Falling Weight Deflectometer Relative Calibration Analysis

FWDCAL Version 3.0

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I. PURPOSE

The purpose of this document is to explain the background and use of the revised FWD relative calibration analysis computer program, **FWDCAL Version 3.0**, developed for the Long Term Pavement Performance (LTPP) Regional Coordination Offices (RCO). The **FWDCAL Version 3.0** program automates the analysis of the results of the relative calibration test procedure performed on the Falling Weight Deflectometer (FWD) geophones. The program performs the following functions:

- Checks FWD relative calibration data file for compliance with LTPP test setup requirements.
- Calculates new relative gain factors for each geophone.
- Checks the ratios between existing and new relative gain factors to determine if they are within established tolerances.
- Performs an analysis of variance on the data to determine the statistical significance of key test factors.
- Provides a statistical summary of the test results.
- Provides guidance to the user on needed gain changes or further testing needs.
- Computes the gains factor for a replacement sensor.
- Processes up to three data sets in the same file.
- Computes average new relative gain factor from relative calibration tests performed as a part of LTPP Reference calibration procedures. All three data sets must be in the same file.
- Processes data sets produced by Version 10, Version 20 and Dyna25 LTPP customized versions of the Dynatest FWD operating system software.
- Ability to process multiple data sets in separate files without exiting the program.

The program displays the results on the screen and writes them to an output file for subsequent printing.

II. BACKGROUND

The LTPP program uses the Dynatest Model 8000 Falling Weight Deflectometer (FWD) to measure the deflection response of the test pavement structures. The **FWDCAL Version 3.0** computer program was developed to automate the analysis of the results of relative calibrations performed with this device.

Relative calibration is a technique used to verify and adjust the response of each of the deflection sensors (geophones on a Dynatest FWD) so that equivalent measurements are obtained when the sensors are subjected to the same displacement. A direct product of this procedure is a set of multipliers necessary to keep the measurements derived from the deflection sensors equivalent.

In the relative calibration procedure, all deflection sensors are placed in a stand that is held vertical on a point located near the load plate so that all sensors are subjected to the same deflection. The measurements consist of subjecting the sensors to a five drop load sequence, rotating the positions of the sensors in the stand, placing the stand on the same point, and repeating the drop sequence. This process is repeated until each sensor has been tested in each position in the stand. The sensor rotation serves to check the proper conduct of the test and cancel out any effect of stand position on the results.

The most basic analysis of the data collected in a relative calibration test consists of the following steps:

1. Calculating the ratio of overall mean deflection of all sensors for all drops to the mean deflection of each sensor for all drops. This is called the means ratio.

2. Computing the new gain value, which is the product of the means ratio multiplied by the existing gain value.

In addition, the following statistical analyses are used as aids in evaluating the validity of the relative calibration test and in investigating anomalous results:

A. Latin Square, analysis of variance (ANOVA). This determines the statistical significance of sensor, set, and position on the test results.

B. Summary statistics:
   - mean, standard deviation and coefficient of variation of the deflection response of **all** sensors for all drops.
   - mean, standard deviation and coefficient of variation of **each** sensor for all drops.
   - mean, standard deviation and coefficient of variation of all sensors by **position** in the stand.
   - mean deflection of each sensor and average of for all sensors for each drop set.

- mean load for each drop set.
- mean, standard deviation and coefficient of variation of the load for all drops.

C. Cochran homogeneity variance test. This statistical test is used to determine if the variance of each deflection sensor's response across all drops is equivalent.

The standard LTPP relative calibration procedure is presented in Appendix A.

III. PROGRAM DESCRIPTION

The **FWDCAL Version 3.0** program contains three analysis options:

1. Standard Analysis
2. Replace Geophone Analysis
3. Reference-Relative Calibration.

The Standard Analysis is designed for use in interpreting the results when a relative calibration is performed as a stand-alone procedure such as for routine checks (e.g. monthly).

The Replace Geophone Analysis is used when one of the geophones is replaced without an immediate reference calibration. In the Replace Geophone Analysis, the response of the replacement geophone is not included in the computation of the overall average mean response of all geophones.

The Reference-Relative Calibration is designed to be used for the relative calibration performed in conjunction with the LTPP reference calibration procedure. This analysis option computes the average new gain setting for a series of three tests.

The program is written in Microsoft® QuickBasic™ 4.5. It uses a proprietary file selection routine written by LAW PCS, a LAWGIBB Group member, and commercial routines written by Crescent Software for the menus and windows. A listing of the **FWDCAL Version 3.0** program is presented in Appendix B. The routines from Crescent Software are not included in the listing.

All of the analyses follow the same basis steps – FWD data file input, data analysis (Gains table, Latin square ANOVA, and summary statistics), and program output. These topics are described in the following sections.

FWD Data File Input

Each Dynatest FWD data file consists of header information and data block(s). The first 40 lines of the Dyna25 data file (25CAL), and the first 37 lines of a Version 10/20 file contain the header information. An example Dyna25data file header is shown in Figure 1. An example of a Version 10/20 header file is included in Appendix D, Figure D1. The second part of the data file, known as the data block, consists of the loads, deflections, temperatures and station information. A data file that contains only one header block can contain multiple data block sets (data sets).

Line No.	File Contents
	Column 1111111111222222222233333333334444444444555555555556666666667777777778 12345678901234567890123456789012345678901234567890123456789012345678901234567890
1	5001,25.11,1,40, 3, 1,"Spring 94 "
2	5002,"25CAL ","8002-131","9000-098"
3	5003,"SYSOP ","LTPPREL4"
4	5010,0,0,0,0,0,0,0,5,1,0,0,0,0,0,1,0,0,0,0,0,0,"H25"
5	5011,0,1,2000,09,26,15,39,2,"Wed",269
6	5200,"F0188 ",2,1.001, 86.8, -1.83, 7.339
7	5201,"1930 ",4,0.993,1.020
8	5202,"1931 ",4,0.993,1.012
9	5203,"1923 ",4,0.993,1.016
10	5204,"1924 ",4,0.994,1.037
11	5205,"1928 ",4,0.997,1.005
12	5206,"1932 ",4,0.995,1.015
13	5207,"1927 ",4,0.999,1.046
14	5208,"1921 ",4,0.991,1.032
15	5209,"1929 ",4,0.992,1.032
16	5210,"NA ",0,0.000,0.000
17	5211,"NA ",0,0.000,0.000
18	5212,"NA ",0,0.000,0.000
19	5213,"NA ",0,0.000,0.000
20	5214,"NA ",0,0.000,0.000
21	5215,"NA ",0,0.000,0.000
22	5216,"NA ",0,0.000,0.000
23	5217,"NA ",0,0.000,0.000
24	5218,"NA ",0,0.000,0.000
25	5020, 150, 0, 200, 400, 600, 800, 1000, 1200, 1500, 1800,N0 ,N0 ,N0 ,N0 ,N0 ,N0 ,N0 ,N0 ,N0
26	5021, 300, 0, 0, 0, 0, 0, 0, 0, 0, 0,N0 ,N0 ,N0 ,N0 ,N0 ,N0 ,N0 ,N0 ,N0
27	5022,0, 200, 208, 50, 100, 200, 390
28	5023,1,3,2,N0 ,N0 ,N0 ,N0 , 328,1,1
29	5024,0,0,0,0,0,0, 3, 2.0, 2, 1.0,0,0,0, 120
30	5029, 1, 45, 4621, 71034
31	5030,"ANY CHANGES MADE AT SYSOP LEVEL "
32	5031,"RENO DOT "
33	5032,"31092600 "
34	5301,0,1,3,5, 0,1,1, 0.0,2000,09,26,15,39
35	5302,0,1,8,2,0,0,0,0,"Monthly Relative Calibration "
36	5303,0, 0.0, 27.3, 31.0
37	5041,"Previous test: "
38	5042,"Next Test(s): "
39	5043," "
40	5044," "

Figure 1. Example of Dyna25 FWD header block.

The user is alerted if the Dynatest FWD operating software is not version 10, 20, or Dyna25 (edition 25.xx) or the selected file contains something other than a Dynatest FWD calibration file. The program is terminated if either of the following conditions are found during the checks performed on the header block:

- The number of sensors is not equal to 7 for version 10 or 20.
- The number of sensors is not equal to 9 for Dyna25.

Other information determined from the header block and used by the program includes:

- Units for data collection, English or Metric
- Data collection date
- FWD serial number
- Deflection sensor gain settings
- Operators' names

A Dyna25 data block starts with LIN 5301 containing the station and date, LIN 5302 containing operator comments, and LIN 5303 containing temperature information. The remainder of the FWD data block consists of a repeating series of lines defining the test sequence of three seating drops and five recorded drops for each position arrangement. The first value in each line defines the drop number in the test sequence, the second value is the load, and the remaining values are the recorded deflections for each sensor starting with sensor number one. The position in the data file of the deflection value for each sensor does not change regardless of the actual position of the sensor in the stand. An excerpt from a Dyna25 FWD relative calibration data block is shown in Figure 2.

The Version 10/20 data block consists of a repeating series of lines defining the test sequence of five repeat drops for each position arrangement. The first line in the data block identifies the location (station) of the test, the character "S" always occupies the first column in this line. The lines following are the data recorded for each drop. If U.S. Customary units are used, the load and deflection data are written twice on the same line, once in metric and then in U.S. Customary units. If metric units are used, only the metric measurements are present. An example of a version 10/20 data block is included in Appendix D, Figure D2.

File Contents

Column

```
         1111111111222222222233333333334444444444555555555566666666677777777778
1234567890123456789012345678901234567890123456789012345678901234567890123456789
5301,0,1,3,5,        0,1,1,N0      ,2000,09,26,15,39
5302,0,1,8,2,0,0,0,0,"Monthly Relative Calibration                                "
5303,0,  0.0, 27.3, 31.0
   4,    990, 478.0, 478.3, 476.8, 477.9, 478.1, 478.3, 477.5, 478.1, 477.1
   5,    993, 477.8, 478.5, 477.0, 478.2, 478.2, 478.3, 477.5, 477.8, 476.7
   6,    995, 476.6, 477.2, 476.2, 477.1, 476.7, 477.2, 477.3, 477.1, 475.8
   7,    998, 478.6, 479.2, 478.7, 479.9, 479.3, 479.7, 479.6, 479.4, 477.6
   8,   1005, 477.4, 478.1, 477.4, 478.3, 477.8, 478.2, 478.2, 478.2, 476.4
   -      -    -       -       -       -       -       -       -       -       -
   -      -    -       -       -       -       -       -       -       -       -
  64,    987, 475.3, 476.1, 475.2, 476.0, 476.1, 475.9, 475.9, 475.3, 474.4
  68,    991, 481.4, 481.7, 480.2, 480.8, 480.7, 480.9, 480.6, 479.1, 479.9
  69,    997, 480.8, 480.9, 479.7, 480.3, 480.2, 480.1, 480.0, 478.6, 479.1
  70,    994, 480.0, 480.5, 479.2, 479.7, 479.5, 479.3, 479.5, 478.0, 478.3
  71,    997, 478.5, 478.6, 477.4, 478.1, 478.2, 477.9, 477.8, 476.8, 476.9
  72,    987, 476.7, 476.8, 475.8, 476.9, 477.0, 477.0, 476.9, 476.0, 475.7
```

Figure 2. Excerpt from a Dyna25 FWD relative calibration data block.

Gains Table

The relative gain settings for a Dynatest FWD are multipliers used to refine the deflection sensor calibration. The manufacturer generally sets these gains to 1.000. The FWD operating program allows the user to adjust these gain settings in the range 0.980 to 1.020. The primary result of the analysis on the relative calibration test data is the computation of new deflection sensor gain settings that will allow all sensors to produce equivalent results. The determination of the need to change gain settings is based on the amount of difference between the sensor responses. This information is provided by the **FWDCAL** program in the gains table.

The gains table contains the following information:

Sensor Number - This is the sensor number read from the header block. This number should correspond to the position or channel that the sensor is connected to on the FWD.

Sensor Serial Number - This is the sensor serial number read from the header block. Each sensor has a serial number assigned by the manufacturer. This number is used by the FWD operating program to determine the proper processing parameters for each sensor.

Existing Gain Factor - This is the current gain setting read from the header block.

Means Ratio - This is the computed ratio of the average response of all sensors to the response of each individual sensor. A tolerance range is set for this number to indicate the need for adjustment of the gain factor.

New Relative Gain - This is the new relative gain factor computed from the results of the test. This is the number that would be entered into the FWD operating program if the gain factors need to be changed.

The overall mean deflection response is computed as follows:

$$\overline{X_o} = \sum_{i=1}^{NumSens} \sum_{k=1}^{NumSets} \sum_{l=1}^{NumReps} \frac{\delta_{ikl}}{(NumSens \times NumSets \times NumReps)} \quad \textbf{(1)}$$

where,

X_o = average deflection for all sensors.
NumSens = number of sensors (9 for LTPP Dyna25 FWD, 7 for Version 10/20).
NumSets = number of drop sets (9 for LTPP Dyna25 relative calibration test, 7 for Version 10/20). This should be equal to the number of sensors and number of positions in the stand.
NumReps = number of repeat drops for each drop set, 5 for LTPP relative calibration test.
δ_{ikl} = deflection for sensor *i*, drop set *k*, and repeat drop *l*.

The mean deflection response for each sensor is computed as,

$$\overline{Xi} = \sum_{k=1}^{NumSets} \sum_{l=1}^{NumReps} \frac{\delta_{ikl}}{(NumSets \times NumReps)} \quad \textbf{(2)}$$

where,

i = Average deflection for sensor *i*.

The means ratio for each sensor is,

$$Ri = \frac{\overline{Xo}}{\overline{Xi}} \quad \textbf{(3)}$$

where,

R_i = means ratio of sensor *i*.

The new relative gain factor is computed as,

$$G_{FN(i)} = G_{FE(i)} \times R_i \quad \textbf{(4)}$$

where,

$G_{FN(i)}$ = new relative gain factor for sensor *i*.
$G_{FE(i)}$ = existing relative gain factor for sensor *i*.

The values of the means ratio are compared against a tolerance range of 1.000 ± 0.003. If the means ratio falls outside of this range a YES is displayed in the out of limit tolerance column in the gains table. The new relative gains are compared against a range from 0.980 to 1.020, which corresponds to the manufacturer's specified 2% tolerance. If a new relative gain value falls outside of this range, a YES is displayed in the out of limit 2% range column. The other messages displayed by the program are discussed in the program output portion of this document.

It is important to note that the geophones on a Dynatest FWD must be in the position indicated in the FWD operating software. If the position of a geophone on the FWD is changed, a change must be made in the geophone set-up table in the operating program so that the program will not use incorrect gain and amplification factors for the geophone.

Latin Square ANOVA

The LTPP relative calibration procedure was designed so that a statistical analysis of variance (ANOVA) procedure could be run on the results. The purpose of this procedure is to provide a tool for evaluating the validity of the relative calibration test and as an aid in interpreting its results. The results of the ANOVA indicate only statistical significance relative to the amount of unexplained variation present in the data set. By themselves, the ANOVA results do not necessarily indicate the need for a sensor gain change, that a test was not valid, or that a repeat test is needed. The ANOVA results must be evaluated relative to the information provided in the gains table and the summary statistics. **Statistical** significance in the ANOVA results does not necessarily imply **engineering** significance.

In the Latin Square ANOVA of the relative calibration test, *F* statistics are computed for each main effect (position, set, and sensor). The computed *F* values are compared to the critical *F* statistic – either 2.14 for seven sensors or 1.96 for nine sensors (5% confidence level). If a computed *F* values is less than the critical *F* statistic, then the effect is judged **not** to be statistically significant. If the computed *F* value is greater than the critical *F* statistic, then the effect is indicated as being statistically significant and instructional messages are displayed in the output. These messages are based on the results of both the gains table and the ANOVA, and are discussed in the program output portion of this document. The details of the Latin Square experiment design layout and computations are presented in Appendix C.

Summary Statistics

The following summary statistics are produced by the program to aid in interpretation of the relative calibration test results:

- Mean deflection of each sensor and average for all sensors for each drop set.
- Mean, standard deviation and coefficient of variation of **each** sensor for all drops.
- Overall mean, standard deviation and coefficient of variation of the deflection response of **all** sensors for all drops.
- Mean, standard deviation and coefficient of variation of all sensors by **position** in the stand.
- Mean load for each drop set.
- Mean, standard deviation and coefficient of variation of the load for all drops.

The coefficient of variation is the standard deviation divided by the mean times 100.

These statistics can be helpful in interpreting the results of a relative calibration test. For example, the systematic variation in the load between drop sets can be directly observed. This can be the cause for the significance of drop set in the ANOVA. The cause for some anomalous results can also be easily identified. For example, it is easy to detect if the effect of one out of range sensor on the overall mean is causing another sensor to be indicated as out of range.

A test is performed on the significance of the variance between deflection sensors. This test is performed to determine if the variation in the response of a sensor is much greater than the other geophones. This can occur even though the mean response is the same as the other sensors. Cochran's test for the homogeneity of variances is used.

The Cochran statistic is

$$g = \frac{Largest S_i^2}{\sum_{i=1}^{NumSens} S_i^2} \qquad \textbf{(5)}$$

where

$$S_i^2 = \frac{(NumSets \times NumReps)\sum_{k=1}^{NumSets}\sum_{l=1}^{NumReps}\delta^2_{ikl} - \left(\sum_{k=1}^{NumSets}\sum_{l=1}^{NumReps}\delta_{ikl}\right)^2}{(NumSets \times NumReps)(NumSets \times NumReps - 1)} \qquad \textbf{(6)}$$

S_i^2 = sample variance for deflection response of sensor i for all drops.
NumSets = number of drop sets.
NumReps = number of repeat drops in each drop set.

To determine significance, the computed g value is compared against the critical $g\alpha$. If $g > g\alpha$, then the hypothesis of equal variances is rejected. This procedure provides a test on the homogeneity of the sensor variance and also provides an indication of which sensor has the greatest variance. The results of this test are only printed if the computed g value is in the critical region. For 7 sensors and 35 measurements, $g_{0.05} = 0.2326$, while for 9 sensors and 45 measurements, $g_{0.05} = 0.1972$

Program Output

The program output is organized into the following screens/pages:

- Gains Table
- ANOVA Table
- Deflection Input Data
- Summary Statistics

An example of the four page output file from the program is shown in Figures 3 through 6. The output file created by the program has a name that consists of the original data file name with an extension of the form ".Cαρ", where:

α = indicates type of analysis:
S for standard analysis,
G for replace geophone analysis, and
R - for Reference-relative calibration

ρ = last character in data file name extension; for example it would be the (1) in the file name 59092289.RC**1**.

The program writes the output file to the same directory as specified in Control Screen 1 as the location of the FWD data file. The output file cannot be viewed or printed from within the program, but may be accessed externally using a text editor or word processing program.

The following information read from the input data file header block is printed on every page:

- FWD Serial Number
- Data of Calibration
- Data File Name
- Operator Name
- Data Set # of #. This indicates the data set number when multiple data blocks are included in a file with only one header block. If a file contains a single data set, then Data Set 1 of 1 will be displayed.

SHRP FWD Relative Calibration - Analysis of Variance - Means and Gains Table
FWD SN: 8002-131 Calibration Date: 09-26-2000
Data File Name: 31093000.F25 Data Set 1 of 1
Operator: ANY CHANGES MADE AT SYSOP LEVEL

Sensor #	Sensor S/N	Existing Gain Factor	Means Ratio	New Relative Gain	Out of Limit Tolerance	Out of Limit 2% Range
1	1930	0.993	1.0000	0.993	NO	NO
2	1931	0.993	0.9991	0.992	NO	NO
3	1923	0.993	1.0016	0.995	NO	NO
4	1924	0.994	0.9998	0.994	NO	NO
5	1928	0.997	0.9999	0.997	NO	NO
6	1932	0.995	0.9990	0.994	NO	NO
7	1927	0.999	0.9994	0.998	NO	NO
8	1921	0.991	0.9999	0.991	NO	NO
9	1929	0.992	1.0013	0.993	NO	NO

Figure 3. Example print of output file for the Gains Table.

SHRP FWD Relative Calibration - Analysis of Variance - Latin Square ANOVA Table
FWD SN: 8002-131 Calibration Date: 09-26-2000
Data File Name: 31093000.F25 Data Set 1 of 1
Operator: ANY CHANGES MADE AT SYSOP LEVEL

Variation Source	Sum of Squares	Degrees of Freedom	Mean Square	Computed F	Critical F
Position	4.59E+01	8	5.74E+00	2.22	1.96
Set	6.18E+02	8	7.72E+01	29.84	1.96
Sensor	6.77E+01	8	8.46E+00	3.27	1.96
Error	9.83E+02	380	2.59E+00		
TOTAL	1.71E+03	404			

Set, sensor, and stand position are statistically significant at the 5% level.
Although gain changes are not indicated, these results are suspect. A repeat calibration is required after conditioning with 50+ drops at height 3.
Extra care should be taken to properly seat the geophones and hold the stand vertical with moderate downward pressure. If deflections from the last 10 drops vary more than 1 mil (25.4 microns) repeat the calibration at a new location. If this message appears in subsequent tests, contact your supervising engineer for further instructions.

Figure 4. Example print of output file of the ANOVA Table.

Relative Calibration - Input Data

FWD SN: 8002-131 Calibration Date: 09-26-2000

Data File Name: 31093000.F25 Data Set 1 of 1

Operator: ANY CHANGES MADE AT SYSOP LEVEL

Set #	Drop #	Load kPa	Deflections Df1	Df2	Df3	Df4	Df5	Df6	Df7	Df8	Df9
1	1	990	478.0	478.3	476.8	477.9	478.1	478.3	477.5	478.1	477.1
1	2	993	477.8	478.5	477.0	478.2	478.2	478.3	477.5	477.8	476.7
1	3	995	476.6	477.2	476.2	477.1	476.7	477.2	477.3	477.1	475.8
1	4	998	478.6	479.2	478.7	479.9	479.3	479.7	479.6	479.4	477.6
1	5	1,005	477.4	478.1	477.4	478.3	477.8	478.2	478.2	478.2	476.4
2	1	988	479.4	482.0	480.8	482.4	481.6	482.2	481.5	481.4	480.6
2	2	990	476.5	477.8	476.1	476.8	477.0	477.7	477.4	477.0	476.2
2	3	999	478.9	481.0	479.7	481.1	480.8	481.2	480.6	480.3	479.6
2	4	992	477.6	479.1	477.6	478.5	478.7	478.9	478.6	478.4	477.9
2	5	989	476.0	477.0	476.1	476.9	476.5	477.5	477.4	477.4	476.2
3	1	997	482.7	481.3	481.8	483.0	483.1	483.4	482.6	482.7	481.8
3	2	990	481.7	480.4	481.0	482.0	482.0	482.1	482.1	481.9	480.8
3	3	997	479.1	478.3	478.2	478.9	479.2	479.8	479.3	479.2	478.0
3	4	982	475.8	476.0	474.6	474.9	475.1	475.7	475.9	476.2	475.2
3	5	986	477.7	477.3	476.8	477.6	477.8	478.2	477.9	477.7	476.7
4	1	989	478.5	479.6	477.7	477.6	477.2	478.4	478.4	478.2	478.0
4	2	996	481.6	481.9	479.6	481.7	481.4	482.2	482.8	481.6	481.1
4	3	994	482.2	482.4	479.8	482.3	482.1	483.1	483.6	482.4	482.0
4	4	1,002	481.7	482.0	479.6	481.7	481.5	482.5	483.0	481.9	481.3
4	5	994	482.9	483.1	480.3	483.2	482.9	484.1	484.1	483.1	482.4
5	1	998	480.9	481.6	480.2	479.7	481.0	482.0	481.9	481.5	480.5
5	2	997	480.7	481.0	479.5	479.0	480.7	481.8	481.3	481.0	479.9
5	3	991	479.6	480.0	478.6	478.4	479.6	480.5	479.7	479.9	479.2
5	4	992	479.5	480.0	478.5	478.2	479.4	480.2	479.6	479.6	478.9
5	5	998	478.8	479.2	477.9	477.8	478.6	479.6	479.1	479.1	478.2
6	1	999	477.9	478.2	477.1	477.8	477.2	478.1	477.6	477.8	477.1
6	2	994	477.1	477.1	476.2	477.0	476.3	477.3	476.9	477.0	476.4
6	3	996	476.9	477.0	476.0	476.9	476.0	477.5	476.9	477.0	476.5
6	4	998	477.1	477.4	476.3	477.2	476.6	477.5	477.0	477.1	476.6
6	5	996	477.8	478.2	477.4	478.2	477.0	477.8	478.5	477.8	477.1
7	1	993	480.2	481.0	479.4	480.5	480.0	479.3	480.4	480.5	479.9
7	2	996	479.3	479.7	478.6	479.5	479.2	478.9	479.4	479.4	478.9
7	3	992	477.9	478.6	477.2	478.1	477.9	477.5	478.0	478.1	477.3
7	4	994	476.3	476.9	475.6	476.6	476.3	476.1	476.4	476.5	475.9
7	5	991	475.4	476.0	474.9	475.6	475.4	475.4	475.5	475.4	474.8
8	1	991	479.5	479.5	478.4	479.1	479.4	479.0	478.0	479.0	478.6
8	2	990	478.5	478.9	477.8	478.6	478.8	478.5	477.7	478.5	478.0
8	3	991	476.5	476.8	475.7	476.5	476.7	476.5	476.0	476.4	475.4
8	4	996	478.1	478.4	477.7	478.4	478.6	478.4	478.0	478.1	477.2
8	5	987	475.3	476.1	475.2	476.0	476.1	475.9	475.9	475.3	474.4
9	1	991	481.4	481.7	480.2	480.8	480.7	480.9	480.6	479.1	479.9
9	2	997	480.8	480.9	479.7	480.3	480.2	480.1	480.0	478.6	479.1
9	3	994	480.0	480.5	479.2	479.7	479.5	479.3	479.5	478.0	478.3
9	4	997	478.5	478.6	477.4	478.1	478.2	477.9	477.8	476.8	476.9
9	5	987	476.7	476.8	475.8	476.9	477.0	477.0	476.9	476.0	475.7

Figure 5. Example print of output file of input file listing.

