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May 19, 1980

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SUBJECT: Research Report No. 547, Computerized Analysis of Moisture-Density Data; HPR-PL-1(15), Part III-B

Attached is the above-cited, research report which describes a computerized approach to the analysis of raw data obtained in moisture-density tests. The computer program has already been implemented here and in Materials as an aid in analyzing maximum density and optimum moisture content in field control and for specification comparisons.

Respectfully submitted,

Jas. H. Havens
Director of Research

RCD/mm/gh
Attachment
cc: Research Committee

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16. Abstract

A mathematical algorithm is described and presented for estimating optimum moisture content and maximum dry density from moisture-density data obtained from ASTM Standard Test Methods D 698 and D 1557, which are often, even though incorrectly, referred to as the *Standard Proctor Test* and *Modified Proctor Test*, respectively. However, the algorithm can be used to analyze moisture-density data obtained by non-standard procedures. The algorithm is written in Fortran IV for use with the IBM 370/165 computer and Calcomp 663 drum plotter. Documentation of this computer program includes detailed input instructions, coding sheets, flow chart, variable descriptions, example problem, example output, and example job control cards.

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Research Report
547

Computerized Analysis of Moisture-Density Data

Interim Report
KYP-64-13; HPR-PL-1(15), Part III B

by

E. Gregory McNulty
Research Engineer

Division of Research
Bureau of Highways
DEPARTMENT OF TRANSPORTATION
Commonwealth of Kentucky

May 1980

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Introduction

The computer program, MOSDEN-0, estimates the optimum moisture content and maximum dry density from a fitted-curve representation of moisture-density data obtained using ASTM Standard Test Methods D 698 and D 1557 or other procedures. Values of dry density are calculated from the input values of moisture content and wet weight plus tare (mold). The computer program uses the IBM 370/165 computer and Calcomp 663 drum plotter and is written in Fortran IV. This program is very useful in analyzing a large number of data sets and provides a systematic procedure for drawing an appropriate curve through a given set of moisture-density data points.

Input/Output Instructions and Examples

A typical data sheet for recording moisture-density data is illustrated in Figure 1. Input instructions and coding sheets, Figure 2, necessary for organizing input data for the computer program are given in APPENDIX A. Also, the relationship between the number of data sets to be analyzed in a given computer run and the amount of central processing unit (CPU) time required is given by Figure 3 in the same appendix. Use of the computer program to analyze a typical set of laboratory data is illustrated in APPENDIX B. First, an actual set of laboratory data is given in Figure 4. Next, the use of the coding sheets is demonstrated in Figure 5, using the laboratory data given in

HIGHWAY MATERIALS RESEARCH LABORATORY
KENTUCKY DEPARTMENT OF HIGHWAYS
LEXINGTON, KENTUCKY

__________ PROCTOR COMPACTION

Identification __________ Tare Weight (lbs.) __________

Operator __________ Date __________

Wet Weight plus Tare (lbs.)	Wet Weight (lbs.)	Wet Density (lbs./cu. ft.)	Moisture Determination							Dry Density (lbs./cu. ft.)
			Dish Number	Wet Weight (gms.)	Dry Weight (gms.)	Water Weight (gms.)	Dish Weight (gms.)	Soil Weight (gms.)	Moisture Content (%)	

Columns 11-20 on Data Card Number 4 (Wet Weight plus Tare column)

Columns 1-10 on Data Card Number 4 (Moisture Content column)

Form S – 2
6 – 1 – 57

Figure 1. Laboratory Data Sheet for Recording Data from Moisture-Density Test.

Figure 4. Figures 6, 7, and 8 of APPENDIX B show the different types of output, both printed and plotted, produced by the computer program. Additional examples of plotted output are given in APPENDIX C.

Source Program

APPENDIX D gives a brief description of the computer system and the storage resources required by the computer program. In addition, a flow chart of MOSDEN-0 is provided in APPENDIX E. Finally, a complete source listing of the computer program is given in APPENDIX F.

Method of Solution

Analytical curve-fitting procedures are used in the computer program to represent the moisture-content-versus-dry-density data. A least-squares polynomial of a preselected degree is fitted to the moisture-content-dry-density-data using the method proposed by Forsythe *(1)* and programmed by Thrailkill, et al. *(2)*. The polynomial has the form

$$p(x) = c_1 + c_2 x + c_3 x^2 + \ldots c_n x^{(k-1)}, \qquad (1)$$

in which p(x) is the polynomial with terms having constant coefficients c_n for the abscissa terms x with integer powers (k - 1) and k is the number of constant coefficients. Derivatives are obtained on the polynomial p(x) as follows:

$$d(p(x))/dx = \Sigma\ (k - 1)c_{(k-1)}x^{(k-2)}. \qquad (2)$$

The peak of the fitted polynomial is taken as the location of the optimum moisture content and maximum dry density. The computer program determines the peak of the fitted polynomial by finding the point where the slope given by Equation 2 becomes zero in the vicinity of the largest value of dry density.

Although the procedure for selecting the degree of polynomial to fit data does not follow rigorous guidelines, this does not pose any great problems. The computer program allows the use of polynomials as large as six degrees, provided there are seven or more data points. Past experience *(3)* indicates that a satisfactory fit can usually be obtained using a degree of polynomial equal to the number of data points minus two. Slightly different results will be obtained if a degree of polynomial equal to the number of data points minus one is used. The choice of the degree of polynomial usually affects the calculated value of maximum dry density more than the optimum moisture content. However, the difference will usually be quite small. Generally, the calculated value of the maximum dry density tends to be greater when a degree of polynomial equal to the number of data points minus one is used.

In APPENDIX C, Examples 1, 3, 4, and 5 compare cases where a degree of polynomial equal to n - 1 yields larger estimates of the maximum dry density than a degree of polynomial equal to n - 2 (n is the number of data points). Therefore, if lower estimates of the maximum dry density are desired, a degree of polynomial equal to the number of data points minus two is recommended.

Inasmuch as the true values for the optimum moisture content and maximum dry density are rarely if ever known, the choice between using a degree of polynomial equal to n - 2 or n - 1 basically remains a matter of individual judgment. APPENDIX C shows examples of plotted output which compare different polynomial fits on the same sets of data. APPENDIX C also shows performance of the computer program on sets of data obtained from soils having different values for the liquid limit.

Program Capabilities

A maximum of 18 data points may be specified for one set of moisture-density data. Each set of moisture-density data must have at least three data values before the computer program can be used. The computer program ignores any data point lying on the "dry side" of the moisture-density curve which has a decreased value of density from the previous point; otherwise this would cause a decrease in dry density before the data point having the largest value of dry density is reached. Similarly, the computer program ignores any data point lying on the "wet side" of the moisture-density curve having an increased value of density relative to the preceding point. These procedures are effective in removing spurious data, and Example 1 in APPENDIX C illustrates a case where this procedure was used.

If any of the plotting software for the Calcomp plotter or line-print plotter is unavailable or incompatible with the version found in the computer program, the program may be adapted for use by either removing the necessary statements or by making the appropriate changes in individual source statements to obtain compatibility. Also, the computer program may be run on Librarian *(4)* using the job control cards given in APPENDIX A. Finally, the program can analyze any number of data sets for each submission and is restricted only by the central processing unit (CPU) time specified by the job control cards and (or) the computer system.

References

1. Forsythe, G. E.; *Generation and Use of Orthogonal Polynomials for Data Fitting on a Digital Computer,* **J. Soc. Indust. Appl.**, 1957, Math Vol. 5, pp. 74-88.
2. Thrailkill, L.; Allen, D.; and Taylor, W.; *Numerical Analysis Library for University of Kentucky 370,* University of Kentucky, Lexington, KY, December 1970, pp. 70-71.
3. McNulty, E. G.; *Computerized Analysis of Stress-Strain Consolidation Data,* Division of Research, Kentucky Department of Transportation, March 1977.
4. Applied Data Research, **The Librarian, OS System Reference Manual**, Princeton, NJ, August 1976.

Appendix A.

INPUT INSTRUCTIONS FOR MOSDEN-0

MOSDEN-0

INPUT INSTRUCTIONS
FOR
ANALYSIS OF MOISTURE-DENSITY DATA

COLUMNS	NAME	FORMAT	REMARKS
1. TEST DESIGNATION CARD			
1-80	BCD	20A4	Alphanumeric information entered on this card serves as the plot title and description of the test.
2. SOIL DESCRIPTION AND DATE OF TEST CARD			
1-20	COLOR	5A4	The color and type of soil used in the moisture-density test are entered.
21-30	WL	2A4,A2	Liquid limit of the soil is entered, as a percent, as alphanumeric information.
31-40	WP	2A4,A2	Plastic limit of the soil is entered, as a percent, as alphanumeric information.
41-52	DATE	3A4	The month, day, and year on which the moisture-density test was performed are entered as alphanumeric information.
3. ANALYSIS AND TEST INFORMATION CARD			
1-2	NDEG	I2	The degree of polynomial to be used in fitting the moisture-density data is entered as a right-justified integer in these two columns. The maximum degree of polynomial which can be used in the computer program is six. For seven or fewer data points, the maximum degree of polynomial which can be used is equal to the number of data points minus one. In addition, experience indicates that an acceptable fit can usually be obtained with a degree of polynomial equal to the number of data points minus two. However, a polynomial having a degree of two generally does not provide an acceptable fit. If Columns 1-2 are left blank, NDEG will be set equal to the number of data points minus two or six, whichever is smaller.

MOSDEN-Ø
Moisture-Density Test
Data Analysis
Computer Program Coding Sheet

1. TEST DESIGNATION TO BE USED AS PLOT TITLE (BCD)

2. COLOR | LIQUID LIMIT (WL) | PLASTIC LIMIT (WP) | DATE

3. NDEG | NLAYER | NBLOWS | WTHAM | DIA | HEIGHT | WEIGHT

NDEG —Degree of polynomial used in curve fitting.

NLAYER —Number of layers or lifts compacted (if left blank, default value is 3).

NBLOWS —Number of blows per compacted lift (if left blank, default value is 25).

WTHAM —Weight of hammer in pounds (if left blank, default value is 5.5 pounds).

DIA —Inner diameter of cylindrical compaction mold in feet (if left blank, default value is 0.333 feet).

HEIGHT —Interior height of compaction mold in feet (if left blank, default value is 0.383 feet).

WEIGHT —Weight of compaction mold (if left blank, default value is 9.36 pounds).

WATER CONTENT (%) WC( )	WET WEIGHT PLUS TARE DRYD( )

NOTE: Wet weight plus tare must have the same units as weight of compaction mold, WEIGHT, found in Card No. 3.

A separate Card No. 4 is needed for each compacted moisture-density specimen.

Repeat Cards 1 through 4 for each set of Moisture-Density data.

Figure 2. Computer Program Coding Sheet.

11-12	NLAYER	I2	The number of layers or lifts of soil placed in the compaction mold is entered as a right-justified integer. If these columns are left blank, a default value of 3 is used.
21-22	NBLOWS	I2	The number of blows applied to each layer of material is entered as a right-justified integer. If these columns are left blank, a default value of 25 is used.
31-40	WTHAM	F10.0	The weight in pounds of the hammer used in compacting each layer of material may be entered if the number is expressed with a decimal. If these columns are left blank, a default value of 5.5 pounds is used.
41-50	DIA	F10.0	The inner diameter in feet of the cylindrical compaction mold can be entered if the number is expressed with a decimal. If these columns are left blank, a default value of 0.33333 feet is used.
51-60	HEIGHT	F10.0	The interior height, in feet, of the cylindrical compaction mold can be entered if the number is expressed with a decimal. If these columns are left blank, a default value of 0.383 foot is used.
61-70	WEIGHT	F10.0	The weight, in pounds or grams, of the cylindrical compaction mold can be entered if the number is expressed with a decimal. If these columns are left blank, a default value of 9.36 pounds is used.

