DEVELOPMENT OF RECOMMENDATIONS AND GUIDELINES FOR PAVEMENT REHABILITATION DESIGN PROCEDURES FOR THE STATE OF IDAHO

PHASE 1: SOFTWARE EVALUATION AND DATA ANALYSIS

Submitted to:

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INTRODUCTION

1.1 General

The most important factor in the analysis of pavement structure is to accurately characterize the material properties. Non-destructive testing of pavements is becoming more popular for characterizing the material properties in terms of pavement layers moduli, as the structural capacity of the pavement can be evaluated without disturbing or destroying its components. The contribution which the non-destructive testing can make to the industry are increased productivity, increased serviceability, safety, identification of material properties and low cost. Many types of non-destructive techniques are available, for example Benkelman beam, dynaflect, road rater and falling weight deflectometer. Out of these, falling weight deflectometer has become more popular due to its ability to impose dynamic loading similar to that of truck tire. The deflections at different offsets are recorded and these deflections are used to backcalculate the pavement layers moduli. Several computer programs are available to calculate the elastic modulus of each pavement layer using backward analysis of multi-layer elastic theory.

The non-destructive testing is done in two ways: 1) The measurement of surface deflection and 2) Wave propagation. The pavement surface deflection is widely used because it is easy to measure. The loading is imposed on the pavement surface and the pavement surface deflections are measured at different offsets from the center line of load using geophones or sensors. The deflections are then used to predict the pavement layers moduli.

In this technique the pavement section is modeled by linear elastic theory, non-linear finite element method or any other method. It is assumed that a unique set of solution for the pavement layers moduli exists. This set of solution is determined by the technique called backcalculation.

1.2 Problem Statement

The Idaho Transportation Department (ITD) is currently investigating into the use of existing computer software for the design of pavement overlays. Use of the existing programs, for instance: MODULUS and EVERCALC has indicated significant variation in the calculated moduli values of existing pavement surface layers. Some of the reasons may have been due in part to errors in the deflection data and/or the back calculation scheme in these programs. A recent cooperative research effort between UI and ITD (ITD Project No. 91-21) indicated the need for a good correlation between cracking condition of the existing asphalt layer and its modulus. This will enable better overlay design for cracked pavements where prediction of moduli values are quite inaccurate. The problem can be identified as:

- There is a need in the State of Idaho to develop and improve the existing methods of overlay deign to incorporate the insitu pavement layers moduli which are typically predicted from non-destructive deflection testing using Falling Weight Deflectometer (FWD).
- How can the existing backcalcualtion programs be used to predict insitu pavement layers moduli with minimum error possible?
- What is needed to modify these programs, if such modification is warranted, to improve the use of these programs?
- How can the results of these programs be incorporated in an overlay/inlay design system?

1.3 Objectives

The overall objective of this project has been stated as to develop design procedures for pavement rehabilitation including inlay and overlay design for the State of Idaho. To achieve the overall objective at least two phases were suggested. In the first phase, study of the existing

software using FWD data from several pavement sections in the State of Idaho was planned

The specific objectives of Phase 1 are :

1) Survey the exiting programs available at ITD. This includes one or more but not limited to MODULUS, and EVERCALC backcalculation computer programs, and DAMA and AASHTO DNPS 86 pavement design computer software.
2) Investigate the existing Falling Weight Deflectometer (FWD) data at ITD and verify moduli calculation using the designated programs.
3) Identify possible causes of deviations and errors which may be the cause for erroneous prediction of the moduli values.
4) Develop recommendations for possible improvement(s).

CHAPTER II

PROJECT PLAN

The plan adopted in this phase of the project was to identify set of pavement sections to represent different possibilities that may face the design engineer when an overlay or an inlay rehabilitation alternative is needed. In addition, these sections would represent wide spectrum of cases for running the backcalculation software. Deflection data from FWD testing are then obtained and incorporating it in running the computer programs. Sensitivity analysis is performed and as well as comparison between the used programs. Details of this plan is followed:

2.1 Selected Sections

Several pavement sections were selected by the ITD research team to represent different pavement sections combination. Table 2.1 summarize the selected sections. The following combinations are existing in the selected sections:

a. Thick AC over thick base

U30D0399 (Stations 399.000 to 378.430)

I90D0045 (Stations 45.540 to 41.520)

U30A0378 (Stations 378.430 to 399.000)

b. Thin AC over thick base

I15A0063 (Stations 63.200 to 66.400)

I15D0066 (Stations 66.400 to 63.200)

S08D0036 (Stations 26.317 to 36.310)

U95A0423 (Stations 423.680 to 424.60)

c. Thick AC over thin base

I84A0136 (Stations 136.000 to 140.900) by combining the top two asphalt layers (9.6")

Table 2.1: Selected Sections for the Analysis

ROUTE	DISTRICT #	COMPUTER FILES	MILE POST		LOCATION	THICKNESSES	
			BEGINNING	END		SECTION 1	SECTION 2
I-84	4	I84A0136.FWD/OUT I84D0140.FWD/OUT	136.0 140.9	140.9 136.0	BLISS WEST - BLISS EAST	136.0 - 140.9" t1 = 4.8" PMX t2 = 4.8" PMX t3 = 3.6" UNTRT	140.9" - 136.0 4.8" PMX 4.8" PMX 3.6" UNTRT
US-30	5	U30A378.FWD/OUT U30D0399.FWD/OUT	378.43 399.0	399.0 378.43	LUND - ALEXANDER	378.43 - 399.0 t1 = 7.6" PMX t2 = 26.4"UNTRT	399.0 - 378.43 7.6" PMX 26.4" UNTRT
I-90	1	I90D0045.FWD/OUT	45.54	41.52	SHOSHONE COLINE - PINE CREEK	45.54 - 41.52 t1 = 9.6" PMX t2 = 8.4" UNTRT	-------
I-84	4	I84A0173.FWD/OUT I84D0177.FWD/OUT	173.5 177.67	174.64 174.64	NOT AVAILABLE	173.5 - 174.64 t1 = 4.8" PMX t2 = 4.8" CTB t3 = 8" UNTRT	177.67 - 174.64 4.8" PMX 4.8" CTB 13.2"UNTRT
US 95	1	U95A0423.FWD/OUT U95D0428.FWD/OUT	423.68 428.82	424.6 424.6	MICA FLATS - COEUR D'ALENE	423.68 - 424.6 t1 = 3.6" PMX t2 = 24" UNTRT	428.82 - 424.60 3.6" PMX 3.6" UNTRT
SH-8	2	S08D0076.FWD/OUT	36.31	26.317	INTER. DEARY - INTER BOVILL	36.31 - 26.317 t1 = 2.4" PMX t2 = 12" UNTRT	-------
I-15	5	I15A0063.FWD/OUT I15D0066.FWD/OUT	63.2 66.4	66.4 63.2	PORTNENT I.C. - SO. 5TH I.C.	63.2 - 66.4 t1 = 4.8" PMX t2 = 13.2"UNTRT t3 = 12" UNTRT	66.4 - 63.2 4.8" PMX 13.2" UNTRT 12" UNTRT

* PMX = Plant mix.
UNTRT = Untreated.
CTB = Cement treated base.

I84D0140 (Stations 140.900 to 136.000) by combining the top two asphalt layers (9.6")

d. Thin AC over thin Base

U95D0428 (Stations 428.820 to 424.600)

e. AC Surface over Cement Treated Base (CTB)

I84A0173 (Stations 173.500 to 174.600)

I84D0177 (Stations 177.600 to 174.737)

2.2 Software Selection and Utilization

The plan included a major task to study the existing computer programs for backcalculation techniques. Two programs were selected from the literature survey on the exciting computer programs for backcalculation (Chapter III). These programs are MODULUS 4.0 (Developed by Texas Transportation Institute, TTI for Texas DOT) and EVERCALC 3.3 (Developed by University of Washington for Washington DOT). For each file obtained these programs were to run using three-layer system or four-layer system and for both cases for some pavement sections.

2.3 Sensitivity Analysis

Preliminary investigation of the FWD files at the Idaho Transportation Department indicated vast variation in the MODULUS 4.0 results when different input ranges were used. Therefore two files were used extensively to investigate the program sensitivity to these input ranges.

2.4 Data Analysis and Development of Recommendations

Files obtained from ITD are then used to develop output data. The data is then analyzed to identify possible causes of programs errors and the means to minimize these errors if possible. A set of recommendations is then developed to how these programs can be best used and what modifications may be needed.

CHAPTER III

REVIEW OF BACKCALCULATION SOFTWARE

The term backcalculation was used by several researchers to indicate a reverse calculation scheme of the multi-layer elastic analysis. In a forward calculation scheme, the pavement section as well as layers properties are known, and the program calculates stresses, strains and deflections. The reverse, however, is not a direct unique solution. For instance, when a known pavement section is used to determine pavement surface deflections under a selected load using a forward calculation computer program (e.g. CHEVRON, BISAR or WES5), the resulting deflections will be unique to that pavement under that load. Now when these deflections are used to predict backward the input layer moduli, the solution is not unique and infinite number of combinations of layers moduli values are obtained. Therefore research have been conducted for decades to develop programs that can reach a reasonable solution based on a preselected criteria. These programs, including MODULUS 4.0 and EVERCALC 3.3, use the multi-layer elastic analysis in an iterative technique and employ a conversion criteria to reach at an acceptable solution.

The theory of elastic analysis was forwarded by Boussinesq *(1)*. The theory was extended to the multi layered elastic analysis by Burmister *(2)*. The theory was further improved by Vesic *(3)* by describing the surface deflections more accurately.

A number of computer programs are available which uses multi layer elastic theory. In these programs, the pavement is considered as a multi layer elastic system under a circular load. The multi layer elastic theory has the following assumptions. (1) The layers are homogeneous and isotropic. (2) All the layers except the bottom one is finite. (3) The load is circular and static. (4) The materials are characterized by young's modulus and poison's ratio.

Experiments were made to compare the measured deflections, stress and strains with the calculated ones by multi layer elastic theory. It was found that they are in good agreement *(4)*.

Due to the complexity of the solution, the multi layer elastic theory was computerized to determine the deflections, stresses and strains due to circular load at different locations. These programs can be called forward calculation programs. Some of these programs are

CHEVRON, ELSYM5, BISAR, WES5 etc.

To determine the structural capacity of the pavement or the moduli of the pavement layer, an inverse technique is used. In this inverse technique, the deflections at different locations at the surface are used to backcalculate the pavement layers moduli. Like forward calculation programs, a number of backcalculation programs are available as MODULUS 4.0, EVERCALC 3.3, ELMOD, CHEVDEF, WESDEF, BOUSDEF etc.

3.1 MODULUS 4.0:

This program is developed by Texas Transportation Institute for the Texas Department of Transportation. This system is used when analyzing the deflection data measured by a Falling Weight Deflectometer (FWD).

Unlike most of the backcalculation computer programs, MODULUS is not an iterative program. It produces a data base of deflections using linear elastic program WES5 and matches the measured deflections with the calculated ones. The pavement layers moduli corresponding to the calculated deflections in the data base, which best matches with the measured deflections are considered to be the correct set of moduli for the pavement layers.

A criterion function is minimized to obtain a squared error. The criterion function is defined by

$$\epsilon^2 = \sum_{i=1}^{s} \frac{[w_i^m - w_i^c]}{w_i^m} \cdot w_{e_i} \qquad (1)$$

Where,

w_i^m = Measured deflection at sensor i.

w_i^c = Computed deflection at sensor i.

s = Number of sensors.

w_{ei} = User provided or program assigned weighing factor for sensor i.

Minimizing ϵ^2, we get

$$\textit{Minimize } \epsilon^2 = \sum_{i=1}^{s} \left|1 - \frac{w_i^c}{w_i^m}\right| . w_{e_i} \qquad (2)$$

Hooke-Jeeves function optimization program called Pattern Search program is used in MODULUS 4.0 to minimize this criterion function or objective function *(5)*. It should be noted that in MODULUS 4.0 the search program or optimization program searches for minimum squared error depending on moduli values only.

MODULUS uses a linear elastic program WES5 to generate a data base of computed deflection bowls, prior to fitting the measured bowls. The data base is generated for the whole pavement section once and the deflection bowl at each station is compared with the data base in the WES.RES file. The procedure make use of the properties of the linear-elastic solution by working in terms of modular ratios.

The linear elastic program WES5 is used to generate the deflection bowl data base, Using the data file TMP.WES. The number of Deflection bowls in the data base depends upon the user provided minimum and maximum moduli values and the number of pavement layers. The deflection bowl in the data base is written to a file called WES.RES. This file contains the pavement layer modular ratios and the deflection bowls calculated by WES5.

As stated earlier Hooke-Jeeves Pattern Search technique is used to minimize the criterion function. This technique finds the optimum solution for an objective function f(X1, X2, X3, ...,Xn) by changing the X_i values until the minimum squared error between measured and calculated deflections determined by the objective function is obtained *(5)*.

The main program utilizes the layer thicknesses, number of modular ratios for each layer,the minimum and maximum input values for the pavement layers moduli, from the file TMP.DEF. This information is used for running the WES5 program to calculate the deflection at each sensor location and the minimum and maximum moduli are used as check values to prevent the PATTERN SEARCH from changing the X_i (modulus) values beyond the rang of

values set by the user. Then the program generates a loop that is repeated for every observed deflection bowl *(5)*. PATTERN SEARCH calls subroutine EPS2 to calculate the error between the measured and calculated deflections in the data base and calculate E_{sg} using equation,

$$E_{sg} = \frac{p f_1 \sum_{i=1}^{s} \frac{f_i^2 \, We_i}{f_1^2 (We_i^m)^2}}{\sum_{i=1}^{s} \frac{f_i \, We_i}{f_i \, W_i^m}} \tag{3}$$

where E_{sg} = Subgrade modulus corresponding to a particular modular ratio

p = Actual pressure.

f_i = Function of modular ratios.

The subgrade moduli obtained by solving this equation is multiplied by the corresponding modular ratios in order to obtain the moduli of the pavement layers. These moduli are used as "seed moduli" and are then passed to the PATTERN SEARCH routine for further error minimization. The calculated subgrade moduli using the above equation is for a nominal pressure of 10 psi. This calculated subgrade modulus is then normalized for the actual pressure. Lagrange interpolation technique is used to calculate the deflection for the "seed moduli" *(5)*. The squared error between the calculated and measured deflections is computed and it is used by PATTERN SEARCH to determine how much and in which direction to change X_i values for the next iteration. When the program determines that the minimum squared error has been calculated, subroutine OUTPUT is called to convert the X_i values to pavement layer and subgrade moduli values *(5)*. The same procedure is repeated for every bowl. MODULUS does not store the results of the run, so it should be printed soon after the run.

3.1.1 Matching Measured Deflections With the Data Base in WES.RES File

The measured deflections by the program are compared with the deflection data base in the WES.RES file. The modular ratios, corresponding to the calculated deflection basin, which best matches the measured deflection basin, are taken and using the above equation, subgrade modulus for the nominal pressure of 10 psi and subgrade modulus 1 ksi is calculated *(5)*. Other pavement layers moduli are calculated based on the subgrade modulus and are normalized for the actual loading condition. As most of the time the subgrade modulus is more accurately calculated by the program, it shows that the problem lies in the normalization and interpolation process. A small error involved in subgrade modulus is magnified in the prediction of surface and base moduli values during the normalization and interpolation process.

3.1.2 Effects of Depth to Rigid Layer on Backcalculation Results

The depth to the rigid layer plays an important role in the in the backcalculation analysis. As stated by Uddin et al *(6)*.

"Ignorance of rigid bottom consideration may lead to substantial errors in the predicted moduli of pavement-subgrade system. The subgrade modulus may be significantly over predicted if a semi-infinite subgrade is falsely assumed, when actual bed rock exists at a shallow depth"

MODULUS 4.0 uses a method to determine the depth to an apparent rigid layer from surface deflections. The method to predict the apparent depth to a rigid layer is based on the hypothesis that the position of zero surface deflection should be strongly related to the depth in the pavement at which no deflection occurs *(7)*. Uzan et al.*(5)* showed that the best fit between the measured and calculated deflections occurs at a rigid layer placement at 300 inches below the surface. But it may be the case for a specific site only. So a better estimate should be done for the depth to the bedrock. Because the depth to the bedrock can have a significant effect on

the resulting backcalculated moduli, especially when the depth is shallow (i.e less than 20 ft). If the measured depth to the bedrock is considerably different from the actual depth, backcalculation usually results in large errors in matching the surface deflections *(8)*.

Although the backcalculated moduli can give an indication of the material stiffness under actual load conditions, the backcalculated moduli are model dependent. Therefore difference between the laboratory results and backcalculation results will always be found. It is suggested that if the rigid layer is predicted at a shallow depth, the top part of the subgrade should be modeled as an individual layer *(7)*.

3.1.3 Using MODULUS For Thin Pavements

For thin pavement especially with thin asphalt surface, the backcalculation results of all existing programs, including MODULUS and EVERCALC, are poor. Experiments have shown that acceptable moduli are backcalculated for the thick pavement sections. The errors in thin pavements are usually greater than 20 percent, indicating that linear elasticity does a relatively poor job at predicting deflections within thin pavements. This non-linearity of the thin pavement is probably is due to the stiffening of the underlying granular layers. Further the surface deflections are often insensitive to changes in the modulus of thin pavement surface *(4)*.

Sometimes the use of infinitely thick subgrade results in a backcalculated base modulus of lower than the subgrade modulus. This over-prediction of subgrade and under-prediction of base moduli is due to assumed thickness of subgrade . In order to match the surface deflections, a too thick subgrade may result in overpredicted stiffness. Another reason for this over-predicted subgrade modulus is the high weighing factors assigned to the outer sensors*(7)*.

3.2 EVERCALC 3.3

EVERCALC is a computer program developed at the University of Washington for the Washington State Department of Transportation. Similar to MODULUS 4.0, the program uses the deflections obtained by the Falling Weight Deflectometer (FWD) at different offsets from the center line of the load. EVERCALC calculates the elastic moduli for each pavement layer, determines the coefficients of stress sensitivity for unstabilized materials, stresses and strains at various depths, and normalizes asphalt concrete modulus to a standard load of 9000 lbs and standard temperature of 77 °F.

EVERCALC uses an inverse technique to determine elastic moduli from FWD pavement surface deflection measurements. It has the capability of evaluating a flexible pavement structure consisting of up to five layers. The program iterates moduli values and the deflections obtained using CHEVRON linear elastic program are compared with the measured deflections. The program terminates when the user provided conditions are reached (e.g. If the Average Root Mean Square (ARMS) error or the number of iteration or the allowable tolerance reaches its limit).

3.2.1 Convergence Scheme

EVERCALC is an iterative computer program. The seed Moduli are used as a input in CHEVRON program and the calculated deflections are compared with the measured ones. If the difference is within the range of allowable tolerance, then the moduli values are considered the correct moduli. If the difference is more, the input moduli values for the next iteration are adjusted based on the difference between the measured and calculated deflections. The adjustment process utilizes the seed moduli, prior iteration moduli and constant correction factor. Depending on the difference between the calculated and measured deflections, the next iteration uses the following equations *(9)*.

If the difference is positive,

$E_i^a = E_1^o * 0.5$ for the first iteration.

$E_i^a = (E_1^o * 3 + E_1^s / 10)/4$ for the later iterations.

If the difference is negative then,

$E_i^a = E_1^o * 1.5$ for the first iteration.

$E_i^a = (E_1^o * 3 + E_1^s / 10)/4$ for the later iterations.

Where,

E_i^a = Next modulus for the ith layer.

E_i^o = Previous modulus of the ith layer.

E_i^s = Seed modulus of the ith layer.

According to Lee *(9)*, the accuracy of results depends upon the number of deflection basins, offsets of the sensors, seed moduli and user provided program termination conditions.

The internal equation option (an internal equation in the program for the determination of the seed moduli) can give better results, although it increases the running time. This option can be helpful if seed moduli estimate can not be done accurately. But the internal equation option has some limitations. It can be selected if the pavement system is three-layer and no stiff layer option is selected. According to Lee *(9)*, the algorithm for determining the seed moduli requires the deflection measurements at the radial offsets (0,8,12,24 and 36 inches). If the deflection data is obtained at different offsets, the seed moduli should be user provided. Information on EVERCALC 3.3 documentation is not available , therefore it is not known that whether this condition for the internal equation option is still valid or not.

Since EVERCALC 3.3 normalizes for the 9000 lbs load level and determines the stress sensitivity co-efficients, it requires deflection data for two or more load levels bracketing 9000 lb.

3.2.2 EVERCALC 3.3 Modified to Run With ITD FWD Files

EVERCALC 3.3 is modified at the university of Washington to run with the FWD files of ITD. The conversion routine has been modified to work with ITD FWD data files. Options are provided to select the first, second, third, all or average of the drops at each station. The backcalculated moduli are not normalized if the load levels does not bracket 9000 lbs. K_1 and K_2 are freezed unless the maximum and minimum load levels at a station varies by at least 0.25 times maximum load.

3.2.3 Effect of the Depth to Rigid Layer on Backcalculation Results

Two main approaches for estimating the depth to the bedrock are available. The first approach is presented by Hossain and Zaniewski*(10)* and the second approach by Rohde and Scullion *(7)*. The later approach is used in MODULUS 4.0 and EVERCALC 3.3. A recent study conducted at the University of Washington *(11)*, has shown the significance of the later approach. The results of there study can be summarized as follows,

1) The stiff layer can be predicted at a saturated soil condition or water table even if there is no stiff layer.

2) If the boring logs data shows the saturated soil condition or water table, then the seed moduli for the stiff layer should be assumed to be about 40 ksi instead of 1000 ksi.
   (It should be noted that MODULUS assigns a modulus value of 1000 ksi to the stiff layer which can not be over ride).

3) Such conditions diminish below depths of about 10 feet.

3.2.4 Nonlinear Least Square Optimization

The use of non-linear least square optimization technique in EVERCALC is proposed by Sivaneswaran et al. *(12)*. This approach may improve the performance of the backcalculation, as it will backcalculate both the thicknesses and moduli of the pavement layers.

Criterion Function:

In EVERCALC the criterion function is defined as the function of the differences between the measured and the calculated model quantities. This criterion function can describe the accuracy of the model predicted parameters. An optimization process minimize the value of the criterion function. Therefore Selection of the appropriate criterion function strongly effects the accuracy of the backcalculation results.

The following criterion function is proposed by Sivaneswaran et al. *(12)*.
Sum of squared relative differences :

$$f(E,h)=\frac{1}{n}\sum_{i=1}^{n}\left|\frac{d_i^c(E,h)-d_i^m}{d_i^m}\right|^2 \qquad (4)$$

Where,

E = Unknown modulus.

h = Unknown layer thickness.

$d_i^c(E,h)$ = Calculated deflections as a function of E and h.

d_i^m = measured deflection at the ith sensor.

The optimization process solves the following problem.

$$\textit{Minimize } f(E,h) = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{d_i^c(E,h)-d_i^m}{d_i^m}\right|^2 \qquad (5)$$

A number of optimization methods can be used to solve the problem. The following optimization method is proposed to be adopted in EVERCALC at University of Washington. The relative error can be defined as ,

$$r_i(E,h)=\frac{d_i^c(E,h)-d_i^m}{d_i^m} \tag{6}$$

The criterion function can also be expressed as,

$$r_i(E,h)=\sum_{i=1}^{n}(r_i(E,h))^2=r^t r \tag{7}$$

Where $r = (r_1, r_2, \ldots\ldots\ldots)$

The gradient of the criterion function is,

$$\nabla f=2Ar. \tag{8}$$

The Hessian can be written as ,

$$H=\nabla^2 f=2AA^T+2\sum_{i=1}^{n} r_i \nabla^2 r_i \tag{9}$$

Where: $A = (\nabla r1, \nabla r2, \ldots, \nabla r)$

The gradient is equivalent to the slope and the Hessian is equivalent to the curvature of the function. The first part of the Hessian is evaluated as the gradient is known. The second part of the Hessian is not taken into consideration since it is negligible.

So the Hessian is approximated as

$$H = 2A\,A^T$$

Log E is used rather than E, to speed up the convergence. It should be noted that the second part of the Hessian which is neglected is not proven to be negligible.

Stress Sensitivity :

The modulus-stress relationship for subgrade and unbound materials are given by

$$E_b = K_1\theta^{k_2} \quad \textit{For coarse grained soils.} \tag{10}$$

$$E_s = K_3\sigma_d^{k_4} \quad \textit{for fine grained soils.} \tag{11}$$

Where σ_d = Deviatoric stress

θ = Bulk stress

The FWD data should be available for two or more load levels at a same point so that the program can determine the stress sensitivity factors, k_1, k_2, k_3 and k_4. Accuracy improves as more load levels are used at the same testing location.

Termination of the program :

The program terminates when any one of the following user provided conditions is reached.

1) Root Mean Square Tolerance

$$RMS = 100\sqrt{\frac{1}{n}\sum_{i=1}^{n}\left\{\frac{D_i^m - D_i^c}{D_i^m}\right\}} \le \textit{Deflection tolerence} \tag{12}$$

Where D_i^m and D_i^c corresponds to measured and calculated deflections at i^{th} sensor.

2) Moduli Tolerance

$$\epsilon_m = \left|\frac{E_i^{(k+1)} - E_i^{(k)}}{E_i^{(k)}}\right| \leq \textit{Modulus Tolerance.} \qquad (13)$$

Where, $E_i^{(k)}$ and $E_i^{(k+1)}$ are the ith layer Moduli at the k and (k+1) iteration, respectively. And m is the number of layers with unknown Modulus.

3) When the number of iterations reaches the user provided maximum number of iterations.

3.3 BISDEF

It was developed at Texas Transportation Institute by modifying the CHEVDEF program developed by the Corp of Engineers. In this program the modification was mainly the replacement of the CHEVRON layered elastic program with the BISAR Program*(13)*.

BISDEF structure is almost the same as the MODULUS. The difference in these programs is that BISDEF uses BISAR linear elastic program to calculate deflection and MODULUS uses WES5 program. Also these backcalculation programs use a different search routine (optimization) to find the optimum set of moduli values to minimize the error between the measured and predicted bowls. BISDEF is slower than MODULUS and it is not very suitable for the case where multiple bowls on the same section are to be processed *(5)*.

3.4 Precision of the Backcalculated Pavement Layer Moduli

The results of backcalculation vary among analysts because of the assumptions made in

each procedure and different input assigned by individual analysts. A study was conducted at Texas A&M University by Y.J Chou and Robert L. Lytton *(8)* to see the variation of results among analyst. Backcalculation results from different agencies using various procedures were compared. The results indicate that discrepancies among agencies can be large, however, a few agencies reached a good agreement in many cases.

The basic assumption of backcalculation is that, the Backcalculated layer moduli represent the material moduli in the field when the computed surface deflections match the measured deflections. A unique set of moduli values are assumed to be existed such that the theoretically calculated deflections are equivalent to the measured deflections. Because of the rounding and truncation error introduction during backcalculation it may be impossible to produce exactly the original layer moduli from a deflections generated by the linear elastic solution*(8)*.

Inaccurate layer thickness, subgrade depth input and the deviation of material behavior from linear elastic modelling prevents the use of small tolerance for surface matching error, because theoretical solution may not exist with the given model that matches the measured basin perfectly.

The objective of backcalculation is not to make surface deflections perfectly but to obtain a reasonably good assessment of the pavement layers moduli. Such an assessment can usually be achieved if other pertinent information for example layer thickness, subgrade depth and component, layer material type, pavement construction history and existing distress is used *(14)*. Without thorough knowledge of the pavement structure, achieving a good match of the calculated and measured surface deflection may not be meaningful.

Pavement materials are generally heterogeneous, anisotropic, and granular. Some material are highly stress dependent and some may become plastic or viscoelastic under high load and temperatures. All of these conditions are contradictory to the assumptions made in the linear elastic theory. The theoretical model need to be improved in simulating a material's nonlinear behavior. This problem may be overcome by the use of finite element method *(14)*.

The backcalculated subgrade moduli is most of the time reasonable. This is due to its greater depth from the surface and the fact that all the sensors are sensitive to its properties.

Many backcalculation programs including MODULUS and EVERCALC, determines the subgrade moduli first and then the other layers moduli are calculated based on the subgrade moduli. Therefore a small error in the subgrade moduli will magnify in the other pavement layers moduli. So the results of surface and base moduli are less reliable.

According to Y.J. Chou and Robert L. Lytton *(8)*, the error in backcalculation process can be divided into two types: random and systematic. Random error include variation of layer thickness from mean thickness, spatial variation of material properties and error in load and deflection measurement. Systematic errors include deviation of the theoretical model from actual pavement behavior (e.g using a linear elastic layer system to describe real pavement that may be nonlinear, viscoelastic, anisotropic and nonhomogeneous and using static analysis to characterize dynamic impulse loading), inaccurate assumed material properties such as poisson's ratios and incorrectly assumed layer thickness and subgrade depth.

The random error can be reduced by the repetition of the test and taking the average. But the systematic errors are difficult to separate. Some systematic errors can be reduced only by a better analysis method than current layer elastic theory. But other systematic errors can be reduced with a better knowledge of actual pavement behavior and limitations of the analysis method. The use of an expert system will make the program more easy to use by a less expert analyst.

According to Ulditz *(15)*,

"The subgrade usually contributes 60 % to 80 % of the total center deflection. A small error in the determination of the subgrade modulus will, therefore, lead to very large errors in the moduli of the other pavement layers."