Relative Calibration - Summary Statistics

FWD SN: 8002-131 Calibration Date: 09-26-2000
Data File Name: 31093000.F25 Data Set 1 of 1
Operator: ANY CHANGES MADE AT SYSOP LEVEL

	Load	Df1	Df2	Df3	Df4	Df5	Df6	Df7	Df8	Df9	Df1-9
Set 1 Av	996	477.7	478.3	477.2	478.3	478.0	478.3	478.0	478.1	476.7	477.9
Set 2 Av	992	477.7	479.4	478.1	479.1	478.9	479.5	479.1	478.9	478.1	478.8
Set 3 Av	990	479.4	478.7	478.5	479.3	479.4	479.8	479.6	479.5	478.5	479.2
Set 4 Av	995	481.4	481.8	479.4	481.3	481.0	482.1	482.4	481.4	481.0	481.3
Set 5 Av	995	479.9	480.4	478.9	478.6	479.9	480.8	480.3	480.2	479.3	479.8
Set 6 Av	997	477.4	477.6	476.6	477.4	476.6	477.6	477.4	477.3	476.7	477.2
Set 7 Av	993	477.8	478.4	477.1	478.1	477.8	477.4	477.9	478.0	477.4	477.8
Set 8 Av	991	477.6	477.9	477.0	477.7	477.9	477.7	477.1	477.5	476.7	477.5
Set 9 Av	993	479.5	479.7	478.5	479.2	479.1	479.0	479.0	477.7	478.0	478.8

Overall Statistics

	Load	Df1	Df2	Df3	Df4	Df5	Df6	Df7	Df8	Df9	Df1-9
Average	994	478.7	479.1	477.9	478.8	478.7	479.1	479.0	478.7	478.0	478.7
Std Dev	4	2.0	1.9	1.8	2.0	2.1	2.2	2.2	2.0	2.1	2.1
COV, %	0.45	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.4	0.4	0.4

Position in Stand

	1	2	3	4	5	6	7	8	9
Avg Df	478.6	478.8	478.9	479.0	478.9	478.8	478.8	478.7	477.8
Std Dev	2.0	2.2	2.4	2.3	2.0	1.9	2.0	1.9	1.5
COV, %	0.4	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.3

Figure 6. Example print of output file of summary statistics.

Gains Table

The gains table contains the following information:

- Existing gain settings read from the input file data block.
- Computed means ratio for each sensor.
- New relative gain factor based on test results.
- Whether means ratio for a sensor is out side the range of 1.000 ± 0.003.
- Whether new relative gain factor is outside the 2% range of 0.980 - 1.020.

The following messages are printed:

- If one of the means ratios is outside of the tolerance limit:

  * Warning: At least one sensor is outside of the tolerance limit.
    Verify these results with an additional test!
  * RESULTS INDICATE THAT THE SENSOR GAINS SHOULD BE RESET.

- If one of the means ratios is outside the tolerance range then the following message is shown on a separate screen displayed after the ANOVA output screen and is printed on the gains table in the output file:

  SHRP FWD Relative Calibration - Analysis of Variance - Gain adjustments

  Results of this test indicate the possible need to adjust the gains.
  This should be confirmed with a repeat test.

  Gain adjustment should be performed when the New Gain Factors for two independent calibrations are within + /- 0.002 of each other.

  Gain adjustments should be made to all geophones.

  After adjusting any gain setting, the relative calibration test must be repeated to confirm that all sensors are within tolerance.

- If one of the New Relative Gain factors are outside the 2% range:

  * Warning: At least one sensor is outside the 2% range limit.
    Notify Supervising Engineer after verifying with additional tests!

- If the replace sensor analysis is selected, and if the means ratio is outside the tolerance range, then for the replaced sensor:

  * Means Ratio for Sensor No. #### is outside the tolerance range.

* New Relative Gain for REPLACED Sensor No. #### is ?.???

Where the serial number is indicated as #### and the new gain factor ?.??? in the example message above)

- If the replace sensor analysis is selected, and if the means ratio is inside the tolerance range, then for the replaced sensor (indicated as #### in the example message below):

  * Means Ratio for Sensor No. #### is within the tolerance range.
  * New Relative Gain for Sensor No. #### is ?.???

An example gains table output for a Dyna25 file is displayed in Figure 3. Figure D3 in Appendix D contains an example gains table output for a Version 10/20 file.

In these messages, the user, who is assumed to be the FWD operator, is advised to contact the supervising RCOC contact prior to making any gain changes. This serves to notify the responsible supervisor that the results of the tests indicate that the gains need to be adjusted and to provide a check on the determination of the new gain factors to be input into the FWD operating computer program. The gains table is the primary determinant of the need to change gains. Because it is possible to obtain abnormal results from a single test, if a gain change is indicated, it is prudent to verify the results with another test. The relative gain factors from the two tests should be in close agreement. If inconsistent results are obtained, additional tests should be performed after sources for the inconsistencies are investigated. Significant or frequent changes in the gain factors may indicate the need for a reference calibration or the presence of abnormalities in the FWD electronics.

ANOVA Table

For each source of variation, the ANOVA table displays the following information:

- Sum of squares
- Degrees of freedom
- Mean Square
- Computed *F*
- Critical *F*

The messages printed on the ANOVA table are conditional on the results of the tolerance checks in the gains table and the significance of the variation sources determined in the ANOVA. For each combination of results a separate message is printed as specified in Table 1 for situations when all of the means ratios are within tolerance, and Table 2 when a means ratio is outside the tolerance range. In these tables, a Y indicates the effect was significant.

The message shown in Table 1 instructs the user to contact the supervising engineer if the situation occurs where the means ratios are within the tolerance limits for all sensors and

sensor, set, and position are all significant. This unlikely situation can occur when the mean square error term has a very small value, less than 1.0×10^{-3}. The data set should be reviewed for potential anomalies. It can be expected that in this situation the coefficient of variation for all deflections will be less than 0.5%. If very good repeatability (low coefficient of variation) is found between sensors and all measurements, then the calibration should be accepted as valid and the gain factors should not be changed.

An example ANOVA Table output produced by the program for a Dyna25 file is shown in Figure 4. Figure D4 in Appendix D contains an example ANOVA Table output for a Version 10/20 file.

Deflection Input Data

An echo listing of the deflection and load data read as input is provided to assure the user that the information was correctly read. This information is included only in the output file and is not accessible while running the **FWDCAL** program. An example listing of the deflection input data for a Dyna25 file is shown in Figure 5. An example of the deflection input data for a Version 10/20 file is included in Appendix D, Figure D5.

Summary Statistics

The summary statistics output contains average deflections for each sensor in each five drop set. It also contains averages, standard deviations, and coefficient of variations for each sensor over all drops, and each position over all drops. This information is only included in the output file and is not accessible while running the program. An example of the summary statistics output is shown in Figure 6. Figure D6 in Appendix D contains an example of a Version 10/20 summary statistics output file.

Table 1. Messages when gain ratios are within the tolerance range.

Set	Sen	Pos	Message
Y	N	N	No gain adjustments are indicated, but drop set is statistically significant at the 5% level. This can be due to warming of the buffers or consolidation of pavement materials during the test. Review the data carefully. If anything appears suspect, repeat the calibration after conditioning the FWD buffers with 50 drops from height 3. If the deflections from the last 10 drops vary by more than 1 mil (25.4 microns), repeat the calibration at a new location.
Y	Y	N	Sensor and drop set are statistically significant at the 5% level, but gain adjustments are not indicated. Review the data carefully. If anything appears suspect, repeat the calibration after conditioning the FWD buffers with 50 drops from height 3. If the deflections from the last 10 drops vary by more than 1 mil (25.4 microns), repeat the calibration at a new location.
Y	N	Y	Set and stand position are statistically significant at the 5% level, but gain adjustments are not indicated. Examine the data carefully. If anything appears suspect, repeat the calibration after conditioning the FWD buffers with 50 drops from height 3. When doing the calibration, extra care should be taken to properly seat the geophones and hold the stand vertically with moderate downward pressure. If deflections for the last 10 drops vary by more than 1 mil (25.4 microns) repeat the calibration at a new location.
Y	Y	Y	Set, sensor, and stand position are statistically significant at the 5% level. Although gain changes are not indicated, these results are suspect. A repeat calibration is required after conditioning with 50 drops at height 3. Extra care should be taken to properly seat the geophones and hold the stand vertically with moderate downward pressure. If deflections for the last 10 drops vary by more than 1 mil (25.4 microns) repeat the calibration at a new location. If this message appears in subsequent tests, contact your supervising engineer for further instructions.
N	N	N	Results indicate that no gain adjustments are needed.
N	Y	N	Sensor is statistically significant at the 5% level, but gain adjustments are not indicated. Test results should be carefully reviewed. If anything appears suspect, repeat the calibration. Otherwise, these results are acceptable.

Table 1. Messages when gain ratios are within the tolerance range (Contd.).

Set	Sen	Pos	Message
N	N	Y	Gains do not needed to be adjusted, but stand position is statistically significant at the 5% level. This may be caused by failure to keep the stand vertical, or improper seating of the geophones. In the future, care should be taken to ensure that the geophone bases are clean and well seated, and the stand is kept vertical with moderate downward pressure.
N	Y	Y	Sensor and stand position are statistically significant at the 5% level, but gain adjustments are not indicated. Review calibration results carefully. If anything appears suspect, repeat the calibration, taking care to ensure that geophone bases are clean and properly seated, and the stand is kept vertical with moderate downward pressure.

Table 2. Messages when a gain ratio is outside of the tolerance range.

Set	Sen	Pos	Message
Y	N	N	Gain adjustments are indicated and drop set is statistically significant at the 5% level. ' Set' significance may be due to warming of the buffers or consolidation of pavement materials during the test. A repeat calibration, after conditioning the FWD buffers with 50 drops from height 3, is required to confirm the need for gain adjustments. If the deflections from the last 10 drops vary by more than 1 mil (25.4 microns), repeat the calibration at a new location.
Y	Y	N	Gain adjustments are indicated. Sensor and drop set are statistically significant at the 5% level. A repeat calibration, after conditioning the FWD buffers with 50 drops at height 3, is required to confirm the need for gain adjustments. If deflections for the last 10 drops vary by more than 1 mil (25.4 microns) repeat the calibration at a new location.
Y	N	Y	Gain adjustments are indicated. Set and stand position are statistically significant at the 5% level. A repeat calibration, after conditioning the FWD buffers with 50 drops at height 3, is required to confirm the need for gain adjustments. When doing the calibration, extra care should be taken to seat the geophones properly, and hold the stand vertically, with a moderate level of downward pressure. If deflections for the last 10 drops vary by more than 1 mil (25.4 microns) repeat the calibration at a new location.
Y	Y	Y	Gain adjustments are indicated. Set, sensor, and stand position are statistically significant at the 5% level. A repeat calibration is required after conditioning the FWD buffers with 50 drops at height 3 for adjustments. When doing the calibration, extra care should be taken to properly seat the geophones, and hold the stand vertically, with a moderate level of downward pressure. If deflections for the last 10 drops vary by more than 1 mil (25.4 microns) repeat the calibration at a new location.
N	N	N	Gain adjustments are indicated. A repeat calibration is required to confirm the need for adjustments.
N	Y	N	The gain ratios and the statistical results indicate that gain adjustments are needed. A repeat calibration is required to confirm the need for gain adjustments.

Table 2. Messages when a gain ratio is outside of the tolerance range (Contd.).

Set	Sen	Pos	Message
N	N	Y	Gain adjustments are indicated. Stand position is statistically significant at the 5% level. A repeat calibration is required to confirm the need for gain adjustments. Care should be taken to ensure that the geophone bases are clean, firmly seated, and that the stand is held vertically with moderate downward pressure.
N	Y	Y	Gain adjustments are indicated. Sensor and Stand position are statistically significant at the 5% level. A repeat calibration is required to confirm the need for gain adjustments. Care should be taken to ensure that the geophone bases are clean, firmly seated, and that the stand is held vertically with moderate downward pressure.

IV. PROGRAM OPERATION

FWDCAL 3.0 is an interactive program that queries the user for the required information. The user program control interface consists of the following screens:

Control Screen 1 - Select Analysis Type
Control Screen 2 - FWD Data File Selection
Control Screen 3 - Select Geophone Replaced
Control Screen 4 - Display Results on Screen

The following four output screens display the results of the analysis and user messages:

Output Screen 1 - Gains Table
Output Screen 2 - ANOVA Table
Output Screen 3 - Gain Change Instructions
Output Screen 4 - Average New Gain Factors

These screens plus instructions on program installation and starting are discussed in the following sections.

Program Installation and Starting

The program is self contained in the file **FWDCAL.EXE**, which is not copy protected. The basic hardware requirement is an IBM®Personal Computer or IBM®-Compatible computer with at least 384 kilobytes (K) of available memory and minimum of 360K disk-drive capacity. A hard disk and 640K of memory are recommended. ***The program must be run under the DOS environment.***

Two copies of the program should be made on two other disks to serve as a working and intermediate backup. The program distribution disk should be stored with other computer software backups. For a computer with a hard disk, the installation process consists of copying the program onto the desired directory or subdirectory. This can be done by using the change directory command to make the destination directory the current directory. Then issuing the DOS command:

COPY < drive> :FWDCAL.EXE /V

where < drive> corresponds to the floppy disk drive containing the disk with the **FWDCAL.EXE** program file. The /V switch verifies that the program was properly copied.

The program can be started by typing:

< Drive> :< Path> **FWDCAL**

where,

< Drive> : - Specifies the name of the hard disk drive or floppy disk drive containing the **FWDCAL.EXE** program file.

< Path> - Specifies the route the computer is to follow through the directory structure to locate the directory which contains the **FWDCAL.EXE** program file.

If the current directory contains the **FWDCAL.EXE** file, or if the directory containing the program is included in the PATH statement in the AUTOEXEC.BAT file, the program can be started by typing **FWDCAL** at the command prompt.

Since the directory that the program is started from becomes the default directory in the FWD Data File Selection screen, Control Screen 2, it is convenient to start the program from the directory and or disk drive containing the FWD data file.

Control Screen 1 - Select Analysis Type

Control screen 1 is used to select the analysis type the program will run, and can be used to exit the program after completing an analysis. This screen is shown in Figure 7. To select the desired analysis press the up and down arrow keys to highlight the desired choice and then press the < Enter> key. The < Home> and < End> keys can be used to jump to the first or last choice on the menu, respectively. The analysis types are:

Standard Analysis - The standard analysis is for use in interpreting the results of routine relative calibration tests not conducted in conjunction with the reference calibration test.

Replace a Geophone - This analysis is used when one of the geophones is replaced or in the instance that the user wishes to exclude the effect of a specified geophone from the computation of the overall mean deflection response. In this analysis the response of the replacement geophone is not included in the computation of the overall average mean response of all geophones.

Reference-Relative Calibration - This analysis is designed to be used for the relative calibration performed in conjunction with the SHRP **Reference** calibration procedure. This analysis option computes and displays the new relative gain factor for a series of three tests and the average gain factor from the tests. All three data blocks for the tests **must** be contained in the same file.

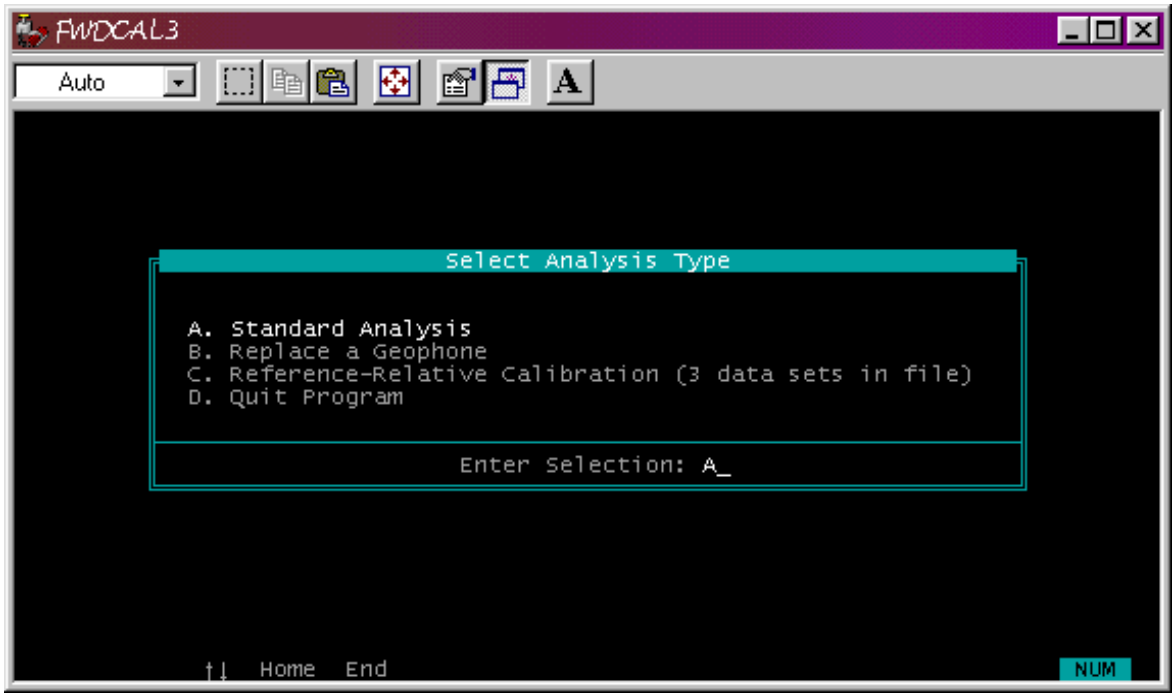


Figure 7. Select analysis control screen.

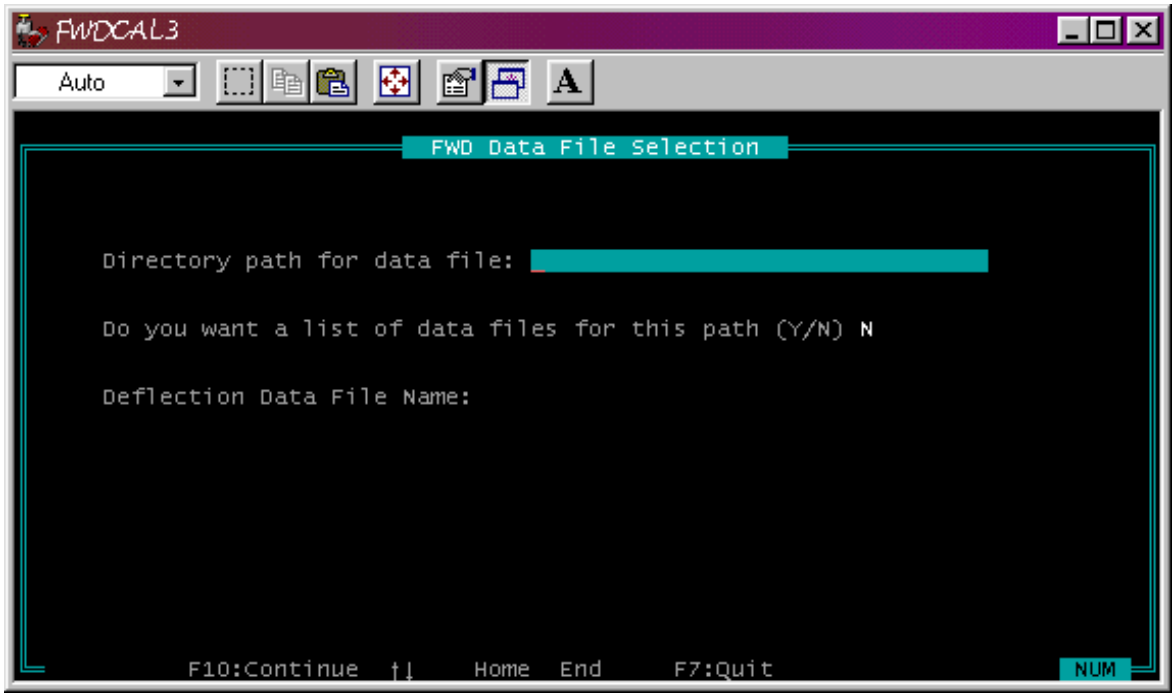


Figure 8. File selection control screen.

The standard analysis and replace geophone analysis can be run on data files containing 1, 2, or 3 data blocks in the same file. After the analysis type is selected, the program reads the data file. If multiple relative calibration data blocks are found, the program displays a message indicating how many data blocks were found. For data files containing multiple data blocks, the program simply cycles through the program and analyzes each data block separately. For these cases, the results are written to the same output file.

Control Screen 2 - FWD Data File Selection

The FWD File Selection screen is used to select the file to be analyzed. This can be done by entering all of the information in the entry fields 1 and 2, or using field 2 to obtain a listing of the files in the directory indicated in field 1. This screen is shown in Figure 8.

Field 1: Directory path for data file - the path to the desired FWD data files may be entered in this field by typing the full drive and path name (assumes default drive if no drive is specified) or by pressing < Enter> for the current directory. Nothing will be displayed in this field if the default current directory is used. The path does not require a backslash as the last character. If an error is detected when attempting to change to an invalid or nonexistent directory, an error message will appear on the screen.

Field 2: Show a list of files - a yes/no question that allows the user to select the file to be analyzed from the list of data files in the specified directory. If the response is (Y)es, then the user is placed in the directory list window and arrow keys are used to highlight a file in the list that can be selected by pressing < Enter> (< Return> on some keyboards). < PgUp> and < PgDn> can also be used to move backwards or forwards one page at a time, where such a quantity of files exists. < Esc> allows the user to exit the file list without selecting a file.

Field 3: Data file name - If a file was selected from the list of files in the directory specified in field 1, its name will appear in this field. If the field is blank, enter the file name. If the file does not exist, an error message will appear on the screen.

Once the data file has been specified, use the < F10> key to continue program operation. The up and down arrow keys can be used to change between the entry fields. The < Home> key can be used to jump to the first entry field and the < End> key to the last field. The < F7> key can be used to return to the main menu

Control Screen 3 - Select Geophone Replaced

This screen is displayed only if the replace geophone analysis is selected. This screen displays the list of geophone serial numbers read from the header block in the data file. The up and down arrow keys are used to highlight the replaced geophone. The selection is made by pressing the < Enter> key. The user is also given the option of either exiting the selection

menu or indicating that no geophone was replaced. The < Home> and < End> keys can be used to jump to the first or last entry in the menu, respectively. An example of this screen for a Dyna25 input file is shown in Figure 9. Figure D7 in Appendix D contains an example of the screen for a Version 10/20 file. The only major difference between these two screens is the number of geophone selections available: 7 for Version 10/20 and 9 for Dyna25.

Control Screen 4 - Display Results on Screen

Field 1: Output file name - the name of the output file is shown . The output file name consists of the original file name with the extension ".Cαρ", where:

α = indicates type of analysis:
S for standard analysis,
G for replace geophone analysis, and
R - for Reference-relative calibration

ρ = last character in data file name extension; for example it would be the (1) in the file name 59092289.RC**1**.

Field 2: If a Y is entered, the Output Screens 1 and 2 are displayed to show the Gains Table and the ANOVA Table on the screen.

The program writes the output files to the same directory as the FWD data files indicated in Control Screen 1. The output file naming convention was created so that the output files from multiple relative calibration tests performed on the same day would not over write each other. Using the SHRP relative calibration file naming convention, the input file should always contain a unique character in the right most digit of the file name extension. An example of this control screen is shown in Figure 10. The screen is the same whether a Version 10/20 or Dyna25 file is used.

