.
      PR(1)=1.
      C(1)=S(1)
      DO 20 I=1,N
      T2=0.
      N1=I+1
      DO 20 IB=1,N1
      T1=(T2-ALPHA(I)*PR(IB)-BETA(I)*PM(IB))/GAMDA
      T2=PR(IB)
      PM(IB)=PR(IB)
      PR(IB)=T1
   20 C(IB)=C(IB)+T1*S(I+1)
      RETURN
      END
      SUBROUTINE FGEFYT(N,NO,X,Y,W,BETA,S,SGMSQ,ALPHA,PR,PO,M,NI)
      IMPLICIT REAL*8 (A-H,O-W,Z)
      DIMENSION X(M),Y(M),BETA(NI),ALPHA(NI),S(NI),SGMSQ(NI),PR(M),
     $PO(M),W(M)
 1000 FORMAT(32H  THERE IS AN ERROR IN YOUR DATA)
      IF (N -NO -M) 10,30,20
   10 IF(N-NO)20,30,30
   20 PRINT 1000
      GOTO 210
   30 BETA(NO+1)=0.
      DSQ=0.
      WPP=0.
      LXACT=0
      IF(N-NO-M+1)50,40,40
   40 LXACT=1
```

```
   50 DO 80 J=1,M
      PR(J)=1.
      PO(J)=0.
   60 WPP=WPP+W(J)
      IF(LXACT)80,70,80
   70 DSQ=DSQ+W(J)*Y(J)*Y(J)
   80 CONTINUE
      NON=NO+1
      NN=N+1
      DO 200 I=NON,NN
      LREEDO=M-I+NO
      WYP=0.
      WXPP=0.
      DO 120 J=1,M
      TEMP=W(J)*PR(J)
      IF(I-NN)90,100,100
   90 WXPP=WXPP+TEMP*X(J)*PR(J)
  100 IF(LREEDO)120,110,110
  110 WYP=WYP+TEMP*Y(J)
  120 CONTINUE
      IF(LREEDO)140,130,130
  130 S(I)=WYP/WPP
  140 IF(LXACT)160,150,160
  150 DSQ=DSQ-S(I)*S(I)*WPP
      BR=LREEDO
      SGMSQ(I)=DSQ/BR
      GOTO 170
  160 SGMSQ(I)=0.
  170 IF(I-NN)180,200,200
  180 ALPHA(I)=WXPP/WPP
      WPPO=WPP
      WPP=0.
      DO 190 J=1,M
      TEMP=(X(J)-ALPHA(I))*PR(J)-BETA(I)*PO(J)
      WPP=WPP+W(J)*TEMP**2
      PO(J)=PR(J)
  190 PR(J)=TEMP
      BETA(I+1)=WPP/WPPO
  200 CONTINUE
  210 RETURN
      END
C
C     ***********************
C     * PLOTTING SUBROUTINE *
C     ***********************
C
      SUBROUTINE CASPLT
C
C
C     - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
C     |                                                               |
C     |                                                               |
C     |  THIS SUBROUTINE PLOTS THE RESULTS OF THE ANALYTICAL APPLI-   |
C     |  CATIONS OF THE MCNULTY, CASAGRANDE, AND SCHMERTMANN CON-     |
C     |  STRUCTIONS.                                                  |
C     |                                                               |
C     - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
C
      COMMON /BLCK1/ P(303),E(303),PE(103),EE(103),C(103)
      DOUBLE PRECISION C
```

```
      COMMON /BLOK2/ AY,SB,BY,SC,CY,SD,DY,SE,EY,SF,FY,SG,GY,B1,B2,B3,B4,
     2B5,BOUND6,NC,NE,POVER,XSLP2,PC,EC,EO,OCR,CC1,CS,CR,SR,NDEG,IN
     3,IOUT,IDIAL
      COMMON /BLOK3/ PO,PRECON,PREMIN,VOIDC,ECMIN,OCRMIN,CRMIN