The input values required for backcalculation are the layers thicknesses, poisson's ratios, minimum and maximum moduli, maximum number of iterations, depth to bedrock, error tolerance etc. Sensitivity analysis of these parameters have shown that all these parameters have significant effects on the backcalculation. The pavement surface modulus is the most sensitive, followed by base and subbase layer moduli. Subgrade moduli shows less variation. The error is present even if the exact moduli of the pavement system are provided as input *(16)*.

3.5 Dynamic Analysis of Backcalculation

All of the existing backcalculation programs estimate the pavement layers moduli by comparing the measured deflections with the calculated deflections by the static analysis. The programs iterate the pavement moduli in the static model and then vary the moduli until a reasonable match between the measured and theoretical deflections is obtained. This solution ignores the dynamic nature of these nondestructive tests. Chang, et al. found out that when dynamic effects occur in the measurements but are not taken into account in the analysis, the modulus of the subgrade is generally underestimated, sometimes by 50 % or more and the moduli of the base and surface layers are overestimated *(17)*. Dynamic effects can influence the magnitude of the deflections and the shape of the deflection basin obtained in the Dynaflect and FWD tests. This effect is a function of depth to bedrock and the material properties when there is a sharp discontinuity in the modulus of subgrade and that of the bedrock. For the FWD, dynamic amplifications occur only for much smaller depths to bedrock, compared to Dynaflect. On the other hand if the depth to the bed rock is greater, then the dynamic deflections will be smaller than the static ones. In this case the backcalculated moduli values of the pavement layers by the static analysis would be overestimated.

Magnuson et al. *(18)* pointed out the following points in support of the Dynamic analysis.

1) In dynamic analysis the time-dependent wave phenomena in the pavement layers is taken into account, which makes the results more accurate.

2) In the elasto-static analysis, only the peak values of the falling weight deflectometer pulses are used. While more information can be extracted in dynamic analysis as all the information in the falling weight deflectometer time-pulse data will be used in the backcalculation.

3) Dynamic analysis characterize the viscoelastic properties of the AC surface layer by

creep compliance functions in the time domain and complex moduli in the frequency domain. Static analysis is limited to elastic modeling because viscoelastic phenomena are inherently dynamic.

4) Because of the additional data available, dynamic analysis is more sensitive to pavement layer properties . So more accurate backcalculation results can be obtained.

In static analysis the dynamic deflection basin caused by the FWD is assumed to be static and the instantaneous pavement deflection at a given point is assumed to be proportional to the instantaneous force on the pavement surface. Therefore in static analysis only the peak values of the force and deflection pulses are used. The FWD time-pulse data contain more information on the pavement layers that can not be extracted without a dynamic analysis program.

CHAPTER IV

ANALYSIS OF THE BACKCALCULATION RESULTS

4.1 Sensitivity analysis of MODULUS 4.0 :

The MODULUS 4.0 backcalculation program requires the minimum and maximum moduli input values for surface, base, subbase and subgrade layers. The program sensitivity towards these input values is studied in detail. Data files **I90D0045** and **I84D0177** are selected to perform a detail sensitivity analysis. MODULUS 4.0 program was run by three-layer system as well as four-layer system. In the Four-layer system E_1, E_2, E_3 and E_4 represent the surface, base, subbase and subgrade moduli respectively. In the Three-layer system, E_1, E_2, and E_3 represent the surface, base and subgrade moduli respectively.

4.1.1 Using Data File I90D0045

The pavement section I90D0045 represents a case of thick surface layer over thick base layer. The details of the section are presented in Table 2.1. The file is run by following six input conditions. Each of these six analysis will be discussed separately.

Case 1

The data file I90D0045 was run by four-layer system for one mile post making the upper limit of E_1, E_2, E_3 , E_4 and subgrade depth values as a variable respectively. The objective of this analysis is to see the variation of results with respect to E_1, E_2, E_3 , E_4 and subgrade depth.

The upper limit of E_1 value is taken as a variable and E_2, E_3 and E_4 are kept constant at a reasonable values. It is seen that the results become consistent after the upper E_1 value of 1000 ksi (Figure. 1). So the upper E_1 value 1100 ksi is selected for input as it gives the minimum absolute error per sensor. By varying the upper limit of E_2 , it is seen that it has no

effect on the calculated moduli of all layers (Figure 2). A input value of 200 ksi is selected for the upper limit of E_2.

The variation of the upper limit of E_3 shows that the results have minimum error per sensor when the upper limit of E_3 value is in the range of 40 ksi to 60 ksi(Figure 3). So the upper limit of E_3 value of 40 ksi is selected as input.

The variation of E_4 shows that the results are consistent and reasonable for the range between 15 ksi to 35 ksi (Figure 4). So E_4 value of 20 ksi is selected as the proper value for input.

By varying the subgrade depth, starting from 20 inches to infinity, it is seen that at the subgrade depth closer to 57", that is assigned by the program, the results are better (Figure 5). The program is very sensitive to the depth to the rigid layer. No continuity can be seen by varying the depth to the stiff layer.

Thus following are the recommended values for the upper limits of the moduli which will be used in further analysis,

E_1 = 1100 ksi

E_2 = 200 ksi

E_3 = 40 ksi

E_4 = 20 ksi

When these input values were provided for running the program for all mile posts, it is seen that the results are different even for the same mile post. This is because the average depth to the bedrock is different when running the program for one mile post and running the program for all mile posts.

Case 2

The Data file I90D0045 was run by four-layer system for all mile posts making upper limit of E_1 as a variable. The purpose of this analysis is to see the variation of results at all mile posts with the variation in the input values of the upper limit of E_1. It is seen that the variation in result is less or acceptable at some mile posts and drastic at others. e.g, less variation in the

backcalculated E_1 values is seen at the mile posts # 1, 3, 4, 10, 12, 15, 16, 17, 18, 19, 23, 24, 25, 27, 28, 34, 35, and 36 (Figure 6). The average of these backcalculated E_1 values at these mile posts can be taken and can be assumed for other mile posts.

For E_2 the results are consistent at mile posts # 1, 3, 4, 5, 10, 12, 17, 18, 19, 23, 24, 25, 27, 28, 34, 35 and 36(Figure 7). It should be noted that these are the same mile posts which give consistent results for E_1. The average of E_2 results for these mile posts can be taken and can be assumed for other mile posts.

For the backcalculated E_3 values it is seen that the results are consistent at almost all the mile posts specially for the mile posts which gives consistent results for surface and base layers moduli (Figure 8).

For the backcalculated E_4 values it is seen that the results are consistent at almost all the mile posts specially for the mile posts which gives consistent results for surface, base and sub-base layers moduli (Figure 9). Average moduli at these mile posts can be assumed for other mile posts which give drastic results.

Case 3

The data file was run by four-layer system for all mile posts making the upper limit of E_1 as a variable and restricting E_2 value to 100 ksi. This analysis is the same as case 2 but here the upper limit of E_2 value is 100 ksi.

The E_1 results are the same as in case 2 (Figure 10). So the same kind of averaging can be done in these runs. E_2 results are a little bit different than the results of analysis # 2, where the max.E_2 input value is 200 ksi. The difference is that the backcalculated base moduli are less in this case. But the same mile posts which shows consistency (as described earlier), the variation is less (Figure 11). The E_3 results does not show any significant variation specially at the mile posts which give consistent results (Figure 12). For the E_4, less variation in the results are found at different mile posts specially at the mile posts which shows less variation in results for surface, base and sub-base layers moduli (Figur 13).

Case 4

The data file was run by three-layer system for one mile posts making the upper limits of E_1, E_2 and E_3 (subgrade modulus in three-layer system) as a variable respectively. This analysis is done by making the pavement as a three-layer system (as is the actual condition) for one mile post only. First, the upper limit of E_1 value is taken as a variable and keeping the other inputs the same, several runs were made. Secondly several runs were made making the upper limit of E_2 as a variable and keeping other input values constant. The same is done with the E_3 in put value.

It was found that for the upper limit of E_1 input value as a variable, the results were consistent for the input value greater than 1000 ksi. A max.E_1 input value of 1100 ksi is considered appropriate. Upper limit of E_2 value of 200 ksi and E_3 input value of 20 ksi is considered appropriate. For the three-layer system the results are more consistent for a wide range of moduli input (Figure 14,15,16), specially the results of E_2 and E_3.

Case 5

The data file I90D0045 was run by three-layer system for all mile posts making the upper limit of E_1 as a variable. The same set of moduli input as obtained in the analysis case 4 were used to run the program for all mile posts. The upper limit of E_1 is the variable in these runs.

Effect of the upper limit of E_1 input value on E_1 backcalculated values is quite significant except for some mile posts that are mile post # 1, 2, 3, 4, 10, 12, 15, 16, 18, 23, 24, 25, 27, 28, 34, 35 and 36, which are the same mile posts that give less variant or consistent results for four-layer system (Figure 17).

The effect of variation of E_1 input value on the results of base moduli is much less as is seen in the four-layer system, specially for the mile posts which gives less variant results at different input values of E_1 (Figure 18).

The backcalculated results of subgrade moduli are more consistent at almost all the mile posts (Figure 19). This can be expected because MODULUS, as well as other backcalculation computer programs, calculates the subgrade modulus first and then calculates other pavement

layers moduli depending upon the subgrade modulus. So a little error in the backcalculation of subgrade modulus can be enlarged in the pavement layers moduli.

Case 6

Run by three-layer system for all mile posts making the upper limit of E_1 as a variable and restricting E_2 value to 100 ksi. Several runs were made keeping the upper limit of E_1 value as the variable and other input values as constant. This analysis is the same as # 5 except that max E_2 input is equal to 100 ksi.

The results show that the effect on the backcalculated values of E_1 is more drastic than that for max E_2 input of 200 ksi. This indicates that in MODULUS, by restricting E_2, the E_1 value values try to increase and the variation of results at different mile posts are also very high (Figure 20).

Since upper E_2 input value is 100 ksi, E_2 results are restricted at 100 ksi. The backcalculated values are less than that at max E_2 input value of 200 ksi (Figure 21). Although the results of E_3 are almost the same as that for the max E_2 input value of 200 ksi, a little variation in result is observed (Figure 22). This shows that when the depth to the bedrock is predicted at a shallow depth then the top 24" of the subgrade should be considered as separate layer.

Conclusion of the Experimental Runs on File I90D0045

At this point, the following conclusions are reached,

1) For a pavement section like in I90D0045, it is recommended that if the depth to the bedrock (either known or estimated) is less than 15 feet, then the top 24" of the subgrade should be taken as a separate layer and the problem should be considered as a four-layer system. Otherwise three-layer system would be an acceptable representation with minimum error.

2) At least 4 runs are to be made for each file using the following recommended limits,

For the four-layer system, input moduli ranges:

	Minimum	Maximum
E_1 =	100 ksi	1000, 1500, 1750, 2000 ksi
E_2 =	10 ksi	150 ksi
E_3 =	4 ksi	60 ksi
E_4 =	20 ksi	

For three-layer system, input moduli ranges:

	Minimum	Maximum
E_1 =	100 ksi	1000, 1500, 1750, 2000 ksi.
E_2 =	10 ksi	150 ksi
E_3 =	20 ksi	

The results are then investigated to identify those mile posts which give consistent results. The backcalculated moduli values of all runs for E_1, E_2, E_3 and E_4 at each milepost should be averaged. The average moduli values for each layer calculated from these mile posts can be considered representitive for those mile posts which show high variation for the recommended runs.

3) The backcalculated moduli values which reach the limit are not reliable.

4.1.2 Using Data File I84D0177

The pavement section I84D0177 represents a pavement section including cement treated base. The details of the section are presented in Table 2.1. This file is run by following six input conditions. Each of these six analysis will be discussed separately.

Case 1

Run by four-layer system (i.e. the actual pavement section) for all mile posts making max E_1 input value as a variable. The purpose of this analysis is to see the variation of results at all mile posts with the variation in the input values of max.E_1.

Effects on E_1 results are indicated in Figure 23, 24. The variation in the backcalculated E_1 value is drastic. But for some mile posts (i.e.# 2, 4, 6, 7, 9, 12, 13, 14, 15, 16, 17, 20, 23, 24, 26, 28 and 29), the backcalculated E_1 values show less variation . E1 values at these mile posts can be averaged to obtain a representative E_1 value for mile posts. The average E_1 value shown in the Figure 24 is the average value at all the mile posts, which is not a good estimate, because it takes into account some very high values. Only the average E_1 values at the mile posts which shows consistent results (and most of the times, the values are low) should be taken into account. The same is true for E_2, E_3 and E_4 values (Figure 25,..30).

Case 2

Run by four-layer system (i.e the actual pavement section) for all mile posts making max E_1 and max E_2 input value as a variable and providing a high maximum input values to them. The purpose of these runs is to see the variation in results by the variation in the max E_1 and max E_2 input values. All of these runs give almost the same results specially at some mile posts.

Case 3

Run by four-layer system (i.e combining CTB with the sub-base and making the top 24" of the subgrade as a separate layer), making max E_1 and max E_2 input value as a variable and

providing a high maximum input values to them. By combining the CTB with the sub-base and making the top 24" of the subgrade as a separate layer, the results are not reasonable. Because it gives very low backcalculated values for the CTB.

Case 4

Run by three-layer system (i.e combining the sub-base with the subgrade), making max E_1 input value as a variable. By combining sub-base with the sub-grade and making E_1 input value as a variable, the following observations were made.

The variation in the E_1, E_2 and E_3 backcalculated values are much more drastic than that in the four-layer system, which is strange in a sense that usually the variation is less in three-layer system. This shows that the sub-base should not be combined with the subgrade for making it three-layer system (Figure 31,...36).

Case 5

Run by three-layer system (i.e combining the CTB with the sub-base), making max E_1 and max E_2 input value as a variable and providing a high maximum input values to them. By combining sub-base with the subgrade and making E_1 and E_2 as a variable, it is seen that the results are not acceptable and the variation in the results are drastic. This again tells that the sub-base should not be combined with the subgrade.

Case 6

Run by three-layer system (i.e combining the sub-base with the subgrade), making max E_1 and max E_2 input value as a variable and providing a high maximum input values to them. By combining CTB with the sub-base and providing high E_1 and E_2 values, it is clear that the results are not acceptable because the program assigns very low value to the CTB. This indicates the CTB should not be combined with the sub-base.

Conclusions of the Experimental Runs on File I84D0177

At this point, the following conclusions are reached,

1) For the pavement section like I84D0177, which involves CTB, the program should only be run by four-layer system that is the actual pavement section. It is recommended that several runs should be made using the following sets of input moduli ranges,

	Minimum	Maximum
E_1 =	100 ksi	1000, 1500, 1750, 2000 ksi
E_2 =	100 ksi	1000, 2000 ksi
E_3 =	4 ksi	60 ksi
E_4 =	15 ksi	

Those mile posts should be observed which give consistent results. The results of E_1, E_2, E_3 and E_4 values should be averaged at these mile posts respectively. For the mile posts which show high variations, the average of these average values can be taken and assumed for them.

2) E_1 backcalculated values should be more carefully calculated than the other moduli values.

3) The backcalculation results are poor for the pavement sections which involve CTB.

4.1.3 Summary of Sensitivity Analysis

During this study, the sensitivity of the backcalculation programs were observed towards different input values required by the program. Following conclusions were made as a result of this analysis.

1) MODULUS is more suitable for use in three-layer system. If possible, the pavement section should be modeled as three-layer for better results. But the sub-base should not be combined with the subgrade and CTB should not be combined with the sub-base.

2) The thicknesses of the pavement layers should be as accurately input as possible. The results of backcalculation involve more errors if the pavement section is thin (specially if the surface layer is less than 3" and the subgrade is weak. Better results were observed for thicker pavements.

3) The depth to the bedrock greatly effects the results. If it is not known then let the program calculate it. When the rigid layer is predicted at a shallow depth (i.e. less than 7 or 8 ft), then the top 24" of the subgrade layer should be considered as a separate layer.

4) MODULUS 4.0 is highly sensitive to input moduli ranges. This sensitivity, however, is much less for input subgrade modulus. It was observed that, even with correct values of seed moduli, the program still shows varied results. It was also observed that varying the lower limit of the input moduli ranges did not effect the results by the same degree of varying the upper limit.

5) Less variation is observed in the calculated subgrade modulus because the program uses a closed form equation to predict the subgrade modulus from the deflections of the far sensors (i.e. 6th and 7th sensor). On the other hand, backcalculated moduli of other layers (which are the function of subgrade moduli) are estimated by numerical iteration. Therefore, it is concluded that high variation in the backcalculated moduli of upper layers may be due to the numerical interpolation scheme.

6) The calculated moduli by MODULUS 4.0 is for the testing temperature and load.

7) The program should be run several times with different input values. Those mile posts which give consistent or less variant results should be observed. The backcalculated E_1, E_2, E_3 and E_4 values should be averaged respectively for those mile posts which give consistent results. The overall average of these average values can be assumed for those mile posts which don't give consistent results. This can be done by importing the .DAT files in a spread sheet software. It is noted that the mile posts which show less variations are generally associated with reasonable backcalculated moduli values. Therefore the average of the backcalculated moduli values at these mile posts can safely be assumed for other mile posts.

4.2 Comparison of the two Programs Using SHRP Guidelines

SHRP guidelines for moduli backcalculation were used to determine the input parameters for the backcalculation programs MODULUS and EVERCALC (Table 4.1). These guidelines were basically developed for MODULUS but can be used with the same success for EVERCALC. A summery of these guidelines is presented as follows.

Asphalt concrete

In most of the cases, the mix data (aggregate grading, maximum and bulk specific gravity of mix, asphalt content) is not available. In this situation, the following equation is given by SHRP to determine the initial moduli for the AC layer.

Table 4.1: Estimated initial, minimum and maximum moduli values for: surface, base, subbase and subgrade using SHRP guidelines.

a) Asphalt Concrete Surface Course

File Name	%Pass #200	Freq Hz	AV %	Visc. Code	Mid depth Temp. F	AC %	Initial E (ksi)	Minimum E (ksi)	Maximum E (ksi)	Modulus Used, ksi	
										Min.	Max.
I90D0045	6	16	4	1	45	6	1477	369	4431	400	3000
I84A0173	6	16	4	1	93	6	208	52	624	60	700
I84D0177	6	16	4	1	60	6	914	229	2742	300	2700
S08D0036	6	16	4	1	103	6	119	30	356	30	400
I15A0063	6	16	4	1	74	6	523	131	1570	150	1500
I15D0066	6	16	4	1	74	6	523	131	1570	150	1500
U30A0378	6	16	4	1	117	6	50	12	149	15	150
U30D0399	6	16	4	1	81	6	381	95	1142	100	1200
I84A0136	6	16	4	1	87	6	284	71	852	100	900
I84D0140	6	16	4	1	87	6	284	71	852	100	900
U95A0423	6	16	4	1	51	6	1237	309	3712	300	3000
U95D0428	6	16	4	1	54	6	1124	281	3372	300	3000

Table 4.1 (Continued) : Estimated initial, minimum and maximum moduli values for: surface, base, subbase and subgrade using SHRP guidelines.

b) Base / Subbase

File Name	Base Type and Moduli Values, ksi				Subbase Type and Moduli Values, ksi			
	Type	Initial	Minimum	Maximum	Type	Initial	Minimum	Maximum
I90D0045	Crushed Agg. Base, CAB	50	10	150				
I84A0173	Cement Treated Base, CTB	1000	100	3000	Gravel	20	5	80
I84D0177	Cement Treated Base, CTB	1000	100	3000	Gravel	20	5	80
S08D0036	Crushed Agg. Base, CAB	50	10	150				
I15A0063	Crushed Agg. Base, CAB	50	10	150				
I15D0066	Crushed Agg. Base, CAB	50	10	150				
U30A0378	Crushed Agg. Base, CAB	50	10	150				
U30D0399	Crushed Agg. Base, CAB	50	10	150				
I84A0136	Crushed Agg. Base, CAB	30	10	100				
I84D0140	Crushed Agg. Base, CAB	50	10	150				
U95A0423	Crushed Agg. Base, CAB	50	10	150				
U95D0428	Crushed Agg. Base, CAB	50	10	150				

Table 4.1 (Continued) : Estimated initial, minimum and maximum moduli values for: surface, base, subbase and subgrade using SHRP guidelines.

c) Subgrade

File Name	Load lbs.	Deflections (mils) at offset (in)						Composite Moduli (ksi) at Offset (in)						Modulus Used, ksi
		8	12	18	24	36	60	8	12	18	24	36	60	
I90D0045	12,482	7.49	6.44	5.76	4.90	4.04	2.74	60	46	35	31	25	22	20
I84A0173	10,924	11.64	9.36	7.39	6.03	4.31	2.37	34	28	24	22	20	22	20
I84D0177	11,155	16.89	13.54	10.29	7.70	4.83	2.00	24	20	17	17	18	27	17
S08D0036	11,497	12.70	11.40	9.65	8.39	6.45	3.33	33	24	19	16	14	17	16
I15A0063	12,120	6.24	5.79	4.86	4.20	3.44	1.96	70	50	40	35	28	30	30
I15D0066	11,596	9.66	7.47	5.06	3.60	2.31	1.22	43	37	37	39	40	46	35
U30A0378	11,572	16.73	15.34	13.21	11.07	7.66	3.80	25	18	14	13	12	15	12
U30D0399	8,183	8.16	7.07	5.59	4.72	3.17	1.58	36	28	23	21	21	25	20
I84A0136	11,175	5.88	5.14	4.33	3.49	2.46	1.29	68	52	41	38	36	41	35
I84D0140	11,691	15.92	13.26	9.98	7.28	3.85	1.17	26	21	19	19	24	48	18
U95A0423	11,604	18.42	16.06	12.52	9.54	5.60	1.98	23	17	15	15	17	28	15
U95D0428	11,691	7.98	7.14	5.97	4.56	3.33	1.54	53	39	31	31	28	36	28

$$\log_{10}[E_o] = 0.553833+0.028829*P_{200}*f^{-0.17033}-0.03476*V_a+0.070377*\eta_{70,10^6} +0.000005*[t_p^{(1.3+0.49825\log(f))}*P_{ac}^{0.5}]-0.00189[t_p^{(1.3+0.49825*\log(f)}*P_{ac}^{0.5}*f^{-1.1}] +0.931757*f^{-0.02774} \quad (14)$$

Where;

E^o = AC modulus,*10^5 psi.

V_a = Percent air voids in mix.

f = Test frequency.

t_p = Mid depth AC layer temperature (in Fahrenheit)

P_{200} = Percent Aggregate weight passing the No.200 Sieve.

$\eta_{70,10^6}$ = Asphalt viscosity at 70 °F.

P_{ac} = Percent asphalt content by weight by weight of mix.

All parameters except mid depth AC temperature, need to be assumed as provided in SHRP guidelines. The most sensitive parameter in this equation is temperature. To avoid the use of this cumbersome equation, a chart has been prepared to determine the initial AC layer moduli (Figure 53). The minimum moduli can be assumed as 1/4 of initial moduli and maximum moduli as 3 times initial moduli.

Unbound Materials

Both the programs are not very sensitive to the base moduli rang. Although a table has been prepared by SHRP to determine the moduli ranges of base and subbase, an initial moduli of 50 ksi, minimum moduli of 10 ksi and maximum moduli of 150 ksi can be assumed for the base and for the subbase, an initial moduli of 30 ksi, minimum moduli of 10 ksi and maximum moduli of 80 ksi can be used.

Subgrade

The subgrade moduli at all sensor locations, except the sensor at zero offset from the load, are estimated by the SHRP's equation and the lowest value is selected as an input for backcalculation programs. The equation is given as follows,

$$E = \frac{P_c * a_c^2 * (1-\mu^2) * C}{def * r} \tag{15}$$

Where: P_c = contact pressure; a_c = load plate radius; μ = poison's ratio; def = radial distance from the center of plate.

$C = 1.1 \log (r/a_c) + 1.15$ or $C = 0.5*\mu + 0.875$

(Lower value should be used).

All the ITD deflection data files were used to run MODULUS and EVERCALC. The pavement sections having CTB were modeled as four-layer system as they can not be modeled as three-layer system. All the other pavement sections were modeled as three-layer system. The untreated base and subbase were combined as one layer and the AC surface and AC base course were combined as one layer.

Graphical Representation

A comparison of the results between the two programs is performed graphically by importing the .DAT files from MODULUS and .SUM files from EVERCALC in QUATTRO PRO 4.0 to plot the backcalculation moduli values (fig. 37...48). These twelve figures are for the twelve files (sections) considered in our analysis. It is to be noted that most of these are modeled as three-layer system. Only two sections with CTB (I84A0173 and I84D0177) were modeled as four-layer system. These figures indicate that the results of the two programs have reasonable agreement especially for bases and subgrade. However, more differences were observed between the two programs in the surface AC layer moduli.

Statistical Analysis

A more objective analysis on the comparison of the two programs is performed using a hypothetical t-test on the significance of the difference between the results of the two programs. The t-test is performed as follows:

H_o : There is no significant difference between the two programs i.e. $\bar{d} = 0$.

$H_a : \bar{d} \neq 0$

X_M = Mean backcalculated moduli by MODULUS.

X_E = Mean backcalculated moduli by EVERCALC.

Decision : Reject H_o if $|t| > t_{\alpha/2}$

$t = \bar{d} / (s_d/\sqrt{n})$

Where:

$\bar{d}$ = mean of the difference between the backcalculated moduli at each mile post (i.e. mean of $(X_M - X_E)$ distribution).

n = number of mile posts.

s_d = standard deviation.

$\alpha = 0.05$.

The results of the statistical analysis for all files are summarized in Tables (4.2, 4.3 and 4.4). The analysis indicates that for most of the sections there is no significant difference between the backcalculated moduli values for base and subgrade by the two programs. The surface layer moduli predicted by the two programs are quite different unless they are restricted by upper or lower limit. Both programs show good match between the backcalculated moduli values for all layers of the section U30A0378 which is the thickest section. Very poor match was observed for the sections I84A0173 and I84D0177 (Both have CTB). For example, for section I84A0173, EVERCALC predicted a subgrade modulus of 29 ksi while MODULUS predicted 8 ksi. Sections I84A0136 and I84D0140, where the top two AC layers were combined as one layer, show poor comparison. Another bad comparison was observed for section U95D0045 which is a very thin section.

Table 4.2: Statistical analysis of AC layer backcalculated moduli by the two programs.

File No.	X_M (ksi)	X_E (ksi)	$\bar{d}$	s_d	n	|t|	$t_{\alpha/2}$	Decision
I90D0045	1296	1080	206	253	37	4.95	2.02	No.
I84A0173	156	183	-27	142	12	0.67	2.17	Yes. (CTB)
I84D0177	500	312	188	188	19	4.3	2.02	No. (CTB)
S08D0036	396	394	2	44	110	0.47	2.02	Yes. (Thin, Reaches limit)
I15A0063	306	236	70	58	31	6.7	2.02	No.
I15D0066	486	402	84	86	38	6.0	2.03	No.
U30A0378	145.5	143	2.5	13.8	99	1.8	2.0	Yes. (Thick section)
U30D0399	500	449	51	146	99	3.5	2.0	No. (Thick section)
I84A0136	241	345	-104	116	49	6.23	2.0	No.
I84D0140	367	487	-120	174	50	4.88	2.0	No.
U95A0423	2727	2929	-201	550	10	1.15	2.22	Yes.
U95A0428	1493	2150	-657	1229	40	3.38	2.0	No. (Thin section)

Note: Yes means there is no significant difference.
No means there is significant difference.

Table 4.3: Statistical analysis of base/subbase layer backcalculated moduli by the two programs.

File No.	X_M (ksi)	X_E (ksi)	$\bar{d}$	s_d	n	|t|	$t_{\alpha/2}$	Decision
I90D0045	98	115	-17	49	36	2.0	2.01	Yes.
I84A0173 (Base) (Subbase)	 130 44	 100 9.5	 30 34	 42 24	 4 12	 1.42 5	 2.77 2.17	 Yes.(Reaches lower limit,CTB) no.
I84D0177 (Base) (Subbase)	 115 35	 100 43	 15 -8	 10.9 11.9	 5 30	 3 3.6	 2.7 2.01	 No. (CTB) No.
S08D0036	60	55	5	12	104	4.2	1.98	No.
I15A0063	62	67	-5	15.6	36	1.9	2.04	Yes.
I15D0066	60	66	-6	18	36	2.0	2.03	Yes.
U30A0378	33	31	2	10	99	1.9	2.0	Yes.
U30D0399	28.9	29.1	-0.2	7	99	0.2	2.0	Yes.
I84A0136	128	150	-22	31	49	-4.9	2.0	No. (X_E reaches upper limit)
I84D0140	116	150	-34	34.4	50	6.9	2.0	No. (X_E reaches upper limit)
U95A0423	90	81	9	13	10	2.18	2.22	Yes.
U95A0428	103	148	-45	40	40	7.1	2.0	No.

Note: Yes means there is no significant difference.
No means there is significant difference.

Table 4.4: Statistical analysis of subgrade backcalculated moduli by the two programs.