4. MOISTURE CONTENT AND WET WEIGHT PLUS TARE DATA CARDS

1-10	WC( )	F10.0	The water content is entered in the first ten columns, as a percent, and expressed with a decimal.
11-20	DRYD( )	F10.0	The wet material weight plus the weight of mold (tare) is entered and expressed with a decimal. This parameter can be expressed in either pounds or grams, but must have the same units as the weight of the compaction mold, WEIGHT, given in Columns 61-70 of Data Card No. 3. If Columns 61-70 of Card No. 3 have been left blank, then the values of DRYD( ) must have units of pounds.
21-22	L	I2	When this parameter has a non-zero integer value, the computer program stops reading data for the current moisture-density curve.

(An additional Card No. 4 is needed for each compacted moisture-density specimen up to a maximum of 18).

Note: Repeat Cards Nos. 1 through 4 for each additional moisture-density curve.

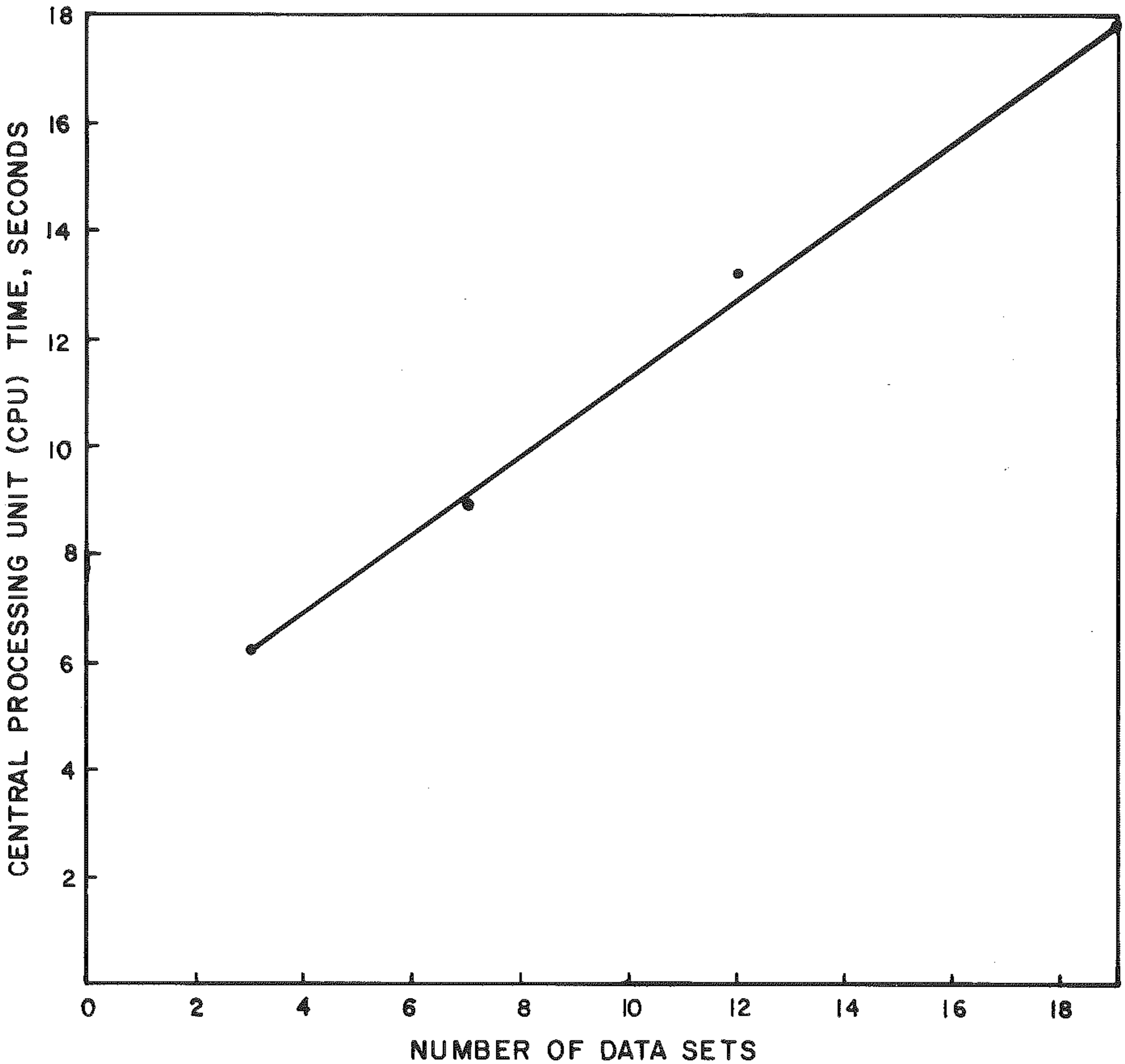


Figure 3. Approximate Central Processing Unit (CPU) Time versus Number of Individual Data Sets for Source Version of Computer Program, MOSDEN-0.

JOB CONTROL CARDS

The following set of job control cards applies when the IBM 370 in McVey Hall at the University of Kentucky is used. These cards describe the JCL necessary for a source deck run on the hands-on reader with a P (Pickup) card in front of the deck. The standard JOB card immediately below includes the waste paper option.

```
//N13EGM JOB(1009-51001,1,,,,,W),MCNULTY,MSGLEVEL=REGION=268K
/*PASSWORD
/*MESSAGE ---> PLOT JOB
/*MESSAGE ---> PLEASE CHARGE PLOT TO 1009-51001
/*SETUP TAPE=(SCRTCH,RINGIN)
/*JOBPARM K=0
//S EXEC LIBRARIAN,SYSTEM=, UKU.@EXT03,.SUBSYS=LIBR2
-OPT INDEX
-SEL MOSDENO,XKTX,EXEC,LIST,SEQ=/73,8,10,10/,TEMP
-END
/*
//T EXEC FORTGCLP,PARM.FORT='ID,SOURCE'
//FORT.SYSIN DD DSN=&&TEMP(MOSDEN0,DISP=(OLD,PASS)
//TO.SYSIN DD*

DATA CARDS

/*
```

The next set of job control cards applies when the IBM 370/168 computer in Frankfort is used via the remote job entry terminal No. 7 located at the Division of Research in Lexington.

```
//DTRN13GM JOB(4317,9019),MCNULTY,TIME=(0,59),CLASS=D
/*JOBPARM P=TT,K=0
//STEP EXEC ADR
//GO.SYSIN DD *
-SEL R020006S,BHLB,EXEC,LIST,SEQ=/73,8,10,10/,NORESEQ,TEMP
-REP 10
$JOB
C
-DEL 3500,3520
-DEL 6070
-DEL 6120,6130
-DEL 6310,6450
-DEL 6500
-DEL 6590
-DEL 6650,6690
-DEL 6760
-DEL 6900,7040
-DEL 7270,7310
-INS 8500
$ENTRY
-DATA

DATA CARDS

-END
/*
//STEPA EXEC WAT567,REGION=320K
//GO.SYSIN DD DSN=&&LIBR,DISP=(OLD,PASS)
/*
```

Appendix B.

EXAMPLE PROBLEM

Highway Materials Research Laboratory
Kentucky Department of Highways
Lexington, Kentucky

111-13-2 PROCTOR COMPACTION

Identification ______ Tare Weight (lbs.) ______

Operator ______ Date 6-23-78

Wet Weight plus Tare (lbs.)	Wet Weight (lbs.)	Wet Density (lbs./cu. ft.)	Moisture Determination							Dry Density (lbs./cu. ft.)
			Dish Number	Wet Weight (gms.)	Dry Weight (gms.)	Water Weight (gms.)	Dish Weight (gms.)	Soil Weight (gms.)	Moisture Content (%)	
13.02			186	87.09	81.5	5.59	30.78	50.72	11.02	
13.33			L-60	100.92	91.82	9.10	21.36	69.89	13.02	
13.55			L-78	129.03	114.72	14.31	30.8	83.92	17.05	
13.45			L-36	77.94	68.49	9.45	23.49	45.00	21.01	

Columns 11-20 on Data Card Number 4 (first column) — Columns 1-10 on Data Card Number 4 (Moisture Content column)

Form S-2
6-1-57

Figure 4. Example Set of Laboratory Data Recorded for Moisture-Density Test 111-13-2.

MOSDEN-Ø
Moisture-Density Test
Data Analysis
Computer Program Coding Sheet

TEST DESIGNATION TO BE USED AS PLOT TITLE (BCD)

1. | 111-13-2 STD. |

	COLOR	LIQUID LIMIT (WL)	PLASTIC LIMIT (WP)	DATE
2.		34.0	21.0	06-23-78

	NDEG	NLAYER	NBLOWS	WTHAM	DIA	HEIGHT	WEIGHT
3.	03						

NDEG —Degree of polynomial used in curve fitting.

NLAYER —Number of layers or lifts compacted (if left blank, default value is 3).

NBLOWS —Number of blows per compacted lift (if left blank, default value is 25).

WTHAM —Weight of hammer in pounds (if left blank, default value is 5.5 pounds).

DIA —Inner diameter of cylindrical compaction mold in feet (if left blank, default value is 0.333 feet).

HEIGHT —Interior height of compaction mold in feet (if left blank, default value is 0.383 feet).

WEIGHT —Weight of compaction mold (if left blank, default value is 9.36 pounds).

WATER CONTENT (%) WC( )	WET WEIGHT PLUS TARE DRYD( )	
11.02	13.02	
13.02	13.33	
17.05	13.55	
21.01	13.45	1

NOTE: Wet weight plus tare must have the same units as weight of compaction mold, WEIGHT, found in Card No. 3.

A separate Card No. 4 is needed for each compacted moisture-density specimen.

Repeat Cards 1 through 4 for each set of moisture-density data.

Figure 5. Example Use of MOSDEN-0 Coding Sheet for Data from Moisture-Density Test 111-13-2.

111—13—2 STD.

DESCRIPTION OF SOIL: LIQUID LIMIT = 34.00 PLASTIC LIMIT = 21.00 DATE OF TESTING = 06—23—78

NUMBER OF LAYERS: 3 NO. OF BLOWS/LAYER 25 WEIGHT OF HAMMER = 5.50 LBS MOLD: WT = 9.4 GR, LBS VOL = 0.0334 CU FT

SAMPLE NUMBER	1	2	3	4
WATER CONTENT, WT%	11.0	13.0	17.0	21.0
WT OF SOIL IN MOLD	3.66	3.97	4.19	4.09
WET UNIT WEIGHTS, PCF	109.51	118.78	125.36	122.37
DRY DENSITY, PCF	98.64	105.10	107.10	101.12

OPTIMUM MOISTURE CONTENT = 15.6% MAXIMUM DRY DENSITY = 107.7 PCF DEGREE POLYNOMIAL = 3

Figure 6. Computer Printout of Results.