      COMMON /BLOK5/ LOC(4),HOL,SAM,TES,OPR(1),DAT(3),DES(4),BCD(20),
     1KK,RUNTYP
      COMMON /BLOK8/ RAD(103),RADMIN,RADMX,IMIN,IPRINT,JPRINT,KIND
      COMMON /BISEC/ XTAN,YTAN,CEPTAN,XANGLE,SLOPBI,CEPTBI
      DIMENSION DATA(1024),X(103),CURVFT(103)
      DIMENSION BOVER(3),VOIDEO(3),DASH(13),DASHY(13),PDUMMY(103)
      REAL  LINEA(103),LINEB(103),LINEC(103),LINED(103),LINEE(103),
     1LINEF(103),LINEG(103)
      DIMENSION  TANGEN(103),BISECT(13)
      INTEGER START,SFAC
      INTEGER STARE,SFAE,STARX,SFACUR
      INTEGER RUNTYP
C
C
      CALL SCALE (E,8.0,NC,1)
      BOVER(1)=POVER
      VOIDEO(1)=EO
      IF (KK.EQ.2) VOIDEO(1)=0.0
      DASHY(1)=PC*SD+DY
      VOIDPC=DASHY(1)
C
C     SETTING UP STARTING AND SCALE FACTOR POSITIONS
C     FOR EACH OF THE RESPECTIVE PLOT VARIABLES.
C
      START=NC+1
      STARE=NE+1
      STARX=101+1
      SFAC=NC+2
      SFAE=NE+2
      SFACUR=101+2
C
      P(START)=-1.000
      PE(STARE)=P(START)
      IF (KK.EQ.2) E(START)=0.0
      EE(STARE)=E(START)
      X(STARX)=P(START)
      CURVFT(STARX)=E(START)
      LINEA(STARX)=E(START)
      LINEB(STARX)=E(START)
      LINEC(STARX)=E(START)
      LINED(STARX)=E(START)
      LINEE(STARX)=E(START)
      LINEF(STARX)=E(START)
      LINEG(STARX)=E(START)
      BOVER(2)=P(START)
      VOIDEO(2)=E(START)
      DASH(12)=P(START)
      DASHY(12)=E(START)
      TANGEN(STARX)=E(START)
      BISECT(12)=E(START)
C
      P(SFAC)=0.3000
      PE(SFAE)=P(SFAC)
      EE(SFAE)=E(SFAC)
      X(SFACUR)=P(SFAC)
      CURVFT(SFACUR)=E(SFAC)
```

```
      LINEA(SFACUR)=E(SFAC)
      LINEB(SFACUR)=E(SFAC)
      LINEC(SFACUR)=E(SFAC)
      LINED(SFACUR)=E(SFAC)
      LINEE(SFACUR)=E(SFAC)
      LINEF(SFACUR)=E(SFAC)
      LINEG(SFACUR)=E(SFAC)
      BOVER(3)=P(SFAC)
      VOIDEO(3)=E(SFAC)
      DASH(13)=P(SFAC)
      DASHY(13)=E(SFAC)
      TANGEN(SFACUR)=E(SFAC)
      BISECT(13)=E(SFAC)
C
      FIRLOG=-1.000
      DELLOG=0.30000
      CALL LOGAXS(0.0,8.0,'LOG( VERTICAL EFF. STRESS, TSF)',31,10.0,0.0,
     1-1.000,0.30000)
      IF (KK.EQ.2) GO TO 10
      CALL AXIS(0.0,0.0,'VOID RATIO (E)',14,8.00,90.0,E(START),E(SFAC))
      GO TO 20
C
   10 CONTINUE
      CALL PLOT (0.0,8.0,-3)
      CALL AXIS (0.0,0.0,'VERTICAL STRAIN (IN/IN)',-23,8.0,270.0,0.0
     1 ,E(SFAC))
   20 CONTINUE
C
C     GENERATE THE PLOTS
C
C
C     COMPRESSION CURVE.J=1.  ONLY SYMBOLS FOR EACH POINT PRODUCED.
      CALL LINE(P,E,NC,1,-1,1)
      CALL LINE(PE,EE,NE,1,-1,1)
C     EXPANSION CURVE, J=1, ONLY SYMBOLS FOR EACH POINT PRODUCED.