File No.	X_M (ksi)	X_E (ksi)	$\bar{d}$	s_d	n	|t|	$t_{\alpha/2}$	Decision
I90D0045	15.76	15.59	0.17	3.81	40	0.29	2.02	Yes.
I84A0173	8	29	-21	7.6	12	9.57	2.17	No.
I84D0177	6.8	6.3	0.5	2.3	30	1.1	2.02	Yes.
S08D0036	9.7	9.8	-0.1	2.79	110	0.38	1.98	Yes.
I15A0063	11.9	9	2.9	9.1	36	1.9	2.04	Yes.
I15D0066	12	10.4	1.6	8.5	36	1.12	2.03	Yes.
U30A0378	7.6	7.3	0.3	3.5	99	0.85	2.0	Yes.
U30D0399	8.8	8.04	0.76	3.9	99	1.9	2.02	Yes.
I84A0136	16.4	14.1	2.3	4.0	49	4.0	2.0	No. (Two AC combined)
I84D0140	15	12.8	2.2	3.95	50	3.9	2.0	No. (Two AC combined)
U95A0423	9.9	14.4	-4.5	3.0	10	4.7	2.22	No.
U95A0428	19.9	18.4	1.5	5	40	1.89	2.0	Yes.

Note: Yes means there is no significant difference.
No means there is significant difference.

The backcalculated base modulus by EVERCALC is higher than MODULUS for most of the pavement sections. In general, both programs predicted good comparable results for base and subgrade moduli if the pavement section was thick and did not have cement treated base.

General Remark

Analysis of all files did not reveal strong recommendations in relation to which program leads to more realistic results. However, close investigation of the deflection basin with predicted moduli values indicates that the EVERCALC predicted values are more reasonable than those of MODULUS because they are in good agreement with the deflection curves.

Another important point need to be mentioned here is that in some cases the absolute error per sensor in MODULUS is less than the ARMS values in EVERCALC. It does not necessarily mean that the calculated deflections by MODULUS match better with the measured deflections than the calculated deflections by EVERCALC. This is because MODULUS predicts the subgrade moduli for the nominal pressure of 10 psi and the other pavement layers moduli are calculated based on the subgrade moduli (modular ratios) and are normalized for the actual loading condition.

4.3 Subsectioning of Pavement Sections Based on SCI

As described earlier, MODULUS estimates the depth to the bed rock at each station and use the average for running the program. Since it is known that the program is very sensitive to the depth to bedrock, the pavement section was divided into more uniform subsections.

The deflection data from .OUT files were imported into a spread sheet program (QUATRO PRO 4.0) and the Surface Curvature Index (SCI) was calculated as:

$$SCI = (R_2 - R_3) / R_2$$

Where R2 and R3 are the surface deflections at sensors number 2 and 3 respectively.

SCI results were plotted against mile posts (Figure 49). A considerable variation was seen in the SCI along with the mile posts. The mile posts having surface curvature index within the same range i.e within a range of 0.05 or 0.1 were considered as seperate sections and all those subsections were run separately.

The backcalculated moduli before and after the subsectioning were compared (Figure 50, 51, 52). For most of the cases the surface layer and subgrade moduli were increased and the base moduli were decreased. The absolute error per sensor was decreased for most of the cases, which is an indicator of the improvement of the results.

It should be noted that if EVERCALC is used to run the .FWD file for these subsections, it will give the same result because EVERCALC uses the estimated subgrade depth at each mile post for running the CHEVRON program, not the average of the subgrade depths at all mile posts. In case of EVERCALC, SCI is helpful to have a general idea about the pavement section. For example, it can reveal the difference in pavement test temperatures, pavement thickness, subgrade strength or pavement strength at different locations. EVERCALC results can be improved if the pavement section is divided into more uniform subsections according to uniform pavement test temperature.

4.4 Performance of Backcakculation Programs for Different Pavement Sections

Considering only one factor to analyze the accuracy of backcalculation results is often misleading. Several factors were analyzed to evaluate the accuracy of backcalculation results for different sections. These factors include deflection curve, percentage difference between the backcalculated moduli values of two programs, engineering judgment, ARMS values of EVERCALC and absolute error per sensor values of MODULUS. The performance of backcalculation programs is better for the pavement sections U30A0378, U30D0399 and I90D0045 (Thick AC over thick base) followed by I15A0063, I15D0066, S08D0036 and U95A0423 (Thin AC over thick base) followed by I84A0136 and I84D0140 (Thick AC over thin

base). The backcalculation results for pavement section U95D0428 (Thin AC over thin base) are relatively poor.

The overall analysis leads to the following general conclusions:

1) Results of the backcalculation software are more reliable for relatively thick pavement sections with AC layer greater than 4 inches.

2) High error is expected for pavement sections with CTB layer.

3) If the pavement test temperature is relatively high (e.g. > than 105 °F) or relatively low (e.g. < 45 °F), results are usually unreasonable for AC layer.

4) It is not recommended to use four-layer system with these backcalculation software. If four-layer system is to be used, MODULUS 4.0 is recommended over EVERCALC 3.3.

CHAPTER V

SUMMARY OF FINDINGS AND RECOMMENDATIONS FOR USING BACKCALCULATION SOFTWARE

5.1 Summary

Two backcalculation software (MODULUS 4.0 and EVERCALC 3.3) were used to determine and analyze pavement layers moduli for twelve road sections in Idaho. Findings from data analysis can be summarized as follows:

1) MODULUS is more suitable for use in three-layer system. If possible, the pavement section should be modeled as three-layer system for better results. But the sub-base should not be combined with the subgrade and CTB should not be combined with the sub-base.

2) The thicknesses of the pavement layers should be as accurately input as possible. The results of backcalculation involve more errors if the pavement section is thin (specially if the surface layer is less than 3" and the subgrade is weak. Better results were observed for thicker pavements.

3) The depth to the bedrock greatly effects the results. If it is not known then let the program calculate it. When the rigid layer is predicted at a shallow depth (i.e. less than 7 or 8 ft), then the top 24" of the subgrade layer should be considered as a separate layer.

4) MODULUS 4.0 is highly sensitive to input moduli ranges. This sensitivity, however, is much less for input subgrade modulus. It was observed that, even with correct values of seed moduli, the program still shows varied results. It was also observed that varying the lower limit of the input moduli ranges did not affect the results by the same degree

of varying the upper limit.

5) Less variation is observed in the calculated subgrade modulus because the program uses a closed form equation to predict the subgrade modulus from the deflections of the far sensors (i.e. 6th and 7th sensor). On the other hand, backcalculated moduli of other layers (which are the function of subgrade moduli) are estimated by numerical iteration. Therefore, it is concluded that the high variation in the backcalculated moduli of upper layers may be due to the numerical interpolation scheme.

6) The calculated moduli by MODULUS 4.0 is for the testing temperature and load.

7) The program should be run several times with different input values. Those mile posts which give consistent or less variant results should be observed. The backcalculated E_1, E_2, E_3 and E_4 values should be averaged respectively for those mile posts which give consistent results. The overall average of these average values can be assumed for those mile posts which don't give consistent results. This can be done by importing the .DAT files in a spread sheet software. It is noted that the mile posts which show less variations are generally associated with reasonable backcalculated moduli values. Therefore the average of the backcalculated moduli values at these mile posts can safely be assumed for other mile posts.

8) EVERCALC normalizes the moduli values to 9000 lbs load. In addition, the AC layer modulus is adjusted to 77 °F. However, the current FWD file of ITD can not be run with EVERCALC. In future if the FWD of the ITD is adjusted for EVERCALC (i.e drop loads bracketing 9000 lbs), then normalization to 9000 lbs can be made. The modified version of EVERCALC 3.3 for Idaho FWD files does not normalize to 9000 lbs load.

9) If the pavement section involve different thicknesses at different mile posts, MODULUS can not be run for the whole section at one time. In that case, each portion of road which has a uniform pavement section should be treated seperately. But in EVERCALC, different thicknesses can be input for different locations and the program can be run once for the whole section.

10) Results of the backcalculation sofware are more reliable for relatively thick pavement sections with AC layer greater than 4 inches.

11) High error is expected for pavement sections with CTB layer.

12) If the pavement test temperature is relatively high (i.e. > than 105 °F) or relatively low (i.e. < 45 °F), results are usually unreasonable for AC layer.

13) It is not recommended to use four-layer system with these backcalculation software. If four-layer system is to be used, MODULUS 4.0 recommended over EVERCALC 3.3.

14) The comparison analysis revealed that both programs show good comparison for base and subgrade moduli value for three-layer pavement sections not having treated base. No strong evidence is obtained towards the reliability of the results of the two programs. However, given the great complexity involved in the backcalculation techniques, we believe that EVERCALC results are more realistic than MODULUS.

5.2 Recommendations for using Backcalculation Software

From the sensitivity analysis, comparison of the two programs by running under the same conditions and dividing the pavement section into subsections, it is concluded that the backcalculation programs can be used successfully to characterize the material properties in terms of pavement layers moduli, if used properly under certain limitations. Based on the findings, the following recommendations are warranted:

1) Try to use three-layer system whenever is possible. If four-layer is to be used, MODULUS may be used and caution should be exercised in determination of moduli values.

2) For three-layer system, the two programs (MODULUS and EVERCALC) may lead to similar results. Since MODULUS is faster, it could be used for a quick review of the entire section. However, for specific overlay/inlay design, it is suggested to use EVERCALC for more exhaustive analysis for moduli determination.

3) Prior to use of backcalculation software, statistical analysis of the deflection basins is to be performed on the variation of R_1 (Deflection at sensor # 1), SCI and subgrade modulus or R_7 (Deflection at sensor # 7) to identify those locations which show more uniform section. If distinct difference is observed between mile posts, the entire section (file) must be subdivided into subsections with more uniform characteristics and with a constant temperature. Each subsection is then used as a separate file in the backcalculation software.

4) Input parameters may be suggested in the following ranges based on the sections analyzed in this study.

a. For the asphalt concrete layer, initial moduli can be estimated from the graph in Figure 53. The minimum and maximum moduli can be estimated as 1/4 of initial modulus and 3 times the initial modulus respectively.

b. For untreated bases an initial modulus of 50 ksi, minimum modulus of 10 ksi and maximum modulus of 150 ksi can be used. For the cases where backcalculated base modulus reaches the upper limit (i.e. 150 ksi), then the base modulus should be determined according to the equation as follows:

$$E_b = K_1 * (\theta)^{K_2}$$

Where: Θ = Bulk stress and can be obtained from the .OUT file of EVERCALC.

K_1 = Stress sensitivity factor and can be assumed with in the range of 8000-9000 psi.

K_2 = Stress sensitivity factor and can be assumed as 0.375.

c. The initial modulus for the subgrade can be estimated from the AASHTO equation.

$$E_{sg} = (P * S_f) \ / \ (d_r * r)$$

where:

E_{sg} = Subgrade modulus.

P = FWD load in pounds.

S_f = Subgrade modulus prediction factor.

d_r = Measured deflection at a radial distance r from the center of load plate.

S_f is dependent on poison's ratio μ and can be assumed as suggested by AASHTO

as follows:

$\mu = 0.50$	$S_f = 0.2686$
0.45	0.2792
0.40	0.2892
0.35	0.2874
0.30	0.2969

The Subgrade modulus at each sensor location should be estimated according to the above AASHTO equation and the lowest value should be used as an input to the backcalculation program.

CHAPTER VI

RECOMMENDATIONS FOR PHASE 2 WORK PLAN

During the course of Phase 1 study, the following were found to be needed to be able to satisfy the overall project objective:

1) **Verification of Moduli Values by Laboratory Testing:**

It is recommended that filed cores are to be collected from representative sections for locations where FWD files are available. These cores are then tested in the M_r test (ASTM D 4123). Testing is recommended to be performed at temperature similar to that of the filed conditions. If this is difficult to attain, temperature adjustment should be made to the lab results.

2) **EVERCALC program modification and testing:**

The purpose of any modifications intended is to make the program more usable by the current FWD data analysis system in ITD. These modifications may include but not limited to:

a. Input system.
b. Calculation scheme and criteria for convergence.
c. Temperature adjustment.
d. Normalization procedures.
e. Output formats.
f. Program flexibility; for example ability to perform analysis using one load level or multiple load levels, one drop or multiple drops.

g. Statistical analysis routine for deflection data prior to as well as after backcalculation.

It is not intended, however, to change the core of the program (Backcalculation Algorithm). Modifications will be tested using the same data files which were used in Phase 1.

3) **Overlay / Inlay Design Systems:**

Investigate the use of inlay and overlay design systems including EVERPAVE (Washington State Design Program), DARWin (The AASHTO Design System), and DAMA (The Asphalt Institute Design Program). In case EVERPAVE is selected, an interface program for data input preparation may be developed. This is contingent on the authorization of WSDOT for program modifications and release of an uncompiled version of the program.

4) **Development of Design Procedures:**

A design procedure is to be developed to be included in the ITD materials manual. The developed method is to be checked against existing methods. The anticipated method should utilize pavement deflections as the basis for design and not a material equivalency factors.

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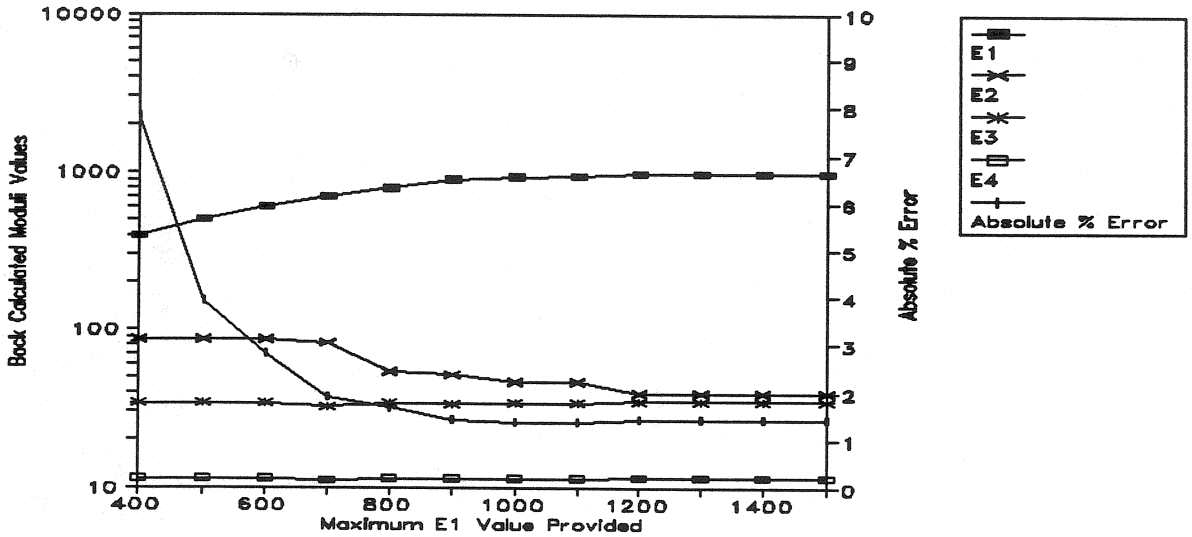

Figure 1. Effect of E1 Variation on Backcalculated Moduli (4 Layer System, Section I90D0045, MP 45.5)

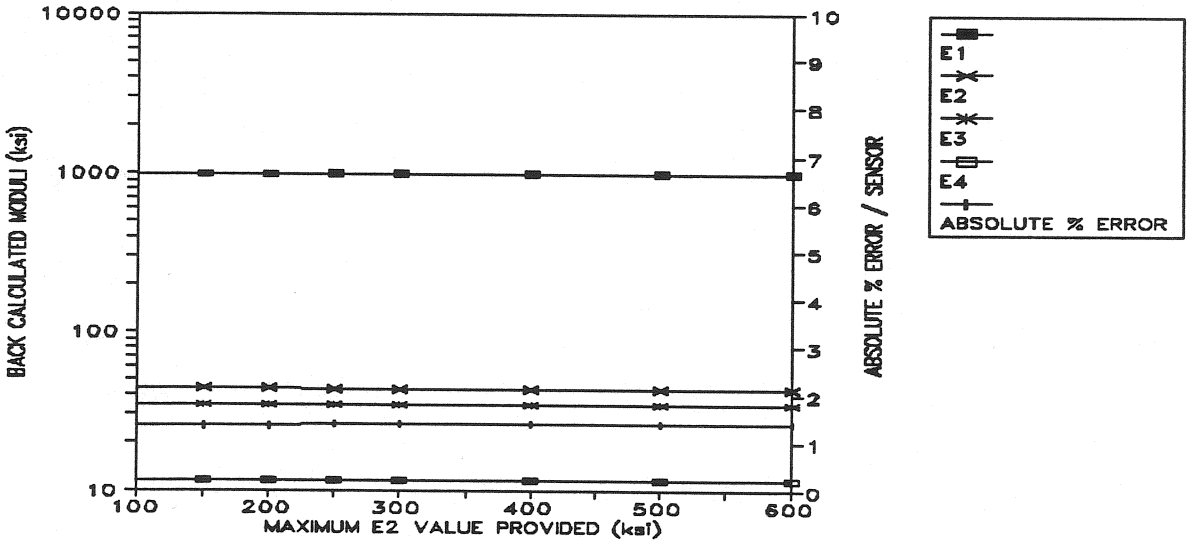

Figure 2. Effect of E2 Variation on Backcalculated Moduli (4 Layer System, Section I90D0045, MP 45.5)

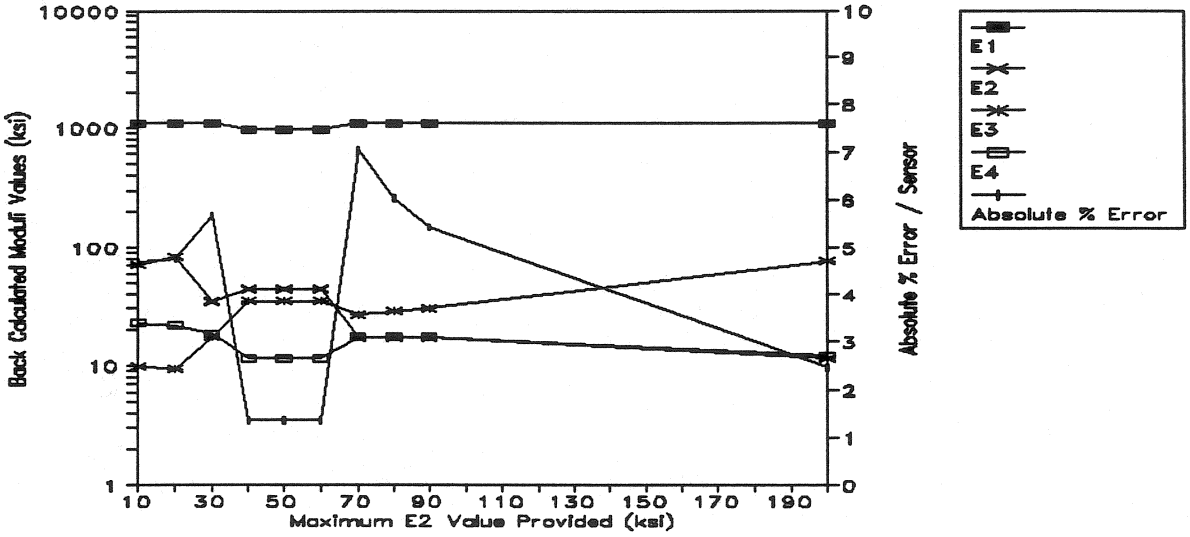

Figure 3. Effect of E3 Variation on Backcalculated Moduli (4 Layer System, Section I90D0045, MP 45.5)

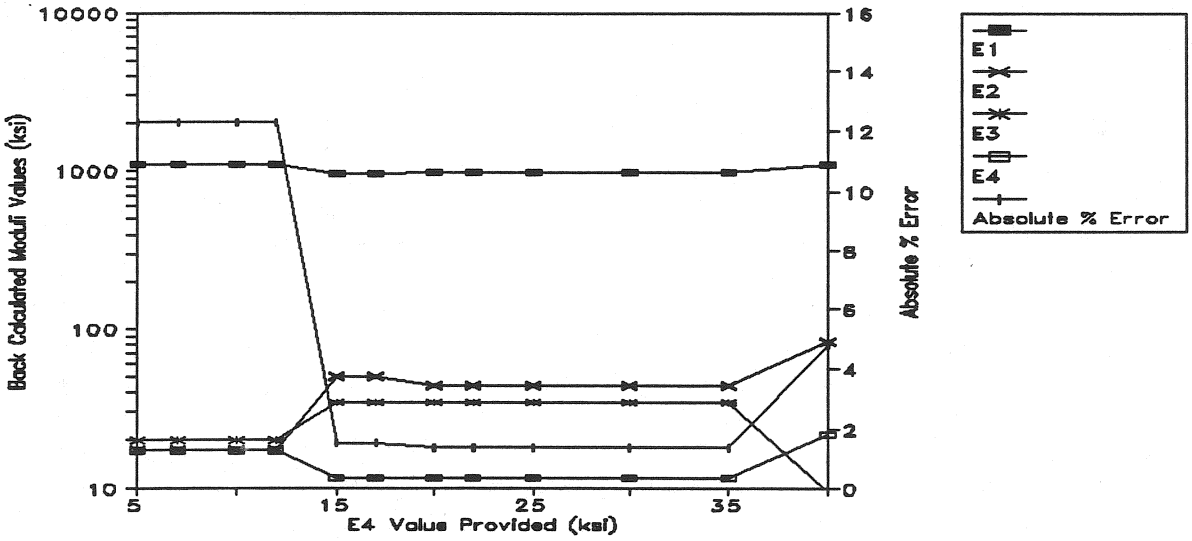

Figure 4. Effect of E4 Variation on Backcalculated Moduli (4 Layer System, Section I90D0045, MP 45.5)

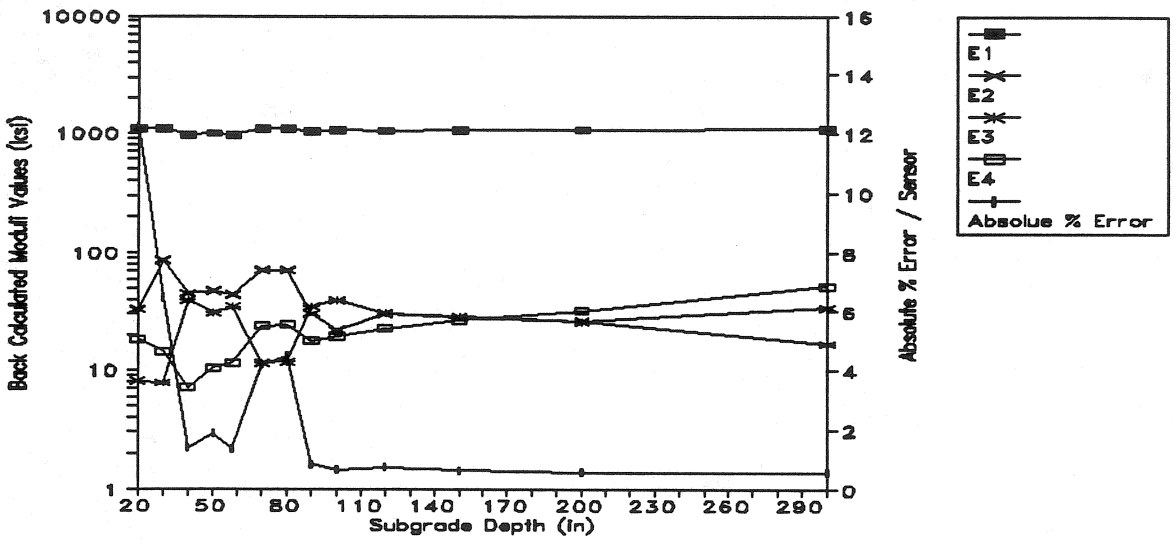

Figure 5. Effect of Subgrade Depth Variation on Backcalculated Moduli (4 Layer System, Section I90D0045, MP 45.5)

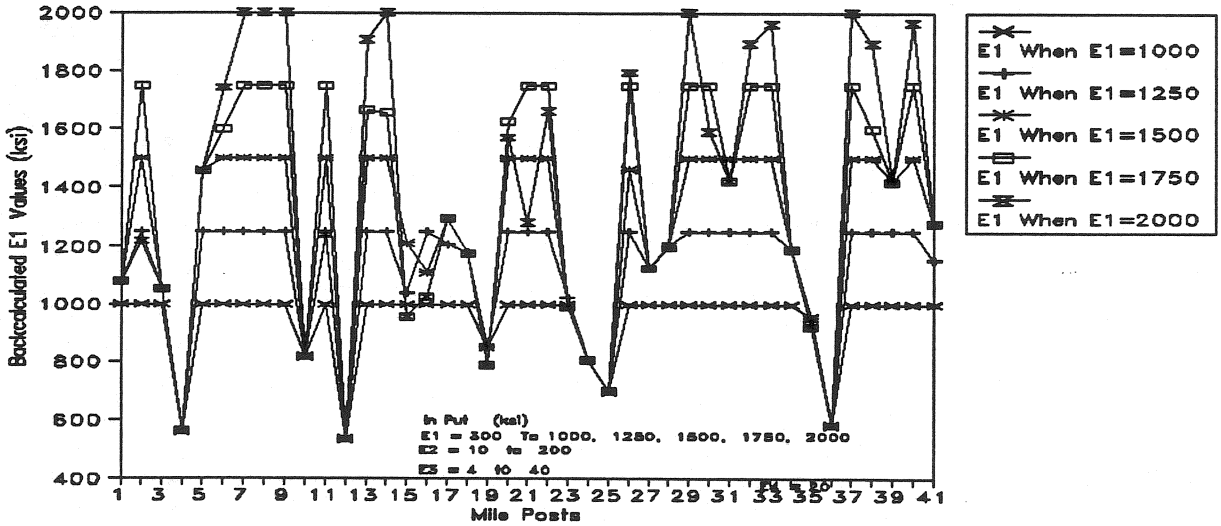

Figure 6. Effect of E1 Variation on Backcalculated E1 (4 Layer System, Section I90D0045, All MP)

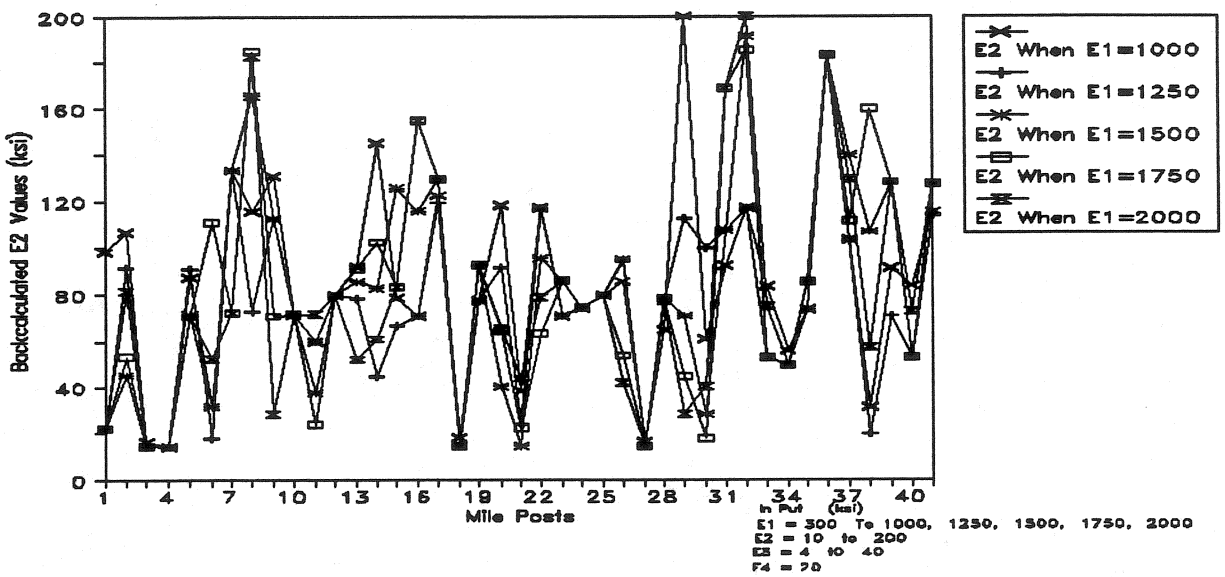

Figure 7. Effect of E1 Variation on Backcalculated E2 (4 Layer System, Section I90D0045, All MP)

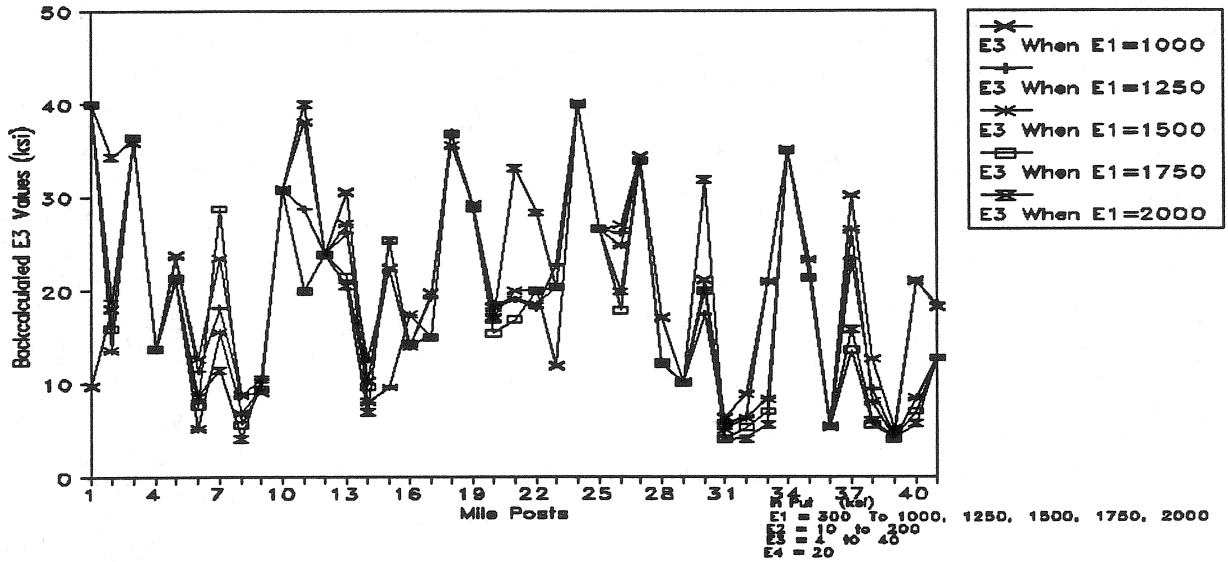

Figure 8. Effect of E1 Variation on Backcalculated E3 (4 Layer System, Section I90D0045, All MP)