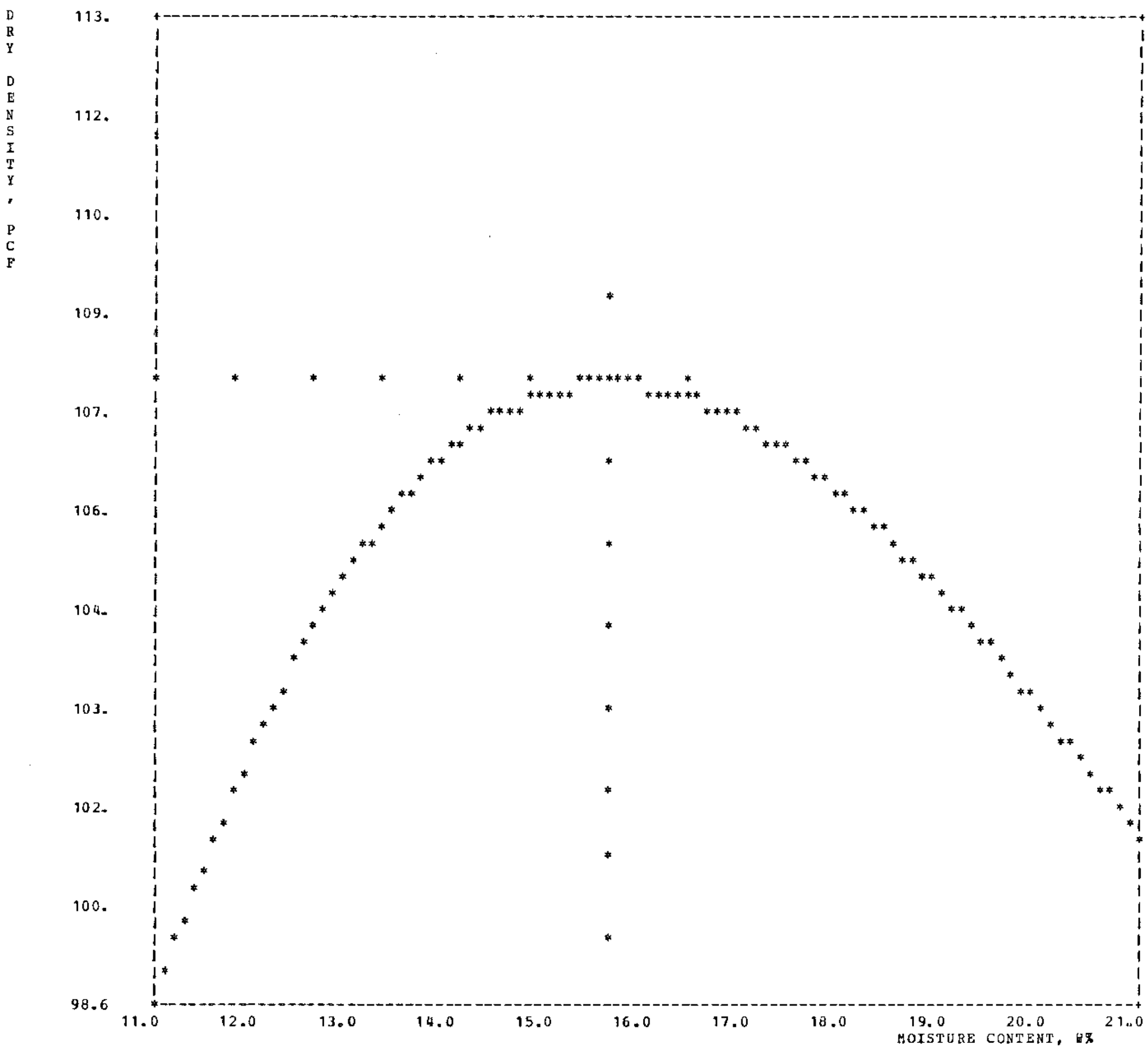


Figure 7. Example of Plot Output Produced by Line Printer.

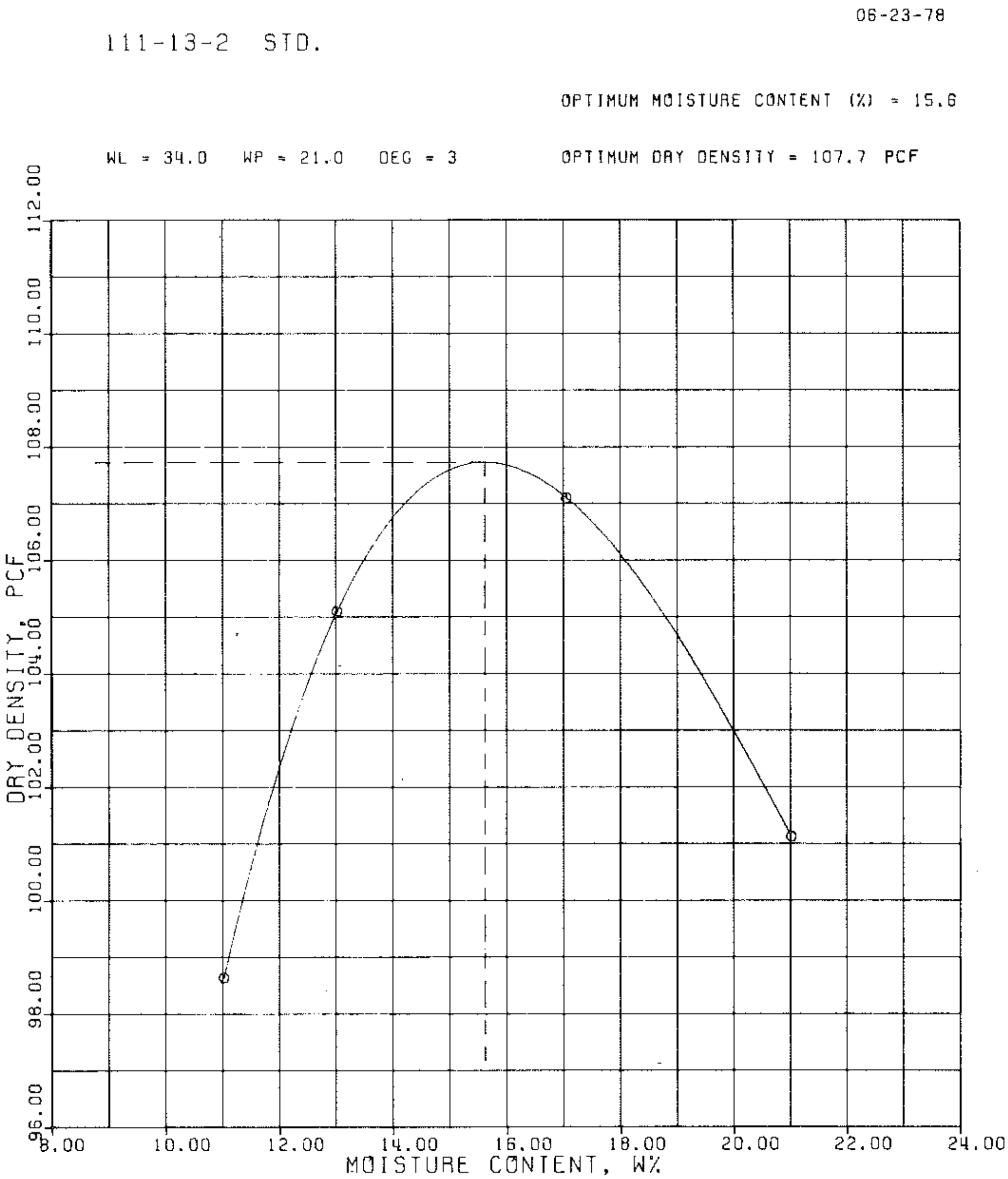


Figure 8. Example of Plot Output Produced by Calcomp Drum Plotter.

Appendix C.

ADDITIONAL EXAMPLES OF ANALYZED

MOISTURE-DENSITY DATA

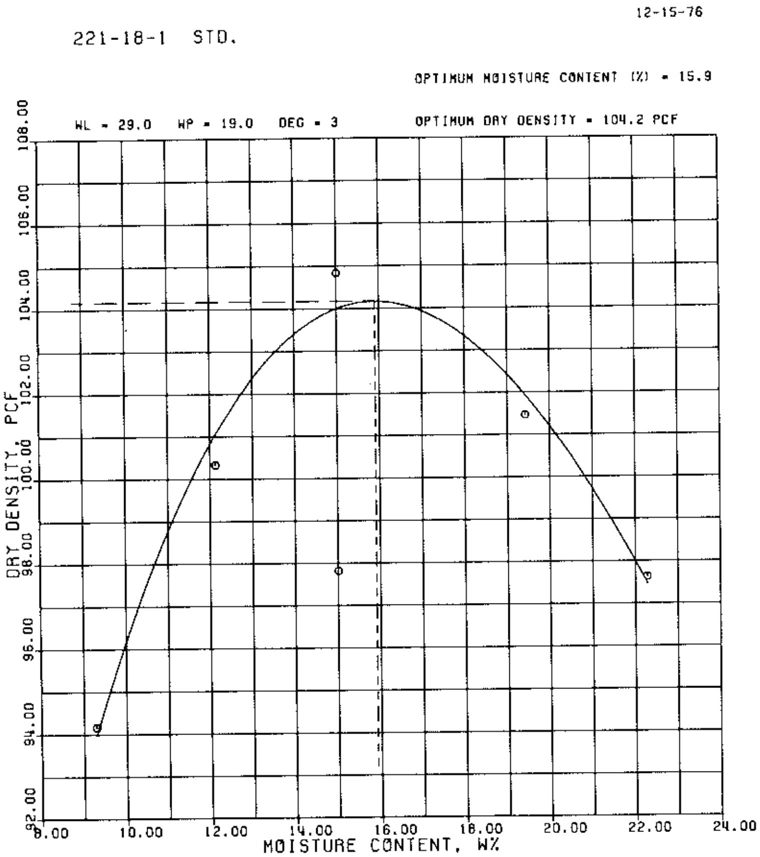


Figure 9. Example 1, Test 221-18-1, Liquid Limit = 29, Degree of Polynomial = 3.

EXAMPLE 1

221-18-1

LIQUID LIMIT = 29

Degree of Polynomial	Optimum Moisture Content (%)	Maximum Dry Density (pcf)
3	15.9	104.2
4	15.9	105.1

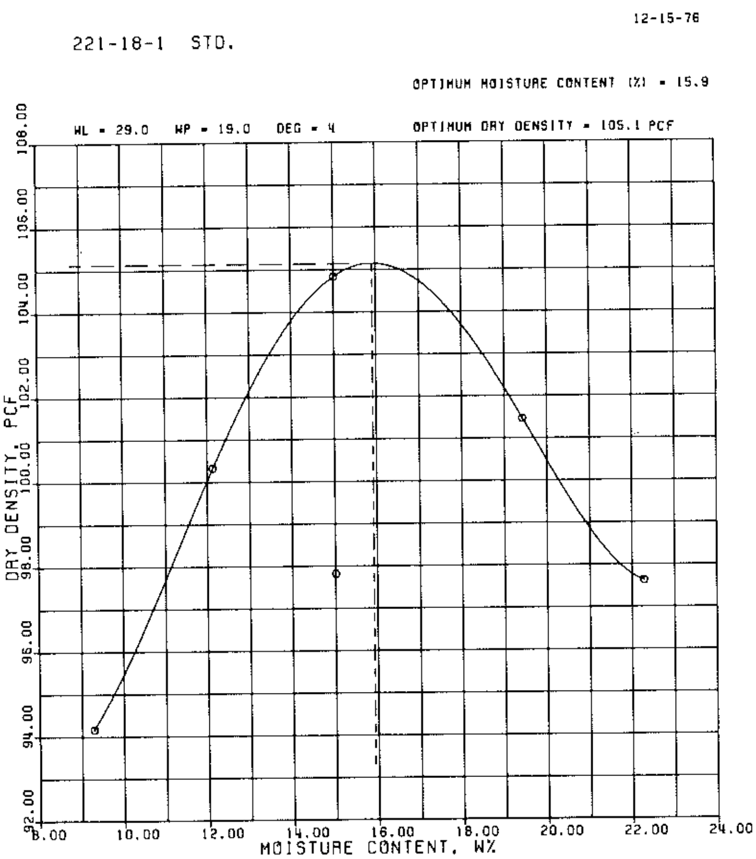


Figure 10. Example 1, Test 221-18-1, Liquid Limit = 29, Degree of Polynomial = 4.