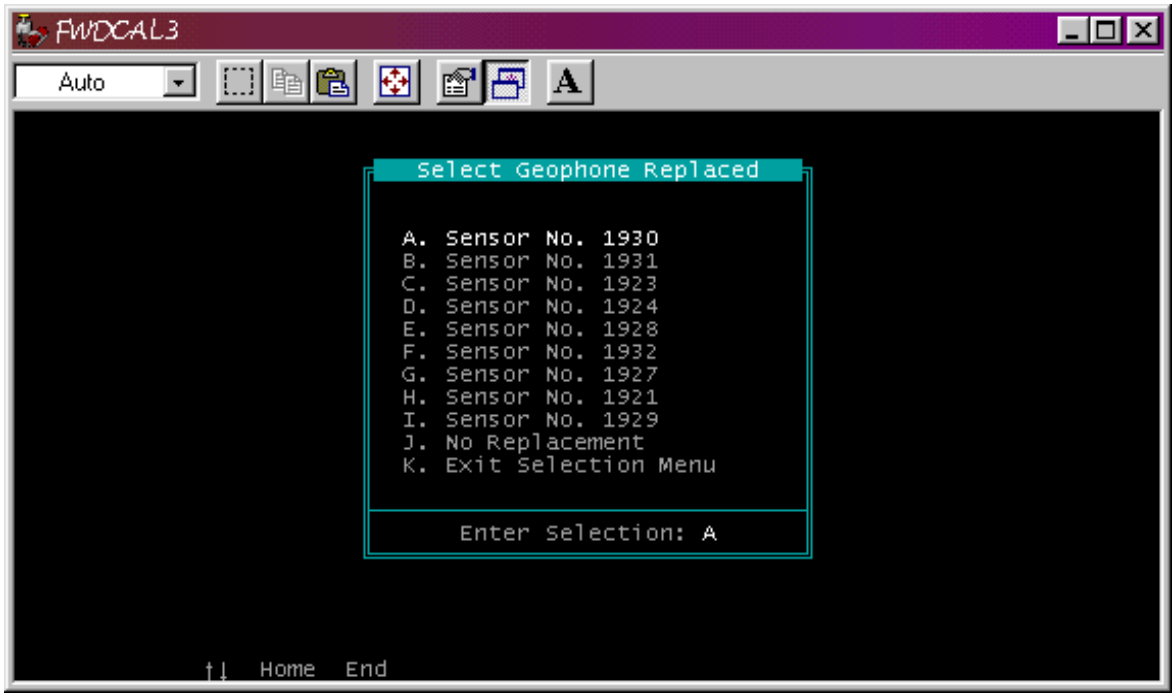


Figure 9. Select replaced geophone control screen.

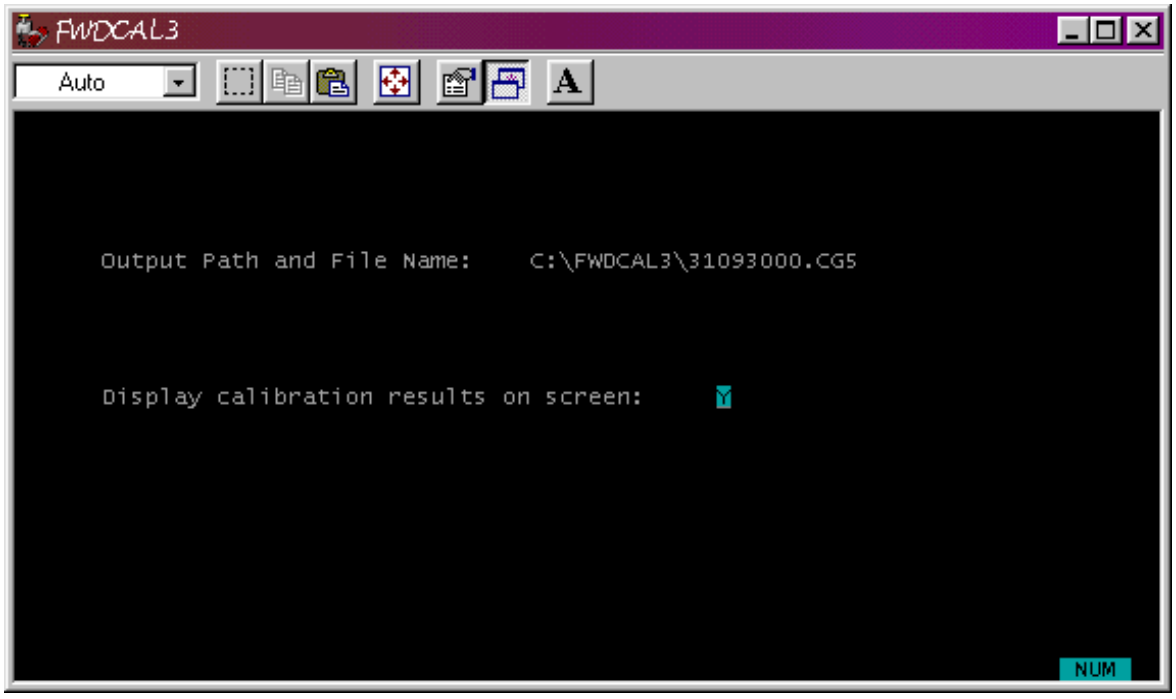


Figure 10. Display results control screen.

Output Screen 1 - Gains Table

If a (Y)es is selected to display the results on the screen in field 2 on Display Results Control Screen, then the Gains Table is displayed on the screen. In this screen, the user has the option of pressiing < Page Down> or < PgDn> to display the ANOVA Table, or < Esc> to exit the output screens. An explanation of the information and summary of the user messages presented in the Gains Table is discussed in the program output section of this document.

An example of the Gains Table screen for a Dyna25 file is shown in Figure 11, and an example of the Gains Table screen for a Version 10/20 file is included in Appendix D, Figure D8. These screens only differ in the number of geophones displayed.

Output Screen 2 - ANOVA Table

The results of the ANOVA are displayed after the < PgDn> key is pressed in the Gains Table screen. In this screen the user has the option of pressing < PgUp> or < Page Up> to return to the Gains Table screen, or < Esc> to exit from the result table screens. An explanation of the information and summary of the messages presented in the ANOVA Table is discussed in the program output section of this document.

An example of the ANOVA Table screen for a Dyna25 file is shown in Figure 12, and an example of the ANVOA Table screen for a Version 10/20 file is included in Appendix D, Figure D9. The difference between the screens is only in the values displayed (used for calculation) – the format is identical.

Output Screen 3 - Gain Change Instructions

This screen is always displayed if one of the means ratio for a sensor is outside of the tolerance limit. The user is not given a choice of displaying this screen. To exit this screen, the user must hit any key. The contents of this screen are shown in Figure 13. This screen does not change regardless of the file format used.

Output Screen 4 - Average New Gain Factors

This screen is only displayed for the results of a relative-reference type of analysis. This screen shows the computed new relative gain factors for each of the three repeat relative calibration tests, and the average of the tests. An example for a Dyna25 file is shown in Figure 14. Except for the number of sensors, the screen is the same for a Verison 10/20 file.

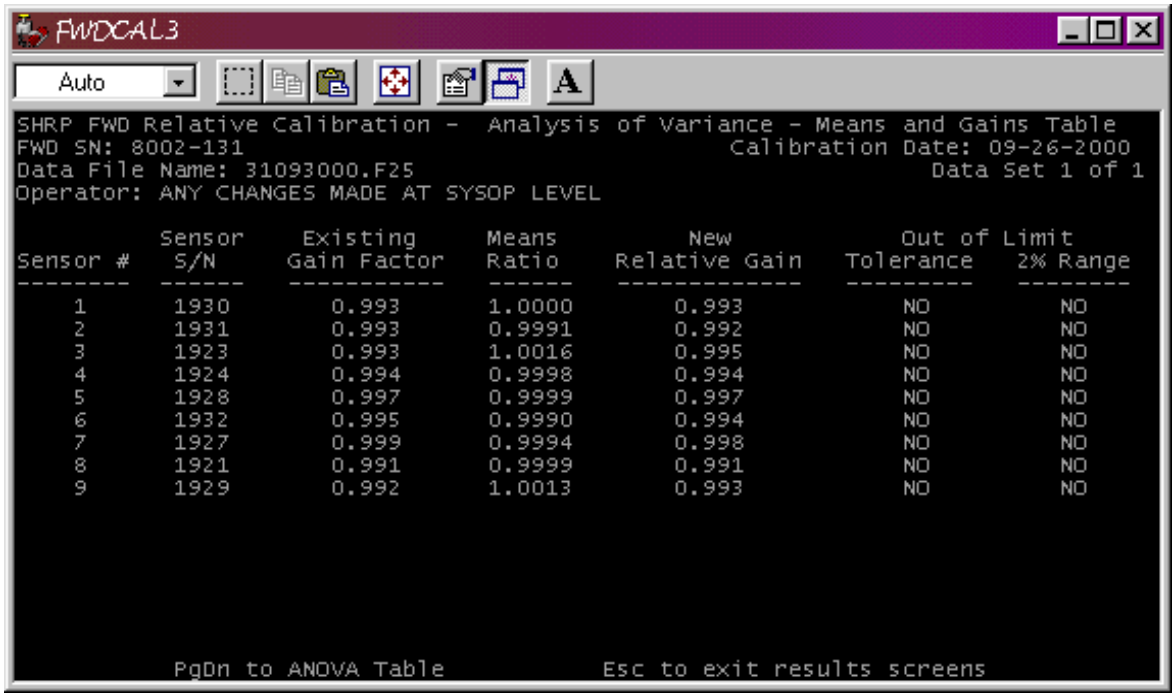


Figure 11. Gains table output screen.

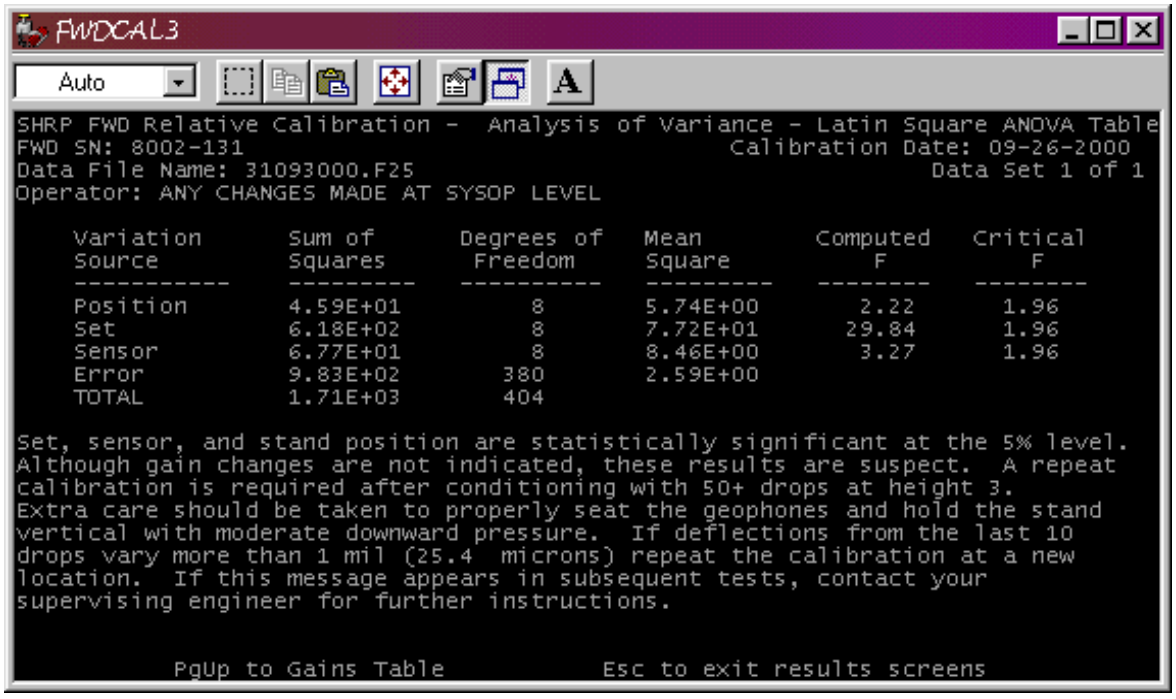


Figure 12. ANOVA table output screen.

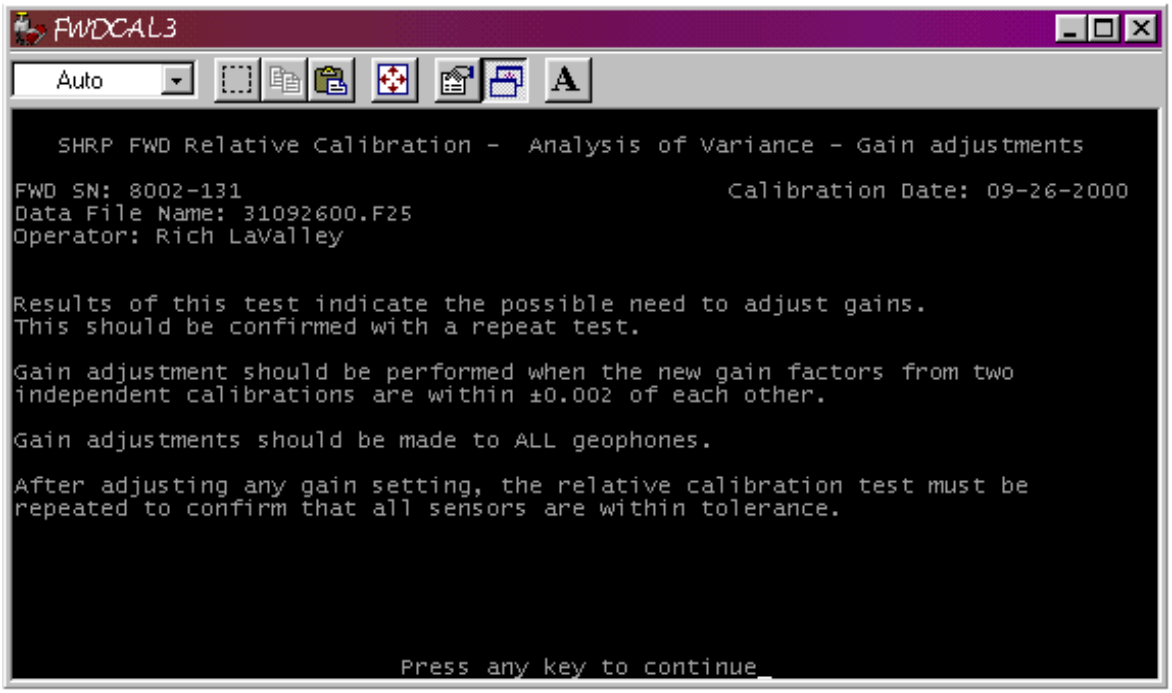
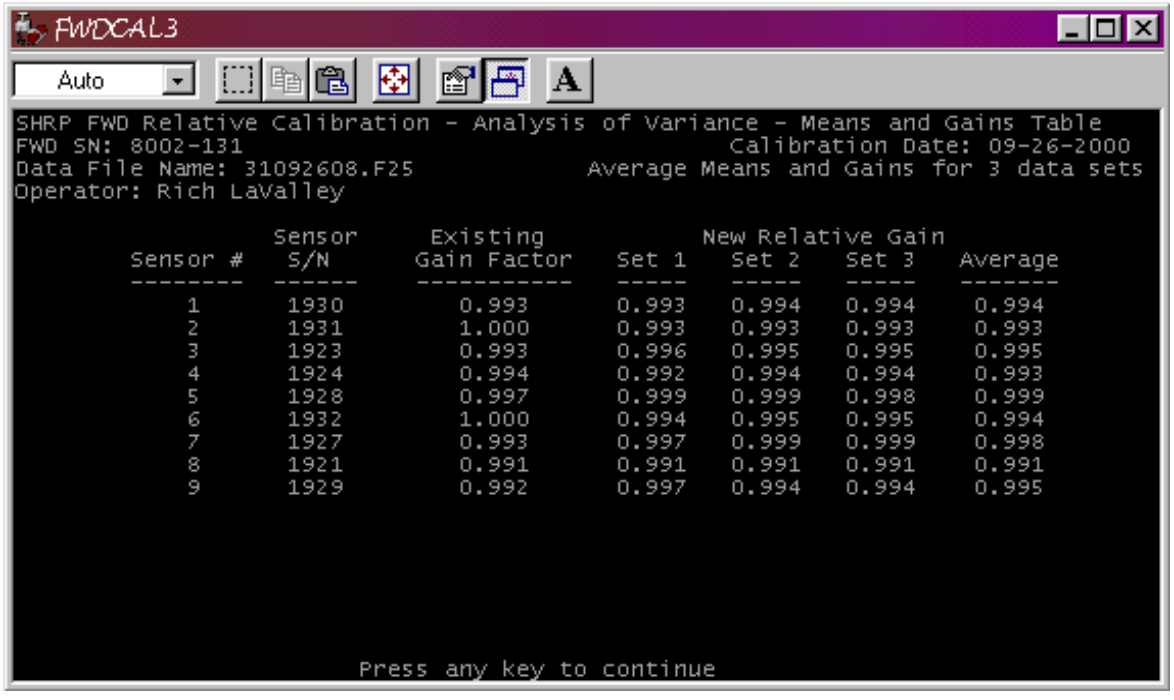


Figure 13. Sensor gain adjustment message.



Sensor #	Sensor S/N	Existing Gain Factor	New Relative Gain Set 1	Set 2	Set 3	Average
1	1930	0.993	0.993	0.994	0.994	0.994
2	1931	1.000	0.993	0.993	0.993	0.993
3	1923	0.993	0.996	0.995	0.995	0.995
4	1924	0.994	0.992	0.994	0.994	0.993
5	1928	0.997	0.999	0.999	0.998	0.999
6	1932	1.000	0.994	0.995	0.995	0.994
7	1927	0.993	0.997	0.999	0.999	0.998
8	1921	0.991	0.991	0.991	0.991	0.991
9	1929	0.992	0.997	0.994	0.994	0.995

Figure 14. Reference-relative calibration average new gain factor screen.

Function Keys

Table 3 presents a summary of the action of selected function and control keys the program uses in the various control screens. The function keys which are active are shown at the bottom of each screen.

Table 3. Function key summary.

Keys	Function
< F10>	Continue - the < F10> key is used to continue the program once all entries have been made in Control Screen 2.
< Esc>	ESCAPE - returns the user to field 2 in Control Screen 2 from the file list without selecting a file. It is also used to exit from the output screens.
< PgDn> ,< PgUp>	PAGE DOWN or PAGE UP - used in the directory window if more than 20 files are present, to move from one page of the list to the next/previous page, or in output screens to move from the Gains Table to/from the ANOVA Table.
< Up> ,< Dn>	ARROW KEYS - these keys allow the user to move from one field to another on the data entry screens, as well as to move from file to file in the directory window. When more than one page of files are available in the directory window, pressing < Down Arrow> on the last row of the window places the cursor on the first row of the next page of the list. Pressing < Up Arrow> when on the top line of a second or subsequent pages will move the cursor to the bottom line of the previous page in the list.
< Home> , < End>	HOME or END - these keys allow the user to quickly move to the first or last field within the data entry screen menu, as well as the first or last file in the current page of the directory window.
< Space Bar>	SPACE BAR - the < Space Bar> key is used to exit the various warnings or errors that appear at the bottom of the data entry screen.
< CR> ,< Enter>	CARRIAGE RETURN or ENTER - used to accept a data input value once it has been entered or selected.
< F7>	QUIT - used to return to the main menu.

V. ANOMALOUS RESULTS

Depending on the results of the calibration analysis procedure, a number of scenarios exist for the case of apparently "bad" or anomalous data. For all scenarios, the first remedial step should be to review the echo print of the input data to identify any irregular or unusual conditions. If a problem exists in the header block or data format, another possibility might be to review the contents of the input file using a text editor, correct any format inconsistencies, and then repeat the analysis.

As suggested in the user messages contained in the ANOVA table, possible sources of abnormal results from the relative calibration test include:

- Failure to keep the stand vertical with moderate downward pressure applied. This typically results in position being statistically significant.

- Systematic change in the applied load to the pavement. Typically the load will decrease during the conduct of the test. This can be due to a change in the resiliency of the buffers or a change in the pavement structure. This condition can be detected by inspection of the change in the load level between drop sets and the occurrence of set being statistically significant. Remedial actions include further "conditioning" of the buffers with additional drops, or movement to a new location.

- Failure to place the stand in the exact same point. This can result in set and/or position being statistically significant.

- Failure to properly set the geophones in the center of the holders in the stand. Cleaning the base of the geophones or greater care in setting them in the stand are two remedial approaches.

- Switching the position of the electrical connections, or "channels", of the geophones on the FWD without making the change in the FWD computer operating program. An example of this would be if sensor 7 is plugged into the channel 6 connection. In this case the operating program will not use the correct gain and analogue to digital conversion factors for the specific geophone. This is the reason why geophones can not be used on other FWDs without a modification to the operating computer software from Dynatest. The position of the geophone connections on the FWD should be compared against the positions shown in the operating computer program.

- Frayed, cracked or worn sensor wires and loose sensor connections can be a source of inconsistent results. Care should be taken not to remove a geophone from its holder by pulling on the lead wire since this can damage the connection.

VII. TECHNICAL ASSISTANCE

If further technical assistance is required in the use of this program, please contact the FHWA LTPP Team at (202) 493-3153.

VIII. REVISION NOTES

Version 3.00 - January 2001

- Processes data sets produced by Version 10, Version 20, Edition25.11 (Spring 94),and Dyna25 Aug 2000 LTPP customized versions of the Dynatest FWD operating system software.
- Resolved operational problems present in Version 3.00B3

Version 3.00β3 - May 1994

- Processes Dynatest FWD software version 10 and 20 with 7 geophones in US and SI units.
- Processes Dynatest FWD software version 25 when using file format 25CAL and either 7 or 9 geophones in US and SI units.
- Not accompanied by user guide.

Version 2.00 - April 1992

- Computes the gains factor for a replacement sensor
- Processes up to three data sets in the same file
- Computes the average new relative gain factor from relative calibration tests performed as a part of the SHRP reference calibration procedure. All three data sets must be in the same file.
- Processes data sets produced by Version 10 and Version 20 of the Dynatest FWD operating software.
- Ability to process multiple data sets in separate files without exiting the program.

Version 1.00 - January 1989

- Initial release.

APPENDIX A

LTPP FWD Relative Calibration Protocol

SHRP/LTPP FWD CALIBRATION PROTOCOL
(March 1994 extract)

RELATIVE CALIBRATION PROCEDURE

General Background

Relative calibration of the FWD deflection sensors is used to ensure that all sensors on a given FWD are in calibration with respect to each other. As such, it serves as the final step in the overall FWD calibration process, and as a quick means to periodically verify that the sensors are functioning properly and consistently.

Relative calibration uses the relative calibration stand supplied by the FWD manufacturer. The sensors are stacked vertically in the stand, one above another, so that all sensors are subjected to the same pavement deflection. Relative calibration assumes that the overall mean deflection, as determined from simultaneous measurements by the full set of deflection sensors, yields an accurate estimate of the true deflection. This assumption requires that the deflection sensors must have first been subjected to the reference calibration procedure.

Some FWDs have fewer than or more than seven active deflection sensors. If they do, these procedures should be modified to calibrate the actual number of active sensors in use on the FWD.

Equipment

FWD relative calibration stand with as many positions as the number of active deflection sensors. For the purpose of illustration a seven-position stand is assumed herein.

FWD relative calibration software (**FWDCAL**) and documentation.

General Procedure

The process involves rotation of each deflection sensor through every position in the calibration stand. Each combination of sensors and levels is considered a "set," and the number of sets of data will be equal to the number of sensors. The test point is "conditioned" before beginning the calibration procedure to reduce the possibility that set will be significant in the data analysis. The required order of movement of the sensors is shown in Table 2. In order for the data processing with **FWDCAL** to be done correctly it is very important that the sensor rotation from set to set be done correctly. Spare deflection sensors do not have to be calibrated until they are in active use.

Table 2 - Relative Calibration Sensor Positions by Set

Level in Sensor Stand	Deflection Sensor Number in the Stand								
	1	2	3	4	5	6	7	8	9
(Top)									
A	1	2	3	4	5	6	7	8	9
B	2	3	4	5	6	7	8	9	1
C	3	4	5	6	7	8	9	1	2
D	4	5	6	7	8	9	1	2	3
E	5	6	7	8	9	1	2	3	4
F	6	7	7	9	1	2	3	4	5
G	7	8	8	1	2	3	4	5	6
H	8	9	9	2	3	4	5	6	7
I	9	1	1	3	4	5	6	7	8
(Bottom)									

Note: **The rotation must be done as prescribed above in order for the software (FWDCAL3) to work properly. For instance, for Set 2, move Sensor 2 to the position formerly occupied by Sensor 1, etc.**

When done in conjunction with reference calibration, the relative calibration procedure shall be repeated twice. Acceptance criteria based upon the repeatability of the calibration factor are identified in the relative calibration procedure. If the results persist in failing the acceptance criteria, then the cause of the erratic results should be identified and corrected.