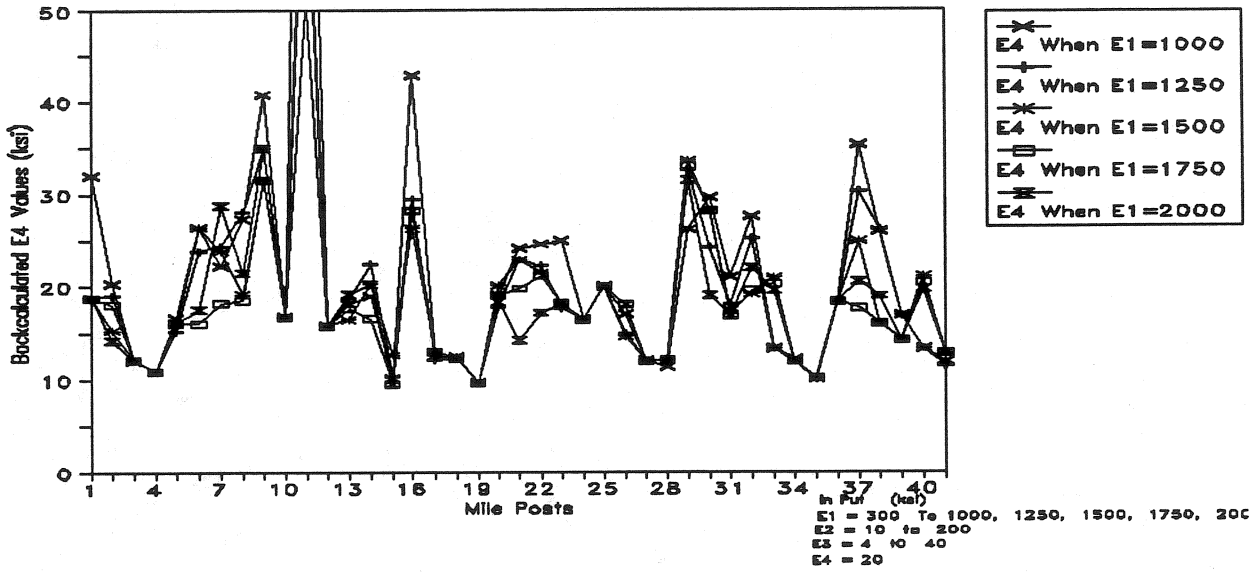

Figure 9. Effect of E1 Variation on Backcalculated E4 (4 Layer System, Section I90D0045, All MP)

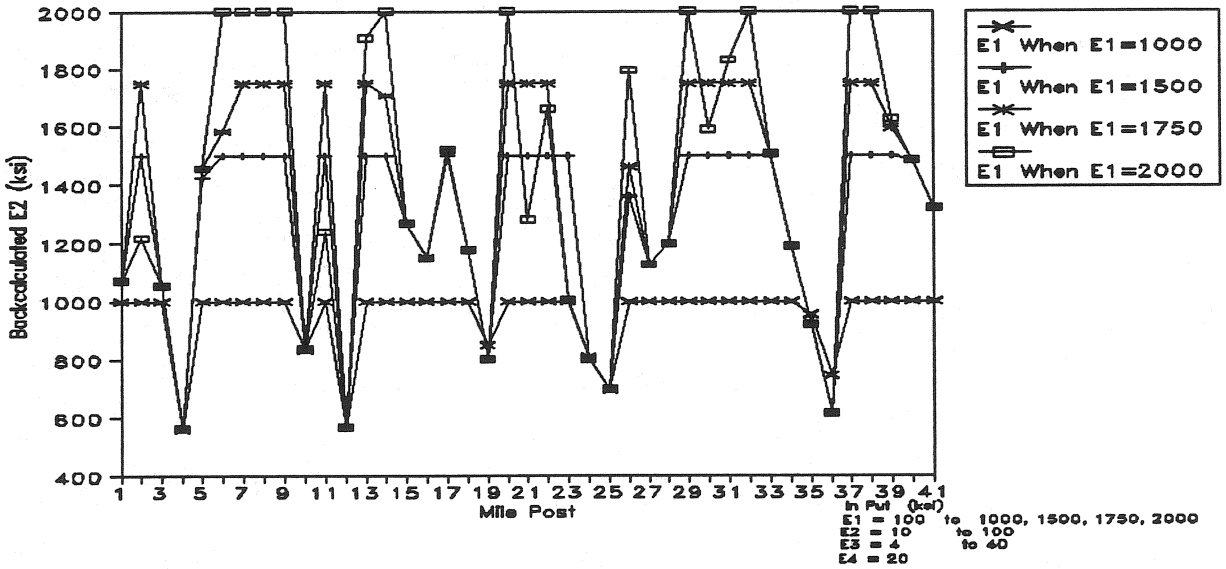

Figure 10. Effect of E1 Variation on Backcalculated E1 When E2 is Restricted to 100 ksi (4 Layer System, Section I90D0045, All MP)

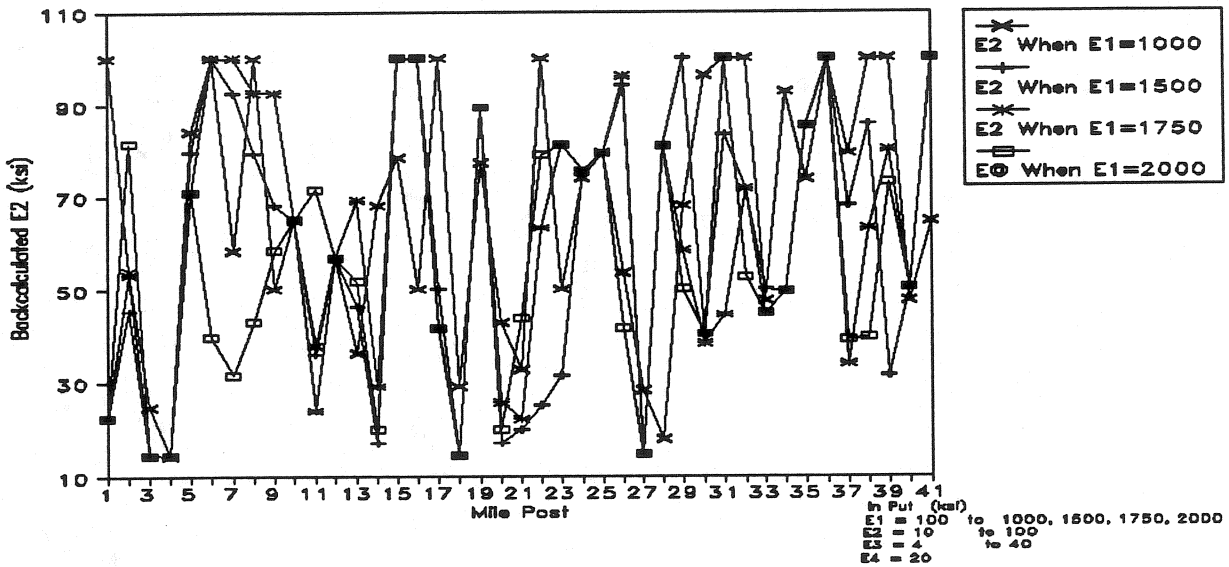

Figure 11. Effect of E1 Variation on Backcalculated E2 When E2 is Restricted to 100 ksi (4 Layer System, Section I90D0045, All MP)

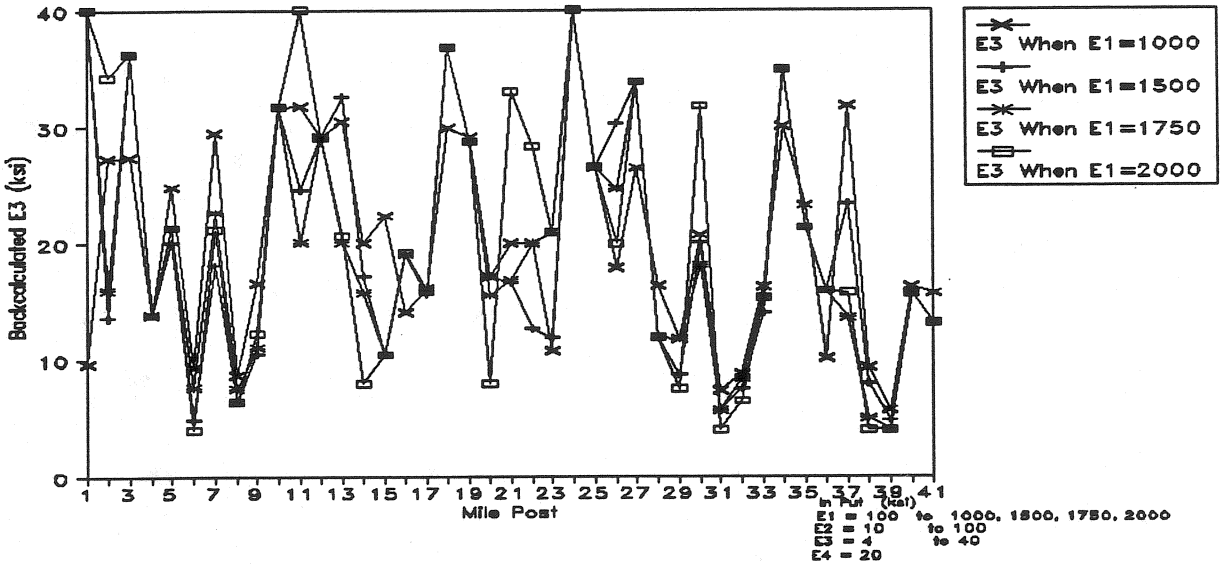

Figure 12. Effect of E1 Variation on Backcalculated E3 When E2 is Restricted to 100 ksi(4 Layer System, Section I90D0045, All MP)

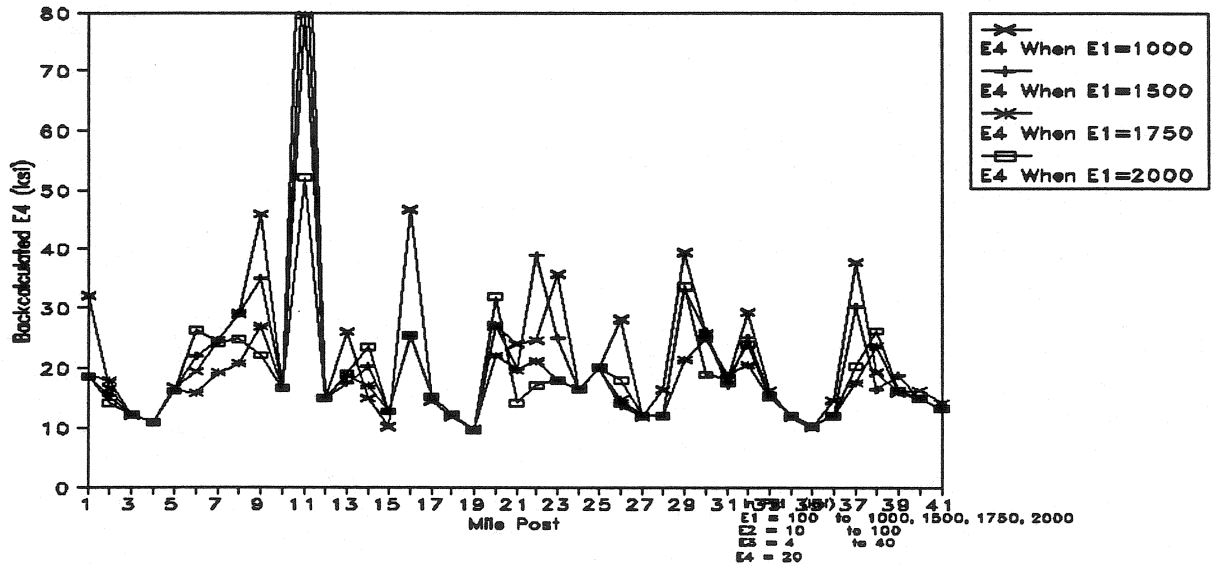

Figure 13. Effect of E1 Variation on Backcalculated E4 When E2 is Restricted to 100 ksi(4 Layer System, Section I90D0045, All MP)

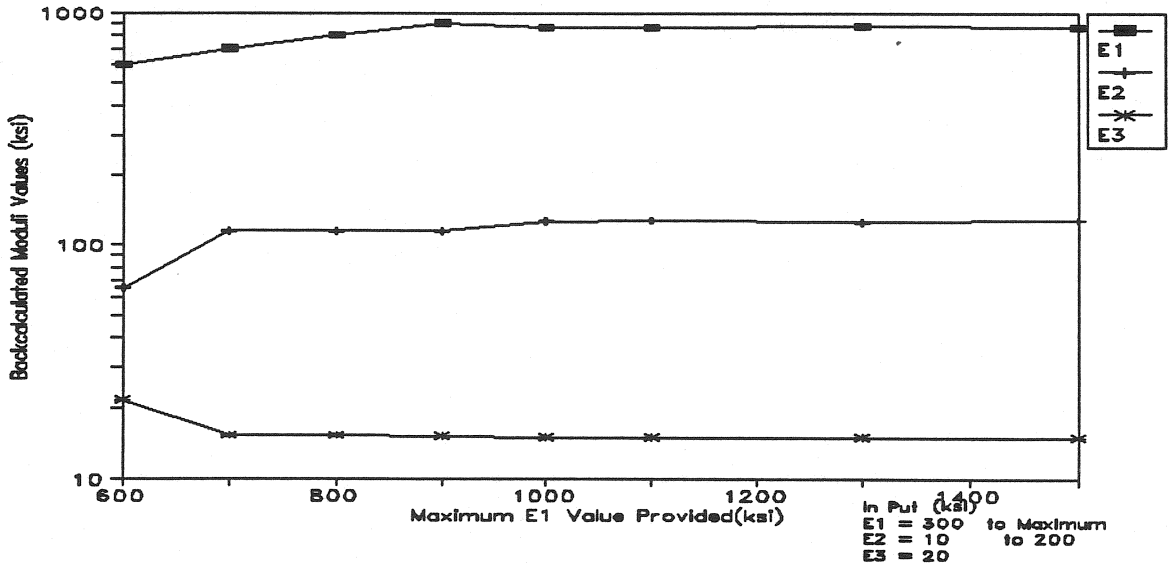

Figure 14. Effect of E1 Variation on Backcalculated Moduli (3 Layer System, Section I90D0045, MP 45.5)

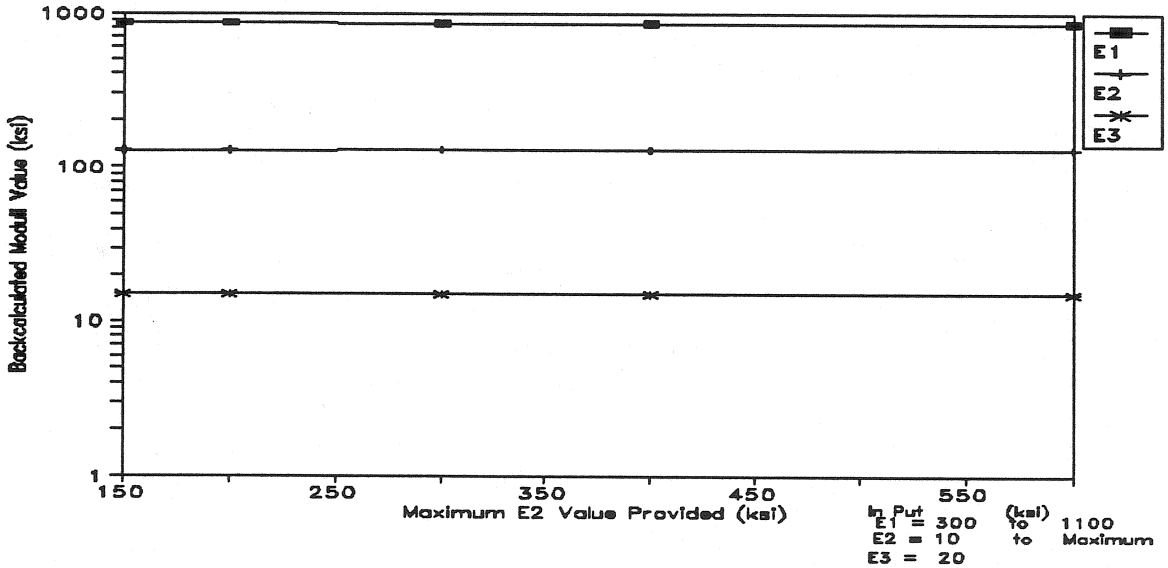

Figure 15. Effect of E2 Variation on Backcalculated Moduli (3 Layer System, Section I90D0045, MP 45.5)

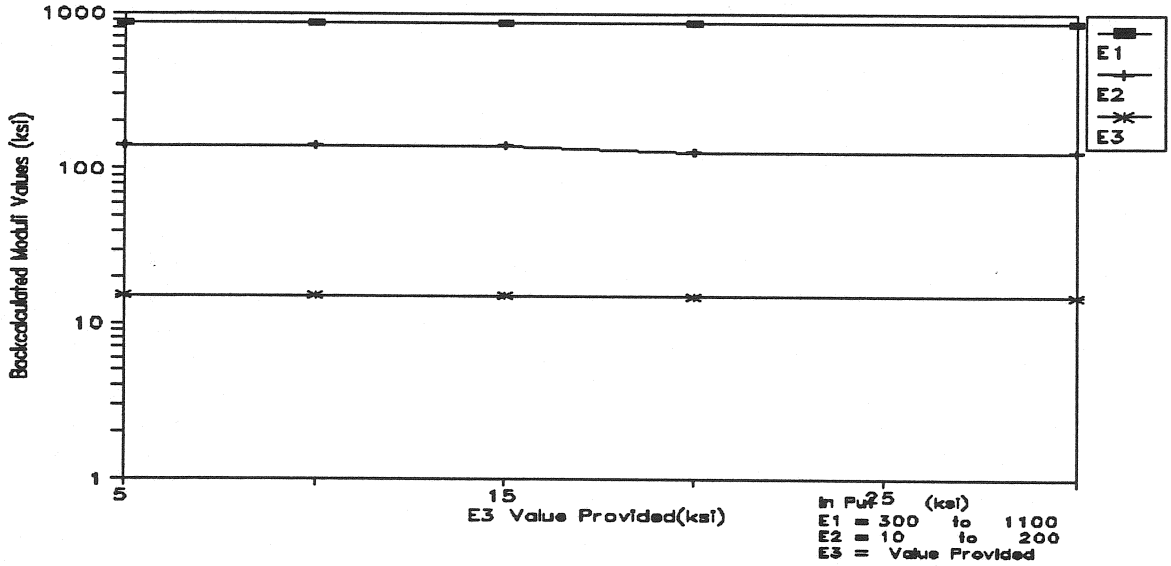

Figure 16. Effect of E3 Variation on Backcalculated Moduli (3 Layer System, Section I90D0045, MP 45.5)

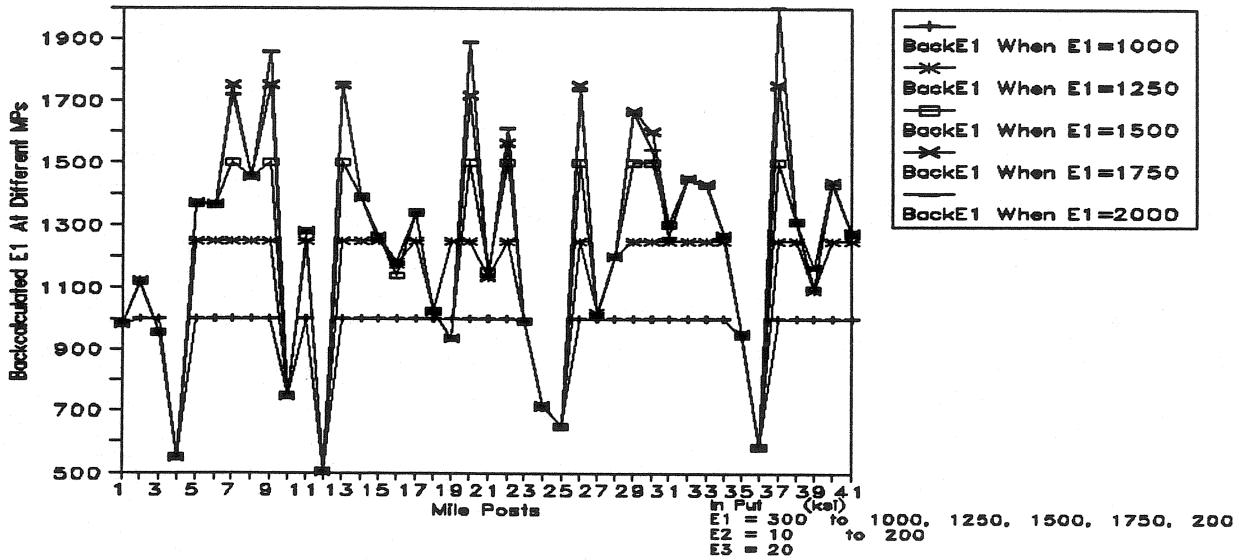

Figure 17. Effect of E1 Variation on Backcalculated E1 (3 Layer System, Section I90D0045, All MP)

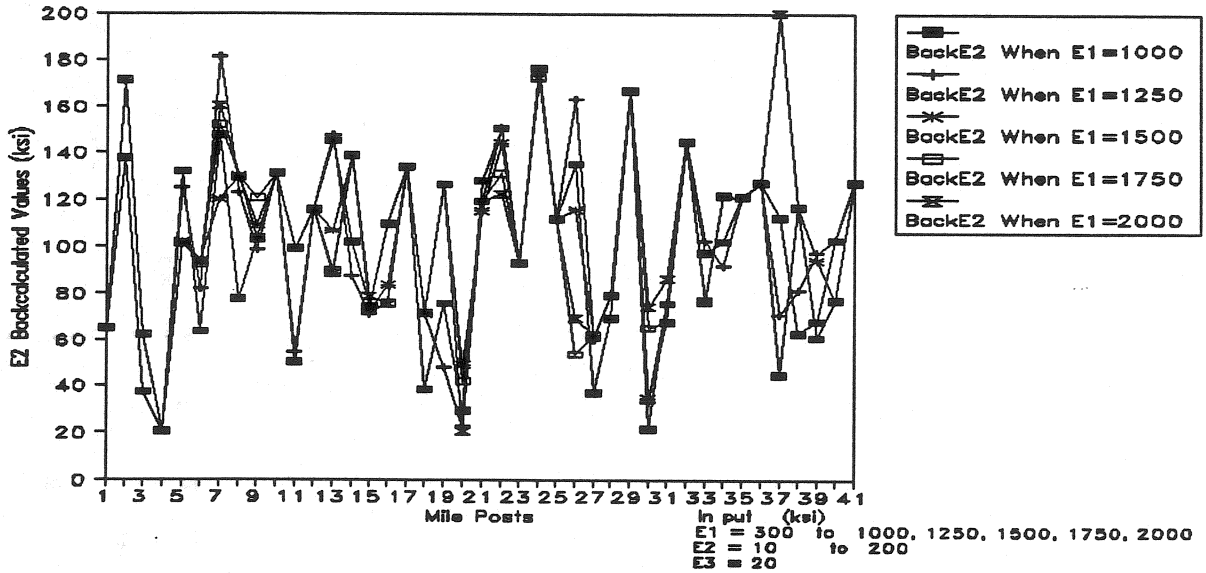

Figure 18. Effect of E1 Variation on Backcalculated E2 (3 Layer System, Section I90D0045, All MP)

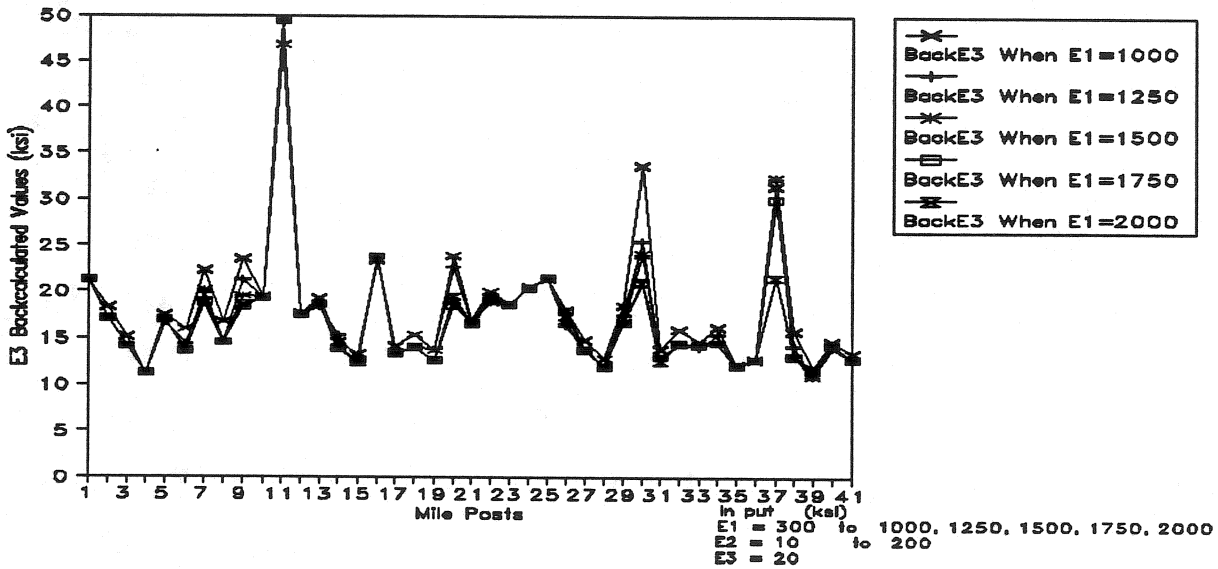

Figure 19. Effect of E1 Variation on Backcalculated E3 (3 Layer System, Section I90D0045, All MP)

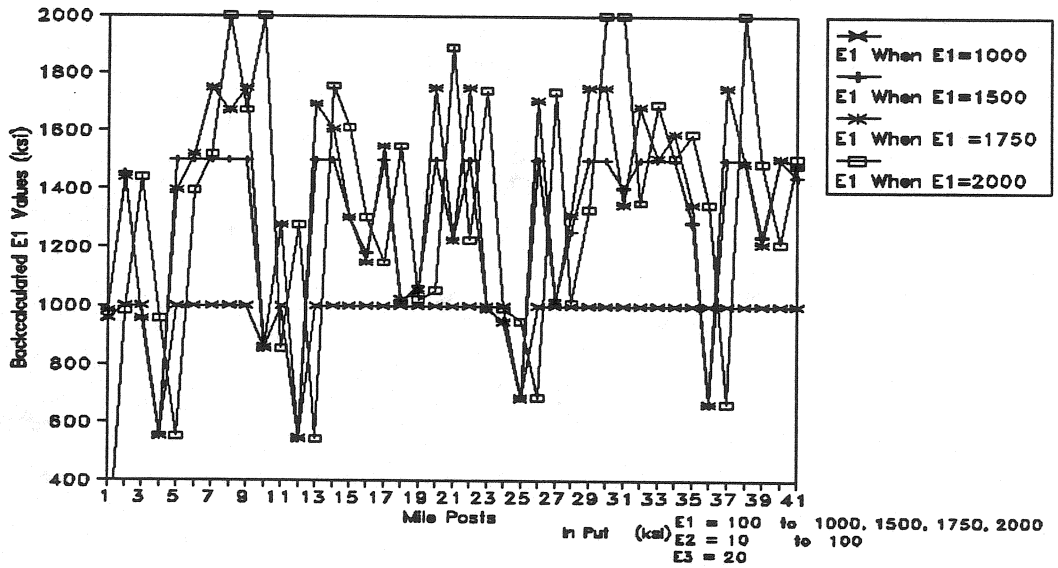

Figure 20. Effect of E1 Variation on Backcalculated E1 When E2 is Restricted to 100 ksi (3 Layer System, Section I90D0045, All MP)