C
C
      X(1)=P(1)
      DELTA=(P(NC)-P(1))/100
      DO 30 I=2,101
   30 X(I)=X(I-1)+DELTA
      DO 40 I=1,101
C
      X1=X(I)
      X2=X(I)*X(I)
      X3=X(I)*X(I)*X(I)
      X4=X(I)*X(I)*X(I)*X(I)
      X5=X(I)*X(I)*X(I)*X(I)*X(I)
      X6=X(I)*X(I)*X(I)*X(I)*X(I)*X(I)
      X7=X(I)*X(I)*X(I)*X(I)*X(I)*X(I)*X(I)
      X8=X(I)*X(I)*X(I)*X(I)*X(I)*X(I)*X(I)*X(I)
      X9=X(I)*X(I)*X(I)*X(I)*X(I)*X(I)*X(I)*X(I)*X(I)
      X10=X(I)*X(I)*X(I)*X(I)*X(I)*X(I)*X(I)*X(I)*X(I)*X(I)
      X11=X(I)*X(I)*X(I)*X(I)*X(I)*X(I)*X(I)*X(I)*X(I)*X(I)*X(I)
      CURVFT(I)=C(1)+  C(2)*X1+  C(3)*X2+  C(4)*X3+  C(5)*X4+  C(6)*X5
     1+C(7)*X6+  C(8)*X7+  C(9)*X8+    C(10)*X9+  C(11)*X10+  C(12)*X11
C
   40 CONTINUE
C
C     FITTED CURVE. J=0.  ONLY A LINE PLOT PRODUCED,  NO SYMBOLS.
```

```
      CALL LINE(X,CURVFT,101,1,0,0)                                     CASP1400
C                                                                       CASP1410
C     NOW PLOTTING EXPANSION-REBOUND CURVE LINE REPRESENTATION.         CASP1420
C                                                                       CASP1430
      X(1)=PE(1)                                                        CASP1440
      DELTA=(PE(NE)-PE(1))/100                                          CASP1450
      DO 50 I=2,101                                                     CASP1460
      X(I)=X(I-1)+DELTA                                                 CASP1470
   50 CONTINUE                                                          CASP1480
      DO 60 I=1,101                                                     CASP1490
      LINEE(I)=SE*X(I)+EY                                               CASP1500
   60 CONTINUE                                                          CASP1510
      CALL LINE(X,LINEE,101,1,0,0)                                      CASP1520
C                                                                       CASP1530
      IF (BOUND6.GT.998) GO TO 110                                      CASP1540
C                                                                       CASP1550
C                                                                       CASP1560
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * CASP1570
C     * MCNULTY'S GRAPHICAL CONSTRUCTION TO DETERMINE PT. OF MAX. CURV.*CASP1580
C     * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * CASP1590
      X(1)=XTAN-0.1                                                     CASP1600
      DELTA=ABS(XANGLE-X(1))/100.0                                      CASP1610
      DO 70 I=2,101                                                     CASP1620
      X(I)=X(I-1)+DELTA                                                 CASP1630
   70 CONTINUE                                                          CASP1640
      DO 80 I=1,101                                                     CASP1650
      TANGEN(I)=SE*X(I)+CEPTAN                                          CASP1660
   80 CONTINUE                                                          CASP1670
      CALL LINE (X,TANGEN,101,1,0,0)                                    CASP1680
      DASH(1)=XSLP2-0.05                                                CASP1690
      DELTA=ABS(XANGLE-DASH(1))/10.0                                    CASP1700
      DO 90 I=2,11                                                      CASP1710
      DASH(I)=DASH(I-1)+DELTA                                           CASP1720
   90 CONTINUE                                                          CASP1730
      DO 100 I=1,11                                                     CASP1740
      BISECT(I)=SLOPBI*DASH(I)+CEPTBI                                   CASP1750