After the relative calibration is completed, the final calibration factors shall be entered into the FWD computer.

A sample relative calibration setup screen for the Dynatest FWD with Edition 10 or Edition 20 software is given in Figure 2. The information in Figure 2 can also be used as the basis for setup of Dynatest FWDs running Edition 25 and higher software.

```
   Relative Calibration
 1. Test UNITS...: lbf.mil.inch    (kPa.mu.mm)
 2. Temperature..: Fahrenheit      (Centigrade)
 3. Stn.Request..: OFF             (ON)
 4. Test Checks..: NONE            (Decreasing defls, Roll-Off, RollOFF+Decr)
 5. Reject prompt: OFF             (ON)
 6. Stationing...: [doesn't matter]
 7. Temp.Request.: OFF             (ON)
 8. Cond.Request.: OFF             (ON)
 9. Variation : Load NOT Checked !  Deflections NOT Checked !
10. Diameter of Plate: 11.8
11. Deflector distances: [doesn't matter - keep what you have]
                         1          2          3          4
12. Drop No.  : 1234567P8901234P5678901P2345678P9012345P6789012P3456789S.......
13. Heights+  : CC44444PCC44444PCC44444PCC44444PCC44444PCC44444PCC44444S1111111
14. Test Plots: ..........................................................
15. Save Peaks: ..*****...*****...*****...*****...*****...*****...*****........
16. Load His. : ..........................................................
17. Whole His.: ..........................................................

18. Load another TEST SETUP.
19. Store the CURRENT TEST SETUP.
```

Figure 2. Relative Calibration Test Setup for the Dynatest FWD

Relative Calibration of the Deflection Sensors

1. Remove all of the deflection sensors from their holders on the FWD. Make sure that the sensors are labeled (e.g., from 1 to 7, or 0 to 6) with respect to their normal position on the FWD. The center sensor is position number "1" on the Dynatest FWD and is position number "0" on the KUAB FWD.

2. Label the seven levels on the sensor stand from "A" to "G." The top level is usually labeled "A."

3. Position the seven deflection sensors in the stand for the first of the seven sets according to Table 2.

4. Support the sensor stand in a vertical position. Mark the location where the stand rests so that it can be relocated precisely on the same spot. This may be done by gluing a washer to the pavement, or by making a small divot in the pavement with a chisel.

5. Select the FWD drop height and the distance from the loading plate to the sensor stand to yield deflections on the order of 400 to 600 microns (16 to 24 mils). If deflections in this

range cannot be achieved, then it may be necessary to relocate the FWD to a different pavement. In general, a concrete pavement on a relatively weak subgrade will yield the required deflection. In most cases the reference calibration test pad should be usable for relative calibration.

6. Warm up the FWD rubber buffers and condition the test point by repeating a sequence of ten drops until the loads and deflections that are registered are nearly uniform. The deflections in a sequence of ten drops should not be showing a steadily increasing or decreasing trend. If liquefaction or compaction is indicated by the warm-up data, relocate the FWD to another pavement.

7. Lower the FWD loading plate. DO NOT raise the loading plate or move the FWD during the relative calibration testing. This will assure a constant distance between the center of the load plate and the base of the sensor stand.

8. For each set make two seating drops (no data recorded) followed by five replicate drops (for which data is recorded) while holding the stand in a vertical position. With seven sets and 5 replicate drops, data for a total of 35 drops is required (see Figure 2).

Relative Calibration Data Analysis

A three-way analysis of variance should be used to evaluate the data. This will partition the variance into four sources: (1) that due to sensor number, (2) that due to position in the calibration stand, (3) that due to set, and (4) that due to random error of measurement. This analysis is performed by the **FWDCAL** software. In this analysis, deflection is the dependent variable, and sensor number, position and set are the three main factors. The three hypotheses that may be tested are:

H_0: Sensor number is a significant source of error

H_0: Data set number is a significant source of error

H_0: Position in the stand is a significant source of error

Through the use of hypothesis testing it is possible to determine whether random error due to sensor number, due to position in the calibration stand, and due to set number are statistically significant. The only factor that should result in a change in the deflection sensor calibration factors is sensor number.

If the random error due to sensor number is found to be statistically significant, then the calculated adjustments in the calibration factors for each sensor should be made. If a change is made in the calibration factor for one sensor, then the calibration factors for all sensors should be changed in accordance with the calculations.

If position in the stand is statistically significant, it is likely that the stand was not held vertical throughout all of the sets during the test. Or a connection in the stand may have been loose. The problem should be corrected, and the test should be repeated.

If set is statistically significant, there may have been a systematic change in the properties of the pavement materials, for instance due to compaction or liquefaction. The test should be repeated after the testing site has been further "conditioned" according to the procedure. If the deflection readings do not become relatively constant during the conditioning, then another site should be selected for the testing.

The mere fact that either position or set, or both, are significant does not necessarily invalidate the relative calibration. Judgement must be used to assess whether or not these factors may be of sufficient physical significance (as opposed to statistical significance) to require that the relative calibration should be repeated or that a new test site should be selected.

The standard error of measurement (e.g., the square root of the mean square error due to error) should be on the order of 2 microns (0.08 mils) or less if the system is working properly and the calibration test was conducted carefully.

The analysis of the data obtained from the relative calibration procedure and the method used to determine revised calibration factors is as follows (calculations are done automatically within the **FWDCAL** software):

1. Compute the mean deflection measurement, x_i, for each sensor (average for the seven sets) and the overall mean, x_o, for all of the sensors averaged together.

2. Compute the adjustment ratio, R_i, of the overall mean to the sensor mean for each sensor. This is also called the "means ratio."

$$R_i = \frac{x_o}{x_i}$$

3. Compute the final calibration factor for each sensor by multiplying the adjustment ratio, R_i, times the current or interim calibration factor for the sensor.

Relative Calibration Acceptance Criteria

When relative calibration is conducted in conjunction with reference calibration, the procedure is repeated two times. If the two sets of calibration factors agree within 0.003 for each deflection sensor, then the results of the two tests shall be averaged. If they are outside the limit, then a third relative calibration shall be performed. If the standard deviation of the three results (based on n - 1 degrees of freedom) is less than 0.0030, then the three results shall be averaged. If the standard deviation exceeds 0.0030, the relative calibration procedure should be repeated.

An example of the calculations following this procedure is shown in Appendix C. The average final calibration factors should be computed, and the factor for each deflection sensor should be entered into the FWD computer software (e.g., the "FWD Field Program").

When relative calibration is done alone, typically on a monthly basis, then adjustment of the calibration factors in the FWD Field Program should be made only when those changes are both significant, and verified to be necessary. The following guidelines are to be used to evaluate the need for adjustment to the calibration factors.

1. Computed sensor adjustment ratios, R_i, between 0.997 and 1.003 inclusive are considered to be equivalent to a ratio of 1.000. In other words the required adjustments are trivial and need not be made.

2. Where the adjustment ratios for one or more sensors fall outside of the range 0.997 to 1.003, the relative calibration process should be repeated. If both sets of data agree within 0.003, the gains should be adjusted for all sensors.

3. According to the recommendations of the FWD manufacturers, a final calibration factor less than 0.98 or greater than 1.02 is possibly indicative of a damaged sensor, which should be repaired by the manufacturer, or replaced. Final calibration factors that are within this range should be entered into the FWD data collection software.

4. If any calibration factors are changed, the relative calibration process must be repeated to verify the accuracy of the final values. The resulting adjustment ratios should be within the range 0.997 to 1.003 for all sensors. If they are not, the test procedure should be repeated.

Reports

The full FWD calibration report shall consist of the following:

- Printouts of the following Dynatest FWD Field Program screens (or equivalent for non-Dynatest FWDs).
- Transducer Setup and Calibration Factors
- Voltages
- Load Cell Calibration

Each of the above printouts is to be annotated with the FWD unit identification (e.g., manufacturer's serial number or agency ID), and the calibration date.

- All printouts from the **FWDREFCL** software
- The final printouts from the **FWDCAL** software for all relative calibration trials.
- The Final Calibration Computation worksheet (see Appendix C)

Distribution of this report shall be as follows:

- Original retained by FWD operator for submission to his agency (LTPP Regional Engineer for LTPP FWDs).
- One copy transmitted to LTPP Division Office within one week of calibration.
- One copy retained on file by the Calibration Center for a period of at least three years.

The diskettes on which the reference and relative calibration data are stored should be kept in the FWD. It is recommended that labeled backup copies be kept on file with the calibration report at the office out of which the FWD is operated. For the LTPP FWDs, additional backup copies of the calibration diskettes are to be kept on file at the LTPP Regional Office.

When relative calibration is done alone (e.g., as a monthly calibration check), the relative calibration report will consist of all printouts from the **FWDCAL** software, annotated as necessary to explain any problems which might have been encountered.