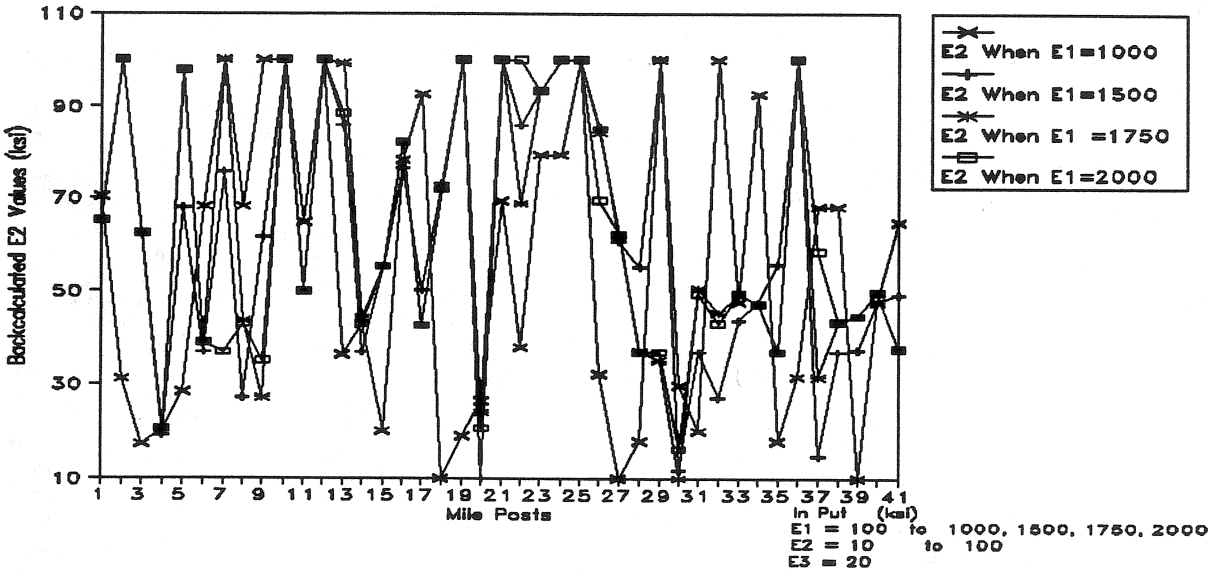

Figure 21. Effect of E1 Variation on Backcalculated E2 When E2 is Restricted to 100 ksi (3 Layer System, Section I90D0045, All MP)

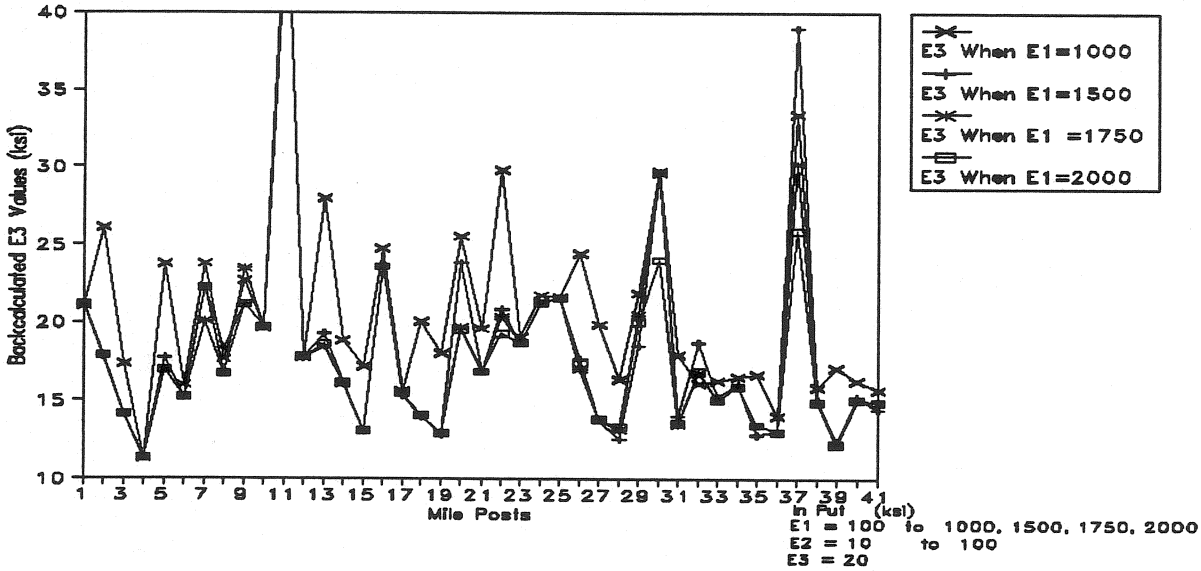

Figure 22. Effect of E1 Variation on Backcalculated E3 When E2 is Restricted to 100 ksi (3 Layer System, Section I90D0045, All MP)

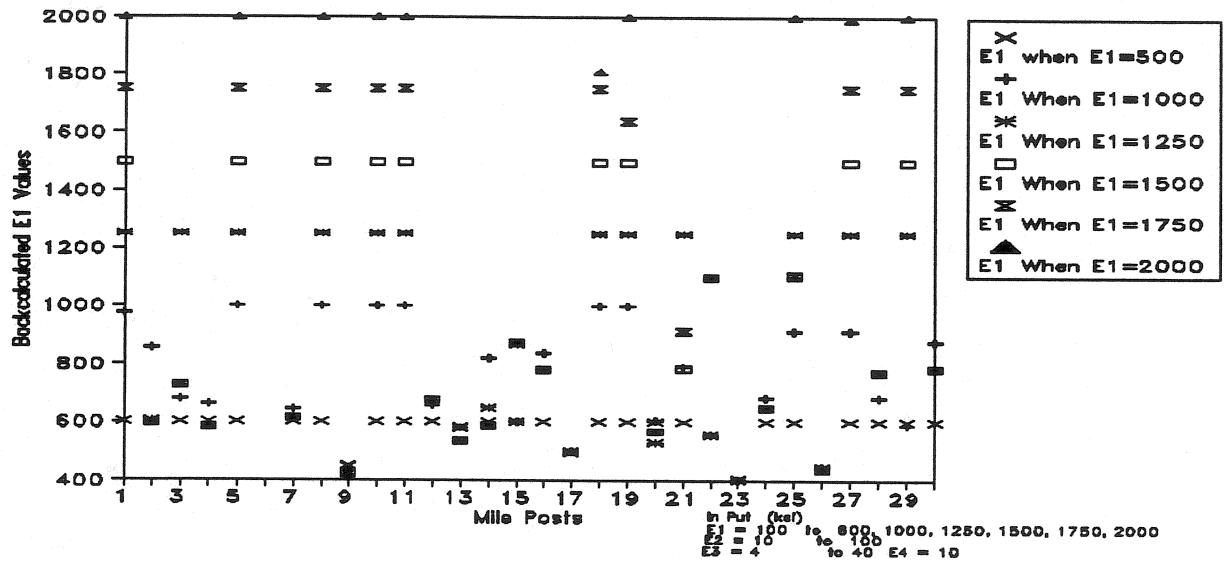

Figure 23. Effect of E1 Variation on Backcalculated E1 (4 layer System, Section I84D0177, All MP)

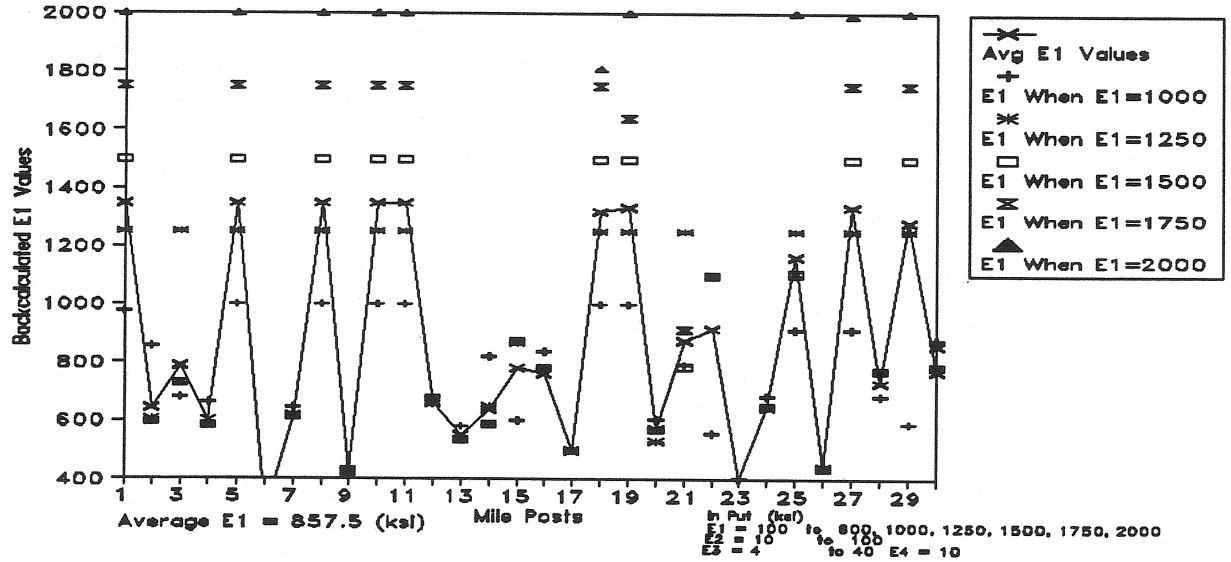

Figure 24. Effect of E1 Variation on Backcalculated E1 (4 layer System, Section I84D0177, All MP)

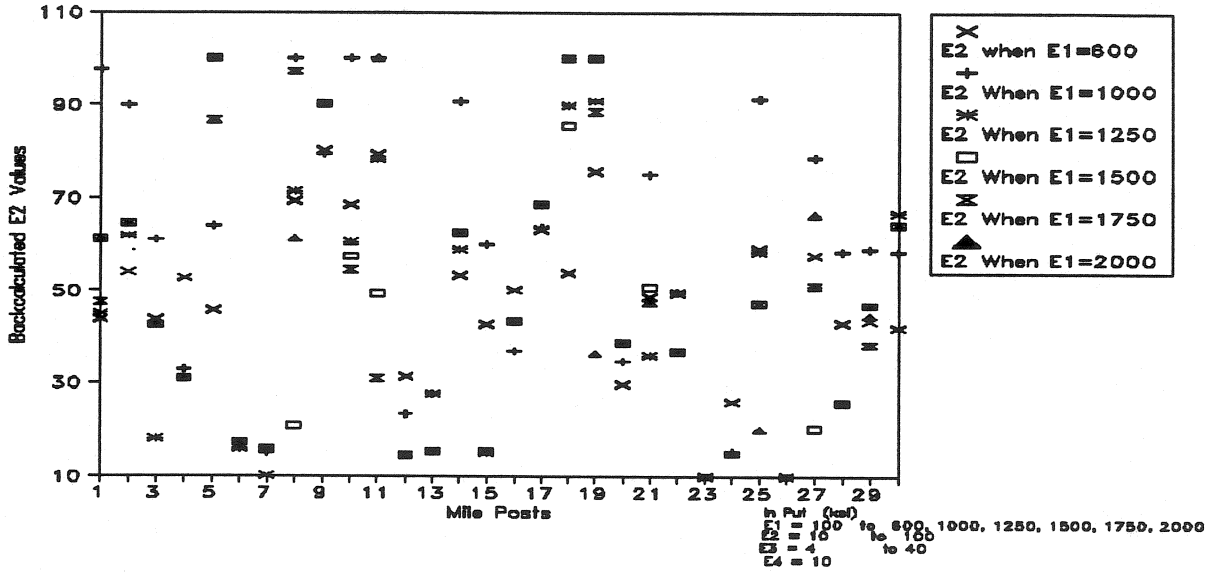

Figure 25. Effect of E1 Variation on Backcalculated E2 (4 layer System, Section I84D0177, All MP)

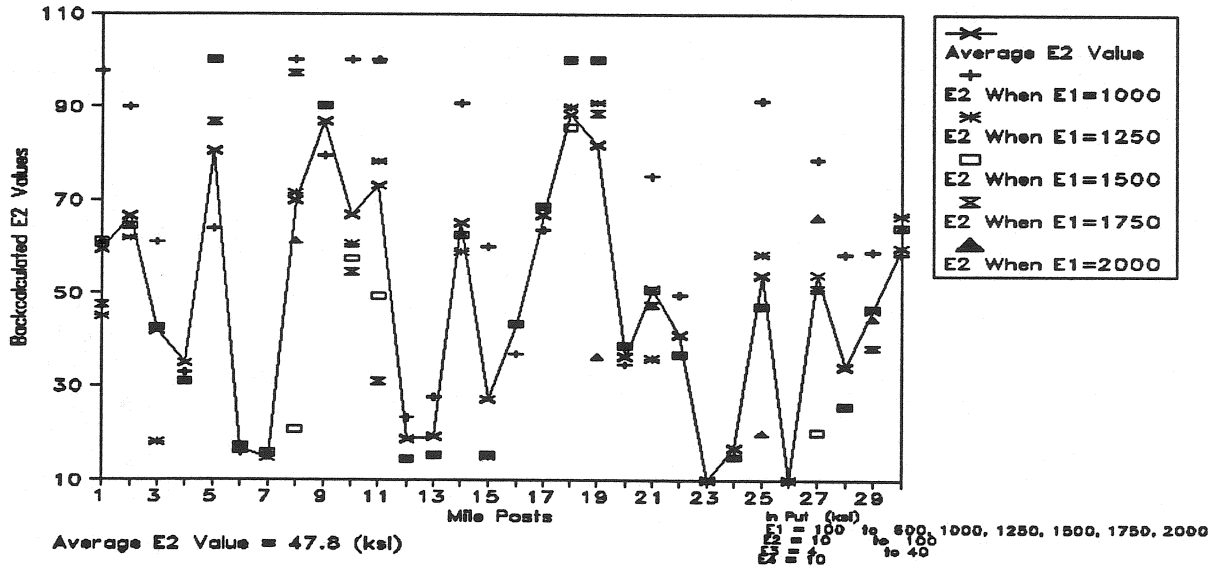

Figure 26. Effect of E1 Variation on Backcalculated E2, Showing the Average (4 layer System, Section I84D0177, All MP)

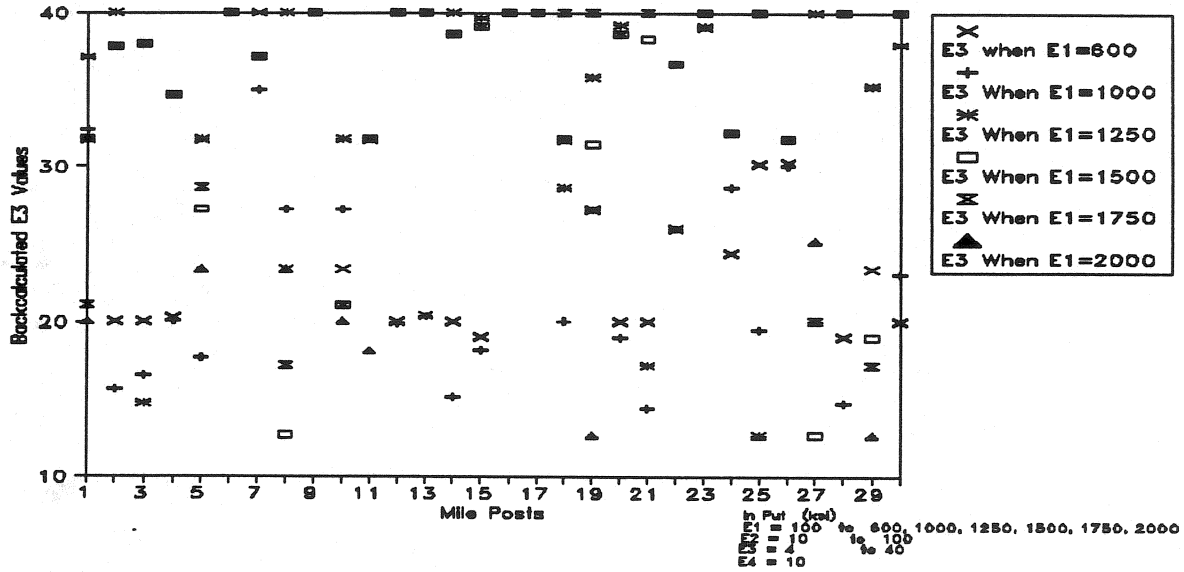

Figure 27. Effect of E1 Variation on Backcalculated E3 (4 layer System, Section I84D0177, All MP)

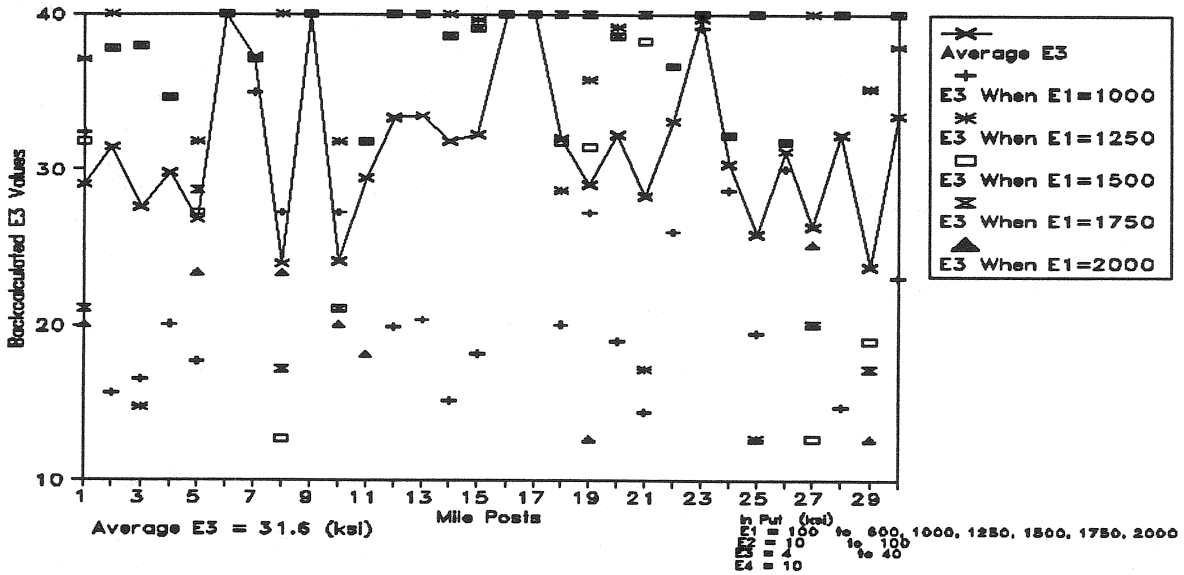

Figure 28. Effect of E1 Variation on Backcalculated E3, Showing the Average (4 layer System, Section I84D0177, All MP)

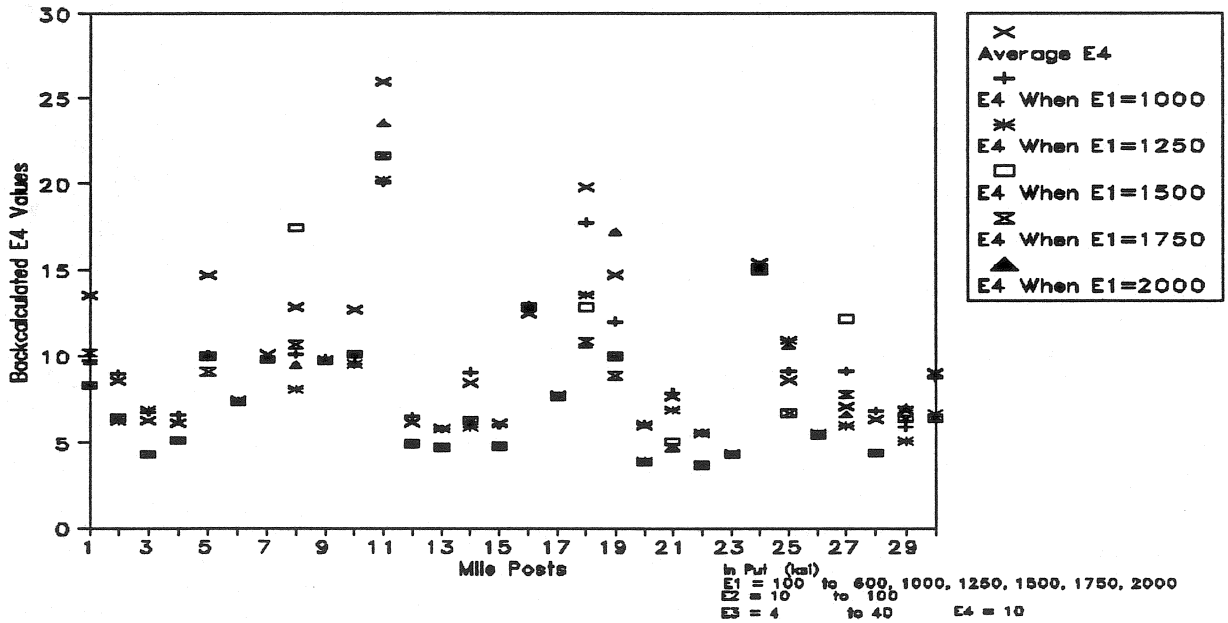

Figure 29. Effect of E1 Variation on Backcalculated E4 (4 layer System, Section I84D0177, All MP)

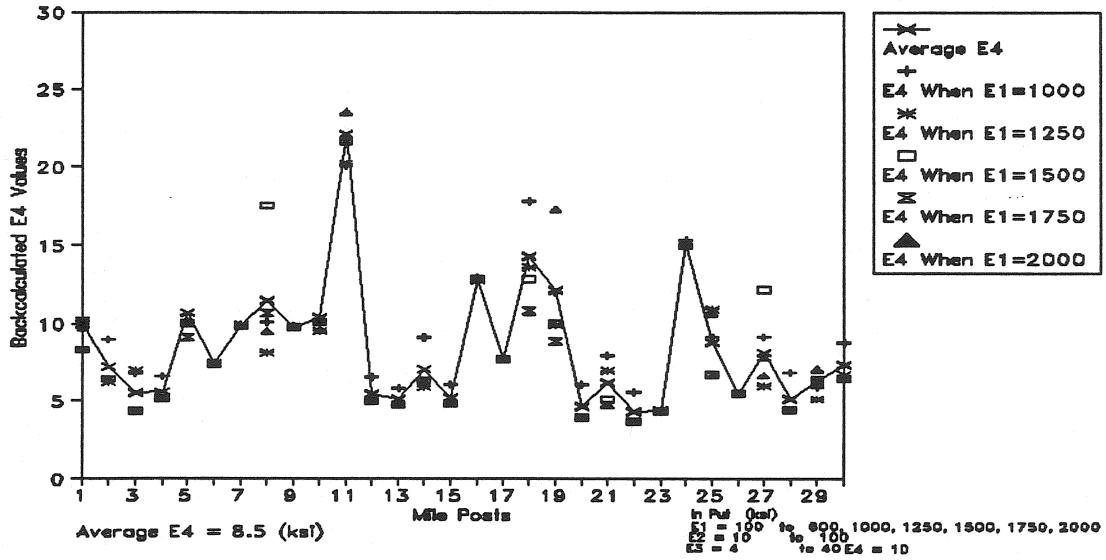

Figure 30. Effect of E1 Variation on Backcalculated E4, Showing the Average (4 layer System, Section I84D0177, All MP)

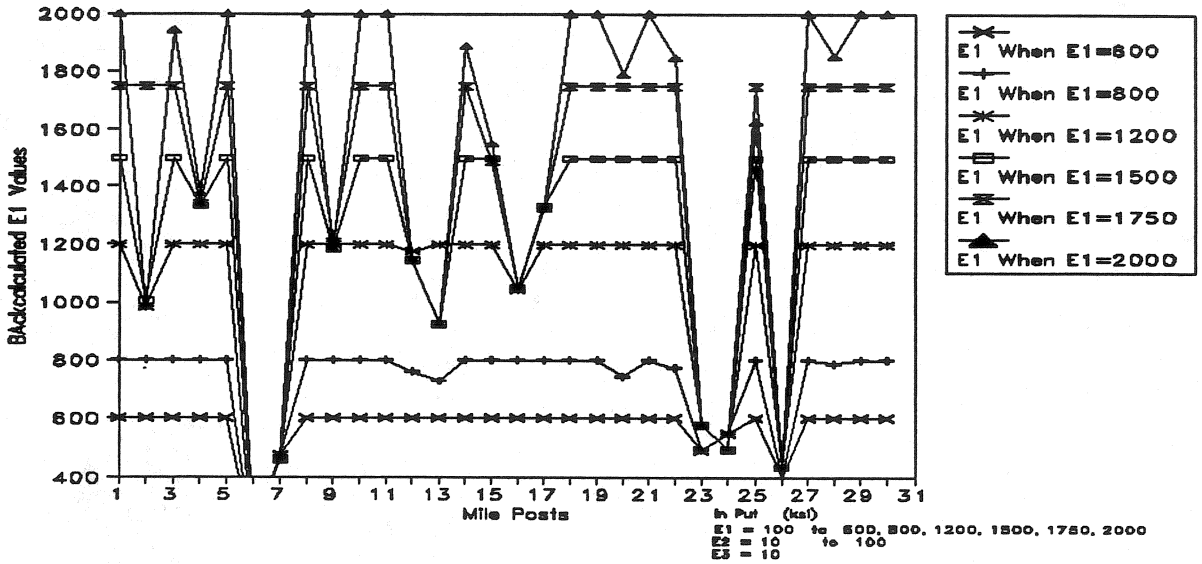

Figure 31. Effect of E1 Variation on Backcalculated E1 (3 layer System, Section I84D0177, All MP)

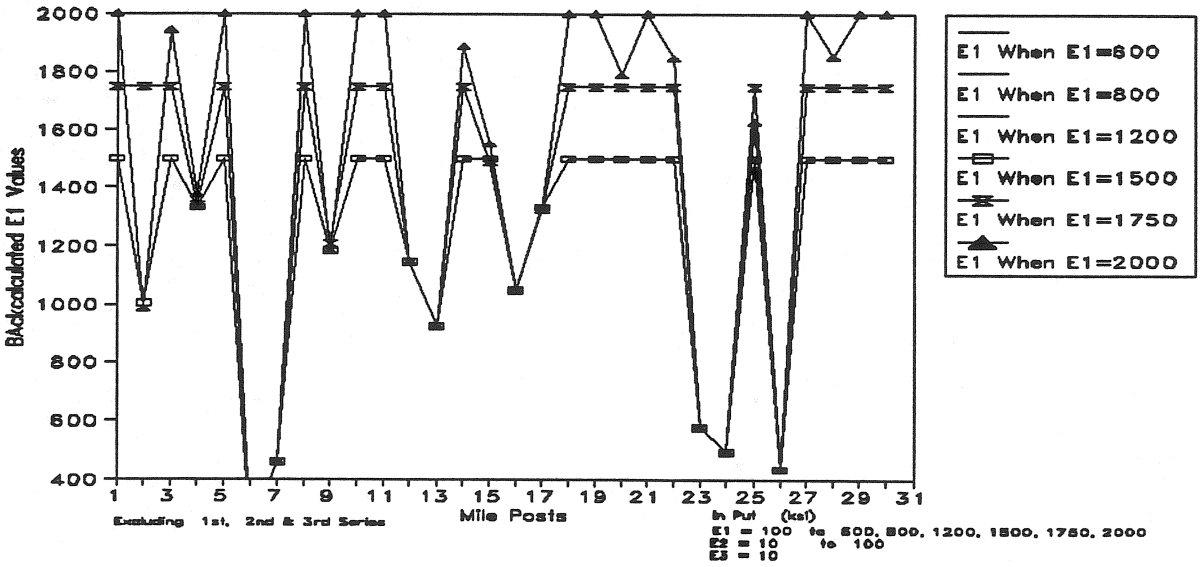

Figure 32. Effect of E1 Variation on Backcalculated E1,Excluding 1st, 2nd & 3rd Series (3 layer System, Section I84D0177, All MP)

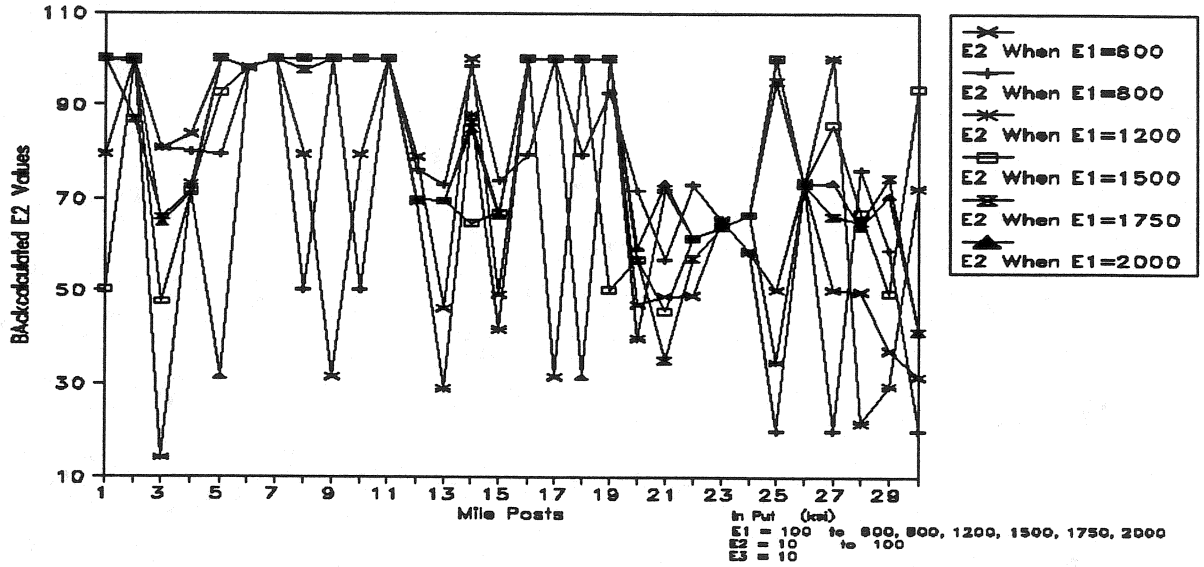

Figure 33. Effect of E1 Variation on Backcalculated E2 (3 layer System, Section I84D0177, All MP)