  100 CONTINUE                                                          CASP1760
      CALL DASHLN (DASH,BISECT,11,1)                                    CASP1770
C                                                                       CASP1780
  110 CONTINUE                                                          CASP1790
C                                                                       CASP1800
C                                                                       CASP1810
C     *************************                                         CASP1820
C                                                                       CASP1830
C     CASAGRANDE'S CONSTRUCTION                                         CASP1840
C                                                                       CASP1850
C     *************************                                         CASP1860
C                                                                       CASP1870
      X(1)=XSLP2                                                        CASP1880
      DELTA=ABS(PC+0.05-XSLP2)/100                                      CASP1890
      DO 120 I=2,101                                                    CASP1900
      X(I)=X(I-1)+DELTA                                                 CASP1910
  120 CONTINUE                                                          CASP1920
C                                                                       CASP1930
      DO 130 I=1,101                                                    CASP1940
      LINEA(I)=AY+0.0*X(I)                                              CASP1950
  130 CONTINUE                                                          CASP1960
      CALL LINE(X,LINEA,101,1,0,0)                                      CASP1970
      A =(X(101)-X(102))/X(103) + 0.1                                   CASP1980
      LINEA(101)=(LINEA(101)-LINEA(102))/LINEA(103)                     CASP1990
```

```
C
      CALL SYMBOL(A,LINEA(101),0.14,'A',0.0,1)
C
C     LINE TANGENT TO CURVE AT POINT OF MAX CURVATURE.
C
      DO 140 I=1,101
      LINEB(I)=SB*X(I)+BY
  140 CONTINUE
      CALL LINE(X,LINEB,101,1,0,0)
C
      B =(X(101)-X(102))/X(103) + 0.10
      LINEB(101)=(LINEB(101)-LINEB(102))/LINEB(103)
      CALL SYMBOL(B,LINEB(101),0.14,'B',0.0,1)
C
C     BISECT LINES 'A' AND 'B'.
C
      DO 150 I=1,101
      LINEC(I)=SC*X(I)+CY
  150 CONTINUE
      CALL LINE(X,LINEC,101,1,0,0)
      CX=(X(101)-X(102))/X(103) + 0.10
      LINEC(101)=(LINEC(101)-LINEC(102))/LINEC(103)
      CALL SYMBOL(CX,LINEC(101),0.14,'C',0.0,1)
C
C
C
C     PROJECT LINE 'D' BACK FROM STRAIGHT PORTION
C     OF VIRGIN COMPRESSION CURVE TO GET AN INTERSECTION
C     WITH LINE 'C' TO SHOW THE PRECONSOLIDATION PRESSURE.
C
      X(1)=XANGLE
      IF (BOUND6.GT.998) X(1)=PC
      DELTA=(P(NC)-X(1))/100.0
      DO 160 I=2,101
      X(I)=X(I-1)+DELTA
  160 CONTINUE
C
      DO 170 I=1,101
      LINED(I)=SD*X(I)+DY
  170 CONTINUE
      CALL LINE(X,LINED,101,1,0,0)
      X(1)=(X(1)-X(102))/X(103)
      LINED(1)=(LINED(1)-LINED(102))/LINED(103) + 0.1
      CALL SYMBOL(X(1),LINED(1),0.14,'D',0.0,1)
C
C
C
C     *************************
C
C     SCHMERTMANN'S CONSTRUCTION
C
C     *************************
C
C     PLOT OVERBURDEN PRESSURE (BOVER,VOIDEO).
      CALL LINE(BOVER,VOIDEO,1,1,-1,0)
C
C     PLOT PRECONSOLIDATION COMPRESSION CURVE 'F'.
C
      X(1)=BOVER(1)
      DELTA=(PC-BOVER(1))/100
```

```
      DO 180 I=2,101
      X(I)=X(I-1)+DELTA
  180 CONTINUE
C
      DO 190 I=1,101
      LINEF(I)=SF*X(I)+FY
  190 CONTINUE
      CALL LINE(X,LINEF,101,1,0,0)
C
C
C     PLOT THE STEPS EMPLOYED IN THE DETERMINATION OF A MINIMUM
C     PRECONSOLIDATION PRESSURE.