APPENDIX B

FWDCAL 3.0 Program Listing

```
DECLARE SUB Cochran ()
DECLARE SUB GainAdjustMsg ()
DECLARE SUB ReplaceSensor ()
DECLARE SUB LatinPage1 ()
DECLARE SUB GainsPage1 ()
DECLARE SUB FileToScreen ()
DECLARE SUB AvgGainToFile ()
DECLARE SUB AvgGainToScreen ()
DECLARE SUB StartAnalysis ()
DECLARE SUB OutputToFile ()
DECLARE SUB LatinSqDesign ()
DECLARE SUB SelectAnalysis ()
DECLARE SUB GetSensorNum ()
DECLARE SUB AssignPosition (Index%, Posit%())
DECLARE SUB BadFile ()
DECLARE SUB Quit ()
DECLARE SUB DisplayCopyright ()
DECLARE SUB ReadPeaks ()
DECLARE SUB ReadNextLine (DataType%, LineLength%)
DECLARE SUB GetFileName (FPath$, File$, Ext$)
DECLARE SUB CheckHeader10 (InitNumPeaks%, InitNumWHBlocks%, ExitCode%)
DECLARE SUB ProcessED25 ()

'$INCLUDE: 'declare.inc'
'$INCLUDE: 'cmnblank.inc'

COMMON SHARED /cal/ LineCounter&, LineData$, English%, Edition!, FWDSN$, Year$, Month$, Day$,
NumDeflectors%
COMMON SHARED /cal/ InitNumPeaks%, Operator$, Posit%(), Analysis$, OExt$, SumTotal#, Ti#(),
SetCount%, TOL$(), RAN$()
COMMON SHARED /cal/ StdDevDef!(), StdDevPos!(), MeanBySet!(), MeanLoad!(), MeanSet#(),
MeanPos#(), MeanDef#(), NumDrops%
COMMON SHARED /cal/ MeanAllLoad!, StdDevAllLoad!, CVAllLoad!, CVPos!(), CVDef!(), MeanAllDef#,
StdDevAllDef!, CVAllDef!
COMMON SHARED /cal/ SSLT#, SSLPos#, SSLSet#, SSLSens#, SSLE#, FLPos#, FLSet#, FLSens#
COMMON SHARED /cal/ DegFreeLPos%, DegFreeLSet%, DegFreeLSens%, DegFreeLE%, DegFreeLT%
COMMON SHARED /cal/ MSLPos#, MSLSet#, MSLSens#, MSLE#, SerialNum%(), RelGain#(), MeansRat#(),
NewGain#()
COMMON SHARED /cal/ DefData!(), LoadData!(), OutDef!(), AvgNewGain#()
COMMON SHARED /cal/ repm1$, repm2$, RepSens%, BigDef!, G!, ProblemExist%, SC%
COMMON SHARED /cal/ Jnum1%, Jnum2%, LSAM$, Deflections!(), MeasLoad!()
COMMON SHARED /cal/ NumSensors%, NumPositions%, NumSetups%, NumReps%, MDY$
COMMON SHARED /cal/ CritFLPos!, CritFLSet!, CritFLSens!, Galph!, Action$

CONST True% = -1, False = 0  'Galph! = .4307  Removed by HZ 12/14/2000 per TT
CONST MaxSensors% = 9, MaxPositions% = 9, MaxSetups% = 9, MaxReps% = 5, MaxSets% = 3

DIM Deflections!(MaxSensors%, MaxSets%, MaxReps% * MaxSetups%)
DIM DefData!(MaxSensors%, MaxPositions%, MaxSetups%, MaxReps%)
DIM LoadData!(MaxSensors% * MaxReps%), MeasLoad!(MaxSets%, MaxReps% * MaxSetups%)
DIM OutDef!(MaxSensors% * MaxReps%, MaxSensors%)
DIM Posit%(MaxSensors%), SerialNum%(MaxSensors% * 2)
DIM Ti#(MaxSensors%), Tj#(MaxPositions%), Tk#(MaxSetups%)
DIM Tij#(MaxSensors%, MaxPositions%), Tik#(MaxSensors%, MaxSetups%), Tjk#(MaxPositions%,
MaxSetups%)
DIM Tijk#(MaxSensors%, MaxPositions%, MaxSetups%), TotalLoad(MaxSetups%)
DIM SSumTi#(MaxSensors%), SSumTj#(MaxPositions%), SSumTk#(MaxSetups%)
DIM MeanDef#(MaxSensors%), MeanPos#(MaxSensors%), MeanSet#(MaxSensors%)
DIM MeanBySet!(MaxSensors%, MaxSetups%), MeanLoad!(MaxSetups%)
DIM StdDevDef!(MaxSensors%), StdDevPos!(MaxSensors%)
DIM CVDef!(MaxSensors%), CVPos!(MaxSensors%)
DIM MeansRat#(MaxSensors%, MaxSensors%), NewGain#(MaxSensors%, MaxSensors%)
DIM RelGain#(MaxSensors%), AvgNewGain#(MaxSensors%)
DIM TOL$(MaxSensors%), RAN$(MaxSensors%)

'The determination of significance is based on a hard coded F-Statistic
'for a given set of degrees of freedom and confidence level.
'To modify the determination of significance, the user must change the value
'for  CritFLPos!, CritFLset!, and CritFLSens!  in _3_ places in this code.

NumSensors% = 7
NumPositions% = 7
NumSetups% = 7
NumReps% = 5
CritFLPos! = 2.14       '7 sensor, 5 %
CritFLSet! = 2.14
CritFLSens! = 2.14
```

```
Galph! = .2326      'Added by HZ on 12/14/2000 per TT

GP.Monitor% = Monitor%
CALL DisplayCopyright
FPath$ = ""
NumHeaderLines% = 37      'for Ed10, 20   will be changed elsewhere for Ed25

DO
   SCREEN 0: WIDTH 80, 25: CLS
   RepSens% = 0
   NumStations% = 0
   SetCount% = 0
   Action$ = "Yes"
   FirstLine$ = "": FirstThreeChr$ = ""

   CALL SelectAnalysis
   CALL GetFileName(FPath$, File$, Ext$)

   IF Action$ = "Yes" THEN                                          'Added by HZ 1/4/2001
    Source$ = FPath$ + File$ + Ext$
    NumLines% = LineCount%(Source$, SPACE$(4096))                  'Added by HZ on 1/4/01
    IF NumLines% > 0 THEN                                        'Added by HZ on 1/4/01
     OPEN Source$ FOR INPUT AS #1                              'Added by HZ on 1/4/01
                    LINE INPUT #1, FirstLine$                   'Added by HZ on 1/4/01
     CLOSE #1                                                  'Added by HZ on 1/4/01
    END IF                                                       'Added by HZ on 1/4/01
    FirstThreeChr$ = LEFT$(FirstLine$, 3)                        'Added by HZ on 1/4/01
    IF FirstThreeChr$ = "R80" OR FirstThreeChr$ = "500" THEN 'Added by HZ on 1/4/01
     OPEN Source$ FOR INPUT AS #1                              'Added by HZ on 1/4/01
    CLS                                                          'Added by HZ on 1/4/01
    CALL NormalColor
    LOCATE 13, 20: PRINT "Reading Input Data from: "; File$ + Ext$
    LineCounter& = 0
    DO
     IF LineCounter& < NumHeaderLines% THEN
                    CALL CheckHeader10(InitNumPeaks%, InitNumWHBlocks%, ExitCode%)
                    IF ExitCode% = 5000 THEN EXIT DO
     ELSE
                    CALL ReadNextLine(DataType%, LineLength%)
                    SELECT CASE DataType%
                             CASE 1
                                      CALL ReadPeaks          'peak deflection data block
                             CASE ELSE
                                      EXIT DO
                    END SELECT
     END IF
    LOOP
    IF ExitCode% = 5000 THEN
     ExitCode% = 0
     CALL ProcessED25
    END IF
    ExitCode% = 0

    CALL NormalColor
    IF (SetCount% > 1) AND (Analysis$ = "S") THEN
     SM1$ = "Input data file has" + STR$(SetCount%) + " data sets"
     SM2$ = "Analysis will be performed sequentially on each set"
    ELSEIF (SetCount% > 1) AND (Analysis$ = "G") THEN
     SM1$ = "Input data file has" + STR$(SetCount%) + " data sets"
     SM2$ = "Analysis will be performed sequentially on each set"
    ELSEIF (SetCount% < 3) AND (Analysis$ = "R") THEN
     SM1$ = "Not enough data sets to run Reference-Relative Calibration Analysis"
     SM2$ = "Please select correct analysis type from the menu"
     ExitCode% = 1
    END IF
    LOCATE 12, 40 - LEN(SM1$) / 2: PRINT SM1$: SM1$ = ""
    LOCATE 13, 40 - LEN(SM2$) / 2: PRINT SM2$: SM2$ = ""
    SLEEP 3

    IF ExitCode% = 0 THEN
     OExt$ = ".C" + Analysis$ + RIGHT$(Ext$, 1)
     Output$ = FPath$ + File$ + OExt$
     OPEN Output$ FOR OUTPUT AS #2
     IF Analysis$ = "G" THEN
                    CALL GetSensorNum
     END IF
     IF Action$ = "Yes" THEN                    'Added by HZ 1/4/2001
```

```
                    CALL StartAnalysis
                    IF SetCount% = 3 AND Analysis$ = "R" THEN
                            CALL AvgGainToFile
                            CALL AvgGainToScreen
                    END IF
                    IF Jnum1% > 0 AND Analysis$ <> "R" THEN
                            CALL GainAdjustMsg
                    END IF
     END IF                          'Added by HZ 1/4/2001
    END IF
    CLOSE
    ELSE                        'The following were added by HZ on 1/4/2001
     REDIM PUText$(1)
     PUText$(1) = "Selected file does not have required format... please try again!"
     CALL PopupError
    END IF

  END IF             'Added by HZ on 1/4/2001
LOOP
CALL Quit

SUB AssignPosition (Index%, Posit%()) STATIC
  Count% = 0
  FOR I% = Index% TO NumSensors%
   Posit%(I%) = I% - Index% + 1
  NEXT I%
  FOR I% = Index% - 1 TO 1 STEP -1
   Count% = Count% + 1
   Posit%(Count%) = NumSensors% - I% + 1
  NEXT I%
END SUB

SUB AvgGainToFile STATIC
  FOR I% = 1 TO NumSensors%
   AvgNewGain#(I%) = (NewGain#(1, I%) + NewGain#(2, I%) + NewGain#(3, I%)) / 3
  NEXT I%
  ' ****************************** Page 1 ******************************
  '**********************  Geophone Calibration Sensor ******************
  PRINT #2, "SHRP FWD Relative Calibration - Analysis of Variance - Means and Gains Table"
  PRINT #2, "FWD SN: "; FWDSN$; SPC(34); "Calibration Date: "; MDY$
  PRINT #2, "Data File Name: "; File$ + Ext$; SPC(12); "Average Means and Gains for 3 data sets"
  PRINT #2, "Operator: "; Operator$
  PRINT #2, ""
  PRINT #2, "                   Sensor     Existing           New Relative Gain"
  PRINT #2, "        Sensor #   S/N      Gain Factor   Set 1   Set 2   Set 3   Average"
  PRINT #2, "        --------  ------    -----------   -----   -----   -----   -------"
  t8$ = "            #      ####        #.###      #.###   #.###   #.###    #.###"
  FOR S% = 1 TO NumSensors%
   PRINT #2, USING t8$; S%; SerialNum%(S%); RelGain#(S%); NewGain#(1, S%); NewGain#(2, S%);
NewGain#(3, S%); AvgNewGain#(S%)
  NEXT S%
END SUB

SUB AvgGainToScreen STATIC
  CLS
  CALL NormalColor
  FOR I% = 1 TO NumSensors%
   AvgNewGain#(I%) = (NewGain#(1, I%) + NewGain#(2, I%) + NewGain#(3, I%)) / 3
  NEXT I%
  ' ****************************** Page 1 ******************************
  '**********************  Geophone Calibration Sensor ******************
  PRINT "SHRP FWD Relative Calibration - Analysis of Variance - Means and Gains Table"
  PRINT "FWD SN: "; FWDSN$; SPC(34); "Calibration Date: "; MDY$
  PRINT "Data File Name: "; File$ + Ext$; SPC(12); "Average Means and Gains for 3 data sets"
  PRINT "Operator: "; Operator$
  PRINT
  PRINT "                   Sensor     Existing           New Relative Gain"
  PRINT "        Sensor #   S/N      Gain Factor   Set 1   Set 2   Set 3   Average"
  PRINT "        --------  ------    -----------   -----   -----   -----   -------"
  t8$ = "            #      ####        #.###      #.###   #.###   #.###    #.###"
  FOR S% = 1 TO NumSensors%
   PRINT USING t8$; S%; SerialNum%(S%); RelGain#(S%); NewGain#(1, S%); NewGain#(2, S%);
NewGain#(3, S%); AvgNewGain#(S%)
  NEXT S%
  LOCATE 25, 25: PRINT "Press any key to continue";
  SLEEP
END SUB
```

```
SUB BadFile STATIC
  CLOSE
  COLOR 7, 0, 0
  CLS
  PRINT : PRINT
  PRINT "*                        EXECUTION HALTED"
  PRINT "*    The data file selected does not match the structure specified "
  PRINT "*    for relative calibration in FWD Operational Field Guidelines"
  PRINT "*                    Version 2.00, TABLE 6"
  PRINT
  IF Edition! <> 10 AND Edition! <> 20 AND Edition! < 25 THEN
   PRINT "* An Unsupported Version of the Dynatest Field Program was Used!"
  ELSEIF NumDeflectors% <> NumSensors% AND NumDeflectors% <> MaxSensors% THEN
   PRINT "* Using an supported number of deflectors"
  ELSEIF DropCount% <> 0 AND DropCount% <> NumDeflectors% * NumReps% THEN
   PRINT "* Not using the correct drop sequence"     'ED25
  ELSEIF InitNumPeaks% <> 0 AND InitNumPeaks% <> NumDeflectors% * NumReps% THEN
   PRINT "* Not using the correct drop sequence"     'ED10, ED20
  END IF
  PRINT : PRINT
  END
END SUB

SUB CheckHeader10 (InitNumPeaks%, InitNumWHBlocks%, ExitCode%) STATIC
  CALL ReadNextLine(DataType%, LineLength%)
  SELECT CASE LineCounter&
   CASE 1
    IF LEFT$(LineData$, 4) = "5001" THEN          'Modified by HZ on 1/3/01
                  Edition! = VAL(MID$(LineData$, 6, 5)) 'Modified by HZ on 1/3/01
                  IF Edition! >= 25 THEN                'Modified by HZ on 1/3/01
                           SEEK #1, 1                    'Modified by HZ on 1/3/01
                           ExitCode% = 5000              'Modified by HZ on 1/3/01
                           EXIT SUB                      'Modified by HZ on 1/3/01
                  END IF                                 'Modified by HZ on 1/3/01
    END IF                                       'Modified by HZ on 1/3/01
    Edition! = VAL(MID$(LineData$, 31, 2))
    IF Edition! <> 10 AND Edition! <> 20 THEN
                  CALL BadFile
    END IF
    FileWidth% = VAL(MID$(LineData$, 2, 4))
    IF FileWidth% = 32 THEN
                  English% = False%
    ELSE
                  English% = True%
    END IF
    FileDate$ = MID$(LineData$, 14, 6)        'Data collected on FileDate$
    Year$ = MID$(FileDate$, 1, 2)
    IF VAL(Year$) > 80 THEN
                  Year$ = "19" + Year$
    ELSE
                  Year$ = "20" + Year$
    END IF
    Month$ = MID$(FileDate$, 3, 2)
    Day$ = MID$(FileDate$, 5, 2)
    MDY$ = Month$ + "-" + Day$ + "-" + Year$
   CASE 2
    IF Edition! = 10 OR Edition! = 20 THEN  'Added by HZ on 1/3/2001
                  NumSensors% = 7                 'Added by HZ on 1/3/2001
                  NumSetups% = 7                  'Added by HZ on 1/3/2001
                  NumPositions% = 7               'Added by HZ on 1/3/2001
                  CritFLPos! = 2.14               'Added by HZ on 1/3/2001 for 7 sensor, 5 %
                  CritFLSet! = 2.14               'Added by HZ on 1/3/2001
                  CritFLSens! = 2.14              'Added by HZ on 1/3/2001
                  Galph! = .2326                  'Added by HZ on 1/3/2001
    END IF                                  'Added by HZ on 1/3/2001
    NumDeflectors% = VAL(LEFT$(LineData$, 1))
    IF NumDeflectors% <> NumSensors% THEN CALL BadFile
    FWDSN$ = MID$(LineData$, 9, 8)
   CASE 3 TO 10, 22 TO 29, 31, 32, 34 TO 36
   CASE 11 TO 20                        'deflector 1 to 10
    IF LineCounter& - 10 <= MaxSensors% THEN
                  SensorNumber% = VAL(MID$(LineData$, 2, 2))
                  SerialNum%(LineCounter& - 10) = VAL(MID$(LineData$, 4, 5))
                  RelGain#(LineCounter& - 10) = VAL(MID$(LineData$, 10, 5))
    END IF
   CASE 21                              'operator
    Operator$ = LTRIM$(RTRIM$(LineData$))
```

```
    CASE 30                             'active sequence drops
      Posit% = INSTR(LineData$, ".")
      ActiveDrops% = Posit% - 1
      IF ActiveDrops% < 46 THEN CALL BadFile
    CASE 33                             'peaks stored
      CheckText$ = LEFT$(LineData$, ActiveDrops%)
      InitNumPeaks% = InCount2%(CheckText$, "*")
      NumDrops% = InitNumPeaks% \ NumSetups%
      IF InitNumPeaks% <> NumDeflectors% * NumReps% THEN CALL BadFile
   END SELECT
END SUB

SUB Cochran STATIC
   'Cochran's test to determine significance of variance between sensors
   'set up Vdef (Mean, Sensor) for sorting
   'Modified on 12/14/2000 by HZ per TT to work for 7 or 9 sensors

   'DIM Vdef(7, 2)                   'Removed by HZ on 12/14/2000 per TT
   REDIM Vdef(9, 2)                  'Modified by HZ on 12/14/2000 per TT
   SumVarDev! = 0                    'Added by HZ 1/5/2001

   'FOR S% = 1 TO MaxSensors%        'Removed by HZ on 12/14/2000 per TT
   FOR S% = 1 TO NumSensors%         'Modified by HZ on 12/14/2000 per TT
     Vdef(S%, 1) = StdDevDef!(S%) ^ 2
     Vdef(S%, 2) = S%
   NEXT S%
   'SORT
   'FOR Iter% = 1 TO 7               'Removed by HZ on 12/14/2000 per TT
   FOR Iter% = 1 TO NumSensors%      'Modified by HZ on 12/14/2000 per TT
     'FOR S% = 1 TO 6                'Removed by HZ on 12/14/2000 per TT
     FOR S% = 1 TO NumSensors% - 1   'Modified by HZ on 12/14/2000 per TT
       IF Vdef(S% + 1, 1) > Vdef(S%, 1) THEN
         SWAP Vdef(S% + 1, 1), Vdef(S%, 1)
         SWAP Vdef(S% + 1, 2), Vdef(S%, 2)
       END IF
     NEXT S%
   NEXT Iter%
   BigVarDev! = Vdef(1, 1)
   BigDef! = Vdef(1, 2)
   'Sum all Means
   'FOR M% = 1 TO 7                  'Removed by HZ on 12/14/2000 per TT
   FOR M% = 1 TO NumSensors%         'Modified by HZ on 12/14/2000 per TT
     SumVarDev! = SumVarDev! + StdDevDef!(M%) ^ 2
   NEXT M%
   G! = BigVarDev! / SumVarDev!
   IF G! > Galph! THEN               'Modified by HZ on 1/5/2001
     ProblemExist% = True%
   ELSE
     ProblemExist% = False%          'Added by HZ on 1/5/2001
   END IF
END SUB

SUB DisplayCopyright STATIC
   Version$ = "3.0 (January 5, 2001)"
   'Version$ = "3.0ß3 (05-19-1994)"
   SCREEN 0: WIDTH 80: CLS
   COLOR 14
   LOCATE 4, 17: PRINT "
   LOCATE 5, 17: PRINT "
   LOCATE 6, 17: PRINT "
   LOCATE 7, 17: PRINT "
   LOCATE 8, 17: PRINT "
   COLOR 15
   LOCATE 11, 21: PRINT "FWD Relative Calibration Analysis Software"
   LOCATE 13, 27: PRINT "Version "; Version$
   LOCATE 15, 21: PRINT "Strategic Highway Research Program (SHRP)"
   LOCATE 16, 19: PRINT "Long-Term Pavement Performance Program (LTPP)"
   LOCATE 19, 8: PRINT "Support material Copyright (c) 1989, 1994, 2001 Law Engineering PCS"
   LOCATE 20, 10: PRINT "Additional material Copyright (c) 1988, 1989  Crescent Software"
   LOCATE 21, 16: PRINT "Portions by Nichols Consulting Engineers, Chtd. 1993"
   SLEEP 4
   CALL NormalColor
   CALL ClearBuf
END SUB

SUB FileToScreen STATIC
   FTS$ = "Y"
```

```
   WindowType% = 1: CLS
   WFile$ = File$ + OExt$
   CALL NormalColor
   LOCATE 7, 7: PRINT "Output Path and File Name: "
   LOCATE 7, 37: PRINT FPath$; WFile$
   LOCATE 13, 7: PRINT "Display calibration results on screen: "
   CALL HiliteColor
   LOCATE 13, 50: PRINT FTS$
   CALL NormalColor
   DO
    OldFTS$ = FTS$
    CALL GetString(13, 50, 1, FTS$, "L", 0, 0, "", "", ExitCode%)
    FTS$ = UCASE$(FTS$)
    SELECT CASE FTS$
      CASE "Y"
                     CALL NormalColor: CLS
                     CALL GainsPage1
                     Img$ = "PgDn to ANOVA Table           Esc to exit results screens"
                     LOCATE 25, 40 - LEN(Img$) / 2: PRINT Img$;
                     DO
                              DO: a$ = INKEY$: LOOP WHILE a$ = ""
                              IF LEN(a$) = 2 THEN
                                       a$ = RIGHT$(a$, 1)
                              END IF
                              SELECT CASE a$
                                       CASE CHR$(73)     'PgUp
                                                CALL GainsPage1
                                                Img$ = "PgDn to ANOVA Table           Esc to exit
results screens"
                                                LOCATE 25, 40 - LEN(Img$) / 2: PRINT Img$;
                                       CASE CHR$(81)     'PgDn
                                                CALL LatinPage1
                                                Img$ = "PgUp to Gains Table           Esc to exit
results screens"
                                                LOCATE 25, 40 - LEN(Img$) / 2: PRINT Img$;
                                       CASE CHR$(27)     'Esc
                                                EXIT DO
                              END SELECT
                     LOOP
                     EXIT DO
      CASE "N"
                     EXIT DO
      CASE ELSE
                     REDIM PUText$(1)
                     PUText$(1) = "Please enter a Y or N only..."
                     CALL PopupError
                     FTS$ = OldFTS$
    END SELECT
   LOOP
   CLS
END SUB

SUB GainAdjustMsg STATIC
   SCREEN 0: WIDTH 80, 25: CLS : CALL NormalColor
   '************************  Geophone Gain Adjustments ******************
   PRINT
   SELECT CASE Analysis$
    CASE "S"
      PRINT "   SHRP FWD Relative Calibration -  Analysis of Variance - Gain adjustments"
    CASE "G"
      PRINT "   SHRP FWD Relative Calibration  -  Gephone Replacement - Gain adjustments"
    CASE "R"
      PRINT "   SHRP FWD Relative Calibration - Reference Calibration - Gain adjustments"
   END SELECT
   PRINT
   PRINT "FWD SN: "; FWDSN$; SPC(34); "Calibration Date: "; MDY$
   PRINT "Data File Name: "; File$ + Ext$
   PRINT "Operator: "; Operator$
   PRINT
   PRINT
   PRINT "Results of this test indicate the possible need to adjust gains.     "
   PRINT "This should be confirmed with a repeat test."
   PRINT
   PRINT "Gain adjustment should be performed when the new gain factors from two"
   PRINT "independent calibrations are within "; CHR$(241); "0.002 of each other."
   PRINT
   PRINT "Gain adjustments should be made to ALL geophones."
```

```
   PRINT
   PRINT "After adjusting any gain setting, the relative calibration test must be"
   PRINT "repeated to confirm that all sensors are within tolerance."

   bm$ = "Press any key to continue"
   LOCATE 25, 40 - LEN(bm$) / 2: PRINT bm$;
   SLEEP
END SUB

SUB GainsPage1 STATIC
   SCREEN 0: WIDTH 80, 25: CLS
   '************************  Geophone Calibration ******************
   SELECT CASE Analysis$
    CASE "S"
      PRINT "SHRP FWD Relative Calibration -  Analysis of Variance - Means and Gains Table"
    CASE "G"
      PRINT "SHRP FWD Relative Calibration  -  Gephone Replacement - Means and Gains Table"
    CASE "R"
      PRINT "SHRP FWD Relative Calibration - Reference Calibration - Means and Gains Table"
   END SELECT
   PRINT "FWD SN: "; FWDSN$; SPC(34); "Calibration Date: "; MDY$
   PRINT "Data File Name: "; File$ + Ext$; SPC(32); "Data Set "; SC%; " of "; SetCount%
   PRINT "Operator: "; Operator$
   PRINT
   PRINT "           Sensor    Existing     Means          New            Out of Limit"
   PRINT "Sensor #   S/N     Gain Factor   Ratio    Relative Gain   Tolerance   2% Range"
   PRINT "--------  ------   -----------   ------   -------------   ---------   --------"
   t8$ = "    #      ###       #.###      #.####       #.###          \   \      \   \"
   FOR S% = 1 TO NumSensors%
    PRINT USING t8$; S%; SerialNum%(S%); RelGain#(S%); MeansRat#(SC%, S%); NewGain#(SC%, S%);
TOL$(S%); RAN$(S%)
   NEXT S%
   PRINT
   IF Jnum1% > 0 THEN
    PRINT "* Warning: At least one sensor is outside the tolerance limit."
    PRINT "  Verify these results with an additional test!"
   END IF
   IF Jnum2% > 0 THEN
    PRINT "* Warning: At least one sensor is outside the 2% range limit."
    PRINT "  Notify Supervising Engineer after verifying with additional tests!"
   END IF
   IF Jnum1% > 0 THEN
    PRINT "* RESULTS INDICATE THAT THE SENSOR GAINS SHOULD BE RESET."
   END IF
   IF RepSens% > 0 THEN
    PRINT repm1$
    PRINT repm2$; USING "#.###"; NewGain#(SC%, RepSens%)
   END IF
END SUB

SUB GetFileName (FPath$, File$, Ext$) STATIC
   STATIC ZP$
   WindowType% = 1: CLS
   IF ZP$ = "" THEN ZP$ = "N"
   WFile$ = File$
   IF Ext$ <> "" THEN
    WFile$ = WFile$ + Ext$
   END IF
   CALL ScreenBorder
   CALL TitleColor
   Title$ = "  FWD Data File Selection  "
   TL% = LEN(Title$)
   Col% = ((80 - TL%) / 2) + 1
   LOCATE 2, Col%: PRINT Title$
   CALL NormalColor
   LOCATE 7, 7: PRINT "Directory path for data file: ";
   LOCATE 10, 7: PRINT "Do you want a list of data files for this path (Y/N) "
   LOCATE 13, 7: PRINT "Deflection Data File Name: "
   CALL HiliteColor
   LOCATE 7, 37: PRINT FPath$
   LOCATE 10, 60: PRINT ZP$
   LOCATE 13, 34: PRINT WFile$
   CALL NormalColor
   LOCATE 25, 4
   PRINT "[F10]=Continue  "; CHR$(24); CHR$(25);
   PRINT "  Home  End  [F7]=Exit File Selection Screen";
   Item% = 1
```

```
  MaxItem% = 3
  DO
   SELECT CASE Item%
     CASE 1
                    OldPath$ = FPath$
                    CALL GetString(7, 37, 32, FPath$, "L", 0, 0, "", "", ExitCode%)
                    FPath$ = LTRIM$(RTRIM$(UCASE$(FPath$)))
                    CurrDrive$ = CHR$(GetDrive%)
                    CurrDir$ = GetDir$(CurrDrive$)
                    CurrPath$ = CurrDrive$ + ":" + CurrDir$
                    IF FPath$ <> "" THEN
                             IF MID$(FPath$, 2, 1) = ":" THEN
                                      ChkDrive$ = LEFT$(FPath$, 1)
                                      IF NOT GoodDrive%(ChkDrive$) THEN       'check if valid
drive
                                               REDIM PUText$(1)
                                               PUText$(1) = "Drive " + ChkDrive$ + " is not a
valid choice... Please try another path."
                                               CALL PopupError
                                               ExitCode% = 0
                                               FPath$ = OldPath$
                                      ELSE                                    'drive OK, check
dir
                                               IF RIGHT$(FPath$, 1) = "\" THEN
                                                        FPath$ = LEFT$(FPath$, LEN(FPath$) - 1)
                                               END IF
                                               IF RIGHT$(FPath$, 1) = ":" THEN
                                                        FPath$ = FPath$ + "\"
                                               END IF
                                               CALL CDir(FPath$, ErrFlag%)
                                               IF NOT ErrFlag% THEN                  'path OK
                                                        CALL CDir(CurrPath$, ErrFlag%)      '
switch back to curr dir
                                               ELSE                                  'path not
OK
                                                        REDIM PUText$(2)
                                                        PUText$(1) = "Error occurred switching
to " + FPath$
                                                        PUText$(2) = "May not be a valid path...
Please try again."
                                                        CALL PopupError
                                                        ExitCode% = 0
                                                        FPath$ = OldPath$
                                               END IF
                                      END IF
                             ELSE                          'no drive letter in specified path
                                      IF RIGHT$(FPath$, 1) = "\" THEN
                                               FPath$ = LEFT$(FPath$, LEN(FPath$) - 1)
                                      END IF
                                      CALL CDir(FPath$, ErrFlag%)
                                      IF NOT ErrFlag% THEN                  'path OK
                                               CALL CDir(CurrPath$, ErrFlag%)      '  switch
back to curr dir
                                      ELSE                                  'path not OK
                                               REDIM PUText$(2)
                                               PUText$(1) = "Error occurred switching to " +
FPath$
                                               PUText$(2) = "May not be a valid path... Please
try again."
                                               CALL PopupError
                                               ExitCode% = 0
                                               FPath$ = OldPath$
                                      END IF
                             END IF
                    END IF
                    IF FPath$ <> "" AND RIGHT$(FPath$, 1) <> "\" THEN FPath$ = FPath$ + "\"
                    LOCATE 7, 37: PRINT FPath$
     CASE 2
                    DO
                             OldZP$ = ZP$
                             CALL GetString(10, 60, 1, ZP$, "L", 0, 0, "", "", ExitCode%)
                             ZP$ = UCASE$(ZP$)
                             SELECT CASE ZP$
                                      CASE "Y"
                                               ShowFiles$ = FPath$ + "*.*"
                                               NumMatchs% = FCount%(ShowFiles$)
                                               IF NumMatchs% > 0 THEN
```

```
                                                CALL DisplayFileNames(NumMatchs%,
ShowFiles$, FPath$, File$, Ext$, ExitCode%, 0)
                                                WFile$ = File$ + Ext$
                                        ELSE
                                                REDIM PUText$(1)
                                                PUText$(1) = "No files found matching "
+ ShowFiles$
                                                CALL PopupError
                                                ZP$ = "N"
                                        END IF
                                CASE "N"
                                        'go on
                                CASE ELSE
                                        REDIM PUText$(1)
                                        PUText$(1) = "Please choose a Y or N only... try
again!"
                                        CALL PopupError
                                        ExitCode% = 0
                        END SELECT
                        IF ExitCode% <> 0 THEN EXIT DO
                LOOP
     CASE 3
                DO
                        OldWFile$ = WFile$
                        CALL GetString(13, 34, 12, WFile$, "L", 0, 0, "", "", ExitCode%)
                        WFile$ = LTRIM$(RTRIM$(UCASE$(WFile$)))
                        IF INSTR(1, WFile$, " ") THEN
                                REDIM PUText$(1)
                                PUText$(1) = "Spaces are NOT allowed in file names..."
                                CALL PopupError
                                WFile$ = OldWFile$
                                ExitCode% = 0
                        END IF
                        IF ExitCode% <> 0 THEN
                                SP% = INSTR(WFile$, ".")
                                IF SP% <> 0 THEN
                                        File$ = LEFT$(WFile$, SP% - 1)
                                        Ext$ = LTRIM$(RTRIM$(RIGHT$(WFile$, LEN(WFile$) -
(SP% - 1))))
                                ELSE
                                        File$ = LTRIM$(RTRIM$(LEFT$(WFile$, 8)))
                                        Ext$ = ""
                                END IF
                                EXIT DO
                        END IF
                LOOP
    END SELECT
    SELECT CASE ExitCode%                        'determine next action
     CASE 71                    'home
                Item% = 1
     CASE 79                    'end
                Item% = MaxItem%
     CASE 15, 75, 72            'Shift-Tab, left arrow, up arrow
                Item% = Item% - 1
     CASE 9, 13, 77, 80         'Tab, CR, right arrow, down arrow
                Item% = Item% + 1
     CASE 68                    'F10:Continue
                IF File$ = "" THEN
                        REDIM PUText$(1)
                        PUText$(1) = "A file name must be entered... please try again!"
                        CALL PopupError
                        Item% = 3
                ELSE
                        ChkName$ = FPath$ + File$ + Ext$
                        IF NOT Exist%(ChkName$) THEN
                                REDIM PUText$(1)
                                PUText$(1) = "File not found...  Please try again."
                                CALL PopupError
                                File$ = ""
                                Ext$ = ""
                                ExitCode% = 0
                                Item% = 3
                        ELSE
                                ExitCode% = 1
                                EXIT SUB
                        END IF
                END IF
```

```
     CASE 65                 'F7: quit
                     CLS
                     'PRINT : PRINT : PRINT "Program Execution Terminated by User"  'Remarked by
HZ 1/4/01
                     'END            'Remarked by HZ 1/4/01
                     Action$ = "No"  'Added by HZ 1/4/01
                     EXIT SUB        'Added by HZ 1/4/01
     CASE ELSE
                     'do nothing
    END SELECT
    IF Item% < 1 THEN Item% = 1
    IF Item% > MaxItem% THEN Item% = MaxItem%
  LOOP
END SUB

SUB GetSensorNum STATIC

  'Modified on 12/14/2000 by HZ per TT to show sensors 8 and 9 if present
  'and allow user to pick 8 or 9 instead of just 1-7

  CLS
  Choice% = 1
  DO
   REDIM Item$(NumSensors% + 2)
   Title$ = " Select Geophone Replaced "
   FOR I% = 1 TO NumSensors%
     Item$(I%) = "Sensor No." + STR$(SerialNum%(I%))
   NEXT I%
   'Item$(8) = "No Replacement"                    'Removed by HZ on 12/14/00
   Item$(NumSensors% + 1) = "No Replacement"       'Modified by HZ
   'Item$(9) = "Quit Program"                      'Removed by HZ on 12/14/00
   Item$(NumSensors% + 2) = "Exit Selection Menu"  'Modified by HZ

   CALL BarMenu(Title$, Item$(), Choice%, 0)
   SELECT CASE Choice%
     'CASE 1 TO 8                            'Removed by HZ on 12/14/00
     CASE 1 TO NumSensors% + 1                'Modified by HZ
       EXIT DO
     'CASE 9                                 'Removed by HZ on 12/14/00
     CASE NumSensors% + 2                    'Modified by HZ
       SCREEN 0: WIDTH 80, 25: CLS
       CLOSE : CALL NormalColor
       'PRINT
       'PRINT "Program terminated by the user"  'Remarked by HZ 1/4/01
       'END                                     'Remarked by HZ 1/4/01
       Action$ = "No"                           'Added by HZ 1/4/01
       EXIT SUB                                 'Added by HZ 1/4/01
     CASE ELSE
       REDIM PUText$(1)
       'PUText$(1) = "Please Select Sensors 1 through 7 only..."
       PUText$(1) = "Please Select Sensors 1 through" + STR$(NumSensors%) + " only..."
       CALL PopupError
   END SELECT
  LOOP
  'IF Choice% = 8 THEN
  IF Choice% > NumSensors% THEN                    'Modified by HZ on 12/14/2000
   RepSens% = 0
  ELSE
   RepSens% = Choice%
  END IF
  CLS
  CALL NormalColor
END SUB

SUB LatinPage1 STATIC
  SCREEN 0: WIDTH 80, 25: CLS
  SELECT CASE Analysis$
   CASE "S"
     PRINT "SHRP FWD Relative Calibration -  Analysis of Variance - Latin Square ANOVA Table"
   CASE "G"
     PRINT "SHRP FWD Relative Calibration  -  Gephone Replacement - Latin Square ANOVA Table"
   CASE "R"
     PRINT "SHRP FWD Relative Calibration - Reference Calibration - Latin Square ANOVA Table"
  END SELECT
  PRINT "FWD SN: "; FWDSN$; SPC(34); "Calibration Date: "; MDY$
  PRINT "Data File Name: "; File$ + Ext$; SPC(32); "Data Set "; SC%; " of "; SetCount%
  PRINT "Operator: "; Operator$
```

```
   PRINT
   '******************* Latin Square Design Analysis Output *****************
   PRINT "    Variation      Sum of      Degrees of   Mean        Computed   Critical"
   PRINT "    Source         Squares      Freedom     Square          F          F"
   PRINT "    -----------    ---------   ----------   ---------   --------   --------"
   Data$ = "    \        \    ##.##^^^^       ###      ##.##^^^^    ####.##     ##.##"
   IF FLPos# > 1000 OR FLSet# > 1000 OR FLSens# > 1000 THEN
    Data$ = "    \        \    ##.##^^^^       ###      ##.##^^^^   ##.##^^^^    ##.##"
   END IF
   PRINT USING Data$; "Position"; CSNG(SSLPos#); DegFreeLPos%; CSNG(MSLPos#); CSNG(FLPos#);
CritFLPos!
   PRINT USING Data$; "Set"; CSNG(SSLSet#); DegFreeLSet%; CSNG(MSLSet#); CSNG(FLSet#); CritFLSet!
   PRINT USING Data$; "Sensor"; CSNG(SSLSens#); DegFreeLSens%; CSNG(MSLSens#); CSNG(FLSens#);
CritFLSens!
   PRINT USING Data$; "Error"; CSNG(SSLE#); DegFreeLE%; CSNG(MSLE#)
   PRINT USING Data$; "TOTAL"; CSNG(SSLT#); DegFreeLT%
   PRINT

   IF Jnum1% > 0 THEN
    SELECT CASE LSAM$
     CASE "YNN"
                    PRINT "Gain adjustments are indicated and drop set is statistically
significant at"
                    PRINT "the 5% level.  'Set' significance may be due to warming of the
buffers or"
                    PRINT "consolidation of pavement materials during the test.  A repeat
calibration,"
                    PRINT "after conditioning the FWD buffers with 50+ drops from height 3, is
required"
                    PRINT "to confirm the need for gain adjustments.  If the deflections from
the last 10"
                    PRINT "drops vary by more than 1 mil (25.4 microns), repeat the calibration
at a"
                    PRINT "new location."
     CASE "YYN"
                    PRINT "Gain adjustments are indicated.  Sensor and drop set are
statistically"
                    PRINT "significant at the 5% level.  A repeat calibration, after
conditioning the FWD"
                    PRINT "buffers with 50+ drops at height 3, is required to confirm the need
for gain"
                    PRINT "adjustments.  If deflections from the last 10 drops vary by more than
1 mil"
                    PRINT "(25.4 microns), repeat the calibration at a new location."
     CASE "YNY"
                    PRINT "Gain adjustments are indicated.  Set and stand position are
statistically"
                    PRINT "significant at the 5% level.  A repeat calibration, after
conditioning the FWD"
                    PRINT "buffers with 50+ drops at height 3, is required to confirm the need
for gain"
                    PRINT "adjustments.  When performing the calibration, extra care should be
taken to"
                    PRINT "seat the geophones properly and hold the stand vertical with
moderate"
                    PRINT "downward pressure.  If deflections from the last 10 drops vary by
more than"
                    PRINT "1 mil (25.4 microns), repeat the calibration at a new location."
     CASE "YYY"
                    PRINT "Gain adjustments are indicated.  Set, sensor, and stand position are"
                    PRINT "statistically significant at the 5% level.  A repeat calibration is
required"
                    PRINT "after conditioning the FWD buffers with 50+ drops at height 3 to
confirm"
                    PRINT "adjustments.  When performing the calibration, extra care should be
taken to"
                    PRINT "properly seat the geophones and hold the stand vertical with
moderate"
                    PRINT "downward pressure.  If deflections from the last 10 drops vary by
more than"
                    PRINT "1 mil (25.4 microns), repeat the calibration at a new location."
     CASE "NNN"
                    PRINT "Gain adjustments are indicated.  A repeat calibration is required to
confirm"
                    PRINT "the need for adjustments."
     CASE "NYN"
```

```
                    PRINT "Means ratios and statistical results indicate the need for gain
adjustments"
                    PRINT "A repeat calibration is required to confirm the need for gain
adjustments."
     CASE "NNY"
                    PRINT "Gain adjustments are indicated.  Stand position is statistically"
                    PRINT "significant at the 5% level.  A repeat calibration is required to
confirm"
                    PRINT "the need for gain adjustments.  Care should be taken to ensure that
the"
                    PRINT "geophone bases are clean and firmly seated, and that the stand is
held"
                    PRINT "vertical with moderate downward pressure."
     CASE "NYY"
                    PRINT "Gain adjustments are indicated.  Sensor and stand position are
statistically"
                    PRINT "significant at the 5% level.  A repeat calibration is required to
confirm"
                    PRINT "the need for gain adjustments.  Care should be taken to ensure that
the"
                    PRINT "geophone bases are clean and firmly seated, and that the stand is
held"
                    PRINT "vertical with moderate downward pressure."
     CASE ELSE
    END SELECT
   ELSE
    SELECT CASE LSAM$
     CASE "YNN"
                    PRINT "No gain adjustments are indicated, but drop set is statistically
significant"
                    PRINT "at the 5% level.  This can be due to warming of the buffers or
consolidation"
                    PRINT "of pavement materials during the test.  Review the data carefully.
If anything"
                    PRINT "appears suspect, repeat the calibration after conditioning the FWD
buffers"
                    PRINT "with 50+ drops from height 3.  If the deflections from the last 10
drops vary"
                    PRINT "more than 1 mil (25.4 microns), repeat the calibration at a new
location."
     CASE "YYN"
                    PRINT "Sensor and drop set are statistically significant at the 5% level,
but gain"
                    PRINT "adjustments are not indicated.  Review the data carefully.  If
anything"
                    PRINT "appears suspect, repeat the calibration after conditioning the FWD