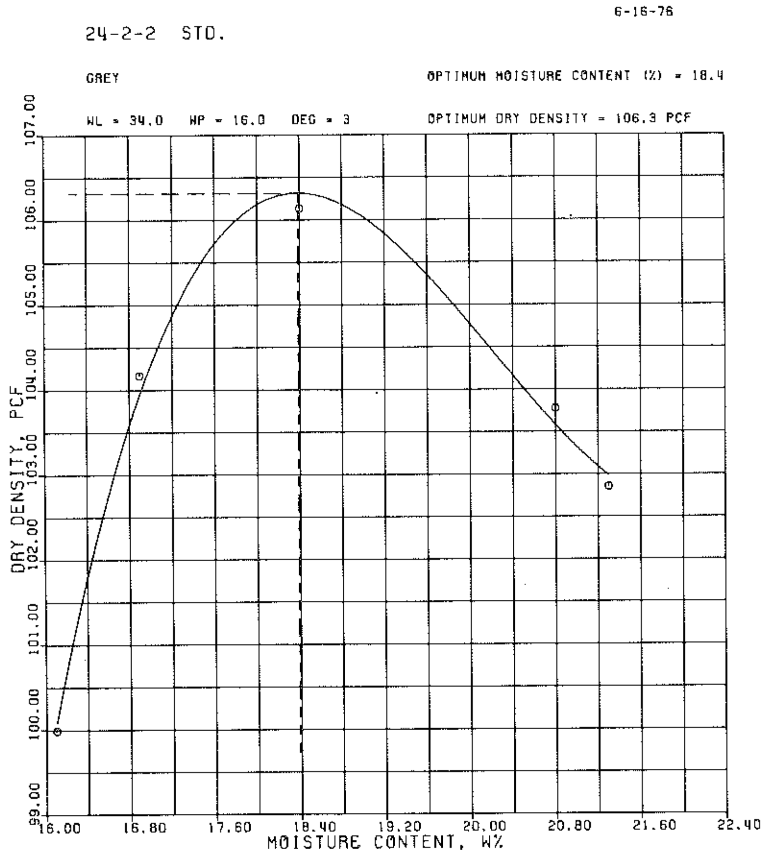


Figure 11. Example 2, Test 24-2-2, Liquid Limit = 34, Degree of Polynomial = 3.

EXAMPLE 2

24-2-2

LIQUID LIMIT = 34

Degree of Polynomial	Optimum Moisture Content (%)	Maximum Dry Density (pcf)
3	18.4	106.3
4	18.3	106.1

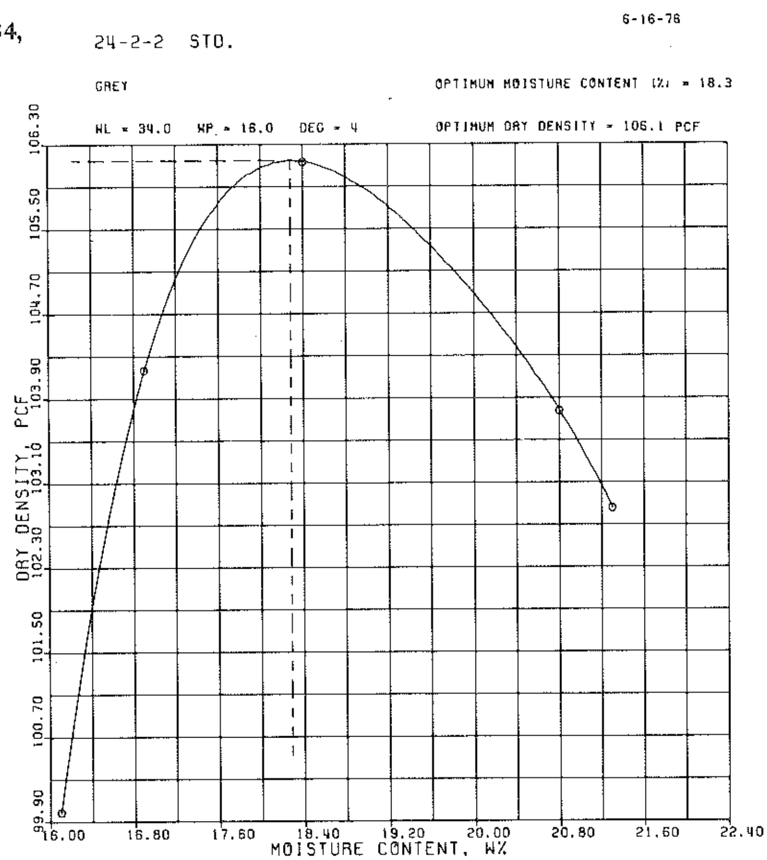


Figure 12. Example 2, Test 24-2-2, Liquid Limit = 34, Degree of Polynomial = 4.

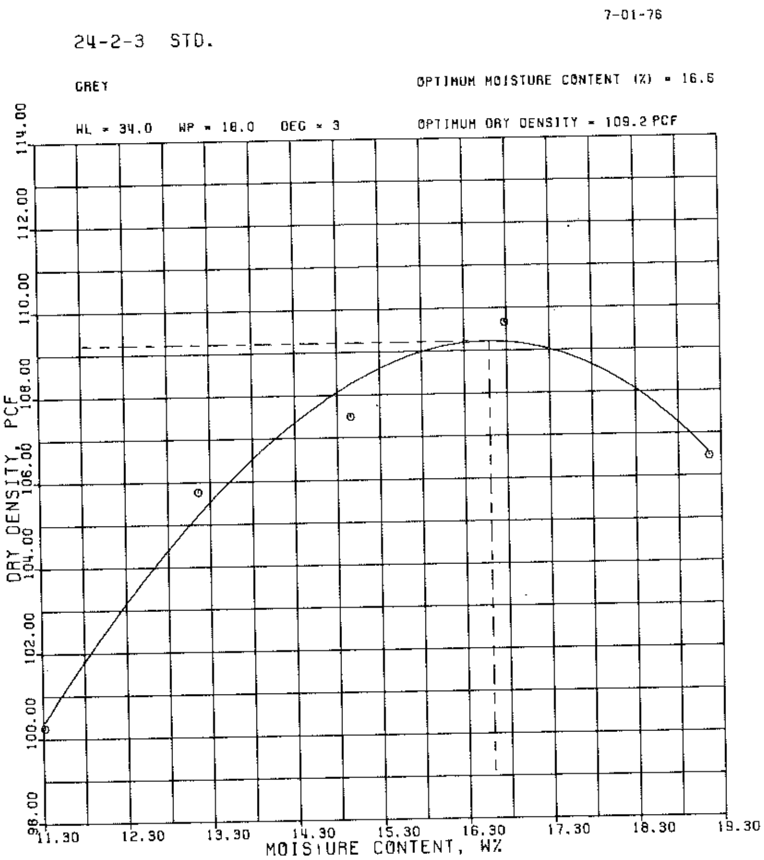


Figure 13. Example 3, Test 24-2-3, Liquid Limit = 34, Degree of Polynomial = 3.

EXAMPLE 3

24-2-3 STD

LIQUID LIMIT = 34

Degree of Polynomial	Optimum Moisture Content (%)	Maximum Dry Density (pcf)
3	16.6	109.2
4	17.6	110.1

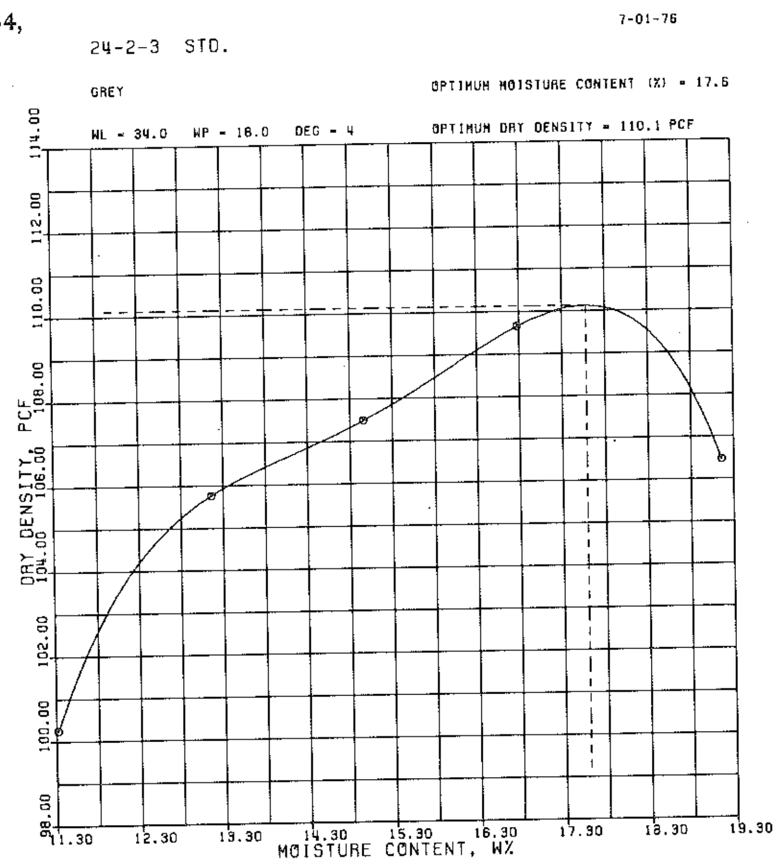


Figure 14. Example 3, Test 24-2-3, Liquid Limit = 34, Degree of Polynomial = 4.

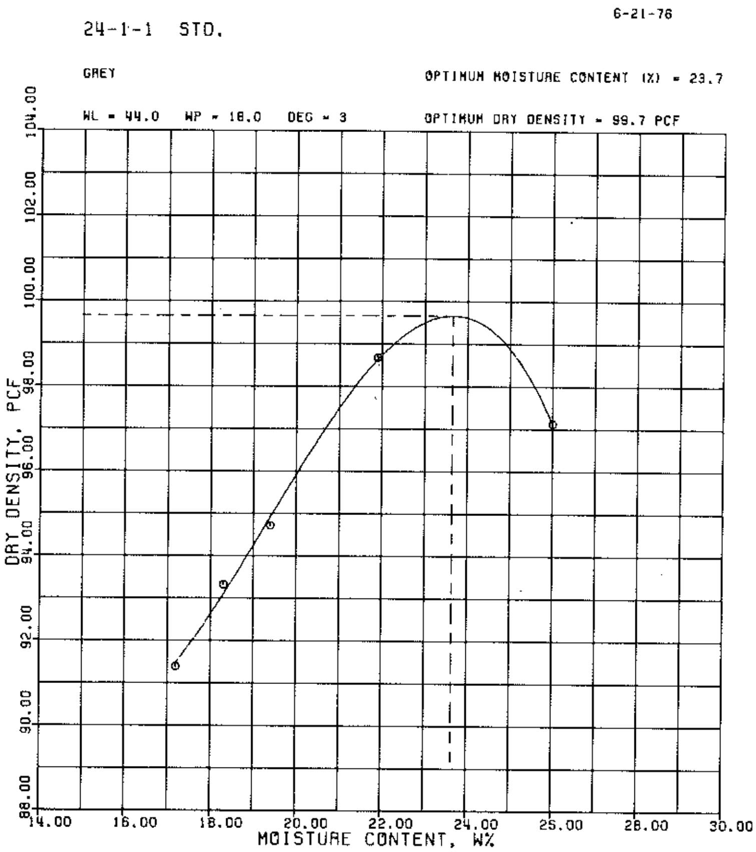


Figure 15. Example 4, Test 24-1-1, Liquid Limit = 44, Degree of Polynomial = 3.