      DASH(1)=ALOG10(PREMIN)
      DASH(11)=XANGLE
      IF (BOUND6.GT.998) DASH(11)=PC
      DELTA=(DASH(11)-DASH(1))/10.00
      DO 200 I=2,11
      DASH(I)=DASH(I-1)+DELTA
  200 CONTINUE
      DO 210 I=1,11
      DASHY(I)=SD*DASH(I)+DY
  210 CONTINUE
      CALL DASHLN(DASH,DASHY,11,1)
      DASHY(1)=ECMIN
      DASH(1)=ALOG10(PREMIN)
      DELTA=(VOIDEO(1)-ECMIN)/10.0
      IF (ABS(DELTA).LT.0.00001.AND.KK.EQ.1) DELTA=0.0015
      IF (ABS(DELTA).LT.0.00001.AND.KK.EQ.2) DELTA=0.00075
      IF (ECMIN.EQ.VOIDEO(1)) DELTA=-DELTA
      DO 220 I =2,11
      DASH(I)=ALOG10(PREMIN)
      DASHY(I)=DASHY(I-1) + DELTA
  220 CONTINUE
      CALL DASHLN(DASH,DASHY,11,1)
C     PLOT TRUE VIRGIN COMPRESSION LINE 'G'.
C
      X(1)=PC
      DELTA=(P(NC)+.13-PC)*SG/LINEG(103)
      B5=EC+DELTA
C
C
C     CHECKING ARGUMENTS TO MAKE SURE LINEG IS NOT DRAWN TOO FAR.
      IF (ABS(B5).GT.8.0) DELTA=8.0-ABS(EC)
C
      DELTA=ABS((DELTA*LINEG(103))/SG)/100.0
C
      DO 230 I=2,101
      X(I)=X(I-1)+DELTA
  230 CONTINUE
      DO 240 I=1,101
      LINEG(I)=SG*X(I)+GY
  240 CONTINUE
      CALL LINE(X,LINEG,101,1,0,0)
      DELTA=ABS(VOIDEO(1)-VOIDPC)/10
      DASH(1)=PC
      DASHY(1)=VOIDPC
      DO 250 I=2,11
      DASH(I)=PC
      DASHY(I)=DASHY(I-1)+DELTA
  250 CONTINUE
```

```
      CALL DASHLN(DASH,DASHY,11,1)                                      CASP3200
      IF (KK.EQ.2) CALL PLOT (0.0,-8.0,-3)                              CASP3210
      CALL SYMBOL(2.5,9.0,0.14,BCD,0.0,80)                              CASP3220
      FPN=NDEG+0.01                                                     CASP3230
      CALL NUMBER (10.,7.0,0.10,FPN,0.0,-1)                             CASP3240
      CALL SYMBOL (9.4,7.0,0.10,'DEG = ',0.0,6)                         CASP3250
      CALL SYMBOL (9.4,6.5,0.10,'PO = ',0.0,5)                          CASP3260
      CALL NUMBER (9.9,6.5,0.10,PO,0.0,3)                               CASP3270
      CALL SYMBOL (10.5,6.5,0.10,'TSF',0.0,3)                           CASP3280
      CALL SYMBOL (11.3,6.5,0.10,'EO = ',0.0,5)                         CASP3290
      CALL NUMBER (11.8,6.5,0.10,EO,0.0,4)                              CASP3300
      CALL SYMBOL (10.3,6.0,0.10,'RANGE OF VALUES',0.0,15)              CASP3310
      CALL SYMBOL (10.1,5.75,0.10,'PROBABLE - MINIMUM',0.0,18)          CASP3320
      CALL SYMBOL (9.4,5.4,0.10,'PC          TSF -        TSF',0.0,27)  CASP3330
      CALL NUMBER (10.,5.4,0.10,PRECON,0.0,2)                           CASP3340
      CALL NUMBER (11.2,5.4,0.10,PREMIN,0.0,2)                          CASP3350
      CALL SYMBOL (9.4,5.0,0.10,'EC              -           ',0.0,27)  CASP3360
      IF (KK.EQ.2) VOIDC=-VOIDC                                         CASP3370
      IF (KK.EQ.1) CALL NUMBER (10.4,5.0,0.10,VOIDC,0.0,3)              CASP3380
      IF (KK.EQ.2) CALL NUMBER (10.3,5.0,0.10,VOIDC,0.0,4)              CASP3390
      IF (KK.EQ.2) VOIDC=-VOIDC                                         CASP3400
      IF (KK.EQ.2) ECMIN=-ECMIN                                         CASP3410
      IF (KK.EQ.1) CALL NUMBER(11.2,5.0,0.10,ECMIN,0.0,3)               CASP3420
      IF (KK.EQ.2) CALL NUMBER (11.2,5.0,0.10,ECMIN,0.0,4)              CASP3430
      IF (KK.EQ.2) ECMIN=-ECMIN                                         CASP3440