buffers"
                    PRINT "with 50+ drops from height 3.  If the deflections from the last 10
drops vary"
                    PRINT "more than 1 mil (25.4 microns), repeat the calibration at a new
location."
     CASE "YNY"
                    PRINT "Set and stand position are statistically significant at the 5% level,
but"
                    PRINT "gain adjustments are not indicated.  Examine the data carefully.  If
anything"
                    PRINT "appears suspect, repeat the calibration after conditioning the FWD
buffers"
                    PRINT "with 50+ drops from height 3.  When performing the calibration, extra
care"
                    PRINT "should be taken to properly seat the geophones and hold the stand
vertical"
                    PRINT "with moderate downward pressure.  If deflections from the last 10
drops vary"
                    PRINT "more than 1 mil (25.4 microns), repeat the calibration at a new
location."
     CASE "YYY"
                    PRINT "Set, sensor, and stand position are statistically significant at the
5% level."
                    PRINT "Although gain changes are not indicated, these results are suspect.
A repeat"
                    PRINT "calibration is required after conditioning with 50+ drops at height
3."
                    PRINT "Extra care should be taken to properly seat the geophones and hold
the stand"
                    PRINT "vertical with moderate downward pressure.  If deflections from the
last 10"
```

```
                    PRINT "drops vary more than 1 mil (25.4  microns) repeat the calibration at
a new"
                    PRINT "location.  If this message appears in subsequent tests, contact your"
                    PRINT "supervising engineer for further instructions."
     CASE "NNN"
                    PRINT "Results indicate that no gain adjustments are needed."
     CASE "NYN"
                    PRINT "Sensor is statistically significant at the 5% level, but gain
adjustments are"
                    PRINT "not indicated.  Test results should be carefully reviewed.  If
anything appears"
                    PRINT "suspect, repeat the calibration.  Otherwise, these results are
acceptable."
     CASE "NNY"
                    PRINT "Gains do not needed to be adjusted, but stand position is
statistically"
                    PRINT "significant at the 5% level.  This may be caused by failure to keep
the stand"
                    PRINT "vertical or improper seating of the geophones.  In the future, care
should be"
                    PRINT "taken to ensure that the geophone bases are clean and well seated,
and the"
                    PRINT "stand is kept vertical with moderate downward pressure."
     CASE "NYY"
                    PRINT "Sensor and stand position are statistically significant at the 5%
level, but"
                    PRINT "gain adjustments are not indicated.  Review calibration results
carefully."
                    PRINT "If anything is suspect, repeat the calibration, taking care to ensure
that"
                    PRINT "geophone bases are clean and properly seated, and the stand is kept
vertical"
                    PRINT "with moderate downward pressure."
     CASE ELSE
    END SELECT
  END IF
  '****************** Cochran test results ************************
  IF ProblemExist% THEN
    PRINT "** Cochran test variance between geophones indicates variance for Sensor No."; BigDef!
    PRINT "is significantly larger than the other sensors. Please consult the output file."
  END IF
END SUB

SUB LatinSqDesign STATIC
  '*************************************************************************
  '            Subprogram for Latin Square Design analysis
  '*************************************************************************
  REDIM Ti#(MaxSensors%), Tj#(MaxPositions%), Tk#(MaxSetups%)
  REDIM Tij#(MaxSensors%, MaxPositions%), Tik#(MaxSensors%, MaxSetups%), Tjk#(MaxPositions%,
MaxSetups%)
  REDIM Tijk#(MaxSensors%, MaxPositions%, MaxSetups%), TotalLoad(MaxSetups%)
  REDIM SSumTi#(MaxSensors%), SSumTj#(MaxPositions%), SSumTk#(MaxSetups%)
  REDIM MeanDef#(MaxSensors%), MeanPos#(MaxSensors%), MeanSet#(MaxSensors%)
  REDIM MeanBySet!(MaxSensors%, MaxSetups%), MeanLoad!(MaxSetups%)
  REDIM StdDevDef!(MaxSensors%), StdDevPos!(MaxSensors%)
  REDIM CVDef!(MaxSensors%), CVPos!(MaxSensors%)
  REDIM MeansRat#(MaxSensors%, MaxSensors%), NewGain#(MaxSensors%, MaxSensors%)
  '*************** Initialize Variables to Zero ***************
  SumTotal# = 0
  TotalSS# = 0
  FOR I% = 1 TO NumSensors%
    Ti#(I%) = 0
    MeanDef#(I%) = 0
    MeanPos#(I%) = 0
    MeanSet#(I%) = 0
    FOR J% = 1 TO NumSetups%
      MeanBySet!(I%, J%) = 0
    NEXT J%
  NEXT I%
  '*************** Compute main statistics for the analysis ***************
  FOR I% = 1 TO NumSensors%
    FOR J% = 1 TO NumPositions%
      FOR K% = 1 TO NumSetups%
                    FOR L% = 1 TO NumReps%
                            SumTotal# = SumTotal# + DefData!(I%, J%, K%, L%)
                            TotalSS# = TotalSS# + (DefData!(I%, J%, K%, L%)) ^ 2
                            Ti#(I%) = Ti#(I%) + DefData!(I%, J%, K%, L%)
```

```
                                SSumTi#(I%) = SSumTi#(I%) + (DefData!(I%, J%, K%, L%)) ^ 2
                                Tj#(J%) = Tj#(J%) + DefData!(I%, J%, K%, L%)
                                SSumTj#(J%) = SSumTj#(J%) + (DefData!(I%, J%, K%, L%)) ^ 2
                                Tk#(K%) = Tk#(K%) + DefData!(I%, J%, K%, L%)
                                Tij#(I%, J%) = Tij#(I%, J%) + DefData!(I%, J%, K%, L%)
                                Tik#(I%, K%) = Tik#(I%, K%) + DefData!(I%, J%, K%, L%)
                                Tjk#(J%, K%) = Tjk#(J%, K%) + DefData!(I%, J%, K%, L%)
                                Tijk#(I%, J%, K%) = Tijk#(I%, J%, K%) + DefData!(I%, J%, K%, L%)
                        NEXT L%
      NEXT K%
    NEXT J%
  NEXT I%
  SumTi# = 0
  SumTj# = 0
  SumTk# = 0
  SumTij# = 0
  SumTik# = 0
  SumTjk# = 0
  FOR I% = 1 TO NumSensors%
    SumTi# = SumTi# + Ti#(I%) ^ 2
    SumTj# = SumTj# + Tj#(I%) ^ 2
    SumTk# = SumTk# + Tk#(I%) ^ 2
    FOR J% = 1 TO NumPositions%
      SumTij# = SumTij# + Tij#(I%, J%) ^ 2
      SumTik# = SumTik# + Tik#(I%, J%) ^ 2
      SumTjk# = SumTjk# + Tjk#(I%, J%) ^ 2
    NEXT J%
  NEXT I%
  '*************** Compute Std. Dev. for the data set ****************
  FOR I% = 1 TO NumSensors%
    FOR K% = 1 TO NumSetups%
      MeanBySet!(I%, K%) = Tik#(I%, K%) / NumReps%
    NEXT K%
    MeanDef#(I%) = Ti#(I%) / (NumSensors% * NumReps%)
    MeanPos#(I%) = Tj#(I%) / (NumPositions% * NumReps%)
    MeanSet#(I%) = Tk#(I%) / (NumSetups% * NumReps%)
  NEXT I%

  SSumLoad# = 0
  TotalAllLoad# = 0
  Set% = 1
  FOR D% = 1 TO NumSetups% * NumReps%
    SSumLoad# = SSumLoad# + LoadData!(D%) ^ 2
    TotalAllLoad# = TotalAllLoad# + LoadData!(D%)
    TotalLoad(Set%) = TotalLoad(Set%) + LoadData!(D%)
    IF D% MOD NumReps% = 0 THEN
      MeanLoad!(Set%) = TotalLoad(Set%) / NumReps%
      Set% = Set% + 1
    END IF
  NEXT D%

  MeanAllLoad! = TotalAllLoad# / (NumSetups% * NumReps%)
  StdDevAllLoad! = SQR((SSumLoad# - ((NumSetups% * NumReps%) * (MeanAllLoad!) ^ 2)) / (NumSetups%
* NumReps% - 1))
  CVAllLoad! = (StdDevAllLoad! / MeanAllLoad!) * 100
  MeanAllDef# = SumTotal# / (NumPositions% * NumSetups% * NumReps%)
  StdDevAllDef! = SQR((TotalSS# - (NumPositions% * NumSetups% * NumReps%) * ((SumTotal# /
(NumPositions% * NumSetups% * NumReps%)) ^ 2)) / (NumPositions% * NumSetups% * NumReps% - 1))
  CVAllDef! = (StdDevAllDef! / MeanAllDef#) * 100

  FOR I% = 1 TO NumSensors%
    Argument1# = (SSumTi#(I%) - ((NumSensors% * NumReps%) * (Ti#(I%) / (NumSensors% * NumReps%))
^ 2)) / (NumSensors% * NumReps% - 1)
    IF Argument1# > 0 THEN
      StdDevDef!(I%) = SQR(Argument1#)
    ELSE
      StdDevDef!(I%) = 0
    END IF
    Argument2# = (SSumTj#(I%) - ((NumPositions% * NumReps%) * (MeanPos#(I%)) ^ 2)) /
(NumPositions% * NumReps% - 1)
    IF Argument2# > 0 THEN
      StdDevPos!(I%) = SQR(Argument2#)
    ELSE
      StdDevPos!(I%) = 0
    END IF
    CVDef!(I%) = (StdDevDef!(I%) / MeanDef#(I%)) * 100
    CVPos!(I%) = (StdDevPos!(I%) / MeanPos#(I%)) * 100
```

```
    MeansRat#(SC%, I%) = MeanAllDef# / MeanDef#(I%)
    NewGain#(SC%, I%) = MeansRat#(SC%, I%) * RelGain#(I%)
  NEXT I%

  '************** Compute final LATIN-SQUARE statistics *****************

  NegTerm# = (SumTotal# ^ 2) / (NumPositions% * NumSetups% * NumReps%)
  SSLT# = TotalSS# - NegTerm#
  SSLPos# = SumTj# / (NumPositions% * NumReps%) - NegTerm#
  SSLSet# = SumTk# / (NumSetups% * NumReps%) - NegTerm#
  SSLSens# = SumTi# / (NumSensors% * NumReps%) - NegTerm#
  SSLE# = SSLT# - SSLPos# - SSLSet# - SSLSens#
  DegFreeLPos% = NumPositions% - 1
  DegFreeLSet% = NumSetups% - 1
  DegFreeLSens% = NumSensors% - 1
  DegFreeLT% = (NumPositions% * NumSetups% * NumReps%) - 1
  DegFreeLE% = DegFreeLT% - DegFreeLPos% - DegFreeLSet% - DegFreeLSens%

  MSLPos# = SSLPos# / DegFreeLPos%
  MSLSet# = SSLSet# / DegFreeLSet%
  MSLSens# = SSLSens# / DegFreeLSens%
  MSLE# = SSLE# / DegFreeLE%
  FLPos# = MSLPos# / MSLE#
  FLSet# = MSLSet# / MSLE#
  FLSens# = MSLSens# / MSLE#
END SUB

SUB OutputToFile STATIC
  DIM Avg$(MaxSetups%)
  Jnum1% = 0
  Jnum2% = 0
  FOR I% = 1 TO NumSensors%
    IF ABS(1 - MeansRat#(SC%, I%)) > .003 THEN
      TOL$(I%) = "YES"
      Jnum1% = Jnum1% + 1
    ELSE
      TOL$(I%) = " NO"
    END IF
    IF ABS(1 - NewGain#(SC%, I%)) > .02 THEN
      RAN$(I%) = "YES"
      Jnum2% = Jnum2% + 1
    ELSE
      RAN$(I%) = " NO"
    END IF
  NEXT I%
  '************************  Geophone Calibration ******************
  SELECT CASE Analysis$
    CASE "S"
      PRINT #2, "SHRP FWD Relative Calibration -  Analysis of Variance - Means and Gains Table"
    CASE "G"
      PRINT #2, "SHRP FWD Relative Calibration  -  Gephone Replacement - Means and Gains Table"
    CASE "R"
      PRINT #2, "SHRP FWD Relative Calibration - Reference Calibration - Means and Gains Table"
  END SELECT
  PRINT #2, "FWD SN: "; FWDSN$; SPC(34); "Calibration Date: "; MDY$
  PRINT #2, "Data File Name: "; File$ + Ext$; SPC(32); "Data Set "; SC%; " of "; SetCount%
  PRINT #2, "Operator: "; Operator$
  PRINT #2, ""
  PRINT #2, "            Sensor    Existing     Means          New            Out of Limit"
  PRINT #2, "  Sensor #   S/N     Gain Factor   Ratio    Relative Gain   Tolerance   2% Range"
  PRINT #2, "  --------  ------   -----------   ------   -------------   ---------   --------"
  t8$ = "       #      ####       #.###      #.####       #.###          \   \      \   \"
  FOR S% = 1 TO NumSensors%
    PRINT #2, USING t8$; S%; SerialNum%(S%); RelGain#(S%); MeansRat#(SC%, S%); NewGain#(SC%, S%);
TOL$(S%); RAN$(S%)
  NEXT S%
  PRINT #2, ""
  IF Jnum1% > 0 THEN
    PRINT #2, "* Warning: At least one sensor is outside the tolerance limit."
    PRINT #2, "  Verify these results with additional tests!"
  END IF
  IF Jnum2% > 0 THEN
    PRINT #2, "* Warning: At least one sensor is outside the 2% range limit."
    PRINT #2, "  Notify Supervising Engineer after verifying with additional tests!"
  END IF
  IF Jnum1% > 0 THEN
    PRINT #2, ""
```

```
    PRINT #2, "* RESULTS INDICATE THAT THE SENSOR GAINS SHOULD BE RESET."
   END IF
   IF RepSens% > 0 THEN
    PRINT #2, ""
    PRINT #2, repm1$
    PRINT #2, repm2$; USING "#.###"; NewGain#(SC%, RepSens%)
   END IF
   PRINT #2, ""
   PRINT #2, ""
   IF Jnum1% > 0 THEN
    '************************  Geophone Gain Adjustments ******************
    SELECT CASE Analysis$
      CASE "S"
                    PRINT #2, "   SHRP FWD Relative Calibration -  Analysis of Variance - Gain
adjustments"
      CASE "G"
                    PRINT #2, "   SHRP FWD Relative Calibration  -  Gephone Replacement - Gain
adjustments"
      CASE "R"
                    PRINT #2, "   SHRP FWD Relative Calibration - Reference Calibration - Gain
adjustments"
    END SELECT
    PRINT #2, ""
    PRINT #2, "Results of this test indicate the possible need for gain adjustment.     "
    PRINT #2, "This should be confirmed with a repeat test."
    PRINT #2, ""
    PRINT #2, "Gain adjustment should be performed when the New Gain Factors for two   "
    PRINT #2, "independent calibrations are within +/- 0.002 of each other."
    PRINT #2, ""
    PRINT #2, "Gain adjustments should be made to ALL geophones."
    PRINT #2, ""
    PRINT #2, "After adjusting any gain setting, the relative calibration test must be"
    PRINT #2, "repeated to confirm that all sensors are within tolerance."
   END IF
   PRINT #2, ""
   PRINT #2, ""
   PRINT #2, CHR$(12)
   '****************** Latin Square Design Analysis Output *****************
   SELECT CASE Analysis$
    CASE "S"
      PRINT #2, "SHRP FWD Relative Calibration -  Analysis of Variance - Latin Square ANOVA Table"
    CASE "G"
      PRINT #2, "SHRP FWD Relative Calibration  -  Gephone Replacement - Latin Square ANOVA Table"
    CASE "R"
      PRINT #2, "SHRP FWD Relative Calibration - Reference Calibration - Latin Square ANOVA Table"
   END SELECT
   PRINT #2, "FWD SN: "; FWDSN$; SPC(34); "Calibration Date: "; MDY$
   PRINT #2, "Data File Name: "; File$ + Ext$; SPC(32); "Data Set "; SC%; " of "; SetCount%
   PRINT #2, "Operator: "; Operator$
   PRINT #2, ""
   PRINT #2, "     Variation      Sum of      Degrees of   Mean        Computed   Critical"
   PRINT #2, "     Source         Squares      Freedom     Square         F          F"
   PRINT #2, "     -----------    ---------   ----------   ---------   --------   --------"
   Data$ = "     \        \    ##.##^^^^       ###      ##.##^^^^    ####.##     ##.##"
   IF FLPos# > 1000 OR FLSet# > 1000 OR FLSens# > 1000 THEN
    Data$ = "     \        \    ##.##^^^^       ###      ##.##^^^^   ##.##^^^^    ##.##"
   END IF
   PRINT #2, USING Data$; "Position"; CSNG(SSLPos#); DegFreeLPos%; CSNG(MSLPos#); CSNG(FLPos#);
CritFLPos!
   PRINT #2, USING Data$; "Set"; CSNG(SSLSet#); DegFreeLSet%; CSNG(MSLSet#); CSNG(FLSet#);
CritFLSet!
   PRINT #2, USING Data$; "Sensor"; CSNG(SSLSens#); DegFreeLSens%; CSNG(MSLSens#); CSNG(FLSens#);
CritFLSens!
   PRINT #2, USING Data$; "Error"; CSNG(SSLE#); DegFreeLE%; CSNG(MSLE#)
   PRINT #2, USING Data$; "TOTAL"; CSNG(SSLT#); DegFreeLT%
   PRINT #2, ""

   IF FLSet# - CritFLSet! > 0 THEN
    IF (FLSens# - CritFLSens! > 0) THEN
      IF FLPos# - CritFLPos! > 0 THEN
                    LSAM$ = "YYY"
      ELSE
                    LSAM$ = "YYN"
      END IF
    ELSE
      IF FLPos# - CritFLPos! > 0 THEN
                    LSAM$ = "YNY"
```

```
     ELSE
                    LSAM$ = "YNN"
     END IF
    END IF
   ELSE
    IF (FLSens# - CritFLSens! > 0) THEN
     IF FLPos# - CritFLPos! > 0 THEN
                    LSAM$ = "NYY"
     ELSE
                    LSAM$ = "NYN"
     END IF
    ELSE
     IF FLPos# - CritFLPos! > 0 THEN
                    LSAM$ = "NNY"
     ELSE
                    LSAM$ = "NNN"
     END IF
    END IF
   END IF
   IF FLSens# - CritFLSens! < 0 AND FLPos# - CritFLPos < 0 AND FLSet# - CritFLSet < 0 THEN
    LSAM$ = "NNN"
   END IF

   IF Jnum1% > 0 THEN
    SELECT CASE LSAM$
     CASE "YNN"
                    PRINT #2, "Gain adjustments are indicated and drop set is statistically
significant at"
                    PRINT #2, "the 5% level.  'Set' significance may be due to warming of the
buffers or"
                    PRINT #2, "consolidation of pavement materials during the test.  A repeat
calibration,"
                    PRINT #2, "after conditioning the FWD buffers with 50+ drops from height 3,
is required"
                    PRINT #2, "to confirm the need for gain adjustments.  If the deflections
from the last 10"
                    PRINT #2, "drops vary by more than 1 mil (25.4 microns), repeat the
calibration at a"
                    PRINT #2, "new location."
     CASE "YYN"
                    PRINT #2, "Gain adjustments are indicated.  Sensor and drop set are
statistically"
                    PRINT #2, "significant at the 5% level.  A repeat calibration, after
conditioning the FWD"
                    PRINT #2, "buffers with 50+ drops at height 3, is required to confirm the
need for gain"
                    PRINT #2, "adjustments.  If deflections from the last 10 drops vary by more
than 1 mil"
                    PRINT #2, "(25.4 microns), repeat the calibration at a new location."
     CASE "YNY"
                    PRINT #2, "Gain adjustments are indicated.  Set and stand position are
statistically"
                    PRINT #2, "significant at the 5% level.  A repeat calibration, after
conditioning the FWD"
                    PRINT #2, "buffers with 50+ drops at height 3, is required to confirm the
need for gain"
                    PRINT #2, "adjustments.  When performing the calibration, extra care should
be taken to"
                    PRINT #2, "seat the geophones properly and hold the stand vertical with
moderate"
                    PRINT #2, "downward pressure.  If deflections from the last 10 drops vary by
more than"
                    PRINT #2, "1 mil (25.4 microns), repeat the calibration at a new location."
     CASE "YYY"
                    PRINT #2, "Gain adjustments are indicated.  Set, sensor, and stand position
are"
                    PRINT #2, "statistically significant at the 5% level.  A repeat calibration
is required"
                    PRINT #2, "after conditioning the FWD buffers with 50+ drops at height 3 to
confirm "
                    PRINT #2, "adjustments.  When performing the calibration, extra care should
be taken to"
                    PRINT #2, "properly seat the geophones and hold the stand vertical with
moderate"
                    PRINT #2, "downward pressure.  If deflections from the last 10 drops vary by
more than"
                    PRINT #2, "1 mil (25.4 microns), repeat the calibration at a new location."
```

```
     CASE "NNN"
                    PRINT #2, "Gain adjustments are indicated.  A repeat calibration is required
to confirm"
                    PRINT #2, "the need for adjustments."
     CASE "NYN"
                    PRINT #2, "Means ratios and statistical results indicate the need for gain
adjustments"
                    PRINT #2, "A repeat calibration is required to confirm the need for gain
adjustments."
     CASE "NNY"
                    PRINT #2, "Gain adjustments are indicated.  Stand position is statistically"
                    PRINT #2, "significant at the 5% level.  A repeat calibration is required to
confirm"
                    PRINT #2, "the need for gain adjustments.  Care should be taken to ensure
that the"
                    PRINT #2, "geophone bases are clean and firmly seated, and that the stand is
held"
                    PRINT #2, "vertical with moderate downward pressure."
     CASE "NYY"
                    PRINT #2, "Gain adjustments are indicated.  Sensor and stand position are
statistically"
                    PRINT #2, "significant at the 5% level.  A repeat calibration is required to
confirm"
                    PRINT #2, "the need for gain adjustments.  Care should be taken to ensure
that the"
                    PRINT #2, "geophone bases are clean and firmly seated, and that the stand is
held"
                    PRINT #2, "vertical with moderate downward pressure."
     CASE ELSE
    END SELECT
   ELSE
    SELECT CASE LSAM$
     CASE "YNN"
                    PRINT #2, "No gain adjustments are indicated, but drop set is statistically
significant"
                    PRINT #2, "at the 5% level.  This can be due to warming of the buffers or
consolidation"
                    PRINT #2, "of pavement materials during the test.  Review the data
carefully.  If anything"
                    PRINT #2, "appears suspect, repeat the calibration after conditioning the
FWD buffers"
                    PRINT #2, "with 50+ drops from height 3.  If the deflections from the last
10 drops vary"
                    PRINT #2, "more than 1 mil (25.4 microns), repeat the calibration at a new
location."
     CASE "YYN"
                    PRINT #2, "Sensor and drop set are statistically significant at the 5%
level, but gain"
                    PRINT #2, "adjustments are not indicated.  Review the data carefully.  If
anything"
                    PRINT #2, "appears suspect, repeat the calibration after conditioning the
FWD buffers"
                    PRINT #2, "with 50+ drops from height 3.  If the deflections from the last
10 drops vary"
                    PRINT #2, "more than 1 mil (25.4 microns), repeat the calibration at a new
location."
     CASE "YNY"
                    PRINT #2, "Set and stand position are statistically significant at the 5%
level, but"
                    PRINT #2, "gain adjustments are not indicated.  Examine the data carefully.
If anything"
                    PRINT #2, "appears suspect, repeat the calibration after conditioning the
FWD buffers"
                    PRINT #2, "with 50+ drops from height 3.  When performing the calibration,
extra care"
                    PRINT #2, "should be taken to properly seat the geophones and hold the stand
vertical"
                    PRINT #2, "with moderate downward pressure.  If deflections from the last 10
drops vary"
                    PRINT #2, "more than 1 mil (25.4 microns), repeat the calibration at a new
location."
     CASE "YYY"
                    PRINT #2, "Set, sensor, and stand position are statistically significant at
the 5% level."
                    PRINT #2, "Although gain changes are not indicated, these results are
suspect.  A repeat"
```

```
                    PRINT #2, "calibration is required after conditioning with 50+ drops at
height 3."
                    PRINT #2, "Extra care should be taken to properly seat the geophones and
hold the stand"
                    PRINT #2, "vertical with moderate downward pressure.  If deflections from
the last 10"
                    PRINT #2, "drops vary more than 1 mil (25.4  microns) repeat the calibration
at a new"
                    PRINT #2, "location.  If this message appears in subsequent tests, contact
your"
                    PRINT #2, "supervising engineer for further instructions."
      CASE "NNN"
                    PRINT #2, "Results indicate that no gain adjustments are needed."
      CASE "NYN"
                    PRINT #2, "Sensor is statistically significant at the 5% level, but gain
adjustments are"
                    PRINT #2, "not indicated.  Test results should be carefully reviewed.  If
anything appears"
                    PRINT #2, "suspect, repeat the calibration.  Otherwise, these results are
acceptable."
      CASE "NNY"
                    PRINT #2, "Gains do not needed to be adjusted, but stand position is
statistically"
                    PRINT #2, "significant at the 5% level.  This may be caused by failure to
keep the stand"
                    PRINT #2, "vertical or improper seating of the geophones.  In the future,
care should be"
                    PRINT #2, "taken to ensure that the geophone bases are clean and well
seated, and the"
                    PRINT #2, "stand is kept vertical with moderate downward pressure."
      CASE "NYY"
                    PRINT #2, "Sensor and stand position are statistically significant at the 5%
level, but"
                    PRINT #2, "gain adjustments are not indicated.  Review calibration results
carefully."
                    PRINT #2, "If anything is suspect, repeat the calibration, taking care to
ensure that"
                    PRINT #2, "geophone bases are clean and properly seated, and the stand is
kept vertical"
                    PRINT #2, "with moderate downward pressure."
      CASE ELSE
    END SELECT
  END IF
  '******************* Cochran test results *************************
  IF ProblemExist% THEN
    PRINT #2, "* Results of Cochran Test on Significance of Variance Between Geophones"
    PRINT #2, ""
    PRINT #2, "  The variance for Sensor No."; BigDef!; " is significantly larger than"
    PRINT #2, "  the other sensors. This could be a result of incorrect seating of the"
    PRINT #2, "  sensor in the stand OR an indication that this sensor is bad and needs"
    PRINT #2, "  to be replaced. Please confirm with additional tests."
  END IF
  PRINT #2, CHR$(12)

  ' ***************************** Data Replay ******************************
  ' ******************************* Page 3 *********************************
  PRINT #2, SPC(23); "Relative Calibration - Input Data"
  PRINT #2, "FWD SN: "; FWDSN$; SPC(34); "Calibration Date: "; MDY$
  PRINT #2, "Data File Name: "; File$ + Ext$; SPC(32); "Data Set "; SC%; " of "; SetCount%
  PRINT #2, "Operator: "; Operator$
  PRINT #2, ""
  PRINT #2, "Set Drop  Load                Deflections"
  t0c$ = "   Df# "
  PRINT #2, " #    #    lbf  ";
  FOR I% = 1 TO NumDeflectors%
    PRINT #2, USING t0c$; I%;
  NEXT I%
  PRINT #2, ""
  PRINT #2, "--- ---- ------ ";
  FOR I% = 1 TO NumDeflectors%
    PRINT #2, " ------";
  NEXT I%
  PRINT #2, ""
  t0a$ = " #    #  ##,### "
  IF OutDef!(1, 1) > 50 THEN
    t0b$ = " ####.#"
  ELSE
```

```
 t0b$ = "  ##.##"
END IF
Lin% = 1
Set% = 1
FOR W% = 1 TO NumSetups% * NumReps%
 drop% = (W% - (Set% - 1) * 5)
 PRINT #2, USING t0a$; Set%; drop%; LoadData!(W%);
 FOR I% = 1 TO NumDeflectors%
  PRINT #2, USING t0b$; OutDef!(W%, I%);
 NEXT I%
 PRINT #2, ""
 IF W% MOD 5 = 0 THEN
  Set% = Set% + 1
  PRINT #2, ""
 END IF
NEXT W%
PRINT #2, ""
PRINT #2, CHR$(12)

' ************************ Summary Statistics ***************************
' ****************************** Page 4 *********************************
PRINT #2, SPC(24); "Relative Calibration - Summary Statistics"
PRINT #2, "FWD SN: "; FWDSN$; SPC(34); "Calibration Date: "; MDY$
PRINT #2, "Data File Name: "; File$ + Ext$; SPC(32); "Data Set "; SC%; " of "; SetCount%
PRINT #2, "Operator: "; Operator$
PRINT #2, ""
t1c$ = "   Df# "
PRINT #2, "          Load  ";
FOR I% = 1 TO NumDeflectors%
 PRINT #2, USING t1c$; I%;
NEXT I%
PRINT #2, " Df1-"; QPTrim$(STR$(NumDeflectors%))
PRINT #2, "          ------ ";
FOR I% = 1 TO NumDeflectors% + 1
 PRINT #2, " ------";
NEXT I%
PRINT #2, ""
t1a$ = "\      \ ##,### "
t1d$ = "\      \  ##.## "
FOR N% = 1 TO NumSetups%
 Avg$(N%) = "Set" + STR$(N%) + " Av"
 PRINT #2, USING t1a$; Avg$(N%); MeanLoad!(N%);
 FOR I% = 1 TO NumDeflectors%
  PRINT #2, USING t0b$; MeanBySet!(I%, N%);
 NEXT I%
 PRINT #2, USING t0b$; MeanSet#(N%)
NEXT N%
PRINT #2, ""
PRINT #2, ""
PRINT #2, "                                    Overall Statistics"
PRINT #2, ""
PRINT #2, "          Load  ";
FOR I% = 1 TO NumDeflectors%
 PRINT #2, USING t1c$; I%;
NEXT I%
PRINT #2, " Df1-"; QPTrim$(STR$(NumDeflectors%))
PRINT #2, "          ------ ";
FOR I% = 1 TO NumDeflectors% + 1
 PRINT #2, " ------";
NEXT I%
PRINT #2, ""
PRINT #2, USING t1a$; "Average"; MeanAllLoad!;
FOR I% = 1 TO NumDeflectors%
 PRINT #2, USING t0b$; MeanDef#(I%);
NEXT I%
PRINT #2, USING t0b$; MeanAllDef#
PRINT #2, USING t1a$; "Std Dev"; StdDevAllLoad!;
FOR I% = 1 TO NumDeflectors%
 PRINT #2, USING t0b$; StdDevDef!(I%);
NEXT I%
PRINT #2, USING t0b$; StdDevAllDef!
PRINT #2, USING t1d$; "COV, %"; CVAllLoad!;
FOR I% = 1 TO NumDeflectors%
 PRINT #2, USING t0b$; CVDef!(I%);
NEXT I%
PRINT #2, USING t0b$; CVAllDef!
PRINT #2, ""
```

```
   PRINT #2, ""
   PRINT #2, "                          Position in Stand"
   t5a$ = "    #  "
   PRINT #2, SPC(11);
   FOR I% = 1 TO NumDeflectors%
    PRINT #2, USING t5a$; I%;
   NEXT I%
   PRINT #2, ""
   PRINT #2, SPC(11);
   FOR I% = 1 TO NumDeflectors%
    PRINT #2, " ------";
   NEXT I%
   PRINT #2, ""
   t5b$ = "\      \   "
   PRINT #2, USING t5b$; "Avg Df ";
   FOR I% = 1 TO NumDeflectors%
    PRINT #2, USING t0b$; MeanPos#(I%);
   NEXT I%
   PRINT #2, ""
   PRINT #2, USING t5b$; "Std Dev";
   FOR I% = 1 TO NumDeflectors%
    PRINT #2, USING t0b$; StdDevPos!(I%);
   NEXT I%
   PRINT #2, ""
   PRINT #2, USING t5b$; "COV, % ";
   FOR I% = 1 TO NumDeflectors%
    PRINT #2, USING t0b$; CVPos!(I%);
   NEXT I%
   PRINT #2, ""
   PRINT #2, ""
   PRINT #2, CHR$(12);
END SUB

SUB ProcessED25 STATIC

   'Modified by HZ on 12/14/2000 per TT to provide correct Galph! if Ed25 data used

   English% = False%
   SetCount% = 0
   LineCounter& = 0
   NumDeflectors% = 0
   DropCount% = 0
   DO WHILE NOT EOF(1)
    LineCounter& = LineCounter& + 1
    INPUT #1, LineNum%
    SELECT CASE LineNum%
     CASE 5001
                    INPUT #1, Edition!
                    INPUT #1, NumHeaders%
                    INPUT #1, NumHeaderLines%
                    INPUT #1, NumStationIDLines%
                    INPUT #1, NumLinesPerDrop%
                    INPUT #1, ProgComment$
     CASE 5002
                    INPUT #1, Dummy$
                    INPUT #1, FWDSN$
                    INPUT #1, ProcSN$
     CASE 5003, 5010, 5200, 5020 TO 5024         'ignore remainder of line
                    LINE INPUT #1, Dummy$
     CASE 5031, 5032, 5041 TO 5044               'ignore remainder of line
                    LINE INPUT #1, Dummy$
     CASE 5011
                    INPUT #1, Dummy%
                    INPUT #1, Dummy%
                    INPUT #1, Year%
                    Year$ = QPTrim$(STR$(Year%))
                    INPUT #1, Month%
                    Month$ = QPTrim$(STR$(Month%))
                    IF Month% < 10 THEN Month$ = "0" + Month$
                    INPUT #1, Day%
                    Day$ = QPTrim$(STR$(Day%))
                    IF Day% < 10 THEN Day$ = "0" + Day$
                    MDY$ = Month$ + "-" + Day$ + "-" + Year$
                    LINE INPUT #1, Dummy$           'ignore remainder
     CASE 5201 TO 5218
                    INPUT #1, SensorSN$
                    IF QPTrim$(SensorSN$) <> "NA" THEN
```

```
                        SerialNum%(LineNum% - 5200) = VAL(SensorSN$)
                        NumDeflectors% = NumDeflectors% + 1
                        INPUT #1, DeflType%             'not currently used
                        INPUT #1, RelGain#(LineNum% - 5200)
                        INPUT #1, AbsGain#              'not currently used
                ELSE
                        LINE INPUT #1, Dummy$
                        IF LineNum% = 5218 THEN         'after last deflector, set
constants
                                NumSensors% = NumDeflectors%
                                NumPositions% = NumDeflectors%
                                NumSetups% = NumDeflectors%
                                IF NumDeflectors% = 7 THEN
                                        CritFLPos! = 2.14       '7 sensor, 5 %
                                        CritFLSet! = 2.14
                                        CritFLSens! = 2.14
                                        Galph! = .2326      'Added by HZ on 12/14/2000
per TT
                                ELSEIF NumDeflectors% = 9 THEN
                                        CritFLPos! = 1.96       '9 sensor, 5 %
                                        CritFLSet! = 1.96
                                        CritFLSens! = 1.96
                                        Galph! = .1792      'Added by HZ on 12/14/2000
per TT
                                ELSE
                                        CALL BadFile
                                END IF
                        END IF
                END IF
     CASE 5029
                INPUT #1, NumSeq&
                INPUT #1, NumDrops&
                INPUT #1, NumTotalSeq&
                INPUT #1, TotalNumDrops&
     CASE 5030                  'operator
                INPUT #1, Operator$
                Operator$ = QPTrim$(Operator$)
     CASE 1 TO 99               'peak deflection records
                DropCount% = DropCount% + 1
                INPUT #1, MeasLoad!(SetCount%, DropCount%)
                FOR I% = 1 TO NumDeflectors%
                        INPUT #1, Deflections!(I%, SetCount%, DropCount%)
                NEXT I%
     CASE 1000 TO 2500          'history records
     CASE 5280, 5281            'GPS info
                LINE INPUT #1, Dummy$
     CASE 5301                  '1st station line
                IF LineCounter& < 40 THEN
                        LINE INPUT #1, Dummy$           'skip remainder, in header
                ELSE
                        IF DropCount% <> 0 AND DropCount% <> NumDeflectors% * NumReps% THEN
CALL BadFile
                        SetCount% = SetCount% + 1
                        DropCount% = 0
                        LINE INPUT #1, Dummy$           'skip remainder, in header
                END IF
     CASE 5302                  '2nd station line
                IF LineCounter& < 40 THEN
                        LINE INPUT #1, Dummy$           'skip remainder, in header
                ELSE
                        LINE INPUT #1, Dummy$           'skip remainder, in header
                END IF
     CASE 5303                  '3rd station line
                IF LineCounter& < 40 THEN
                        LINE INPUT #1, Dummy$           'skip remainder, in header
                ELSE
                        LINE INPUT #1, Dummy$           'skip remainder, in header
                END IF
     CASE 5185                  'sensor history block header
                LINE INPUT #1, Dummy$
     CASE ELSE
                'unexpected line found (customized?)
                LINE INPUT #1, Dummy$
   END SELECT
  LOOP
END SUB
```

```
SUB Quit STATIC
  CLOSE
  COLOR 7, 0, 0
  CLS
  PRINT : PRINT
  IF File$ <> "" THEN
   PRINT "       Output results are contained in file: "; FPath$ + File$ + OExt$
  END IF
  PRINT
  END
END SUB

SUB ReadNextLine (DataType%, LineLength%) STATIC
  STATIC OldDataType%
  IF NOT EOF(1) THEN
   LINE INPUT #1, LineData$
   DataType$ = LEFT$(LineData$, 1)
   DataType% = INSTR("SB'E*- 1234567890", DataType$)
   OldDataType% = DataType%
   LineCounter& = LineCounter& + 1
   IF DataType% = 4 THEN
    IF UCASE$(LEFT$(LineData$, 3)) = "EOF" THEN
                  DataType% = -1
    END IF
   END IF
  ELSE
   DataType% = -1                      'end of file occurred
  END IF
END SUB

SUB ReadPeaks
  SetCount% = SetCount% + 1
  FOR K% = 1 TO InitNumPeaks%
   CALL ReadNextLine(DataType%, LineLength%)
   SELECT CASE DataType%
    CASE -1                            'end of file encountered
                  EXIT FOR
    CASE 0, 4                          'unknown data in line #xxxx
                  EXIT FOR
    CASE 1
                  CALL ReadPeaks
                  EXIT SUB
    CASE 2                             'start of history block
                  EXIT SUB
    CASE 3                             'found a comment
                  EXIT FOR
    CASE 5                             'found subsection id
                  EXIT FOR
    CASE ELSE                          'normal processing
                  IF NOT English% THEN
                           MeasLoad!(SetCount%, K%) = VAL(MID$(LineData$, 1, 4))
                           FOR I% = 1 TO NumSensors%
                                    Positn% = I% * 4 + 1
                                    Deflections!(I%, SetCount%, K%) = VAL(MID$(LineData$,
Positn%, 4))
                           NEXT I%
                  ELSE
                           MeasLoad!(SetCount%, K%) = VAL(MID$(LineData$, 34, 5))
                           FOR I% = 1 TO NumSensors%
                                    Positn% = I% * 6 + 33
                                    Deflections!(I%, SetCount%, K%) = VAL(MID$(LineData$,
Positn%, 6))
                           NEXT I%
                  END IF
   END SELECT
  NEXT K%
END SUB

SUB ReplaceSensor STATIC
  'IF RepSens% < 1 OR RepSens% > 7 THEN          'Remarked HZ on 1/4/2001
  IF RepSens% < 1 OR RepSens% > NumSensors% THEN  'Changed to Number of sensors by HZ on 1/4/01
   EXIT SUB
  END IF
  MeanRepDef# = (SumTotal# - Ti#(RepSens%)) / ((NumSensors% - 1) * NumSensors% * NumReps%)
  FOR S% = 1 TO NumSensors%
   MeansRat#(SC%, S%) = MeanRepDef# / MeanDef#(S%)
   NewGain#(SC%, S%) = MeansRat#(SC%, S%) * RelGain#(S%)
```

```
   NEXT S%
   IF ABS(1 - MeansRat#(SC%, RepSens%)) > .003 THEN
    repm1$ = "* Means Ratio for REPLACED Sensor No." + STR$(SerialNum%(RepSens%)) + " is outside
the tolerance range."
    repm2$ = "* New Relative Gain for REPLACED Sensor No." + STR$(SerialNum%(RepSens%)) + " is "
   ELSE
    repm1$ = "* Means Ratio for REPLACED Sensor No." + STR$(SerialNum%(RepSens%)) + " is within
the tolerance range."
    repm2$ = "* New Relative Gain for REPLACED Sensor No." + STR$(SerialNum%(RepSens%)) + " is "
   END IF
END SUB

SUB SelectAnalysis STATIC
   CLS
   IF SetCount% > 1 THEN
    Choice% = 3
   ELSE
    Choice% = 1
   END IF
   DO
    REDIM Item$(4)
    Title$ = " Select Analysis Type "
    Item$(1) = "Standard Analysis "
    Item$(2) = "Replace a Geophone "
    Item$(3) = "Reference-Relative Calibration (3 data sets in file)"
    Item$(4) = "Quit Program          "
    CALL BarMenu(Title$, Item$(), Choice%, 0)
    SELECT CASE Choice%
     CASE 1
                    Analysis$ = "S"
                    EXIT DO
     CASE 2
                    Analysis$ = "G"
                    EXIT DO
     CASE 3
                    Analysis$ = "R"
                    EXIT DO
     CASE 4
                    SCREEN 0: WIDTH 80, 25: CLS
                    CLOSE
                    CALL NormalColor
                    PRINT
                    PRINT "Program terminated by the user"
                    END
     CASE ELSE
                    REDIM PUText$(1)
                    PUText$(1) = "Please Select an Option"
                    CALL PopupError
    END SELECT
   LOOP
END SUB

SUB StartAnalysis STATIC
   'IF InitNumPeaks% = 0 THEN InitNumPeaks% = NumDeflectors% * NumReps%    'Remarked by HZ on
1/3/2001
   REDIM DefData!(MaxSensors%, MaxPositions%, MaxSetups%, MaxReps%)        'Added by HZ on
1/3/2001
   REDIM OutDef!(MaxSensors% * MaxReps%, MaxSensors%)                      'Added by HZ on
1/3/2001
   InitNumPeaks% = NumDeflectors% * NumReps%
   FOR Sets% = 1 TO SetCount%
    StringSpace& = FRE("")
    SCREEN 0: WIDTH 80, 25: CLS : CALL NormalColor
    SELECT CASE Analysis$
     CASE "S"
                    anat1$ = "Standard relative calibration analysis is being performed"
                    anat2$ = "on data set " + STR$(Sets%) + " in file " + FPath$ + File$ + Ext$
     CASE "G"
                    anat1$ = "Replacement geophone relative calibration analysis is being
performed"
                    anat2$ = "on data set " + STR$(Sets%) + " in file " + FPath$ + File$ + Ext$
     CASE "R"
                    anat1$ = "Relative calibration analysis as part of Reference calibration is
being"
                    anat2$ = "performed on data set " + STR$(Sets%) + " in file " + FPath$ +
File$ + Ext$
    END SELECT
```

```
    LOCATE 12, 40 - LEN(anat1$) / 2: PRINT anat1$
    LOCATE 13, 40 - LEN(anat2$) / 2: PRINT anat2$
    SLEEP 3
    SC% = Sets%
    Setup% = 1: RCount% = 0
    CALL AssignPosition(Setup%, Posit%())
    FOR M% = 1 TO InitNumPeaks%
      RCount% = RCount% + 1
      FOR I% = 1 TO NumSensors%
                     J% = Posit%(I%)
                     DefData!(I%, J%, Setup%, RCount%) = Deflections!(I%, Sets%, M%)
                     OutDef!(M%, I%) = Deflections!(I%, Sets%, M%)
      NEXT I%
      LoadData!(M%) = MeasLoad!(Sets%, M%)
      IF RCount% MOD NumReps% = 0 THEN
                     RCount% = 0
                     Setup% = Setup% + 1
                     CALL AssignPosition(Setup%, Posit%())
      END IF
    NEXT M%
    CALL LatinSqDesign
    IF Analysis$ = "G" AND RepSens% > 0 THEN
      CALL ReplaceSensor
    END IF

    CALL Cochran          'Added by HZ on 1/3/2001

    CALL OutputToFile
    IF Analysis$ <> "R" THEN
      CALL FileToScreen
    END IF
   NEXT Sets%
END SUB
```