EXAMPLE 4
24-1-1 STD
LIQUID LIMIT = 44

Degree of Polynomial	Optimum Moisture Content (%)	Maximum Dry Density (pcf)
3	23.7	99.7
4	24.2	101.6

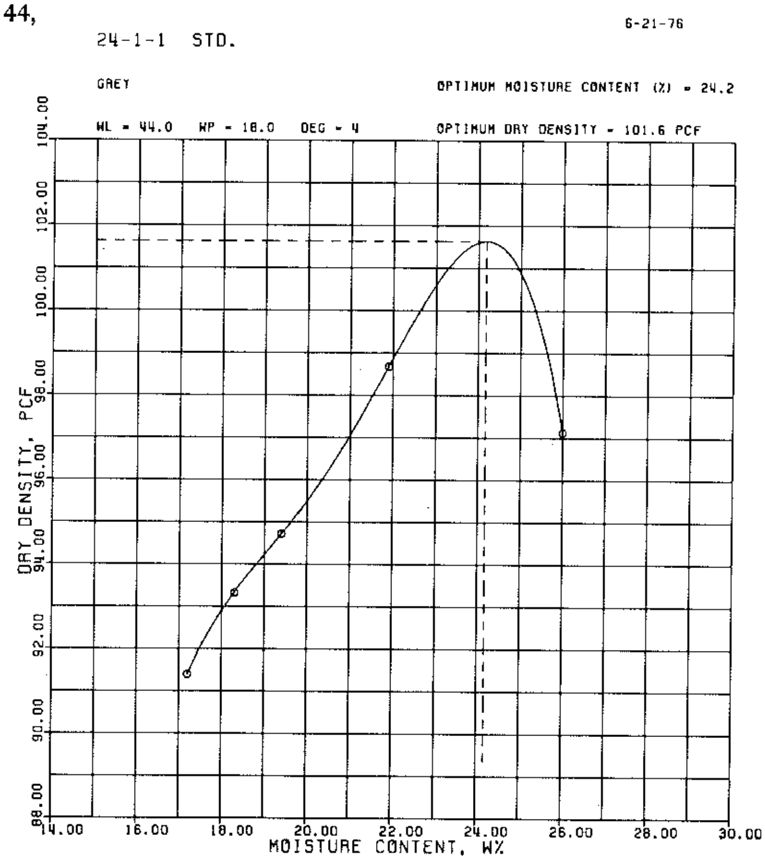


Figure 16. Example 4, Test 24-1-1, Liquid Limit = 44, Degree of Polynomial = 4.

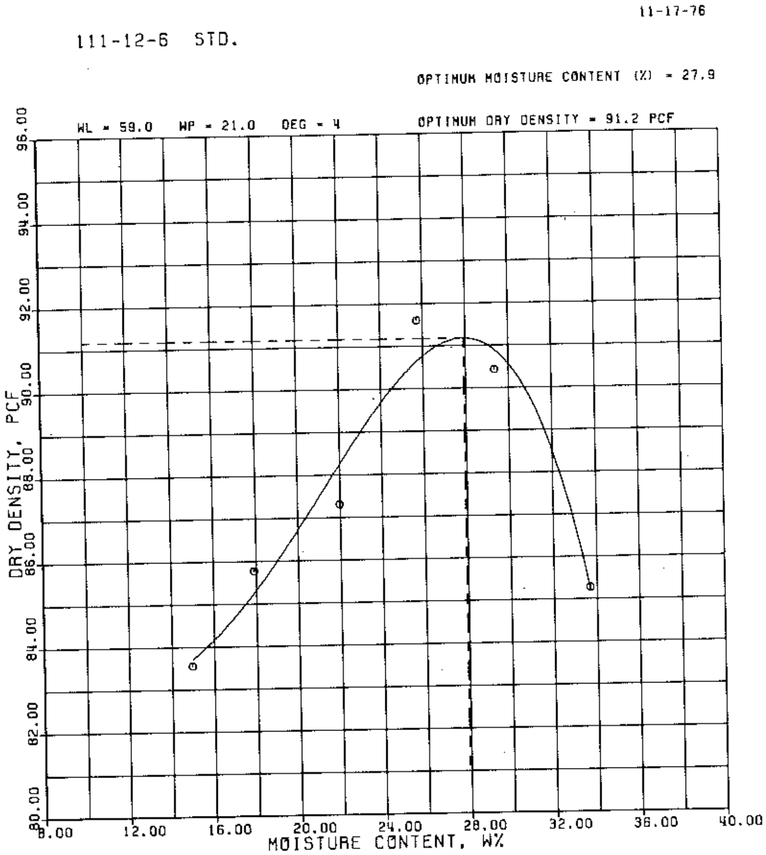


Figure 17. Example 5, Test 111-12-6, Liquid Limit = 59, Degree of Polynomial = 4.

EXAMPLE 5

111-12-6

LIQUID LIMIT = 59

Degree of Polynomial	Optimum Moisture Content (%)	Maximum Dry Density (pcf)
4	27.9	91.2
5	27.1	92.1

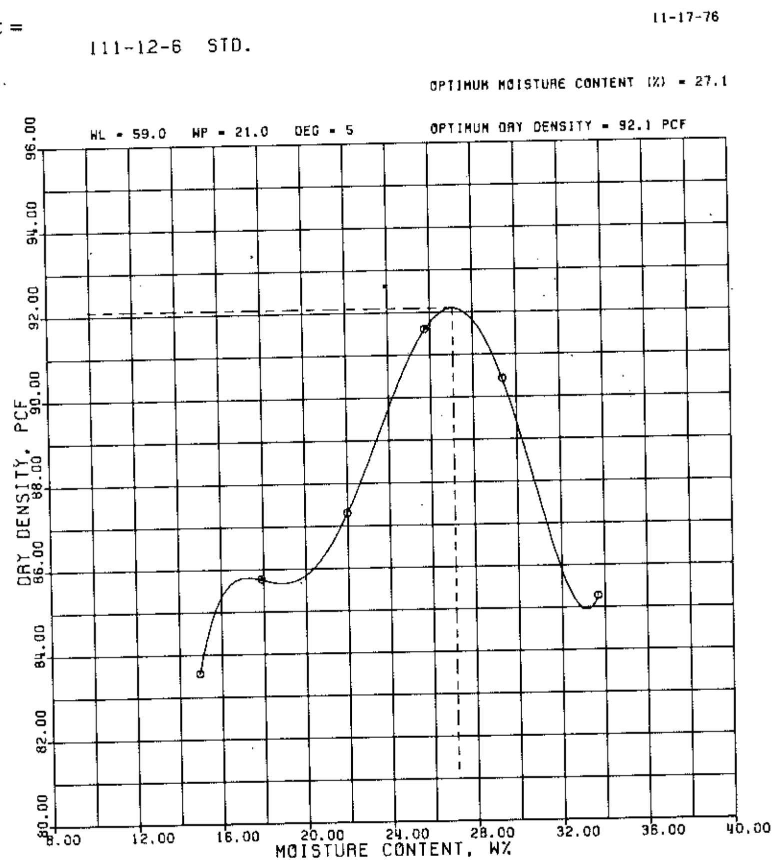


Figure 18. Example 5, Test 111-12-6, Liquid Limit = 59, Degree of Polynomial = 5.

Appendix D.

COMPUTER SYSTEM DESCRIPTION

COMPUTER SYSTEM DESCRIPTION

Computer	
Manufacturer	IBM
Model number	System/370 Model 165 II
Work 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/O Control Unit
Card readers	IBM/3505 Card Reader
Card punch	IBM/029 Card Key Punch
Magnetic tape drives	IBM Tape Unit 2401 processes tape 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

Storage Requirements of Source Program

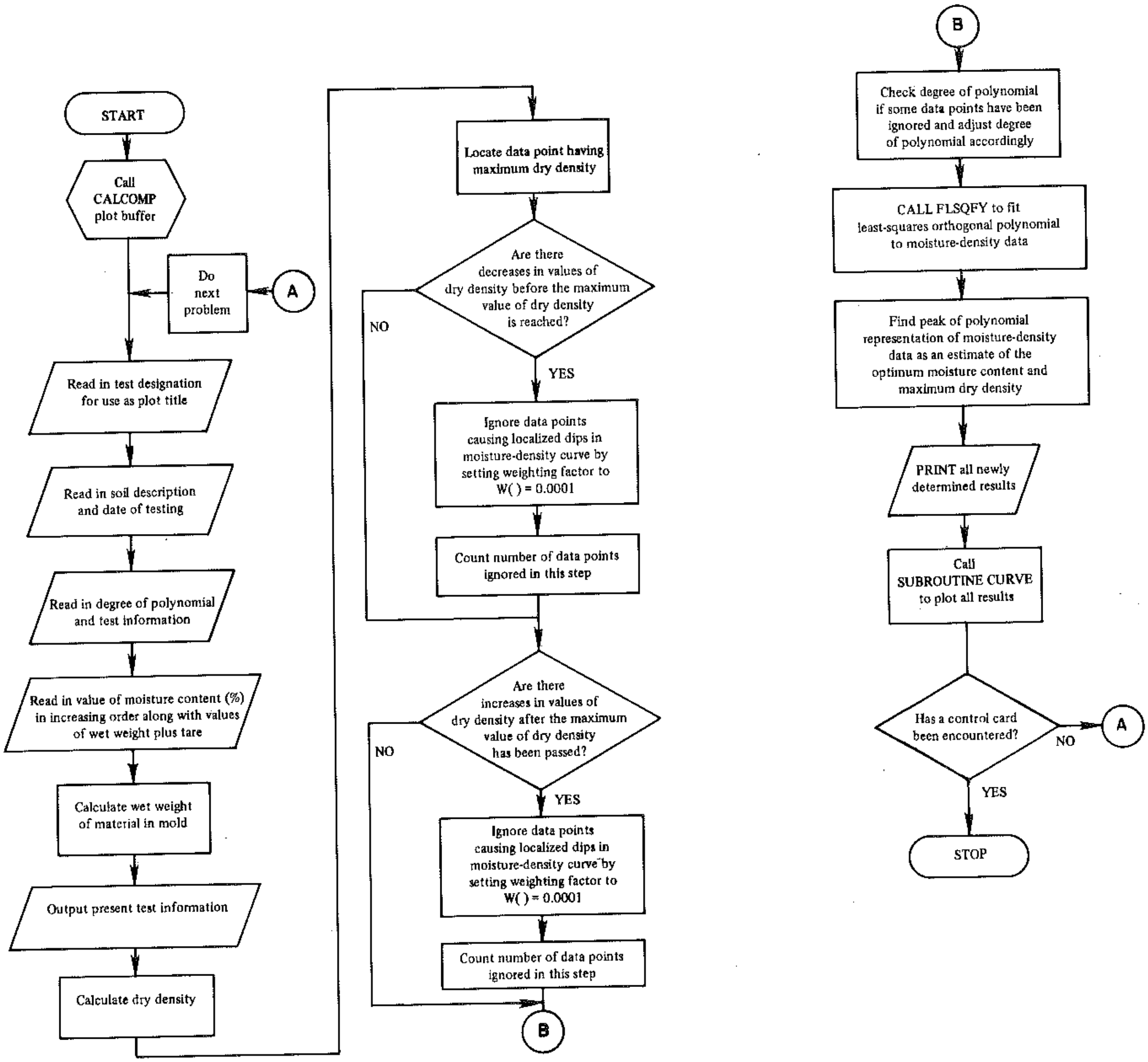
Total storage requirements of computer program is around 110K

MAIN	11156
CURVE	4012
FLSQFY	954
FCODA	908
FGEFTY	1816
Plot buffer requires up to	80K

Appendix E.