      CALL SYMBOL (9.4,4.6,0.10,'OCR             -           ',0.0,27)  CASP3450
      CALL NUMBER (10.5,4.6,0.10,OCR,0.0,1)                             CASP3460
      CALL NUMBER (11.2,4.6,0.10,OCRMIN,0.0,1)                          CASP3470
      IF (KK.EQ.2) GO TO 260                                            CASP3480
      CALL SYMBOL (9.4,4.2,0.10,'CC              -           ',0.0,27)  CASP3490
      CALL SYMBOL  (9.4,3.8,0.10,'CS',0.0,2)                            CASP3500
  260 CONTINUE                                                          CASP3510
      IF (KK.EQ.1) GO TO 270                                            CASP3520
      CALL SYMBOL (9.4,4.2,0.10,'CR              -           ',0.0,27)  CASP3530
      CALL SYMBOL (9.4,3.8,0.10,'SR',0.0,2)                             CASP3540
  270 CONTINUE                                                          CASP3550
      CALL NUMBER (10.3,4.2,0.10,CR,0.0,3)                              CASP3560
      CALL NUMBER (11.2,4.2,0.10,CRMIN,0.0,3)                           CASP3570
      CALL NUMBER (10.2,3.8,0.10,SR,0.0,4)                              CASP3580
      IF(NC.GT.10) GO TO 320                                            CASP3590
      IF (KK.EQ.2) GO TO 280                                            CASP3600
      CALL SYMBOL (9.4,3.5,0.10,'EFF. STRESS     VOID RATIO (E)',0.0,30)CASP3610
      IF (KK.EQ.1) GO TO 290                                            CASP3620
  280 CONTINUE                                                          CASP3630
      CALL SYMBOL (9.4,3.3,0.10,'EFF. STRESS    VERT. STRAIN',0.0,27)   CASP3640
  290 CONTINUE                                                          CASP3650
      ORDINA=3.0                                                        CASP3660
      DO 300 I=1,NC                                                     CASP3670
      PDUMMY(I)=10.0**P(I)                                              CASP3680
      CALL NUMBER (9.7,ORDINA,0.10,PDUMMY(I),0.0,3)                     CASP3690
      IF (KK.EQ.2) E(I)=-E(I)                                           CASP3700
      CALL NUMBER (11.3,ORDINA,0.10,E(I),0.0,4)                         CASP3710
      ORDINA=ORDINA-0.2                                                 CASP3720
  300 CONTINUE                                                          CASP3730
      DO 310 J=1,NE                                                     CASP3740
      PDUMMY(J)=10.0**PE(J)                                             CASP3750
      CALL NUMBER (9.7,ORDINA,0.10,PDUMMY(J),0.0,3)                     CASP3760
      IF (KK.EQ.2) EE(J)=-EE(J)                                         CASP3770
      CALL NUMBER (11.3,ORDINA,0.10,EE(J),0.0,4)                        CASP3780
      ORDINA=ORDINA-0.2                                                 CASP3790
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310 CONTINUE                                                            CASP3800
320 CONTINUE                                                            CASP3810
    CALL PLOT(15.0,0.0,-3)                                              CASP3820
    RETURN                                                              CASP3830
    END                                                                 CASP3840
```