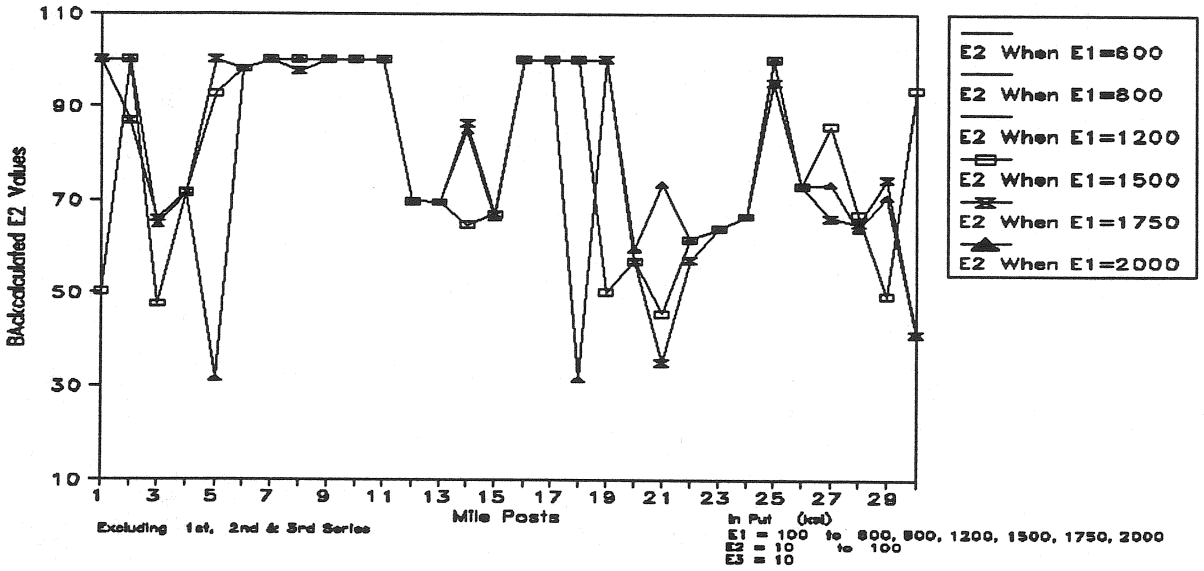

Figure 34. Effect of E1 Variation on Backcalculated E2, Excluding 1st, 2nd & 3rd Series (3 layer System, Section I84D0177, All MP)

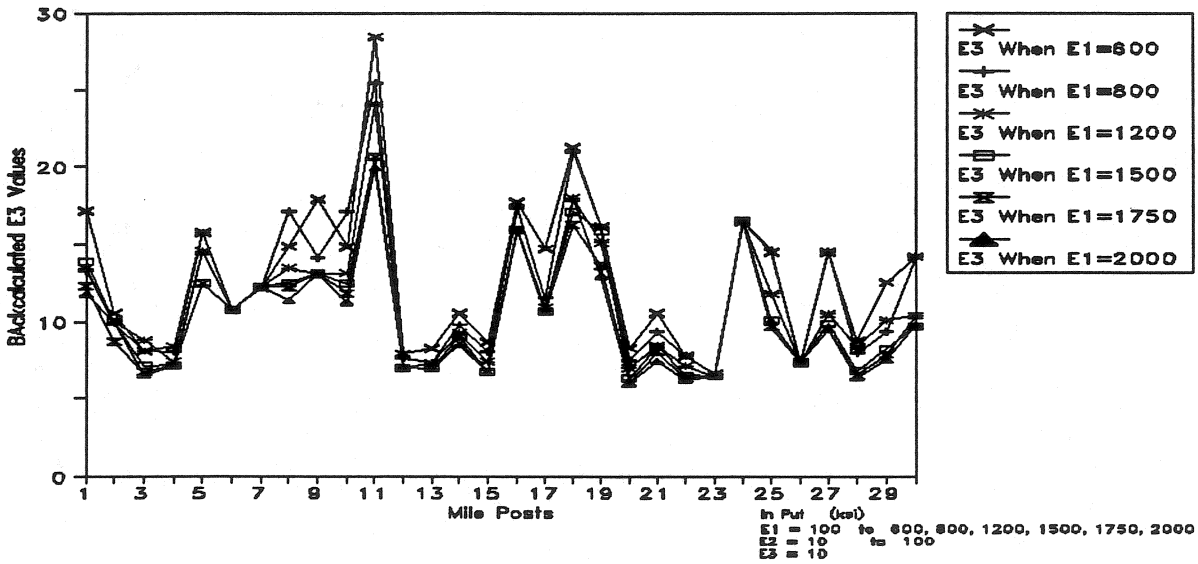

Figure 35. Effect of E1 Variation on Backcalculated E3 (3 layer System, Section I84D0177, All MP)

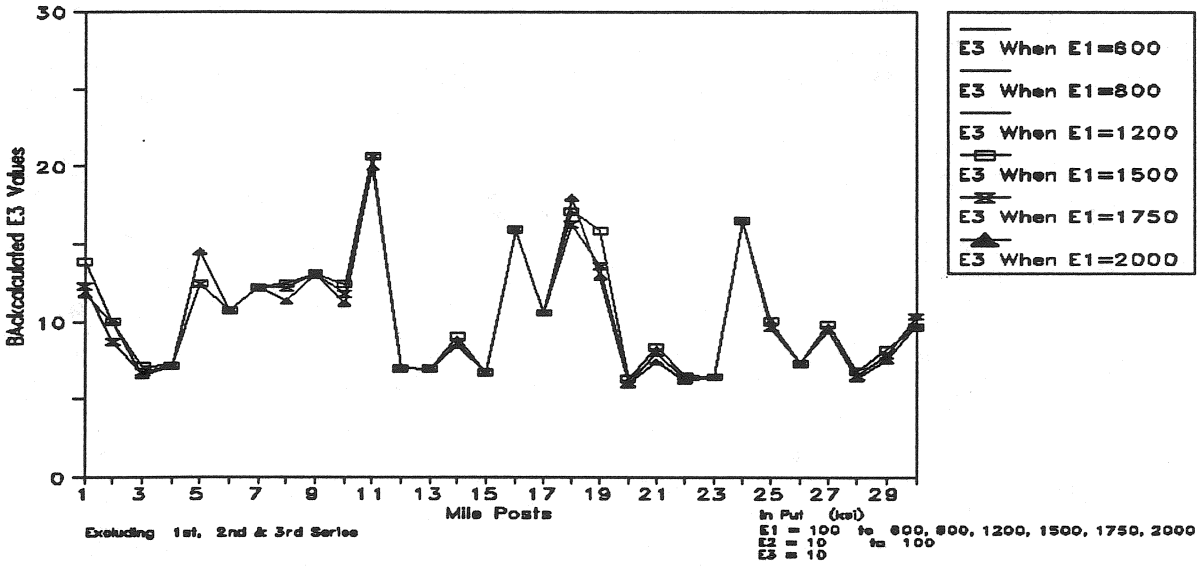

Figure 36. Effect of E1 Variation on Backcalculated E3, Excluding 1st, 2nd & 3rd Series (3 layer System, Section I84D0177, All MP)

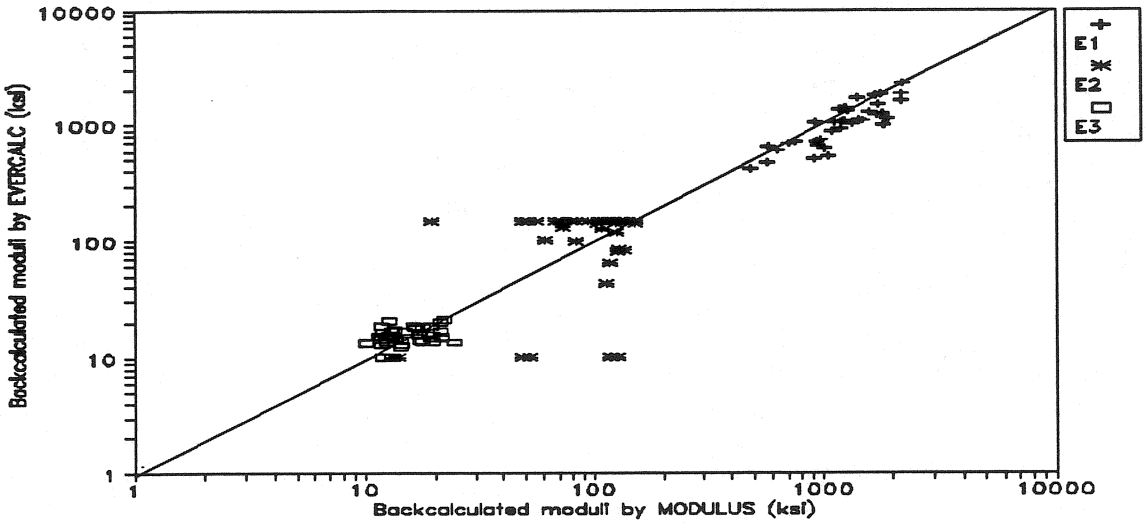

Figure 37. Comparison of Backcalculated moduli by MODULUS and EVERCALC (Section I90D0045)

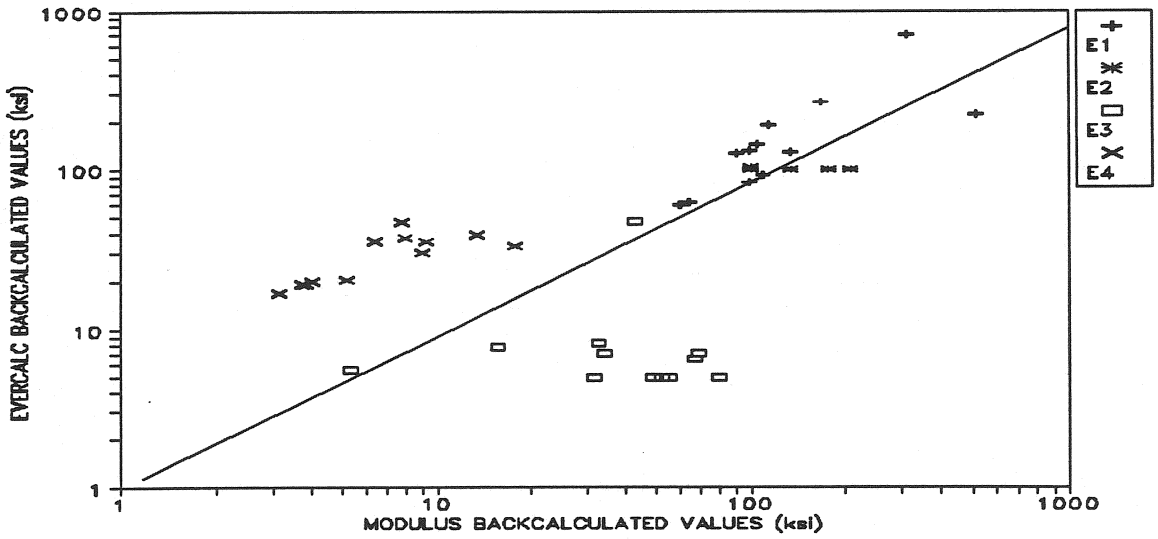

Figure 38. Comparison of Backcalculated moduli by MODULUS and EVERCALC (Section I84A0173, CTB).

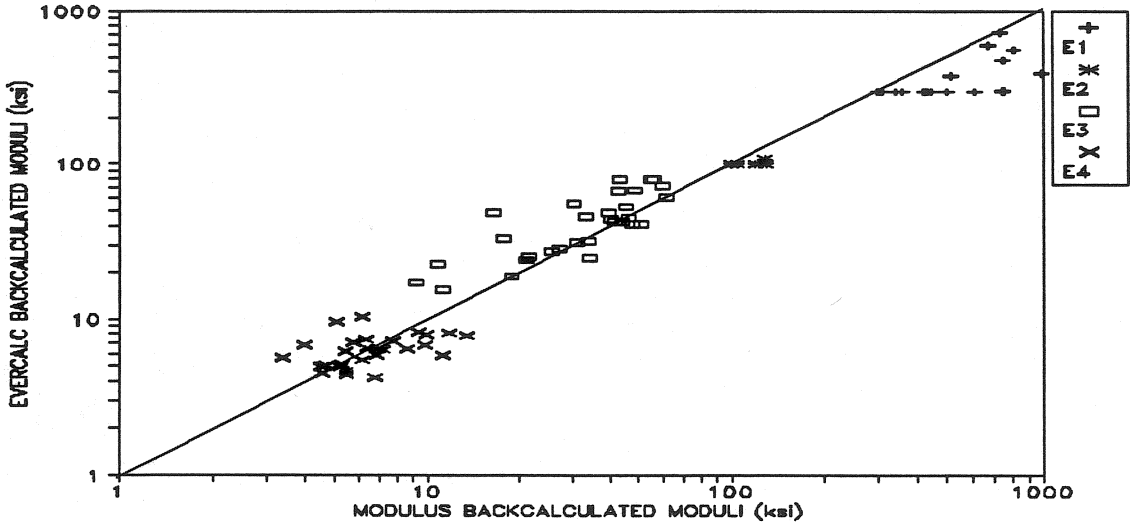

Figure 39. Comparison of Backcalculated moduli by MODULUS and EVERCALC (Section I84D0177, CTB).

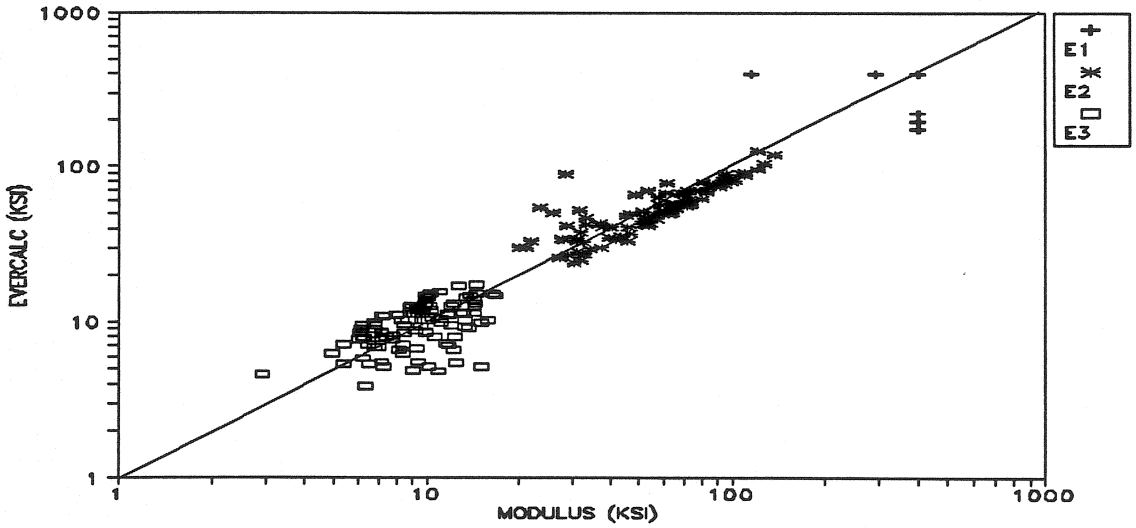

Figure 40. Comparison of Backcalculated moduli by MODULUS and EVERCALC (Section SO8D0036).

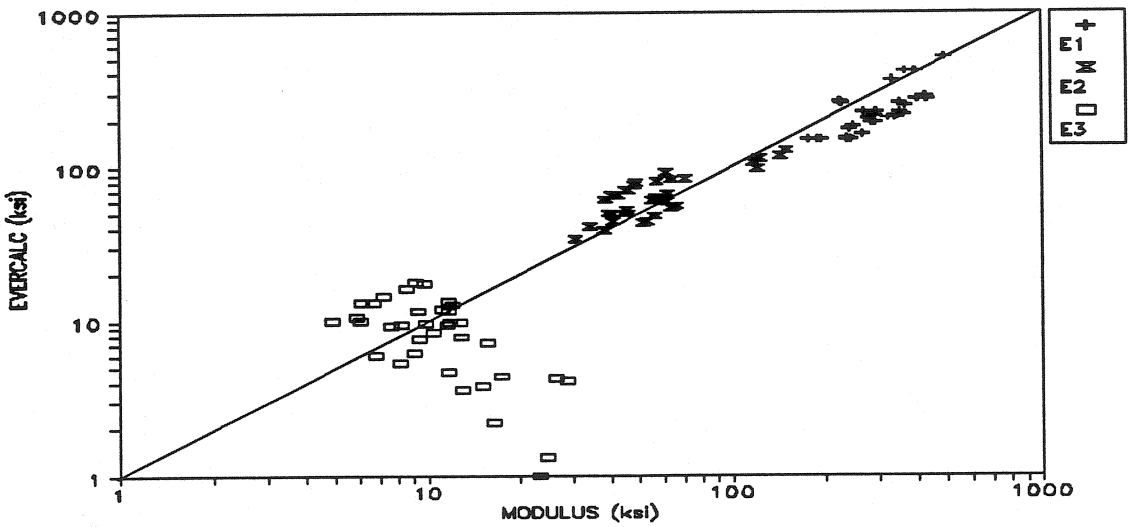

Figure 41. Comparison of Backcalculated moduli by MODULUS and EVERCALC (Section I15A0063).

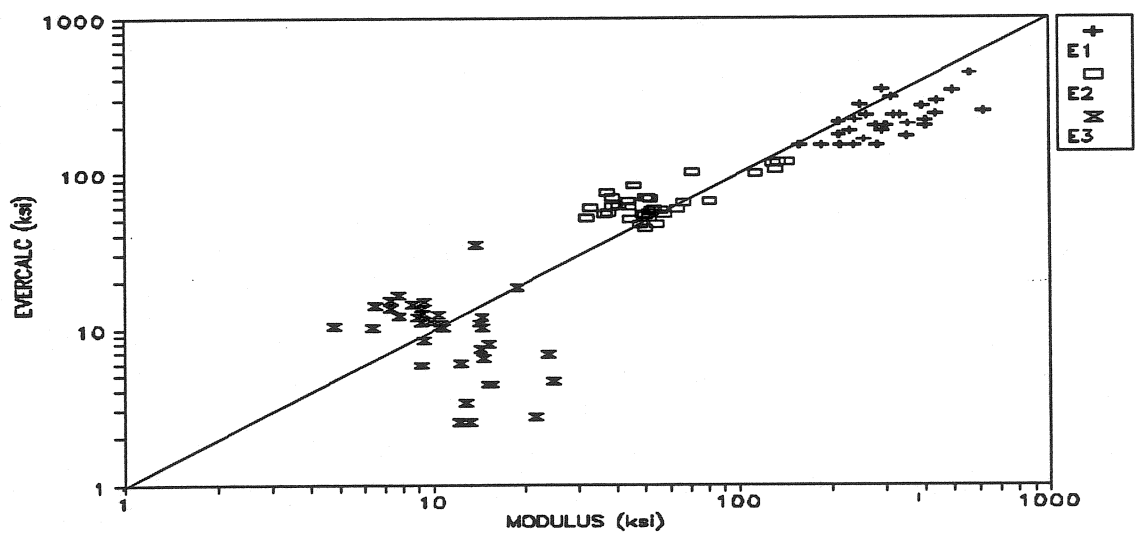

Figure 42. Comparison of Backcalculated moduli by MODULUS and EVERCALC (Section I15D0066).

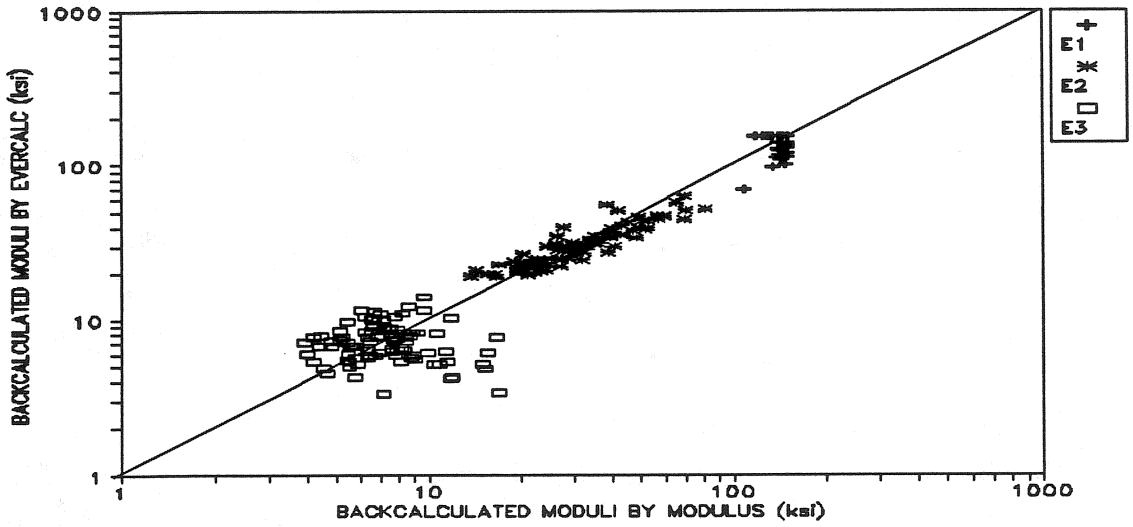

Figure 43. Comparisom of Backcalculated moduli by MODULUS and EVERCALC (Section U30A0378).

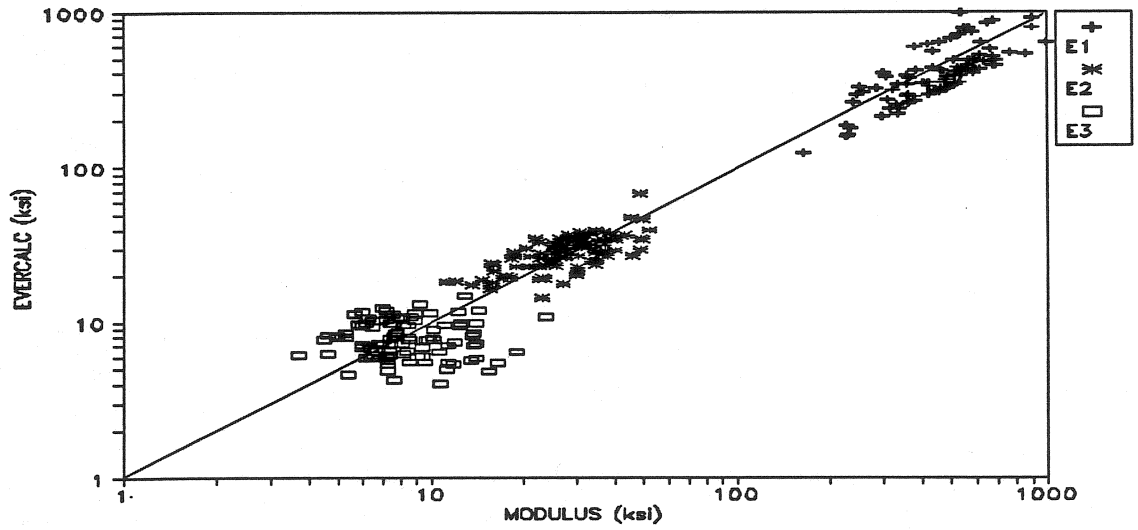

Figure 44. Comparison of Backcalculated moduli by MODULUS and EVERCALC (Section U30D0399).

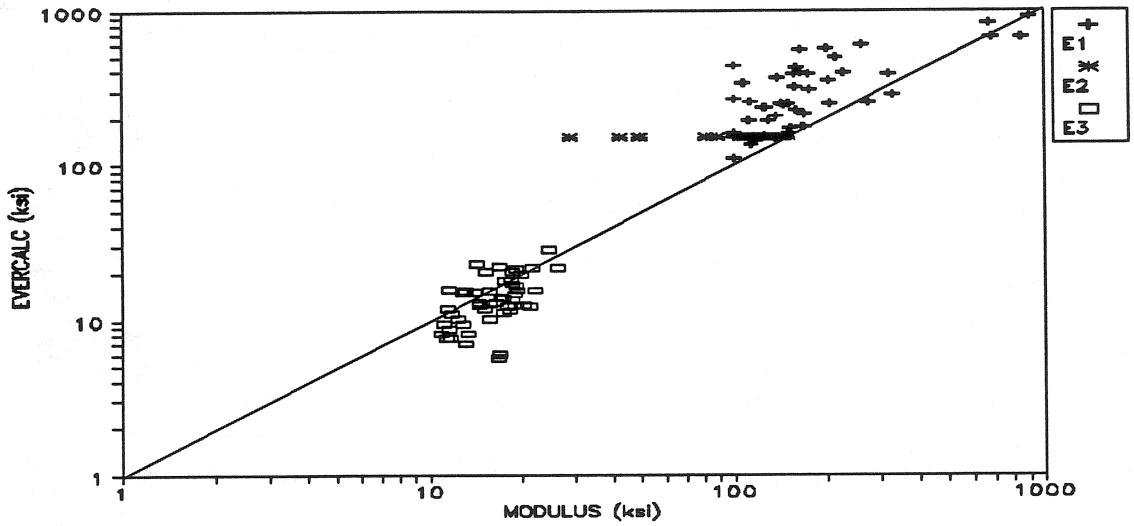

Figure 45. Comparison of Backcalculated moduli by MODULUS and EVERCALC (Section I84A0136).

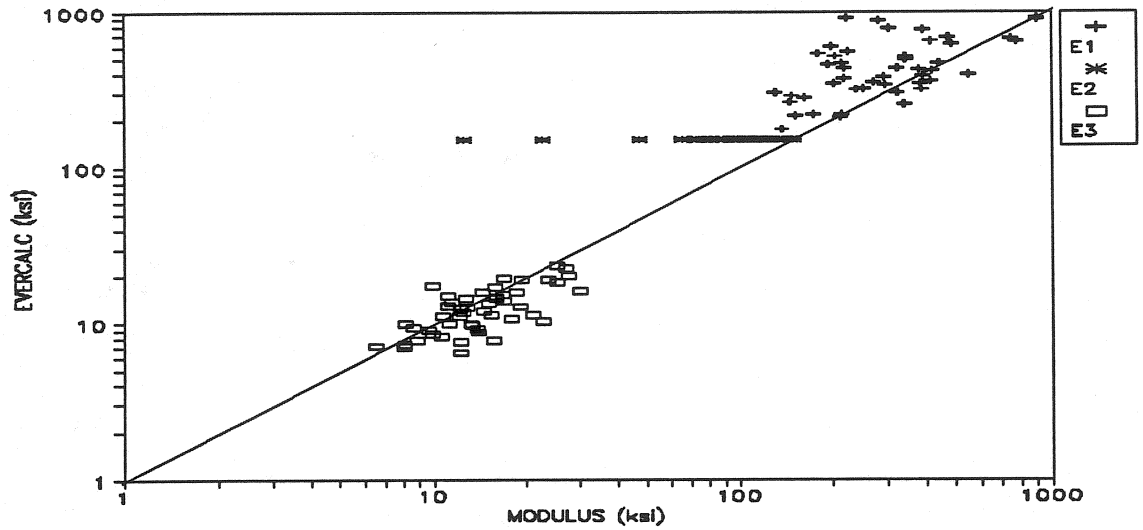

Figure 46. Comparison of Backcalculated moduli by MODULUS and EVERCALC (Section I84D0140).

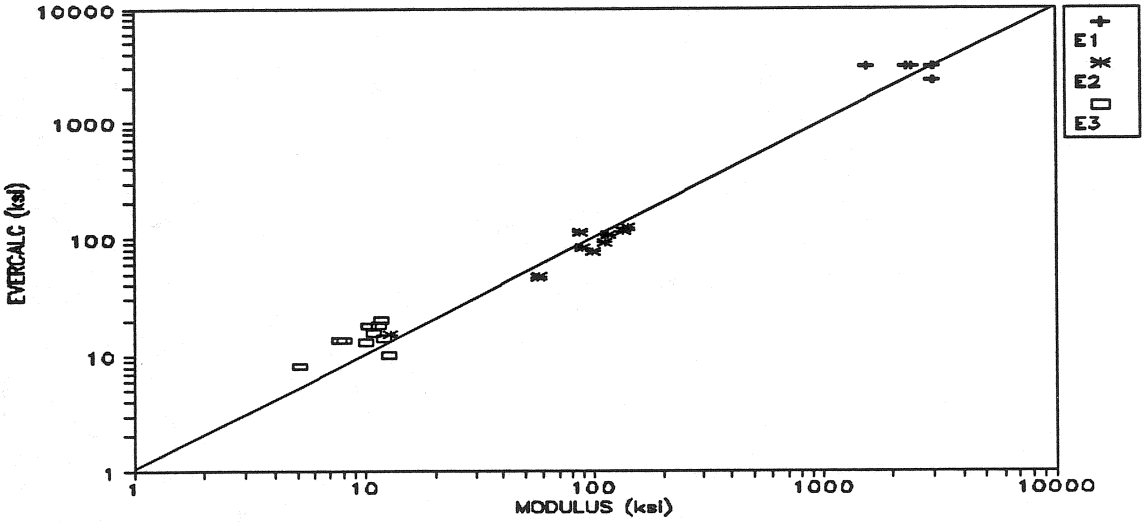

Figure 47. Comparison of Backcalculated moduli by MODULUS and EVERCALC (Section U95A0423).