APPENDIX C

Latin Square Analysis of Variance (ANOVA)

Latin Square ANOVA

The Latin Square experiment design layout for the relative calibration test is shown in Table 1. In this design, the sensor number S_i represents the treatment for each combination of drop set and stand position. Drop set represents the 5 drop sequence used to test each combination of sensor and stand position. For purposes of classification, within each cell in the experiment design the measured deflections are designated as $\ddot{a}_{ijkl}$ where *i* represents the sensor number, *j* represents the position in the stand, *k* represents the drop set, and *l* represents the repeat drops in each drop set. An equivalent and more convenient designation for the deflection values is $\ddot{a}_{ikl}$ where the subscripts are the same as above. This is because position in the stand is dependent on sensor number and drop set. All combinations of *i, j, k*, and *l* do not exist in the data set.

Table 1. 9x9 Latin square design for relative calibration analysis.

Position in Stand	Drop Set								
	1	2	3	4	5	6	7	8	9
1	S_1	S_9	S_8	S_7	S_6	S_5	S_4	S_3	S_2
2	S_2	S_1	S_9	S_6	S_5	S_6	S_4	S_4	S_3
3	S_3	S_2	S_1	S_9	S_8	S_5	S_6	S_5	S_4
4	S_4	S_3	S_2	S_1	S_9	S_8	S_6	S_6	S_5
5	S_5	S_4	S_3	S_2	S_1	S_9	S_8	S_7	S_6
6	S_6	S_5	S_4	S_3	S_2	S_1	S_9	S_8	S_7
7	S_7	S_6	S_5	S_4	S_3	S_2	S_1	S_9	S_8
8	S_8	S_7	S_6	S_5	S_4	S_3	S_3	S_1	S_9
9	S_9	S_8	S_7	S_6	S_5	S_4	S_4	S_4	S_1

The response model for the relative Latin square experiment Design is:

$$\delta_{ijkl} = \mu + \alpha_j + \beta_k + \tau_i + \varepsilon_{ijkl} \qquad \textbf{(7)}$$

where,

δ_{ijkl} = Observed deflection response for sensor *i*, in position *j*, for drop set *k*, and repeat drop number *l*.
α_j = Effect of stand position *j*.
β_k = Effect of drop set *k*.
τ_{ti} = Effect of sensor *i*.
ε_{ijkl} = random error.

The following restriction are imposed on the effects as follows:

$$\sum_{j=1}^{NumPos} \alpha_j = \sum_{k=1}^{NumSets} \beta_k = \sum_{i=1}^{NumSets} \tau_i = 0 \quad \textbf{(8)}$$

where,

NumPos = Number of positions in the stand.

The δ_{ijkl} are assumed to have a normal distribution with means

$$\mu_{ijk} = \mu + \alpha_j + \beta_k + \tau_i \quad \textbf{(9)}$$

and with a common variance σ^2.

The following three hypothesis are tested with the Latin Square ANOVA:

1. H'_0: $\alpha_1 = \alpha_2 = \cdots = \alpha_{NumPos} = 0$
   H'_1: At least one α_j is not equal to zero, i.e. position is significant.