FLOW CHART FOR
MOSDEN-0

FLOW CHART FOR
MOSDEN-0



Appendix F.

MOSDEN-0 COMPUTER PROGRAM

```
C
C              ***********************************************
C              *                                             *
C              *                                             *
C              *                                             *
C              *             MOSDEN - 0                      *
C              *                                             *
C              *                                             *
C              *         1ST VERSION  JULY 1978              *
C              *                                             *
C              *         UPDATES, VERSIONS: NONE             *
C              *                                             *
C              *                                             *
C              ***********************************************
C              *                                             *
C              *                                             *
C              *         COMPUTERIZED ANALYSIS               *
C              *                                             *
C              *                 OF                          *
C              *                                             *
C              *          MOISTURE-DENSITY DATA              *
C              *               (PROCTOR)                     *
C              *                                             *
C              *             TO DETERMINE                    *
C              *                                             *
C              *                 THE                         *
C              *                                             *
C              *        OPTIMUM MOISTURE CONTENT             *
C              *                                             *
C              *               AND THE                       *
C              *                                             *
C              *          MAXIMUM DRY DENSITY                *
C              *                                             *
C              *                                             *
C              *                 BY                          *
C              *                                             *
C              *         EDMUND GREGORY MCNULTY              *
C              *                                             *
C              *                                             *
C              ***********************************************
C              *                                             *
C              *        THIS COMPUTER PROGRAM USES A         *
C              *  LEAST-SQUARES ORTHOGONAL POLYNOMIAL TO     *
C              *  FIT THE MOISTURE-DENSITY DATA.  THE CURVE  *
C              *  FITTINGS SUBROUTINE, FLSQFY, IS BASED ON   *
C              *  THE METHOD PROPOSED BY FORSYTHE (1957).    *
C              *  THE OPTIMUM MOISTURE CONTENT AND MAXIMUM   *
C              *  DRY DENSITY IS DETERMINED FROM THE FITTED  *
C              *  POLYNOMIAL REPRESENTATION OF THE DATA.     *
C              *                                             *
C              ***********************************************
C              *                                             *
C              *                                             *
C              *                                             *
C   ***************************************************************
C
C       THIS COMPUTER PROGRAM IS WRITTEN IN FORTRAN IV AND PRODUCES
C   PLOTTED OUTPUT USING THE IBM 370/165 II COMPUTER AND CALCOMP 663
```

```
C  DRUM PLOTTER.  THE COMPUTER PROGRAM WAS DEVELOPED UNDER THE
C  AUSPICES OF THE
C
C                 KENTUCKY DEPARTMENT OF TRANSPORTATION
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 29
C
C
C
C  *******************************************************************
C
C                         VARIABLE DEFINITIONS
C
C  *******************************************************************
C
C ALPHA( )
C     SCRATCH ARRAY FOR SUBROUTINE FLSQFY.
C
C BCD( ) 20A4
C     PLOT TITLE AND COMPUTER PRINTOUT HEADING.
C
C BETA( )
C     SCRATCH ARRAY FOR SUBROUTINE FLSQFY.
C
C BIG
C     ORDINATE VALUE OF DATA POINT HAVING GREATEST DRY DENSITY.
C
C BOUND1
C     STARTING ABSCISSA VALUE USED IN SEARCH FOR LOCATION OF MAXIMUM
C     DRY DENSITY ON POLYNOMIAL REPRESENTATION OF MOISTURE-DENSITY
C     DATA.  VALUES OF % MOISTURE CONTENT ARE ABSCISSAS.
C
C BOUND2
C     ENDING ABSCISSA VALUE USED IN SEARCH FOR LOCATION OF MAXIMUM
C     DRY DENSITY ON POLYNOMIAL REPRESENTATION OF MOISTURE-DENSITY
C     DATA.
C
C C( )
C     COEFFICIENTS USED IN SETTING UP ALL POLYNOMIAL EQUATIONS.
C
C COLOR 5A4
C     DESCRIPTION OF SOIL APPEARANCE.
C
C DATA( )
C     PRINCIPLE SCRATCH ARRAY FOR PLOTTING LIBRARY BUFFER.
C
C DATE 3A4
C     DATE ON WHICH MOISTURE-DENSITY COMPACTION TEST WAS RUN.
C
C DELTA
C     INCREMENT TO BE USED IN GENERATION OF EVENLY SPACED VALUES OF A
C     GIVEN PARAMETER.
C
C DIA
C     DIAMETER OF COMPACTION MOLD IN FEET.
C
C
C DMAX
C     MAXIMUM ORDINATE VALUE USED FOR SCALING MOISTURE-DENSITY DATA FOR
C     PLOTTING BY LINE PRINTER.
C
C DMIN
C     MINIMUM ORDINATE VALUE USED FOR SCALING MOISTURE-DENSITY DATA FOR
C     PLOTTING BY LINE PRINTER.
C
C DRYD( )
C     ARRAY IN WHICH DRY DENSITIES OF DATA POINTS ARE STORED.
C
```

```
C DRYMAX
C     MAXIMUM VALUE OF DRY DENSITY AS FOUND ON POLYNOMIAL REPRESENTATION
C     OF MOISTURE-DENSITY DATA.
C
C FACTOR
C     THE VARIABLE IS USED IN MAIN PROGRAM TO ALLOW CALCULATION OF
C     VALUES OF DRY DENSITY IN CORRECT UNITS OF WEIGHT.
C
C FPN
C     FLOATING POINT NUMBER USED IN PLOTTING NUMERICAL VALUES ON
C     CALCOMP PLOTTER.
C
C HEIGHT
C     HEIGHT OF COMPACTION MOLD IN FEET.
C
C I
C     DO LOOP PARAMETER.
C
C IBIG
C     ARRAY LOCATION FOR THE DATA POINT HAVING THE LARGEST DRY DENSITY.
C
C IDEG
C     INTEGER PARAMETER USED TO TEST WHETHER POLYNOMIAL DEGREE
C     CAN BE REDUCED TO ACCOUNT FOR DATA POINTS WHICH HAD BEEN THROWN
C     OUT BECAUSE OF LOCALIZED DIPS IN MOISTURE-DENSITY CURVE.
C
C IFIRST
C     THIS VARIABLE IS SET EQUAL TO ONE WHEN THE FIRST PORTION OF
C     THE POLYNOMIAL FIT THAT HAS A POSITIVE SLOPE IS FOUND.  THEN
C     TESTS ARE MADE FROM THIS POINT ON TO DETECT WHERE POLYNOMIAL
C     PEAKS, THAT IS, WHERE SLOPE BECOMES NEGATIVE AGAIN.
C
C IN
C     COMPUTER INPUT UTILITY DEVICE NUMBER FOR READ STATEMENTS.
C
C IOUT
C     COMPUTER OUTPUT UTILITY DEVICE NUMBER FOR WRITE STATEMENTS.
C
C ISTART
C     INTERGER DO-LOOP PARAMETER USED TO LOCATE WHERE POLYNOMIAL CURVE
C     PEAKS.  THIS VARIABLE IS USED TO GET A MORE PRECISE ESTIMATE
C     OF OPTIMUM MOISTURE CONTENT.
C
C ISUM
C     INTEGER COUNTER THAT KEEPS TRACK OF HOW MANY DATA POINTS WILL NOT
C     BE FITTED BECAUSE OF LOCALIZED DIPS IN MOISTURE-DENSITY CURVE.
C     THIS VARIABLE IS THEN USED TO TRY AND REDUCE THE SPECIFIED DEGREE
C     OF POLYNOMIAL IF POSSIBLE.
C
C ITEST
C     THIS PARAMETER IS USED IN TWO WAYS:  ONE, IT SERVES AS A
C     TEST TO CHECK THAT THE SPECIED DEGREE OF POLYNOMIAL IS NOT LARGER
C     THAN POSSIBLE AFTER SOME DATA POINTS HAVE BEEN REJECTED;
C     ALSO, THIS PARAMETER IS USED TO INCLUDE THE PEAK OF THE FITTING
C     POLYNOMIAL IN THE SCALING OF VERTICAL VALUES.
C
C J
C     DO-LOOP PARAMETER.
C
C L
C     TRIP ARGUMENT THAT INDICATES END OF CURRENT DATA SET DURING INPUT
C     WHEN IT BECOMES EQUAL TO ONE.
C
C MDC
C     WATFIV PARAMETER FOR SUBROUTINE FLSQFY THAT REPRESENTS THE NUMBER
C     OF DATA POINTS, PLUS THE DEGREE OF POLYNOMIAL, AND PLUS ONE.
C
C NBLOWS
C     NUMBER OF BLOWS APPLIED TO EACH LAYER PLACED INTO COMPACTION MOLD.
C
C NDATA
C     NUMBER OF DATA POINTS ON MOISTURE-DENSITY CURVE.
C
C NDC
C     WATFIV PARAMETER FOR SUBROUTINE FLSQFY THAT IS SET EQUAL TO THE
C     DEGREE OF POLYNOMIAL PLUS ONE.  IN OTHER WORDS, NDC REPRESENTS
```

```
C     THE NUMBER OF COFFIENTS NEEDED TO DESCRIBE A POLYNOMIAL OF A
C     GIVEN DEGREE.
C
C NDEG
C     DEGREE OF POLYNOMIAL USED IN CURVE FITTING.
C
C NLAYER
C     NUMBER OF LAYERS PLACED INTO COMPACTION MOLD.
C
C OPTMOS
C     OPTIMUM MOISTURE CONTENT EXPRESSED AS A PERCENT.
C
C PI
C     PLASTICITY INDEX.
C
C PLOTS( )
C     PLOT LIBRARY SUBROUTINE WHICH SETS UP LIBRARY BUFFER FOR
C     IBM 370/165 II COMPUTER.
C
C PO( )
C     SCRATCH ARRAY FOR SUBROUTINE FLSQFY.
C
C PR( )
C     SCRATCH ARRAY FOR SUBROUTINE FLSQFY.
C
C S( )
C     SCRATCH ARRAY FOR SUBROUTINE FLSQFY.
C
C SGMSQ( )
C     SCRATCH ARRAY FOR SUBROUTINE FLSQFY.
C
C VOL
C     VOLUME OF COMPACTION MOLD IN CUBIC FEET.
C
C W( )
C     WEIGHTING ARRAY FOR DATA POINTS FROM MOISTURE DENSITY CURVE.
C     DATA POINTS CAUSING LOCALIZED DIPS IN CURVE ARE ELIMINATED
C     FROM FITTING CONSIDERATIONS BY ASSIGNING W( ) TO BE 0.0001
C     INSTEAD OF THE USUAL 1.0.
C
C WC( )
C     WATER CONTENT EXPRESSED AS A PERCENT.
C
C WEIGHT
C     WEIGHT OF COMPACTION MOLD IN GRAMS OR POUNDS.
C
C WL
C     LIQUID LIMIT EXPRESSED AS A PERCENT.
C
C
C WMAX
C     MAXIMUM ABSCISSA VALUE FOR SCALING MOISTURE-DENSITY DATA FOR
C     PLOTTING BY LINE PRINTER.
C
C WMIN
C     MINIMUM ABSCISSA VALUE FOR SCALING MOISTURE-DENSITY DATA FOR
C     PLOTTING BY LINE PRINTER.
C WP
C     PLASTIC LIMIT EXPRESSED AS A PERCENT.
C
C WTHAM
C     WEIGHT OF COMPACTION HAMMER IN POUNDS OR GRAMS.
C
C X( )
C     ARRAY PARAMETER FOR STORAGE OF GENERATED SEARCH ABSCISSAS FOR
C     USE WITH FITTED POLYNOMIAL.
C
C XBIG
C     MOISTURE CONTENT (%) AT DATA POINT HAVING MAXIMUM DRY DENSITY.
C
C X1 = X
C X2 = X*X
C X3 = X*X*X
C X4 = X*X*X*X
C X5 = X*X*X*X*X
```

```
C X6 = X*X*X*X*X*X
C     THESE VARIABLES SET UP POLYNOMIAL TERMS FOR A PARTICULAR ABSCISSA
C     VALUE, X.  THESE TERMS WILL BE PAIRED WITH THEIR RESPECTIVE
C     COEFFICIENTS TO CALCULATE ORDINATE VALUES AND SLOPES AT
C     DIFFERENT PORTIONS OF POLYNOMIAL FIT.
C
C Y( )
C     ARRAY FOR STORAGE OF VARIOUS ORDINATE VALUES.
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 CURVE  - PLOTTING OF REDUCED DATA AND
C                                  THE POLYNOMIAL REPRESENTATION
C                                  OF THIS DATA.  CALCOMP AND
C                                  LINE-PRINTER PLOTTING PROCEDURES
C                                  ARE FOUND IN THIS SUBROUTINE.
C
C          3.  SUBROUTINE FLSQFY - LEAST-SQUARES CURVE FITTING
C                                  ALGORITHM THAT USES ORTHOGONAL
C                                  POLYNOMIALS.  THIS SUBROUTINE
C                                  CALLS SUBROUTINES FCODA AND