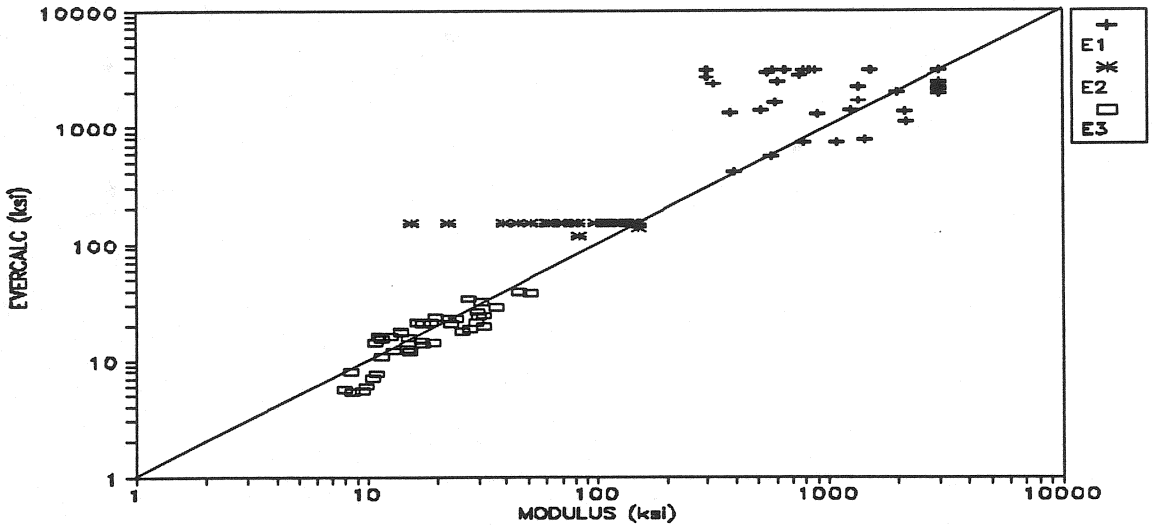

Figure 48. Comparison of Backcalculated moduli by MODULUS and EVERCALC (Section U95D0428).

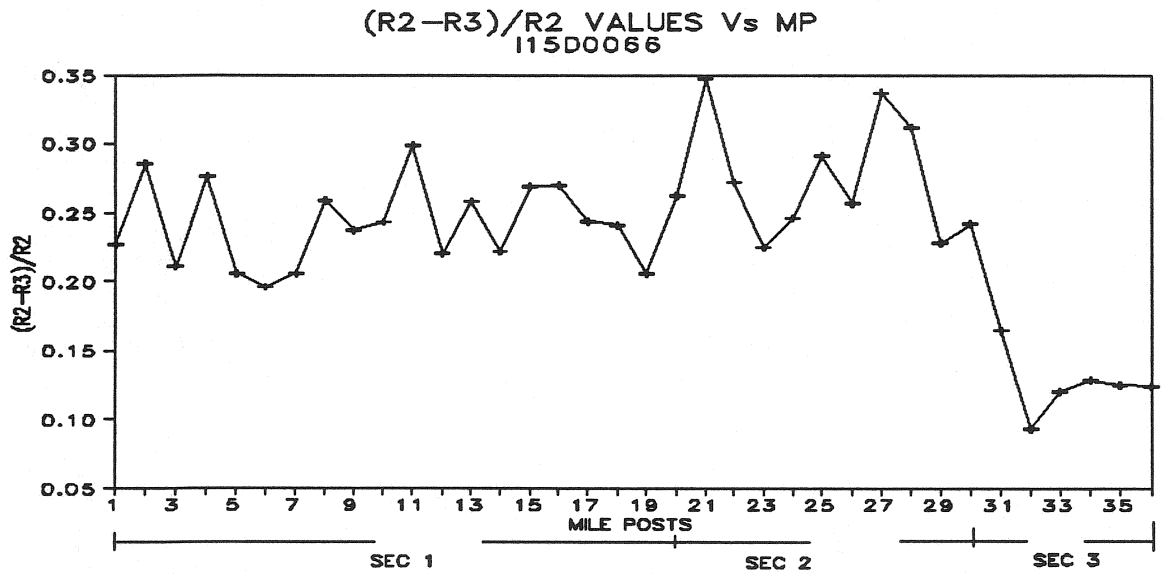

Figure 49. Surface curvature index (SCI) Vs mile posts (Section I15D0066).

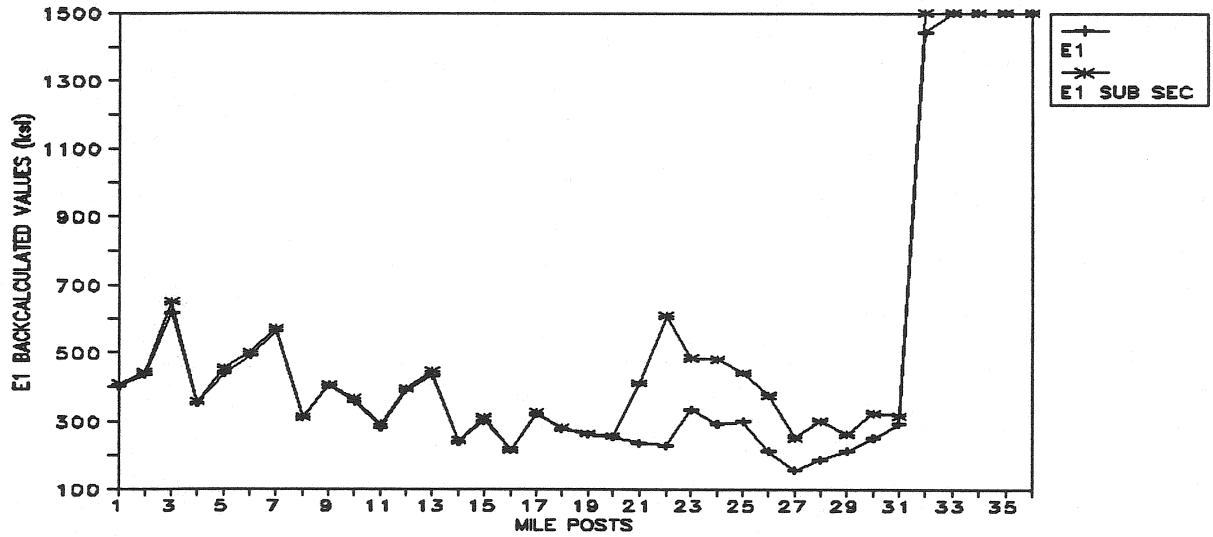

Figure 50. E1 Backcalculated moduli before and after subsectioning (Section I15D0066).

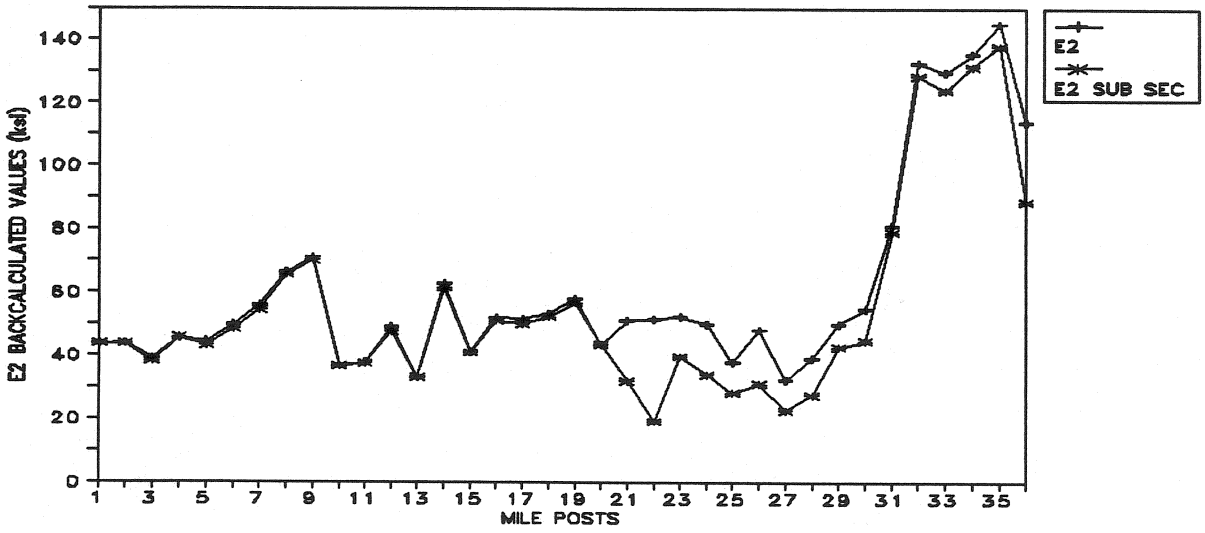

Figure 51. E2 Backcalculated moduli before and after subsectioning (Section I15D0066).

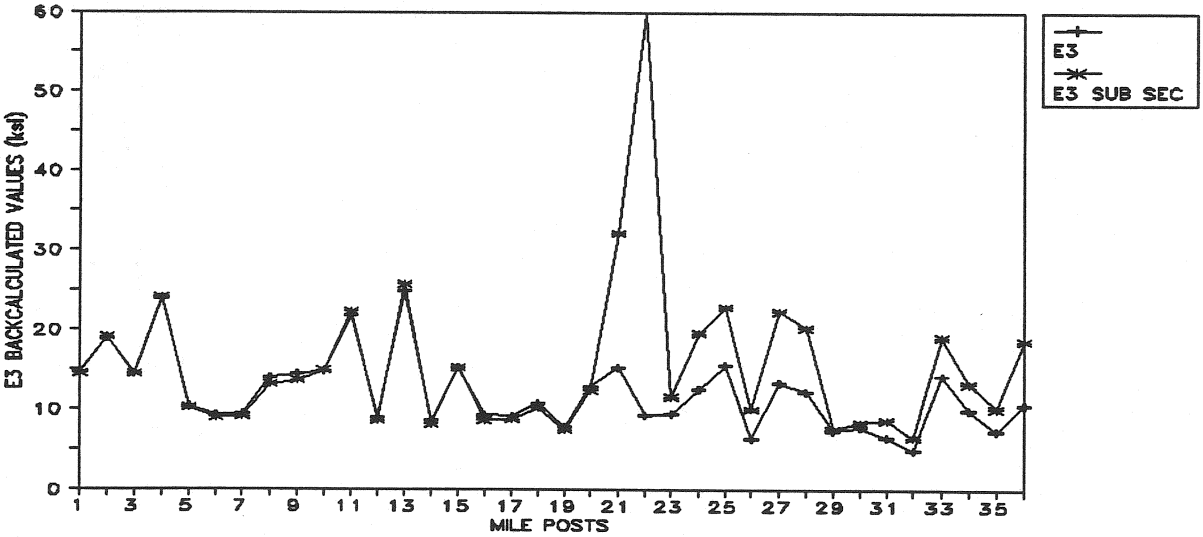

Figure 52. E3 Backcalculated moduli before and after subsectioning (Section I15D0066).

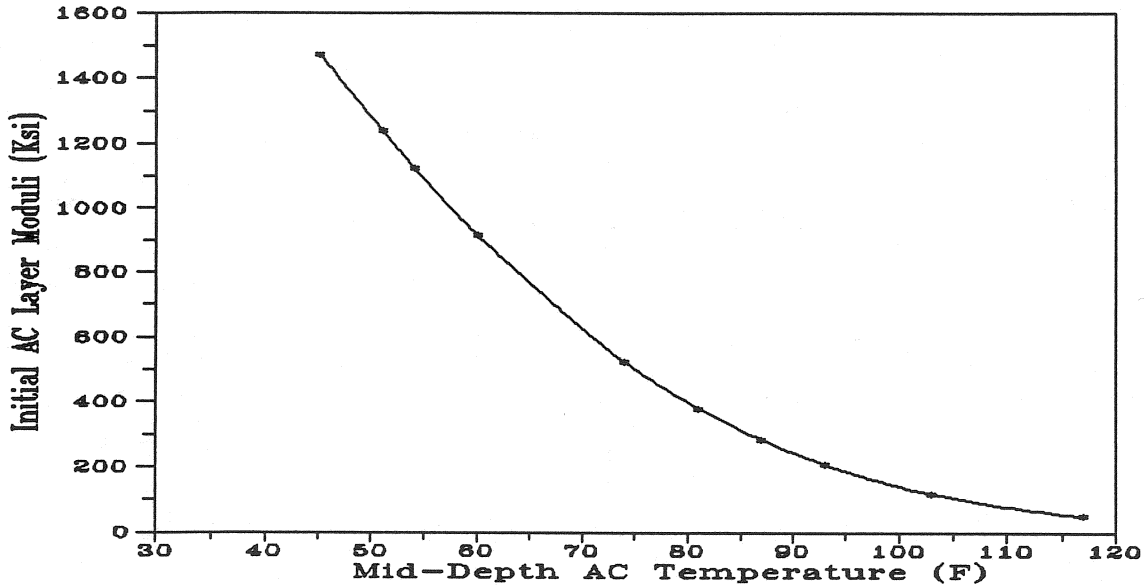

Figure 53. Graphical Representation of SHRP's equation for the initial AC layer moduli.

APPENDIX "A"

SAMPLE OF INPUT AND OUTPUT FILES FOR MODULUS 4.0 AND EVERCALC 3.3 (Modified for Idaho FWD Files)

File No. I84D0177

I 8400

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700031008002-09377808.8103111  8
150 0   203 305 457 610 914 1524 5.9   0     8     12    18    24    36    60
A:\                          .DAT
I 084
S 173.506d51 16     37 19 7376  61  98  66  Heights ............................
S 172.163d51 16     37 19 7376  61  98  66  Heights ............................
800 208027303730173.506 184.399
8   15  3.5 5   2   15  10  8
Ld 144   1     88.14
D1 1251  1     1.023
D2 1252  1     1.010
D3 1253  1     1.005
D4 1254  1     1.007
D5 1255  1     1.001
D6 1256  1     1.007
D7 1257  1     1.012
D0 1258  1     1.021
D* ***** 1     1
D* ***** 1     1
Darrell Sibert
11010301........................
6   .5  3   .5   ...............
*
FMMDDYYD
FMMDDYYD
*000+0.0 000+0.0 st
...............................
10422   -10422      0   1Peak...32  0   .....
...123.......................................................................
CCC3333333333333333333333333333333333333333333333333333333333333333333333333333
.............................................................................
*****************************************************************************
.............................................................................
......*...*...*...*........................................................
RIGID/FLEX"  Basin/Edge Test.
*000+0.0 000+0.0 st
S 177.600D50 15.5   27 19 D3090860  80  65  Heights ............................
702 336 283 247 208 171 122  55 11155 13.21 11.15  9.72  8.18  6.74  4.79  2.17
704 332 281 245 207 171 123  55 11187 13.06 11.07  9.65  8.15  6.74  4.83  2.18
705 331 281 245 207 171 122  56 11203 13.02 11.05  9.65  8.13  6.73  4.79  2.19
'GR,L/L
S 177.498D50 15.5   27 19 D3090960  80  66  Heights ............................
702 472 380 319 257 208 142  58 11159 18.57 14.96 12.55 10.11  8.19  5.57  2.27
702 463 374 314 253 206 140  59 11155 18.22 14.71 12.38  9.97  8.10  5.49  2.31
703 461 371 313 252 204 139  58 11163 18.17 14.62 12.34  9.94  8.04  5.46  2.28
'C
S 177.399D50 15.5   27 18 D3091060  81  64  Heights ............................
696 542 455 394 325 268 182  80 11060 21.33 17.89 15.52 12.80 10.54  7.16  3.15
697 529 446 388 321 264 180  80 11075 20.81 17.56 15.28 12.63 10.41  7.09  3.15
696 527 444 387 319 263 179  80 11064 20.73 17.49 15.22 12.57 10.35  7.05  3.15
'GR,L/L
S 177.300D50 15.5   27 19 D3091160  81  66  Heights ............................
697 575 467 396 318 253 168  63 11079 22.63 18.37 15.59 12.51  9.95  6.60  2.48
698 562 459 390 313 249 166  62 11087 22.11 18.05 15.36 12.34  9.81  6.54  2.43
699 563 460 390 313 251 165  64 11111 22.16 18.13 15.35 12.32  9.89  6.50  2.51
'C
S 177.191D50 15.5   28 19 D3091260  81  65  Heights ............................
708 308 266 235 204 173 131  62 11242 12.13 10.45  9.26  8.04  6.81  5.17  2.45
708 305 264 233 204 170 132  59 11250 12.00 10.38  9.17  8.02  6.69  5.19  2.34
```