2. H''_0: $\beta_1 = \beta_2 = \cdots = \beta_{NumSet} = 0$
   H''_1: At least one β_k is not equal to zero, i.e. set is significant.

3. H'''_0: $\tau_1 = \tau_2 = \cdots = \tau_{NumSens} = 0$
   H'''_1: At least one τ_i is not equal to zero, i.e. sensor is significant.

The sum of squares identity can be written as:

$$SST = SSp + SSd + SSs + SSE \quad \textbf{(10)}$$

where,

SST = Total sum of squares
SSp = Position sum of squares
SSd = Drop Set sum of squares
SSs = Sensor sum of squares

SSE = Error sum of squares

Since the position subscript *j* is dependent upon the sensor number subscript *i* and drop set subscript *k*, it is convenient to show the computing formulas for the sum of squares using the following notation:

$T_{i\cdots}$ = Sum of all deflections for sensor *i*.
$T_{\cdot j\cdot}$ = Sum of all deflections for position *j*.
$T_{\cdot\cdot k\cdot}$ = Sum of all deflections for drop set *k*.
$T_{\cdots\cdot}$ = Sum of all deflection measurements.

The computational formulas for the sum of squares can be written as follows.

$$SST = \sum_{i=1}^{NumSens} \sum_{k=1}^{NumSets} \sum_{l=1}^{NumReps} \delta_{ikl}^2 - \frac{T_{\cdots\cdot}^2}{(NumPos \times NumSets \times NumReps)} \quad \textbf{(11)}$$

$$SSp = \frac{\sum_{j=1}^{NumSets} T_{\cdot j\cdot}^2}{(NumPos \times NumReps)} - \frac{T_{\cdots\cdot}^2}{(NumPos \times NumSets \times NumReps)} \quad \textbf{(12)}$$

$$SSd = \frac{\sum_{k=1}^{NumSets} T_{\cdot\cdot k\cdot}^2}{(NumSets \times NumReps)} - \frac{T_{\cdots\cdot}^2}{(NumPos \times NumSets \times NumReps)} \quad \textbf{(13)}$$

$$SSs = \frac{\sum_{i=1}^{NumSens} T_{i\cdots}^2}{(NumSens \times NumReps)} - \frac{T_{\cdots\cdot}^2}{(NumPos \times NumSets \times NumReps)} \quad \textbf{(14)}$$

$$SSE = SST - SSp - SSd - SSs \quad \textbf{(15)}$$

The mean square error estimates are computed as follows.

$$S_{Position}^2 = \frac{SSp}{(NumPos - 1)} \quad \textbf{(16)}$$

$$S_{Set}^2 = \frac{SSd}{(NumSets - 1)} \quad \textbf{(17)}$$

$$S^2_{Sensor} = \frac{SSs}{(NumSens - 1)} \quad \textbf{(18)}$$

$$S^2 = \frac{SSE}{[(NumReps \times NumPos \times NumSets) - 3(NumPos) + 2]} \quad \textbf{(19)}$$

The computed F values are

$$F_{Position} = \frac{S^2_{Position}}{S^2} \qquad F_{Set} = \frac{S^2_{Set}}{S^2} \qquad F_{Sensor} = \frac{S^2_{Sensor}}{S^2} \quad \textbf{(20)}$$

For the LTPP relative calibration test with nine sensors (Dyna25), each main effect being tested has 8 degrees of freedom, the error term has 380 degrees of freedom, and the critical F statistic at the 5% confidence level is 1.96.

For the LTPP relative calibration test with seven sensors (Version 10/20), each main effect being tested has 6 degrees of freedom, the error term has 226 degrees of freedom, and the critical F statistic at the 5% confidence level is 2.14.

The computed F values are compared to the critical F statistic. If a computed F value is less than the critical F statistic, then the corresponding $\boldsymbol{H_0}$ hypothesis is accepted and the effect is judged not to be statistically significant at the 5% level. If the computed F value is greater than the critical F statistic, then the corresponding $\boldsymbol{H_0}$ hypothesis is rejected and the effect is indicated as being statistically significant.

APPENDIX D

Version 10/20 Figures

Line No.	File Contents
	Column 1111111111222222222233333333334444444444555555555556666666667777777778 12345678901234567890123456789012345678901234567890123456789012345678901234567890
1	R80 73 910814RCAL42B 36F10
2	700031018002-05876173.1803111 6
3	150 0 203 305 457 610 914 1524 5.9 0 8 12 18 24 36 60
4	C:\FWD\DATA\ .FWD
5	
6	S 0 30 29 38 86 84 Heights .....
7	S 0 30 29 74 86 84 Heights .....
8	796 1934273037300 0
9	18 15 4 5 2 15 2 8
10	Ld 110 1 89.9
11	D1 801 1.015 1.059
12	D2 802 1.011 1.093
13	D3 803 1.013 1.066
14	D4 804 1.014 1.045
15	D5 805 1.011 1.126
16	D6 808 1.009 1.079
17	D7 807 1.01 1.059
18	D0 810 1.015 1.130
19	D0 809 1.008 1.089
20	D0 3015 1.025 1.026
21	DOUGLAS J. MARSHALL
22	11020600.....
23	0 0 0 0 .....
24	*
25	
26	
27	*
28	.....
29	16388 -4839 0 .....32 0 .....
30	123P45678P90123P45678P90123P45678P90123P45678S.....
31	BBBP22222P22222P22222P22222P22222P22222P22222S11111111111111111144444444444444444
32	.....
33	....*****.*****.*****.*****.*****.*****.*****.**********************************
34	.....
35	.....
36	RELATIVE CALIBRATION.....
37	*

Figure D1. Example of Version 10 FWD header block (Version 20 similar)

File Contents

```
                                                  Column
         1111111111222222222233333333334444444444555555555566666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890

S       0           30 29 I61356    86  84  Heights ..........................
 540 656 659 660 659 660 663 664  8576 25.81 25.93 25.98 25.95 25.99 26.10 26.15
 544 661 665 666 665 667 668 671  8648 26.03 26.19 26.23 26.20 26.26 26.32 26.40
 546 663 665 667 668 669 671 672  8680 26.11 26.19 26.27 26.28 26.35 26.40 26.44
 544 657 660 662 660 663 664 665  8640 25.86 25.97 26.06 25.99 26.08 26.15 26.19
 545 657 659 661 660 661 664 665  8656 25.86 25.93 26.02 25.99 26.04 26.15 26.19
 536 644 644 648 647 647 648 644  8512 25.35 25.36 25.51 25.49 25.46 25.50 25.35
 544 658 659 661 659 661 662 657  8640 25.90 25.93 26.02 25.95 26.04 26.06 25.86
 544 656 654 658 657 658 660 654  8640 25.81 25.75 25.89 25.86 25.90 25.97 25.73
 543 660 660 662 661 663 664 658  8632 25.98 25.97 26.06 26.03 26.08 26.15 25.90
 542 660 660 663 662 664 665 659  8616 25.98 25.97 26.10 26.07 26.13 26.19 25.94
 534 648 648 651 651 650 645 649  8496 25.52 25.49 25.64 25.61 25.59 25.37 25.56
 544 662 660 665 665 663 658 663  8640 26.07 25.97 26.19 26.20 26.08 25.89 26.11
 543 659 657 661 662 659 655 660  8632 25.94 25.89 26.02 26.07 25.95 25.80 25.98
 543 655 653 657 656 656 651 655  8624 25.77 25.71 25.85 25.82 25.82 25.63 25.77
 542 656 655 659 658 657 653 657  8616 25.81 25.80 25.93 25.91 25.86 25.72 25.86
 535 647 645 649 651 642 647 649  8504 25.48 25.41 25.55 25.61 25.28 25.46 25.56
 542 658 656 660 661 652 658 659  8616 25.90 25.84 25.98 26.03 25.68 25.89 25.94
 542 657 656 661 660 651 656 659  8616 25.86 25.84 26.02 25.99 25.64 25.85 25.94
 541 658 657 662 661 652 658 660  8592 25.90 25.89 26.06 26.03 25.68 25.89 25.98
 541 661 660 664 664 656 661 663  8600 26.03 25.97 26.15 26.16 25.82 26.02 26.11
 535 643 643 645 643 642 642 645  8504 25.31 25.32 25.38 25.32 25.28 25.29 25.39
 543 651 653 654 651 651 651 655  8624 25.64 25.71 25.76 25.61 25.64 25.63 25.77
 541 648 646 650 647 644 647 648  8600 25.52 25.45 25.59 25.49 25.37 25.46 25.52
 542 652 652 654 652 647 651 652  8616 25.69 25.67 25.76 25.66 25.46 25.63 25.69
 543 651 652 653 651 650 650 652  8632 25.64 25.67 25.72 25.61 25.59 25.59 25.69
 535 647 646 644 646 648 647 649  8496 25.48 25.45 25.34 25.45 25.50 25.46 25.56
 542 660 659 657 657 659 660 661  8616 25.98 25.93 25.85 25.86 25.95 25.97 26.02
 542 657 655 653 655 656 656 659  8616 25.86 25.80 25.72 25.78 25.82 25.85 25.94
 542 660 659 655 657 658 660 661  8608 25.98 25.93 25.81 25.86 25.90 25.97 26.02
 542 660 659 655 658 659 660 662  8616 25.98 25.93 25.81 25.91 25.95 25.97 26.07
 535 650 643 650 650 648 650 652  8504 25.60 25.32 25.59 25.57 25.50 25.59 25.69
 540 657 650 658 656 655 658 660  8576 25.86 25.58 25.89 25.82 25.77 25.89 25.98
 540 657 650 657 656 655 658 660  8592 25.86 25.58 25.85 25.82 25.77 25.89 25.98
 542 658 651 658 657 656 659 660  8608 25.90 25.62 25.89 25.86 25.82 25.93 25.98
 540 657 650 657 656 655 658 659  8584 25.86 25.58 25.85 25.82 25.77 25.89 25.94
```

Figure D2. Excerpt from a Version 10 FWD relative calibration data block (Version 20 same).

SHRP FWD Relative Calibration - Analysis of Variance - Means and Gains Table
FWD SN: 8002-058 Calibration Date: 08-14-1991
Data File Name: RCAL42B.FWD Data Set 1 of 1
Operator: DOUGLAS J. MARSHALL

Sensor #	Sensor S/N	Existing Gain Factor	Means Ratio	New Relative Gain	Out of Limit Tolerance	Out of Limit 2% Range
1	801	1.015	1.0010	1.016	NO	NO
2	802	1.011	1.0028	1.014	NO	NO
3	803	1.013	0.9986	1.012	NO	NO
4	804	1.014	0.9993	1.013	NO	NO
5	805	1.011	1.0013	1.012	NO	NO
6	808	1.009	0.9995	1.008	NO	NO
7	807	1.010	0.9976	1.008	NO	NO

Figure D3. Example print of output file for the Gains Table (Version 10/20).

SHRP FWD Relative Calibration - Analysis of Variance - Latin Square ANOVA Table
FWD SN: 8002-058 Calibration Date: 08-14-1991
Data File Name: RCAL42B.FWD Data Set 1 of 1
Operator: DOUGLAS J. MARSHALL

Variation Source	Sum of Squares	Degrees of Freedom	Mean Square	Computed F	Critical F
Position	4.84E-02	6	8.06E-03	0.22	2.14
Set	5.62E+00	6	9.36E-01	25.00	2.14
Sensor	4.45E-01	6	7.41E-02	1.98	2.14
Error	8.46E+00	226	3.74E-02		
TOTAL	1.46E+01	244			

No gain adjustments are indicated, but drop set is statistically significant at the 5% level. This can be due to warming of the buffers or consolidation of pavement materials during the test. Review the data carefully. If anything appears suspect, repeat the calibration after conditioning the FWD buffers with 50+ drops from height 3. If the deflections from the last 10 drops vary more than 1 mil (25.4 microns), repeat the calibration at a new location.

Figure D4. Example print of output file of the ANOVA Table (Version 10/20).

Relative Calibration - Input Data

FWD SN: 8002-058 Calibration Date: 08-14-1991

Data File Name: RCAL42B.FWD Data Set 1 of 1

Operator: DOUGLAS J. MARSHALL

Set #	Drop #	Load lbf	Deflections Df1	Df2	Df3	Df4	Df5	Df6	Df7
1	1	8,576	25.81	25.93	25.98	25.95	25.99	26.10	26.15
1	2	8,648	26.03	26.19	26.23	26.20	26.26	26.32	26.40
1	3	8,680	26.11	26.19	26.27	26.28	26.35	26.40	26.44
1	4	8,640	25.86	25.97	26.06	25.99	26.08	26.15	26.19
1	5	8,656	25.86	25.93	26.02	25.99	26.04	26.15	26.19
2	1	8,512	25.35	25.36	25.51	25.49	25.46	25.50	25.35
2	2	8,640	25.90	25.93	26.02	25.95	26.04	26.06	25.86
2	3	8,640	25.81	25.75	25.89	25.86	25.90	25.97	25.73
2	4	8,632	25.98	25.97	26.06	26.03	26.08	26.15	25.90
2	5	8,616	25.98	25.97	26.10	26.07	26.13	26.19	25.94
3	1	8,496	25.52	25.49	25.64	25.61	25.59	25.37	25.56
3	2	8,640	26.07	25.97	26.19	26.20	26.08	25.89	26.11
3	3	8,632	25.94	25.89	26.02	26.07	25.95	25.80	25.98
3	4	8,624	25.77	25.71	25.85	25.82	25.82	25.63	25.77
3	5	8,616	25.81	25.80	25.93	25.91	25.86	25.72	25.86
4	1	8,504	25.48	25.41	25.55	25.61	25.28	25.46	25.56
4	2	8,616	25.90	25.84	25.98	26.03	25.68	25.89	25.94
4	3	8,616	25.86	25.84	26.02	25.99	25.64	25.85	25.94
4	4	8,592	25.90	25.89	26.06	26.03	25.68	25.89	25.98
4	5	8,600	26.03	25.97	26.15	26.16	25.82	26.02	26.11
5	1	8,504	25.31	25.32	25.38	25.32	25.28	25.29	25.39
5	2	8,624	25.64	25.71	25.76	25.61	25.64	25.63	25.77
5	3	8,600	25.52	25.45	25.59	25.49	25.37	25.46	25.52
5	4	8,616	25.69	25.67	25.76	25.66	25.46	25.63	25.69
5	5	8,632	25.64	25.67	25.72	25.61	25.59	25.59	25.69
6	1	8,496	25.48	25.45	25.34	25.45	25.50	25.46	25.56
6	2	8,616	25.98	25.93	25.85	25.86	25.95	25.97	26.02
6	3	8,616	25.86	25.80	25.72	25.78	25.82	25.85	25.94
6	4	8,608	25.98	25.93	25.81	25.86	25.90	25.97	26.02
6	5	8,616	25.98	25.93	25.81	25.91	25.95	25.97	26.07
7	1	8,504	25.60	25.32	25.59	25.57	25.50	25.59	25.69
7	2	8,576	25.86	25.58	25.89	25.82	25.77	25.89	25.98
7	3	8,592	25.86	25.58	25.85	25.82	25.77	25.89	25.98
7	4	8,608	25.90	25.62	25.89	25.86	25.82	25.93	25.98
7	5	8,584	25.86	25.58	25.85	25.82	25.77	25.89	25.94

Figure D5. Example print of output file of input file listing (Version 10/20).

Relative Calibration - Summary Statistics

FWD SN: 8002-058 Calibration Date: 08-14-1991
Data File Name: RCAL42B.FWD Data Set 1 of 1
Operator: DOUGLAS J. MARSHALL

	Load	Df1	Df2	Df3	Df4	Df5	Df6	Df7	Df1-7
Set 1 Av	8,640	25.93	26.04	26.11	26.08	26.14	26.22	26.27	26.12
Set 2 Av	8,608	25.80	25.80	25.92	25.88	25.92	25.97	25.76	25.86
Set 3 Av	8,602	25.82	25.77	25.93	25.92	25.86	25.68	25.86	25.83
Set 4 Av	8,586	25.83	25.79	25.95	25.96	25.62	25.82	25.91	25.84
Set 5 Av	8,595	25.56	25.56	25.64	25.54	25.47	25.52	25.61	25.56
Set 6 Av	8,590	25.86	25.81	25.71	25.77	25.82	25.84	25.92	25.82
Set 7 Av	8,573	25.82	25.54	25.81	25.78	25.73	25.84	25.91	25.77

Overall Statistics

	Load	Df1	Df2	Df3	Df4	Df5	Df6	Df7	Df1-7
Average	8,599	25.80	25.76	25.87	25.85	25.79	25.84	25.89	25.83
Std Dev	49	0.21	0.24	0.23	0.23	0.27	0.27	0.25	0.24
COV, %	0.57	0.79	0.91	0.89	0.90	1.03	1.06	0.98	0.95

Position in Stand

	1	2	3	4	5	6	7
Avg Df	25.84	25.82	25.81	25.82	25.84	25.82	25.86
Std Dev	0.24	0.24	0.24	0.24	0.25	0.24	0.27
COV, %	0.92	0.95	0.94	0.92	0.97	0.94	1.04

Figure D6. Example print of output file of summary statistics (Version 10/20).

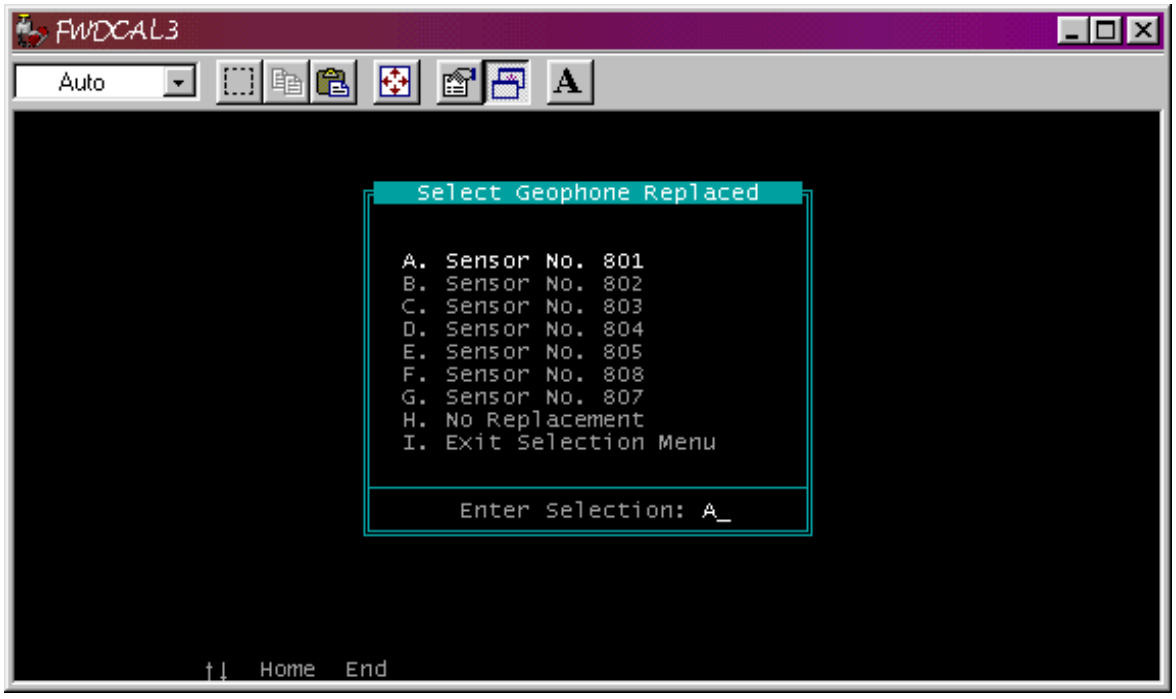


Figure D7. Select Geophone Replaced Screen (Version 10/20).

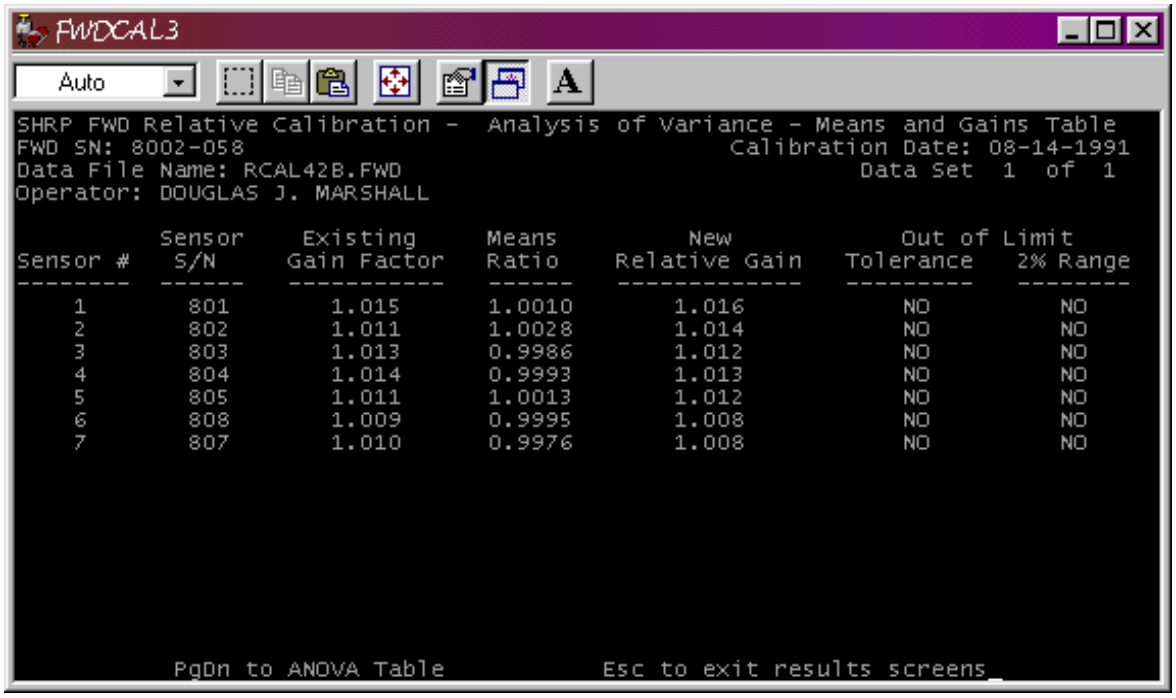


Figure D8. Gains Table Output Screen (Version 10/20).

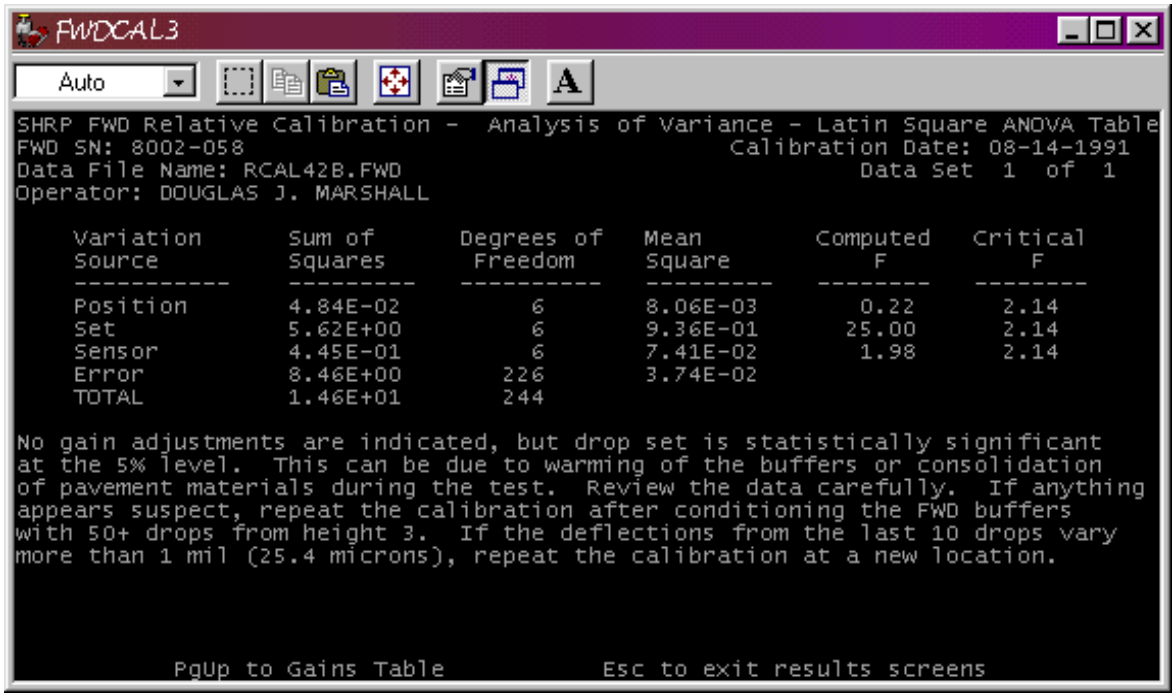


Figure D9. ANOVA Table Output Screen (Version 10/20).