C                                  FGEFYT.
C
C          4.  SUBROUTINE PLOTS  - SET UP PLOT LIBRARY BUFFER
C                                  FOR IBM 370/165 II COMPUTER.
C
C          5.  PLOT LIBRARY SUBROUTINES:  AXIS
C                                         DASHLN
C                                         GRID
C                                         FACTOR
C                                         LINE
C                                         LOGAXS
C                                         NUMBER
C                                         PLOT
C                                         PLOTS
C                                         SCALE
C                                         SYMBOL
C
C          6.  LINE-PRINTER PLOTTING SUBROUTINES:  BOX
C                                                  GRAPH
C                                                  PLOTEM
C                                                  SCALER
C                                                  SQUARE
C
C
C  *****************************************************************
C
      COMMON /BLOK1/ COLOR(5),WL(3),WP(3),DATE(3)
C
      COMMON /BLOK2/ XWORK(150),YWORK(150)
C
      COMMON /BLOK3/ IBIG
C
      DIMENSION W(20),C(20),ALPHA(34),BETA(34),S(34),SGMSQ(34),PR(34),
     1PO(34)
C
      DIMENSION WC(20),DRYD(20),DATA(1024),BCD(20)
      DIMENSION X(103),Y(103)
C
      CALL PLOTS(DATA,4096)
      CALL PLOT (0.0,-12.0,-3)
      CALL PLOT(0.0,1.0,-3)
C
C     INPUT AND OUTPUT UTILITY DEVICE NUMBERS FOR COMPUTER.
      IN=5
      IOUT=6
C
      PI=355./113.
C
      WRITE(IOUT,1000)
```

```
 1000 FORMAT('1')
C
   10 CONTINUE
C
      WRITE(IOUT,1140)
C
C     READ IN TEST DESIGNATION FOR USE AS OUTPUT LABEL AND PLOT TITLE.
      READ(IN,1010,END=160) BCD
 1010 FORMAT(20A4)
C
C     READ IN DESCRIPTION OF SOIL (COLOR,TYPE), ATTERBERG LIMITS,
C     AND DATE OF TESTING.
      READ(IN,1020) COLOR,WL,WP,DATE
 1020 FORMAT(5A4,2A4,A2,2A4,A2,3A4)
C
C
C     READ IN DEGREE OF POLYNOMIAL USED IN FITTING MOISTURE-DENSITY
C     DATA.  EXPERIENCE HAS SHOWN THAT FOR 8 OR FEWER DATA POINTS
C     THE BEST DEGREE IS USUALLY EQUAL TO THE NUMBER OF DATA POINTS
C     MINUS TWO.  HOWEVER THE MAXIMUM DEGREE WHICH CAN BE USED IS SIX.
C     IF NDEG=0 OR CARD COLUMNS 1-10 ARE LEFT BLANK, NDEG WILL BE SET
C     EQUAL TO THE NUMBER OF DATA POINTS MINUS TWO OR SIX, WHICH EVER
C     IS SMALLER.
C
C     ALSO, READ IN ON SAME CARD THE NUMBER OF LAYERS (OR LIFTS),
C     NUMBER OF BLOWS PER LAYER, AND WEIGHT OF THE HAMMER (EITHER IN
C     POUNDS OR GRAMS).  IF COLUMNS 11-30 ARE LEFT BLANK, THEN DEFAULT
C     VALUES FOR THESE QUANITIES WILL BE 25, 3, AND 5.50 RESPECTIVELY.
C
C     ALSO, READ IN MOLD DIMENSIONS (INNER DIAMETER AND HEIGHT) IN FEET
C     AND WEIGHT OF MOLD IN POUNDS OR GRAMS.  IF COLUMNS 31-70 ARE
C     LEFT BLANK, DEFAULT VALUES FOR THESE QUANITIES WILL BE
C     0.33333, 0.383, AND 9.36 RESPECTIVELY.
C
      READ(IN,1030) NDEG,NLAYER, NBLOWS,WTHAM,DIA,HEIGHT,WEIGHT
 1030 FORMAT(3(I2,8X),4F10.0)
C
      IF(NLAYER.LT.0.0001) NLAYER=3
      IF(NBLOWS.LT.0.0001) NBLOWS=25
      IF(WTHAM.LT.0.0001)  WTHAM=5.50
      IF(DIA.LT.0.0001)     DIA=0.3333333
      IF(HEIGHT.LT.0.0001) HEIGHT=0.383
      IF(WEIGHT.LT.0.0001) WEIGHT=9.36
C
 1040 FORMAT(4F10.0)
C
      FACTOR=1.0
      IF (WEIGHT.LT.20) FACTOR=453.6
      VOL = PI*(DIA**2/4)*HEIGHT
C
C     READ IN UP TO TWENTY DATA POINTS,WATER CONTENT (%), WEIGHT OF
C     MOLD PLUS SOIL (IN GRAMS OR LBS.).  A PLUS ONE IN COLUMNS 21-22
C     ENDS A GIVEN SET OF MOISTURE-DENSITY DATA.  THE COMPUTER PROGRAM
C     WILL STOP LOOKING FOR MORE DATA WHEN A CONTROL CARD (/*) IS
C     ENCOUNTERED AT END OF DATA.
C
      DO 20 I =1,20
C
C     NOTE: DATA MUST BE READ IN ORDER OF INCREASING WATER CONTENT.
      READ (IN,1050) WC(I),DRYD(I),L
 1050 FORMAT(2F10.0,I2)
      NDATA = I
      IF (L.NE.0) GO TO 30
   20 CONTINUE
C
   30 CONTINUE
C
      IF(NDEG.EQ.0.AND.NDATA.EQ.3) NDEG=2
      IF(NDEG.EQ.0.AND.NDATA.EQ.4) NDEG=3
      IF(NDEG.EQ.0.AND.NDATA.LE.8) NDEG=NDATA-2
      IF(NDEG.EQ.0.AND.NDATA.GT.8) NDEG=6
C
C     CALCULATION OF WET WEIGHT OF MATERIAL IN MOLD.
      DO 40 I = 1,NDATA
      DRYD(I)=DRYD(I)-WEIGHT
   40 CONTINUE
```

```
C
C     OUTPUT PRESENT TEST INFORMATION
C
      WRITE(IOUT,1060) BCD
 1060 FORMAT('0',10X,20A4)
C
      WRITE(IOUT,1070) COLOR,WL,WP,DATE
 1070 FORMAT('0',5X,'DESCRIPTION OF SOIL:',5A4,3X,'LIQUID LIMIT =',2A4,
     1A2,3X,'PLASTIC LIMIT =',2A4,A2,'   DATE OF TESTING =',3A4)
C
      WRITE(IOUT,1080) NLAYER,NBLOWS,WTHAM,WEIGHT,VOL
 1080 FORMAT('0',5X,'NUMBER OF LAYERS:',I2,4X,'NO. OF BLOWS/LAYER',I3,4X
     1,'WEIGHT OF HAMMER =',F5.2,' LBS',5X,'MOLD:  WT =',F7.1,' GR,LBS',
     1'  VOL =',F7.4,' CU. FT')
C
      WRITE(IOUT,1120) (J,J=1,NDATA)
C
      WRITE(IOUT,1090) (WC(J),J=1,NDATA)
 1090 FORMAT('0',' WATER CONTENT, W% ',5X,10(F4.1,6X))
C
      WRITE(IOUT,1100) (DRYD(J),J=1,NDATA)
 1100 FORMAT('0','WT. OF SOIL IN MOLD',1X,10(F9.2,1X))
C
C     CALCULATE DRY DENSTY
C
C
      DO 50 I =1,NDATA
      DRYD(I)=DRYD(I)/(PI*(DIA**2/4)*HEIGHT*453.6)*FACTOR
   50 CONTINUE
C
      WRITE(IOUT,1110) (DRYD(J),J=1,NDATA)
 1110 FORMAT('0','WET UNIT WEIGHTS, PCF',1X,10(F7.2,3X))
C
 1120 FORMAT('0',/4X,'SAMPLE NUMBER',10( 8X,I2))
C
C     LOCATE DATA POINT WITH MAXIMUM DRY DENSITY.
C
      IBIG=0.0
      BIG=0.0
      XBIG=0.0
      DO 60 I = 1,NDATA
      DRYD(I)=DRYD(I)/(1+WC(I)/100.)
      IF (DRYD(I).GT.BIG) IBIG=I
      IF (DRYD(I).GT.BIG) XBIG=WC(I)
      IF (DRYD(I).GT.BIG) BIG=DRYD(I)
   60 CONTINUE
C
      WRITE(IOUT,1130) (DRYD(J),J=1,NDATA )
 1130 FORMAT('0',' DRY DENSITY, PCF ',2X,10(F9.2,1X))
C
C     INITIALIZING ALL POLYNOMIAL COEFFICIENTS AND WEIGHTING FACTORS.
C
      DO 70 I=1,20
      C(I)=0.0
      W(I)=1.0
   70 CONTINUE
C
C     NEGLECT DATA POINTS PRODUCING LOCALIZED DIPS IN THE MOISTURE-
C     DENSITY CURVE.
C
      ISUM=0
      DO 80 I = 1,IBIG
      IF (I.EQ.1) GO TO 80
      IF (DRYD(I).LT.DRYD(I-1)) W(I)=0.0001
      IF (DRYD(I).LT.DRYD(I-1)) ISUM=1+ISUM
   80 CONTINUE
      DO 90 I = IBIG,NDATA
      IF (I.EQ.IBIG) GO TO 90
      IF(DRYD(I).GT.DRYD(I-1)) ISUM=1+ISUM
      IF(DRYD(I).GT.DRYD(I-1)) W(I-1) = 0.0001
   90 CONTINUE
C
C     MUST REDUCE DEGREE OF POLYNOMIAL IF THERE ARE DATA POINTS WHICH
C     HAVE BEEN GIVEN LOW WEIGHTING FACTORS.
      IDEG=NDEG
```

```
      ITEST=NDATA-ISUM-1
      IF(NDEG.LE.ITEST) GOTO 95
      IDEG=NDEG-ISUM
      IF(IDEG.GE.3)  NDEG=NDEG-ISUM
   95 CONTINUE
C
C     EXPERIENCE HAS SHOWN ANYTHING LESS THAN A POLYNOMIAL DEGREE OF
C     THREE IS NOT VERY EFFECTIVE IN FITTING THE DATA IN A REASONABLE
C     FASHION.
C
      IF(IDEG.LE.2) NDEG=2
C
C     PREPARING DATA TO BE FITTED BY LEAST-SQUARES ORDINARY POLYNOMIAL.
C
      NDC=NDEG+1
      MDC=NDEG+NDATA+1
      DO 100 I = 1,NDATA
      Y(I)=DRYD(I)
      XWORK(I)=WC(I)
      YWORK(I)=DRYC(I)
  100 CONTINUE
C
      CALL FLSQFY(NDEG,NDATA,WC,Y,W,C,ALPHA,BETA,S,SGMSQ,PR,PO,NDC,MDC)
C
C     SEARCHING FOR OPTIMUM MOISTURE CONTENT ON FITTED POLYNOMIAL
C     REPRESENTATION OF MOISTURE-DENSITY CURVE.
C
C
C     INITIALLY SETTING SEARCH INTERVAL TO FIND LOCATION OF PEAK IN
C     MOISTURE-DENSITY CURVE AT DATA POINTS BEFORE AND AFTER ONE
C     HAVING MAXIMUM DRY-DENSITY.
C
      IF(IBIG.GT.1) BOUND1=WC(IBIG-1)
      IF(IBIG.EQ.1) BOUND1=WC(1)
      IF(IBIG.LT.NDATA) BOUND2=WC(IBIG+1)
      IF(IBIG.EQ.NDATA) BOUND2=WC(NDATA)
      ISTART=0
C
C
      DO 150 J=1,3
C
      X(1)=BOUND1
      DELTA=(BOUND2-BOUND1)/100.
C
      DO 110 I=2,101
      X(I)=X(I-1) + DELTA
  110 CONTINUE
C
      DO 130 I =1,101
      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)
      Y(I)=C(2)+2*C(3)*X1+3*C(4)*X2+4*C(5)*X3+5*C(6)*X4+6*C(7)*X5
      IF (J.EQ.1.AND.I.EQ.1.AND.Y(I).LE.0) IFIRST=999
      IF (J.EQ.1.AND.Y(I).GT.0) IFIRST=1
      IF (J.EQ.1.AND.IFIRST.EQ.1) GO TO 120
      IF (J.EQ.1.AND.IFIRST.GT.1) GO TO 130
  120 CONTINUE
      IF(Y(I).LT.0) ISTART=I
      IF(Y(I).LT.0) GO TO 140
  130 CONTINUE
C
      IF(ISTART.EQ.0) ISTART=50
  140 CONTINUE
C
      BOUND1=X(ISTART-1)
      BOUND2=X(ISTART+1)
  150 CONTINUE
C
      OPTMOS=(X(ISTART-1)+X(ISTART+1))/2.0
      X1=OPTMOS
      X2=OPTMOS*OPTMOS
```

```
      X3=OPTMOS*OPTMOS*OPTMOS
      X4=OPTMOS*OPTMOS*OPTMOS*OPTMOS
      X5=OPTMOS*OPTMOS*OPTMOS*OPTMOS*OPTMOS
      X6=OPTMOS*OPTMOS*OPTMOS*OPTMOS*OPTMOS*OPTMOS
      DRYMAX=C(1)+C(2)*X1+C(3)*X2+C(4)*X3+C(5)*X4+C(6)*X5+C(7)*X6
C
 1140 FORMAT('0',130('-'))
C
      WRITE(IOUT,1150) OPTMOS,DRYMAX,NDEG
 1150 FORMAT('0','OPTIMUM MOISTURE CONTENT =',F5.1,'%',5X,     'MAXIMUM
     1DRY DENSITY =',F5.1,' PCF',3X,' DEGREE POLYNOMIAL =',I2)
C
      WRITE(IOUT,1140)
C
C
C     CALL PLOTTING SUBROUTINE THAT PLOTS DATA USING CALCOMP DRUM
C     PLOTTER AND LINE PRINTER.
C
      CALL CURVE (NDEG,NDATA,WC,DRYD,C,BCD,OPTMOS,DRYMAX)
C
      CALL PLOT(15.0,0.0,-3)
      IF(L.NE.0) GOTO 10
C
  160 CONTINUE
C
      CALL PLOT (15.0,0.0,-3)
      CALL PLOT (15.0,0.0,999)
C
      STOP
      END
```



```
C
C
C     PLOTTING SUBROUTINE
C
      SUBROUTINE CURVE (NDEG,NDATA,WC,DRYD,C,BCD,OPTMOS,DRYMAX)
C
      COMMON /BLOK1/ COLOR(5),WL(3),WP(3),DATE(3)
C
      COMMON /BLOK2/ XWORK(150),YWORK(150)
C
      COMMON /BLOK3/ IBIG
C
      DIMENSION WC(20),DRYD(20),C(20),X(103),Y(103),BCD(20)
C
      ITEST=NDATA
      IF(DRYMAX.GT.DRYD(IBIG)) DRYD(NDATA+1)=DRYMAX
      IF(DRYMAX.GT.DRYD(IBIG)) ITEST=1+NDATA
      CALL SCALE(DRYD,8.0,ITEST,1)
      IF(DRYMAX.GT.DRYD(IBIG)) DRYD(NDATA+1)=DRYD(ITEST+1)
      IF(DRYMAX.GT.DRYD(IBIG)) DRYD(NDATA+2)=DRYD(ITEST+2)
      CALL SCALE(WC,8.0,NDATA,1)
      CALL FACTOR(0.83)
      CALL SYMBOL(0.5, 9.5,0.14,BCD,0.0,80)
      CALL AXIS(0.0,0.0,'DRY DENSITY, PCF',16,8.0,90.0,DRYD(NDATA+1),
     1DRYD(NDATA+2))
      CALL AXIS(0.0,0.0,'MOISTURE CONTENT, W%',-20,8.0,0.0,WC(NDATA+1),
     1WC(NDATA+2))
      CALL LINE(WC,DRYD,NDATA,1,-1,1)
C
      DELTA=(OPTMOS-WC(1))/10.0
C     DELETE FOLLOWING DEFINITION OF DELTA WHEN WATFIV IS BEING USED
C     TO RUN COMPUTER PROGRAM.
C
      DELTA=(WC(NDATA+1)-OPTMOS)/10.0
C
      YWORK(1+NDATA)=DRYMAX
      XWORK(1+NDATA)=OPTMOS
      X(1)=OPTMOS
      Y(1)=DRYMAX
```

```
C
      DO 10 I = 2,10
      X(I)=X(I-1)-DELTA
      X(I)=X(I-1)+DELTA
      Y(I)=DRYMAX
      XWORK(I+NDATA)=X(I-1)-DELTA
      YWORK(I+NDATA)=DRYMAX
   10 CONTINUE
C
      X(11)=WC(NDATA+1)
      X(12)=WC(NDATA+2)
      Y(11)=DRYD(NDATA+1)
      Y(12)=DRYD(NDATA+2)
      CALL DASHLN(X,Y,10,1)
C
      DELTA=-(DRYMAX-DRYD(1))/10.0
C
C     DELETE FOLLOWING DEFINITION FOR DELTA WHEN WATFIV IS BEING USED
C     TO RUN COMPUTER PROGRAM.
```

G LEVEL 20.1 CURVE DATE = 78229 09/00/55

```
C
      DELTA=(DRYD(NDATA+1)-DRYMAX)/10.0
C
      X(1)=OPTMOS
      Y(1)=DRYMAX
      XWORK(11+NDATA)=OPTMOS
      YWORK(11+NDATA)=DRYMAX
C
      DO 20 I =2,10
      XWORK(10+I+NDATA)=OPTMOS
      YWORK(10+I+NDATA)=Y(I-1)-DELTA
      X(I)=OPTMOS
      Y(I)=Y(I-1)+DELTA
   20 CONTINUE
C
      CALL DASHLN(X,Y,10,1)
      CALL SYMBOL(0.5,9.0,0.10,COLOR,0.0,20)
      CALL SYMBOL(0.5,8.5,0.10,'WL =          WP =',0.0,16)
      CALL SYMBOL(1.0,8.5,0.10,WL,0.0,10)
      CALL SYMBOL(2.2,8.5,0.10,WP,0.0,10)
      CALL SYMBOL (2.9,8.5,0.10,'DEG =',0.0,5)
      CALL SYMBOL(6.7,9.75,0.10,DATE,0.0,12)
      FPN = NDEG
      CALL NUMBER(3.5,8.5,0.10,FPN,0.0,-1)
      CALL SYMBOL(4.5,9.0,0.10,'OPTIMUM MOISTURE CONTENT (%) =',0.0,30)
      CALL NUMBER(7.6,9.0,0.10,OPTMOS,0.0,1)
      CALL SYMBOL(4.5,8.5,0.10,'OPTIMUM DRY DENSITY =        PCF',0.0,31)
      CALL NUMBER(6.7,8.5,0.10,DRYMAX,0.0,1)
      CALL GRID(0.0,0.0,0.5,0.5,16,16)
      CALL GRID(-1.0,-1.0,10.0,11.0,1,1)
C
      DELTA=(WC(NDATA)-WC(1))/100.
      X(1)=WC(1)
C
      DO 30 I=2,101
      X(I)=X(I-1)+DELTA
   30 CONTINUE
C
      DO 40 I = 1,101
      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)
      Y(I)=C(1)+C(2)*X1+C(3)*X2+C(4)*X3+C(5)*X4+C(6)*X5+C(7)*X6
C
      XWORK(20+I+NDATA)=X(I)
      YWORK(20+I+NDATA)=Y(I)
C
```

```
   40 CONTINUE
C
      X(102)=WC(NDATA+1)
      X(103)=WC(NDATA+2)
      Y(102)=DRYD(NDATA+1)
      Y(103)=DRYD(NDATA+2)
      CALL LINE (X,Y,101,1,0,0)
C
      DMAX=1.05*DRYMAX
      DMIN=DRYD(1)
      WMAX=WC(NDATA)
      WMIN=WC(1)
      NPTS=20+101+NDATA
      CALL SCALER(WMAX,WMIN,DMAX,DMIN)
      CALL SQUARE
      CALL BOX
      CALL PLOTEM('*',XWORK,YWORK,NPTS)
      CALL GRAPH('MOISTURE CONTENT, W%',20,'DRY DENSITY, PCF',16)
C
      RETURN
      END
```

```
G LEVEL  20.1                  MAIN                 DATE = 78229           09/00/55

C
C     *************************************************************
C     * LEAST-SQUARES ORTHOGONAL POLYNOMIAL CURVE FITTING SUBROUTINE.*
C     *************************************************************
C
C
C                                NUMAL1B
C
C                         UNIVERSITY OF KENTUCKY
C
C                            COMPUTER CENTER
C
C                               MCVEY HALL
C                           LEXINGTON,KENTUCKY
C
C     BASIC REFERENCE:   FORSYTHE, G.E. (1957) "GENERATION AND USE OF
C                        ORTHOGONAL POLYNOMIALS FOR DATA FITTING ON A
C                        DIGITAL COMPUTER."  J. SOC. INDUST. APPL.
C                        MATH VOL. 5, PP 74-88.
C
C
      SUBROUTINE FLSQFY(N,M,X,Y,W,C,ALPHA,BETA,S,SGMSQ,PR,PO,N1,MN1)
      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
```

```
G LEVEL  20.1                  FCODA                DATE = 78229           09/00/55

      SUBROUTINE FCODA(N,C,PM,PR,ALPHA,BETA,GAMDA,S,NN)
      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
```

G LEVEL 20.1 FGEFYT DATE = 78229 09/00/55

```
      SUBROUTINE FGEFYT(N,NO,X,Y,W,BETA,S,SGMSQ,ALPHA,PR,PO,M,NI)
      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
```