```
711 306 264 233 204 171 132  62 11290 12.03 10.40  9.18  8.02  6.74  5.19  2.45
'F A/L
S 177.100D50 15.5   28 20 D3091360  81  67  Heights ..........................
683 658 480 370 249 176 111  54 10849 25.90 18.91 14.57  9.79  6.94  4.38  2.13
685 638 472 366 249 176 112  55 10877 25.13 18.60 14.42  9.79  6.93  4.40  2.15
685 634 470 366 249 177 113  55 10889 24.97 18.52 14.41  9.79  6.96  4.43  2.16
'F
S 177.001D50 15.5   27 18 D3091760  81  64  Heights ..........................
700 484 379 310 230 165  93  29 11123 19.04 14.93 12.21  9.04  6.48  3.67  1.14
701 484 379 310 229 165  93  29 11139 19.04 14.91 12.22  9.02  6.48  3.67  1.14
699 483 378 310 229 164  93  29 11111 19.00 14.89 12.20  9.00  6.47  3.66  1.13
'F
S 176.898D50 15.5   27 19 D3091960  81  66  Heights ..........................
702 343 287 252 208 168 115  50 11147 13.52 11.29  9.92  8.18  6.61  4.52  1.95
703 337 283 249 206 167 115  50 11171 13.28 11.14  9.81  8.10  6.56  4.52  1.95
703 336 282 249 207 167 115  49 11175 13.24 11.12  9.81  8.14  6.57  4.52  1.94
'F
S 176.799D50 15.5   28 19 D3092060  82  66  Heights ..........................
692 406 309 254 193 146  93  40 10992 15.98 12.15 10.00  7.59  5.74  3.66  1.56
693 397 302 248 191 143  95  40 11004 15.61 11.91  9.78  7.50  5.63  3.73  1.56
693 395 301 248 189 143  92  41 11016 15.55 11.87  9.77  7.43  5.61  3.62  1.61
'F
S 176.699D50 15.5   29 19 D3092160  83  65  Heights ..........................
698 349 285 243 202 167 119  66 11091 13.72 11.22  9.56  7.94  6.56  4.70  2.59
700 344 283 241 200 166 120  66 11119 13.56 11.15  9.48  7.87  6.52  4.70  2.61
700 344 283 241 201 166 120  66 11119 13.55 11.16  9.48  7.90  6.52  4.71  2.61
'F
S 176.591D50 15.5   29 20 D3092260  84  67  Heights ..........................
706 232 191 168 145 117  78  31 11218  9.15  7.52  6.60  5.72  4.60  3.07  1.22
707 230 188 166 143 115  77  31 11230  9.04  7.41  6.52  5.62  4.53  3.03  1.20
705 229 188 165 143 115  77  30 11195  9.00  7.39  6.50  5.63  4.52  3.03  1.17
'F
S 176.499D50 15.5   29 20 D3092360  84  67  Heights ..........................
683 588 490 418 326 249 160  67 10845 23.14 19.28 16.44 12.83  9.80  6.30  2.62
684 577 483 414 323 249 160  67 10869 22.71 19.00 16.28 12.72  9.81  6.28  2.65
683 572 482 412 323 249 160  66 10845 22.53 18.96 16.22 12.72  9.82  6.31  2.60
'GR
S 176.399D50 15.5   30 21 D3092460  85  69  Heights ..........................
690 637 521 445 343 258 156  77 10964 25.06 20.52 17.53 13.52 10.17  6.13  3.03
689 619 511 439 339 257 157  77 10940 24.38 20.13 17.28 13.35 10.11  6.16  3.05
687 614 508 436 338 255 155  77 10920 24.15 19.98 17.17 13.29 10.06  6.11  3.05
'C
S 176.295D50 15.5   30 21 D3092560  85  70  Heights ..........................
693 481 372 313 252 200 138  69 11012 18.94 14.65 12.34  9.91  7.89  5.42  2.70
693 474 367 310 250 199 138  69 11004 18.65 14.46 12.22  9.85  7.83  5.42  2.73
693 471 367 309 249 199 138  68 11008 18.54 14.43 12.16  9.79  7.83  5.44  2.67
'F
S 176.197D50 15.5   30 21 D3092660  85  70  Heights ..........................
689 562 477 416 336 261 164  70 10948 22.13 18.78 16.39 13.21 10.28  6.44  2.74
690 549 469 410 332 259 163  70 10964 21.62 18.46 16.12 13.07 10.20  6.43  2.76
690 547 466 408 330 257 163  70 10960 21.53 18.36 16.04 12.97 10.13  6.42  2.75
'C
S 176.094D50 15.5   31 22 D3092860  87  71  Heights ..........................
700 356 279 232 173 127  71  25 11115 14.01 11.00  9.13  6.79  5.00  2.81  0.97
701 351 277 230 172 126  71  25 11131 13.83 10.89  9.04  6.78  4.95  2.80  0.98
698 349 276 229 171 125  71  24 11083 13.73 10.87  9.01  6.73  4.92  2.80  0.96
'C
S 176.016D50 15.5   29 20 D3093260  84  67  Heights ..........................
689 427 340 282 217 167 108  49 10952 16.81 13.37 11.11  8.53  6.57  4.26  1.93
689 426 338 281 215 166 108  49 10940 16.75 13.32 11.06  8.48  6.53  4.23  1.93
```

687 426 339 282 217 167 109 49 10913 16.78 13.36 11.09 8.56 6.56 4.28 1.91
'C
S 175.899D50 15.5 31 19 D3093360 87 66 Heights .....
695 291 231 199 172 134 91 35 11040 11.46 9.09 7.83 6.76 5.28 3.59 1.36
695 286 227 196 169 131 90 35 11036 11.28 8.94 7.72 6.64 5.17 3.56 1.37
695 284 226 195 167 130 89 35 11036 11.20 8.91 7.69 6.57 5.13 3.52 1.36
'F
S 175.800D50 15.5 32 21 D3093560 89 69 Heights .....
695 310 267 233 190 153 101 41 11048 12.22 10.50 9.17 7.47 6.00 3.96 1.61
693 305 262 229 186 150 101 40 11004 11.99 10.32 9.02 7.33 5.90 3.97 1.57
693 304 262 229 186 150 101 40 11012 11.96 10.30 9.00 7.34 5.89 3.96 1.59
'F
S 175.700D50 15.5 31 22 D3093660 88 72 Heights .....
684 580 494 421 335 264 185 99 10873 22.84 19.45 16.59 13.17 10.39 7.29 3.91
685 568 487 418 332 263 185 102 10881 22.37 19.15 16.45 13.06 10.36 7.27 4.03
680 564 483 416 331 262 184 101 10809 22.21 19.02 16.38 13.04 10.30 7.26 3.99
'GR
S 175.599D50 15.5 32 20 D3093960 89 67 Heights .....
687 493 400 342 281 228 166 79 10917 19.43 15.74 13.46 11.06 8.97 6.52 3.11
688 486 392 337 280 227 170 79 10928 19.13 15.44 13.27 11.04 8.93 6.68 3.11
692 484 392 336 281 227 170 80 10988 19.07 15.42 13.24 11.07 8.94 6.71 3.15
'C
S 175.499D50 15.5 32 20 D3094060 89 67 Heights .....
684 523 455 404 340 285 213 108 10873 20.57 17.92 15.92 13.38 11.23 8.37 4.23
682 511 448 400 337 283 213 106 10837 20.13 17.64 15.73 13.28 11.14 8.37 4.19
686 511 449 400 336 283 211 112 10905 20.13 17.68 15.73 13.21 11.15 8.30 4.42
'F
S 175.398D50 15.5 32 22 D3094260 89 72 Heights .....
671 726 608 500 367 275 165 88 10662 28.57 23.93 19.70 14.46 10.82 6.48 3.46
676 720 606 498 367 275 166 88 10746 28.33 23.85 19.61 14.43 10.83 6.52 3.45
677 718 607 499 369 277 167 88 10762 28.25 23.89 19.65 14.52 10.89 6.57 3.47
'C
S 175.342D50 15.5 32 23 D3094360 90 72 Heights .....
680 427 334 268 186 127 59 19 10809 16.83 13.17 10.57 7.31 4.99 2.32 0.74
680 416 326 263 182 124 58 18 10797 16.38 12.84 10.35 7.16 4.87 2.27 0.72
679 414 324 262 181 123 57 18 10793 16.30 12.77 10.32 7.11 4.85 2.26 0.72
'GR
S 175.197D50 15.5 32 21 D3094560 89 69 Heights .....
689 405 341 299 245 194 124 55 10948 15.94 13.43 11.76 9.63 7.65 4.87 2.15
688 399 338 296 243 192 125 54 10936 15.69 13.29 11.67 9.56 7.57 4.92 2.12
684 390 330 289 237 187 119 52 10861 15.33 13.00 11.39 9.32 7.35 4.69 2.03
'GR
S 175.100D50 15.5 33 23 D3094660 90 72 Heights .....
680 721 581 474 350 260 152 54 10797 28.37 22.87 18.66 13.77 10.25 5.97 2.13
679 696 566 464 345 258 152 52 10789 27.39 22.28 18.28 13.59 10.15 5.97 2.04
678 690 562 461 344 257 151 56 10770 27.15 22.11 18.15 13.52 10.11 5.96 2.21
'GR
S 175.000D50 15.5 31 19 D3095060 87 66 Heights .....
680 386 322 281 233 193 138 80 10801 15.18 12.67 11.06 9.19 7.61 5.43 3.13
683 388 324 283 235 195 139 81 10845 15.26 12.76 11.12 9.24 7.66 5.47 3.17
680 387 324 282 235 194 139 78 10809 15.23 12.74 11.10 9.23 7.65 5.46 3.08
'C
S 174.896D50 15.5 32 21 D3095360 89 69 Heights .....
678 542 462 403 322 258 171 78 10777 21.33 18.17 15.85 12.67 10.17 6.74 3.07
680 533 454 397 320 256 173 80 10797 20.98 17.89 15.61 12.59 10.07 6.82 3.15
680 528 451 394 317 255 170 77 10797 20.77 17.74 15.51 12.48 10.02 6.70 3.05
'C
S 174.800D50 15.5 33 22 D3095460 91 72 Heights .....
692 449 378 338 283 235 168 82 10996 17.68 14.90 13.31 11.13 9.24 6.61 3.22
692 442 374 336 282 234 170 76 10996 17.41 14.72 13.21 11.08 9.20 6.70 3.00

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693 440 371 334 282 233 171  76 11004 17.33 14.62 13.16 11.10  9.19  6.73  3.00
'C
S 174.737D50 15.5   32 23 D3095560  90  72  Heights ..............................
690 430 344 300 243 197 127  52 10968 16.93 13.56 11.80  9.58  7.75  5.00  2.04
690 424 340 295 241 195 129  50 10968 16.70 13.40 11.63  9.47  7.66  5.08  1.97
691 426 339 298 239 195 125  58 10980 16.76 13.34 11.74  9.41  7.69  4.91  2.30
'C
S 174.495D50 15.5   31 20 D3095860  88  68  Heights ..............................
678 495 371 298 227 175 114  54 10774 19.47 14.61 11.74  8.93  6.89  4.50  2.11
678 482 366 296 225 174 114  54 10770 18.98 14.41 11.65  8.87  6.85  4.47  2.11
679 478 365 295 225 174 114  54 10789 18.83 14.35 11.60  8.86  6.85  4.47  2.11
'F
S 174.400D50 15.5   31 22 D3095960  87  71  Heights ..............................
688 473 354 282 197 136  68  23 10924 18.63 13.95 11.11  7.74  5.34  2.66  0.92
686 462 349 279 195 133  68  25 10905 18.19 13.76 11.00  7.66  5.24  2.66  0.97
688 459 348 279 194 133  67  24 10924 18.09 13.70 10.96  7.62  5.23  2.65  0.95
'F
S 174.298D50 15.5   31 23 D3100060  87  72  Heights ..............................
681 510 383 302 203 136  65  30 10821 20.07 15.09 11.90  7.99  5.36  2.55  1.17
683 495 375 298 200 135  66  30 10849 19.49 14.76 11.72  7.88  5.30  2.58  1.19
683 491 373 297 200 135  66  30 10845 19.34 14.67 11.69  7.87  5.31  2.60  1.17
'F
S 174.199D50 15.5   31 23 D3100160  87  72  Heights ..............................
680 519 361 275 196 146  88  39 10801 20.41 14.21 10.84  7.71  5.75  3.44  1.52
680 507 356 272 193 144  87  39 10797 19.95 14.00 10.71  7.61  5.67  3.43  1.52
680 503 354 271 193 144  88  38 10805 19.79 13.94 10.66  7.58  5.66  3.45  1.49
'GR
S 174.099D50 15.5   31 22 D3100260  87  71  Heights ..............................
686 475 378 310 234 178 112  49 10901 18.71 14.86 12.21  9.22  7.02  4.43  1.94
684 466 370 306 232 177 112  50 10865 18.33 14.57 12.03  9.13  6.95  4.41  1.96
684 462 368 304 231 176 112  50 10873 18.19 14.47 11.98  9.07  6.93  4.40  1.95
'GR
S 174.000D50 15.5   30 20 D3100660  85  67  Heights ..............................
688 343 283 232 168 124  76  32 10928 13.50 11.14  9.14  6.63  4.87  3.00  1.28
689 344 284 233 168 124  76  33 10948 13.54 11.17  9.15  6.63  4.89  2.98  1.31
688 344 283 232 168 123  75  34 10928 13.52 11.15  9.15  6.63  4.85  2.97  1.32
'GR
S 173.900D50 15.5   31 20 D3100760  87  68  Heights ..............................
684 410 309 251 183 134  79  36 10869 16.15 12.18  9.89  7.19  5.26  3.11  1.40
686 402 305 249 181 132  79  35 10905 15.83 11.99  9.79  7.12  5.18  3.11  1.38
687 399 303 247 181 131  79  34 10913 15.70 11.94  9.73  7.12  5.16  3.11  1.34
'F
S 173.800D50 15.5   31 21 D3100860  88  69  Heights ..............................
691 379 283 229 166 123  71  26 10984 14.91 11.15  9.02  6.54  4.85  2.81  1.01
689 367 276 223 164 119  70  25 10944 14.44 10.88  8.79  6.44  4.70  2.77  0.96
689 365 275 222 164 119  70  24 10944 14.37 10.84  8.75  6.46  4.69  2.77  0.94
'C
S 173.699D50 15.5   30 21 D3101060  86  69  Heights ..............................
693 397 341 289 235 198 138  57 11004 15.64 13.43 11.37  9.24  7.78  5.43  2.25
695 392 339 287 235 197 139  57 11044 15.44 13.33 11.30  9.24  7.74  5.46  2.23
692 391 338 286 236 196 138  57 10988 15.39 13.29 11.27  9.27  7.72  5.44  2.23
'F,A/M
S 173.600D50 15.5   30 21 D3101260  86  70  Heights ..............................
674 655 539 464 377 300 201  85 10714 25.78 21.22 18.28 14.84 11.82  7.93  3.34
675 646 534 462 375 298 202  84 10726 25.45 21.03 18.18 14.76 11.75  7.94  3.30
675 643 533 461 375 297 201  84 10722 25.33 20.98 18.15 14.74 11.70  7.93  3.31
'F
S 173.507D50 15.5 j 31 20 D3101360  87  68  Heights ..............................
692 367 313 281 242 208 152  79 10996 14.46 12.32 11.06  9.51  8.18  5.99  3.10
693 363 311 279 241 207 151  79 11016 14.30 12.23 10.98  9.47  8.14  5.96  3.12
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I84D0177.31 +

0	84	177.600	0	11203	13.02	11.05	9.65	8.13	6.73	4.79	2.19
0	84	177.498	0	11163	18.17	14.62	12.34	9.94	8.04	5.46	2.28
0	84	177.399	0	11064	20.73	17.49	15.22	12.57	10.35	7.05	3.15
0	84	177.300	0	11111	22.16	18.13	15.35	12.32	9.89	6.50	2.51
0	84	177.191	0	11290	12.03	10.40	9.18	8.02	6.74	5.19	2.45
0	84	177.100	0	10889	24.97	18.52	14.41	9.79	6.96	4.43	2.16
0	84	177.001	0	11111	19.00	14.89	12.20	9.00	6.47	3.66	1.13
0	84	176.898	0	11175	13.24	11.12	9.81	8.14	6.57	4.52	1.94
0	84	176.799	0	11016	15.55	11.87	9.77	7.43	5.61	3.62	1.61
0	84	176.699	0	11119	13.55	11.16	9.48	7.90	6.52	4.71	2.61
0	84	176.591	0	11195	9.00	7.39	6.50	5.63	4.52	3.03	1.17
0	84	176.499	0	10845	22.53	18.96	16.22	12.72	9.82	6.31	2.60
0	84	176.399	0	10920	24.15	19.98	17.17	13.29	10.06	6.11	3.05
0	84	176.295	0	11008	18.54	14.43	12.16	9.79	7.83	5.44	2.67
0	84	176.197	0	10960	21.53	18.36	16.04	12.97	10.13	6.42	2.75
0	84	176.094	0	11083	13.73	10.87	9.01	6.73	4.92	2.80	0.96
0	84	176.016	0	10913	16.78	13.36	11.09	8.56	6.56	4.28	1.91
0	84	175.899	0	11036	11.20	8.91	7.69	6.57	5.13	3.52	1.36
0	84	175.800	0	11012	11.96	10.30	9.00	7.34	5.89	3.96	1.59
0	84	175.700	0	10809	22.21	19.02	16.38	13.04	10.30	7.26	3.99
0	84	175.599	0	10988	19.07	15.42	13.24	11.07	8.94	6.71	3.15
0	84	175.499	0	10905	20.13	17.68	15.73	13.21	11.15	8.30	4.42
0	84	175.398	0	10762	28.25	23.89	19.65	14.52	10.89	6.57	3.47
0	84	175.342	0	10793	16.30	12.77	10.32	7.11	4.85	2.26	0.72
0	84	175.197	0	10861	15.33	13.00	11.39	9.32	7.35	4.69	2.03
0	84	175.100	0	10770	27.15	22.11	18.15	13.52	10.11	5.96	2.21
0	84	175.000	0	10809	15.23	12.74	11.10	9.23	7.65	5.46	3.08
0	84	174.896	0	10797	20.77	17.74	15.51	12.48	10.02	6.70	3.05
0	84	174.800	0	11004	17.33	14.62	13.16	11.10	9.19	6.73	3.00
0	84	174.737	0	10980	16.76	13.34	11.74	9.41	7.69	4.91	2.30

J84D0177.SUM

EVERCAL

BACKCALCULATION BY EVERCALC VERSION 3.3

Route: I 084 MP 184.400 - 173.506 Tested on 6/ 7/

							Sensor Readings							
STN	Load	EAD	E(1)	E(2)	E(3)	E(4)	1	2	3	4	5	6	7	ARMS
177.600	11203.0	177.3	392.3	100.0	73.0	6.5	13.02	11.05	9.65	8.13	6.73	4.79	2.19	2.8
177.498	11163.0	135.6	300.0	100.0	42.5	5.4	18.17	14.62	12.34	9.94	8.04	5.46	2.28	5.0
177.399	11064.0	135.6	300.0	100.0	31.6	4.9	20.73	17.49	15.22	12.57	10.35	7.05	3.15	3.9
177.300	11111.0	135.6	300.0	100.0	27.7	4.4	22.16	18.13	15.35	12.32	9.89	6.50	2.51	5.6
177.191	11290.0	279.6	618.6	107.7	80.0	5.8	12.03	10.40	9.18	8.02	6.74	5.19	2.45	3.8
177.100	10889.0	135.6	300.0	100.0	22.7	7.9	24.97	18.52	14.41	9.79	6.96	4.43	2.16	17.4
177.001	11111.0	135.6	300.0	100.0	33.0	5.8	19.00	14.89	12.20	9.00	6.47	3.66	1.13	9.1
176.898	11175.0	164.0	362.9	100.0	67.3	6.3	13.24	11.12	9.81	8.14	6.57	4.52	1.94	2.3
176.799	11016.0	135.6	300.0	100.0	52.5	8.2	15.55	11.87	9.77	7.43	5.61	3.62	1.61	8.2
176.699	11119.0	252.8	559.4	100.0	60.6	10.4	13.55	11.16	9.48	7.90	6.52	4.71	2.61	3.6
176.591	11195.0	269.1	595.4	222.7	80.0	8.1	9.00	7.39	6.50	5.63	4.52	3.03	1.17	3.5
176.499	10845.0	135.6	300.0	100.0	24.3	4.6	22.53	18.96	16.22	12.72	9.82	6.31	2.60	7.0
176.399	10920.0	135.6	300.0	100.0	18.9	6.2	24.15	19.98	17.17	13.29	10.06	6.11	3.05	9.5
176.295	11008.0	135.6	300.0	100.0	41.2	7.0	18.54	14.43	12.16	9.79	7.83	5.44	2.67	6.3
176.197	10960.0	135.6	300.0	100.0	25.3	4.9	21.53	18.36	16.04	12.97	10.13	6.42	2.75	5.2
176.094	11083.0	135.6	300.0	100.0	55.5	7.8	13.73	10.87	9.01	6.73	4.92	2.80	.96	7.0
176.016	10913.0	135.6	300.0	100.0	43.9	7.2	16.78	13.36	11.09	8.56	6.56	4.28	1.91	7.4
175.899	11036.0	171.1	378.7	126.9	80.0	6.8	11.20	8.91	7.69	6.57	5.13	3.52	1.36	3.0
175.800	11012.0	206.1	456.1	100.0	67.2	6.4	11.96	10.30	9.00	7.34	5.89	3.96	1.59	2.1
175.700	10809.0	135.6	300.0	100.0	24.9	6.8	22.21	19.02	16.38	13.04	10.30	7.26	3.99	6.0
175.599	10988.0	135.6	300.0	100.0	44.7	4.9	19.07	15.42	13.24	11.07	8.94	6.71	3.15	5.5
175.499	10905.0	216.3	478.6	100.0	31.7	5.6	20.13	17.68	15.73	13.21	11.15	8.30	4.42	3.8
175.398	10762.0	135.6	300.0	100.0	15.5	5.1	28.25	23.89	19.65	14.52	10.89	6.57	3.47	14.2
175.342	10793.0	135.6	300.0	100.0	48.5	4.7	16.30	12.77	10.32	7.11	4.85	2.26	.72	17.2
175.197	10861.0	136.3	301.7	100.0	46.0	6.4	15.33	13.00	11.39	9.32	7.35	4.69	2.03	3.6
175.100	10770.0	135.6	300.0	100.0	17.2	4.2	27.15	22.11	18.15	13.52	10.11	5.96	2.21	11.5
175.000	10809.0	328.2	726.3	100.0	41.0	9.6	15.23	12.74	11.10	9.23	7.65	5.46	3.08	3.2
174.896	10797.0	135.6	300.0	100.0	28.5	5.0	20.77	17.74	15.51	12.48	10.02	6.70	3.05	4.8
174.800	11004.0	135.6	300.0	100.0	48.6	4.5	17.33	14.62	13.16	11.10	9.19	6.73	3.00	2.6
174.737	10980.0	135.6	300.0	100.0	42.3	7.4	16.76	13.34	11.74	9.41	7.69	4.91	2.30	4.0

Note: STN = Station ID
Load = FWD load (lbs)
EAD = AC layer moduli adjusted for temperature (ksi)
E(i) = Modulus of i-th layer (ksi)
i = i-th sensor reading (mils)
ARMS = Average RMS error at this station (%)

The above quantities are average values at a station, if there is more than one drop (used)

TTI MODULUS ANALYSIS SYSTEM (SUMMARY REPORT) (Version 4.0)

District: 0
County: 84
Highway/Road:

	Thickness(in)	MODULI RANGE(psi) Minimum	Maximum
Pavement:	4.80	300,000	1,500,000
Base:	4.80	50,000	250,000
Subbase:	13.20	4,000	50,000
Subgrade:	71.60	7,700	

Station	Load (lbs)	Measured Deflection (mils): R1	R2	R3	R4	R5	R6	R7	Calculated Moduli values (ksi): SURF(E1)	BASE(E2)	SUBB(E3)	SUBG(E4)	Absolute ERROR/Sens.	Depth to Bedrock
177.600	11,202	13.02	11.05	9.65	8.13	6.73	4.79	2.19	887.	184.7	50.0	6.7	1.48	96.16 *
177.498	11,162	18.17	14.62	12.34	9.94	8.04	5.46	2.28	549.	50.3	49.6	5.9	0.31	88.09
177.399	11,063	20.73	17.49	15.22	12.57	10.35	7.05	3.15	679.	50.0	37.0	4.4	0.60	100.89 *
177.300	11,110	22.16	18.13	15.35	12.32	9.89	6.50	2.51	487.	50.8	30.7	5.3	0.33	83.65
177.191	11,289	12.03	10.40	9.18	8.02	6.74	5.19	2.45	1500.	250.0	22.4	8.6	9.00	96.93 *
177.100	10,888	24.97	18.52	14.41	9.79	6.96	4.43	2.16	300.	50.0	20.6	8.3	11.94	89.68 *
177.001	11,110	19.00	14.89	12.20	9.00	6.47	3.66	1.13	429.	50.0	25.4	10.2	2.74	68.44 *
176.898	11,174	13.24	11.12	9.81	8.14	6.57	4.52	1.94	1073.	102.5	50.0	7.2	0.80	87.98 *
176.799	11,015	15.55	11.87	9.77	7.43	5.61	3.62	1.61	436.	65.9	50.0	9.4	4.07	90.24 *
176.699	11,118	13.55	11.16	9.48	7.90	6.52	4.71	2.61	842.	191.1	50.0	6.5	5.93	163.37 *
176.591	11,194	9.00	7.39	6.50	5.63	4.52	3.03	1.17	1500.	250.0	22.4	16.8	11.47	75.92 *
176.499	10,844	22.53	18.96	16.22	12.72	9.82	6.31	2.60	489.	50.0	26.0	5.3	2.82	87.04 *
176.399	10,919	24.15	19.98	17.17	13.29	10.06	6.11	3.05	368.	50.0	27.1	5.0	5.90	113.10 *
176.295	11,007	18.54	14.43	12.16	9.79	7.83	5.44	2.67	429.	65.8	50.0	5.6	3.28	113.77 *
176.197	10,959	21.53	18.36	16.04	12.97	10.13	6.42	2.75	673.	50.0	26.0	5.1	2.70	93.79 *
176.094	11,082	13.73	10.87	9.01	6.73	4.92	2.80	0.96	726.	50.0	41.6	12.7	2.72	71.17 *
176.016	10,912	16.78	13.36	11.09	8.56	6.56	4.28	1.91	502.	50.0	50.0	7.5	3.19	92.62 *
175.899	11,035	11.20	8.91	7.69	6.57	5.13	3.52	1.36	672.	250.0	50.0	10.2	2.12	76.46 *
175.800	11,011	11.96	10.30	9.00	7.34	5.89	3.96	1.59	1500.	73.0	49.7	8.5	0.70	80.72 *
175.700	10,808	22.21	19.02	16.38	13.04	10.30	7.26	3.99	464.	50.0	38.7	3.9	4.76	164.91 *
175.599	10,987	19.07	15.42	13.24	11.07	8.94	6.71	3.15	422.	93.5	46.1	4.6	2.25	101.14 *
175.499	10,904	20.13	17.68	15.73	13.21	11.15	8.30	4.42	800.	121.4	33.3	3.3	2.84	151.09 *
175.398	10,761	28.25	23.89	19.65	14.52	10.89	6.57	3.47	300.	50.0	19.2	4.8	8.81	104.97 *
175.342	10,792	16.30	12.77	10.32	7.11	4.85	2.26	0.72	468.	50.0	21.4	15.5	6.88	53.48 *
175.197	10,860	15.33	13.00	11.39	9.32	7.35	4.69	2.03	1084.	50.0	41.3	6.7	1.95	92.92 *
175.100	10,769	27.15	22.11	18.15	13.52	10.11	5.96	2.21	300.	50.0	16.7	5.9	4.66	78.55 *
175.000	10,808	15.23	12.74	11.10	9.23	7.65	5.46	3.08	697.	127.0	50.0	5.2	4.03	193.31 *
174.896	10,796	20.77	17.74	15.51	12.48	10.02	6.70	3.05	633.	50.0	33.4	4.5	2.17	101.54 *
174.800	11,003	17.33	14.62	13.16	11.10	9.19	6.73	3.00	1500.	100.0	11.2	7.1	9.45	95.26 *
174.737	10,979	16.76	13.34	11.74	9.41	7.69	4.91	2.30	648.	56.7	50.0	6.1	2.16	107.93 *
Mean:		18.01	14.80	12.62	10.03	7.90	5.25	2.38	712.	91.1	36.3	7.2	4.07	94.36
Std. Dev:		4.83	4.03	3.34	2.51	2.02	1.47	0.87	374.	66.1	12.9	3.2	3.25	23.64
Var Coeff(%):		26.83	27.20	26.43	25.07	25.63	28.09	36.51	53.	72.6	35.5	44.6	79.76	25.05

I84D0177

(94)

TTI MODULUS ANALYSIS SYSTEM (SUMMARY REPORT) (Version 4.0)

District: 0
County: 84
Highway/Road:

	Thickness(in)	MODULI RANGE(psi) Minimum	Maximum
Pavement:	4.80	100,000	400,000
Base:	4.80	10,000	200,000
Subbase:	13.20	4,000	40,000
Subgrade:	71.60	20,000 Provided → 11,600	

Station	Load (lbs)	Measured Deflection (mils): R1	R2	R3	R4	R5	R6	R7	Calculated Moduli values (ksi): SURF(E1)	BASE(E2)	SUBB(E3)	SUBG(E4)	Absolute ERROR/Sens.	Depth to Bedrock
177.600	11,202	13.02	11.05	9.65	8.13	6.73	4.79	2.19	400.	161.9	27.3	10.0	15.58	96.16 *
177.498	11,162	18.17	14.62	12.34	9.94	8.04	5.46	2.28	400.	94.7	40.0	6.2	1.50	88.09 *
177.399	11,063	20.73	17.49	15.22	12.57	10.35	7.05	3.15	400.	70.2	20.0	6.3	11.66	100.89 *
177.300	11,110	22.16	18.13	15.35	12.32	9.89	6.50	2.51	400.	39.6	20.0	7.1	11.45	83.65 *
177.191	11,289	12.03	10.40	9.18	8.02	6.74	5.19	2.45	400.	123.8	31.8	12.7	23.70	96.93 *
177.100	10,888	24.97	18.52	14.41	9.79	6.96	4.43	2.16	254.	19.2	40.0	7.5	7.64	89.68 *
177.001	11,110	19.00	14.89	12.20	9.00	6.47	3.66	1.13	400.	57.8	23.1	10.5	3.05	68.44 *
176.898	11,174	13.24	11.12	9.81	8.14	6.57	4.52	1.94	400.	175.7	31.8	9.5	10.15	87.98 *
176.799	11,015	15.55	11.87	9.77	7.43	5.61	3.62	1.61	400.	24.5	31.8	17.0	23.64	90.24 *
176.699	11,118	13.55	11.16	9.48	7.90	6.52	4.71	2.61	400.	137.2	27.3	9.9	17.34	163.37 *
176.591	11,194	9.00	7.39	6.50	5.63	4.52	3.03	1.17	400.	112.3	40.0	25.1	30.03	75.92 *
176.499	10,844	22.53	18.96	16.22	12.72	9.82	6.31	2.60	400.	39.6	21.1	6.1	6.73	87.04 *
176.399	10,919	24.15	19.98	17.17	13.29	10.06	6.11	3.05	400.	22.8	20.0	6.8	11.84	113.10 *
176.295	11,007	18.54	14.43	12.16	9.79	7.83	5.44	2.67	400.	96.6	40.0	6.0	4.65	113.77 *
176.197	10,959	21.53	18.36	16.04	12.97	10.13	6.42	2.75	400.	86.5	24.1	5.3	3.65	93.79 *
176.094	11,082	13.73	10.87	9.01	6.73	4.92	2.80	0.96	400.	29.3	31.8	20.9	23.85	71.17 *
176.016	10,912	16.78	13.36	11.09	8.56	6.56	4.28	1.91	400.	54.0	28.7	10.2	11.08	92.62 *
175.899	11,035	11.20	8.91	7.69	6.57	5.13	3.52	1.36	400.	200.0	37.0	11.7	11.29	76.46 *
175.800	11,011	11.96	10.30	9.00	7.34	5.89	3.96	1.59	400.	112.3	25.2	14.9	20.96	80.72 *
175.700	10,808	22.21	19.02	16.38	13.04	10.30	7.26	3.99	400.	61.2	19.0	5.5	10.99	164.91 *
175.599	10,987	19.07	15.42	13.24	11.07	8.94	6.71	3.15	400.	171.9	20.1	6.3	9.47	101.14 *
175.499	10,904	20.13	17.68	15.73	13.21	11.15	8.30	4.42	400.	71.3	23.8	5.4	14.18	151.09 *
175.398	10,761	28.25	23.89	19.65	14.52	10.89	6.57	3.47	400.	10.6	20.0	6.3	11.27	104.97 *
175.342	10,792	16.30	12.77	10.32	7.11	4.85	2.26	0.72	400.	69.8	17.1	16.8	8.05	53.48 *
175.197	10,860	15.33	13.00	11.39	9.32	7.35	4.69	2.03	400.	112.3	40.0	7.2	4.26	92.92 *
175.100	10,769	27.15	22.11	18.15	13.52	10.11	5.96	2.21	400.	17.9	23.9	5.7	2.83	78.55 *
175.000	10,808	15.23	12.74	11.10	9.23	7.65	5.46	3.08	400.	183.2	27.3	7.1	11.58	193.31 *
174.896	10,796	20.77	17.74	15.51	12.48	10.02	6.70	3.05	400.	68.7	20.0	5.9	8.62	101.54 *
174.800	11,003	17.33	14.62	13.16	11.10	9.19	6.73	3.00	400.	200.0	20.0	6.7	10.01	95.26 *
174.737	10,979	16.76	13.34	11.74	9.41	7.69	4.91	2.30	400.	200.0	23.4	7.4	7.04	107.93 *
Mean:		18.01	14.80	12.62	10.03	7.90	5.25	2.38	395.	94.2	27.2	9.5	11.60	94.36
Std. Dev:		4.83	4.03	3.34	2.51	2.02	1.47	0.87	27.	60.9	7.5	4.9	7.03	23.64
Var Coeff(%):		26.83	27.20	26.43	25.07	25.63	28.09	36.51	7.	64.7	27.6	52.3	60.60	25.05

① The min. value of Base does not change the result by increasing or decreasing, but it will be atleast the min value provided (∴ min value should be less)

② The Subgrad value did not change the result.

TTI MODULUS ANALYSIS SYSTEM (SUMMARY REPORT) (Version 4.0)

District: 0
County: 84
Highway/Road: I 84D0177 (51)

	Thickness(in)	MODULI RANGE(psi) Minimum	Maximum
Pavement:	4.80	100,000	400,000
Base:	4.80	4,000	200,000
Subbase:	13.20	4,000	40,000
Subgrade:	71.60	10,000	

	Station	Load (lbs)	Measured Deflection (mils): R1	R2	R3	R4	R5	R6	R7	Calculated Moduli values (ksi): SURF(E1)	BASE(E2)	SUBB(E3)	SUBG(E4)	Absolute ERROR/Sens.	Depth to Bedrock
1	177.600	11,202	13.02	11.05	9.65	8.13	6.73	4.79	2.19	400.	161.9	27.3	10.0	15.58	96.16 *
	177.498	11,162	18.17	14.62	12.34	9.94	8.04	5.46	2.28	400.	94.7	40.0	6.2	1.50	88.09 *
	177.399	11,063	20.73	17.49	15.22	12.57	10.35	7.05	3.15	400.	70.2	20.0	6.3	11.66	100.89 *
5	177.300	11,110	22.16	18.13	15.35	12.32	9.89	6.50	2.51	400.	39.6	20.0	7.1	11.45	83.65 *
	177.191	11,289	12.03	10.40	9.18	8.02	6.74	5.19	2.45	400.	123.8	31.8	12.7	23.70	96.93 *
	177.100	10,888	24.97	18.52	14.41	9.79	6.96	4.43	2.16	254.	19.2	40.0	7.5	7.64	89.68 *
9	177.001	11,110	19.00	14.89	12.20	9.00	6.47	3.66	1.13	400.	21.8	28.7	12.4	11.29	68.44 *
8	176.898	11,174	13.24	11.12	9.81	8.14	6.57	4.52	1.94	400.	175.7	31.8	9.5	10.15	87.98 *
	176.799	11,015	15.55	11.87	9.77	7.43	5.61	3.62	1.61	400.	24.5	31.8	17.0	23.64	90.24 *
	176.699	11,118	13.55	11.16	9.48	7.90	6.52	4.71	2.61	400.	137.2	27.3	9.9	17.34	163.37 *
11	176.591	11,194	9.00	7.39	6.50	5.63	4.52	3.03	1.17	400.	200.0	29.8	23.5	25.96	75.92 *
	176.499	10,844	22.53	18.96	16.22	12.72	9.82	6.31	2.60	400.	39.6	21.1	6.1	6.73	87.04 *
	176.399	10,919	24.15	19.98	17.17	13.29	10.06	6.11	3.05	400.	22.8	20.0	6.8	11.84	113.10 *
14	176.295	11,007	18.54	14.43	12.16	9.79	7.83	5.44	2.67	400.	96.6	40.0	6.0	4.65	113.77 *
15	176.197	10,959	21.53	18.36	16.04	12.97	10.13	6.42	2.75	400.	86.5	24.1	5.3	3.65	93.79 *
	176.094	11,082	13.73	10.87	9.01	6.73	4.92	2.80	0.96	400.	29.3	31.8	20.9	23.85	71.17 *
	176.016	10,912	16.78	13.36	11.09	8.56	6.56	4.28	1.91	400.	54.0	28.7	10.2	11.08	92.62 *
18	175.899	11,035	11.20	8.91	7.69	6.57	5.13	3.52	1.36	400.	200.0	37.0	11.7	11.29	76.46 *
	175.800	11,011	11.96	10.30	9.00	7.34	5.89	3.96	1.59	400.	178.5	40.0	10.7	9.57	80.72 *
	175.700	10,808	22.21	19.02	16.38	13.04	10.30	7.26	3.99	400.	61.2	19.0	5.5	10.99	164.91 *
21	175.599	10,987	19.07	15.42	13.24	11.07	8.94	6.71	3.15	400.	171.9	20.1	6.3	9.47	101.14 *
	175.499	10,904	20.13	17.68	15.73	13.21	11.15	8.30	4.42	400.	71.3	23.8	5.4	14.18	151.09 *
	175.398	10,761	28.25	23.89	19.65	14.52	10.89	6.57	3.47	400.	10.6	20.0	6.3	11.27	104.97 *
24	175.342	10,792	16.30	12.77	10.32	7.11	4.85	2.26	0.72	400.	69.8	17.1	16.8	8.05	53.48 *
25	175.197	10,860	15.33	13.00	11.39	9.32	7.35	4.69	2.03	400.	44.8	35.1	9.1	14.23	92.92 *
	175.100	10,769	27.15	22.11	18.15	13.52	10.11	5.96	2.21	400.	8.9	20.0	7.5	12.12	78.55 *
	175.000	10,808	15.23	12.74	11.10	9.23	7.65	5.46	3.08	400.	183.2	27.3	7.1	11.58	193.31 *
27	174.896	10,796	20.77	17.74	15.51	12.48	10.02	6.70	3.05	400.	68.7	20.0	5.9	8.62	101.54 *
	174.800	11,003	17.33	14.62	13.16	11.10	9.19	6.73	3.00	400.	200.0	20.0	6.7	10.01	95.26 *
	174.737	10,979	16.76	13.34	11.74	9.41	7.69	4.91	2.30	400.	200.0	23.4	7.4	7.04	107.93 *
	Mean:		18.01	14.80	12.62	10.03	7.90	5.25	2.38	395.	95.5	27.2	9.5	12.00	94.36
	Std. Dev:		4.83	4.03	3.34	2.51	2.02	1.47	0.87	27.	67.6	7.3	4.7	5.92	23.64
	Var Coeff(%):		26.83	27.20	26.43	25.07	25.63	28.09	36.51	7.	70.8	26.9	49.2	49.28	25.05

Some times, ~~it~~ some of the holes take more time in search process. It depends upon the input Moduli values. It seems that the deflection curve can not match any one of the generated curve. But what does it do when it could not ~~generate~~ match?

APPENDIX "B"

SAMPLE OF INPUT AND OUTPUT FILES FOR MODULUS 4.0 AND EVERCALC 3.3 (Modified for Idaho FWD Files)

File No. I90D0045

I 90 Doug. FW97,

```
R80    242    9010161190D004536F20
700031008002-09377808.8103111  8
150 0   203 305 457 610 914 1524 5.9   0     8     12    18    24    36    60
C:\DYNA\TESTDATA\            .FWD
I 090YYD
S  41.500D50 7      9  8  243   45  47  45  Heights ..........................
S  41.000A50 7      9  8  243   45  47  45  Heights ..........................
800 20802730373041.5    45.5
8   15  3.5 5   2   15  10  8
Ld 144   1     88.14
D1 1251  1     1.023
D2 1252  1     1.010
D3 1253  1     1.005
D4 1254  1     1.007
D5 1255  1     1.001
D6 1256  1     1.007
D7 1257  1     1.012
D0 1258  1     1.021
D* ***** 1     1
D* ***** 1     1
JOANNE PAYNE
11010300........................
6   .5  3   .5   ...............
*000+0.0 000+0.0 st
FMMDDYYD
FMMDDYYD
*000+0.0 000+0.0 st
...............................
10422   -10422      0   1Peak...32  0   .....
123456.......................................................................
CCC33312222333344441111111111111111111111111111111111111111111111111444444444444444
.............................................................................
...*****************************************************************************
.............................................................................
......*...*...*...*........................................................
"FLEX TESTING, STANDARD/SHRP
*000+0.0 000+0.0 st
S  45.500D50 7      3  4  D3101645  37  39  Heights ..........................
 785 191 165 147 125 104  71  32 12478  7.53  6.48  5.80  4.91  4.07  2.79  1.28
 785 190 164 147 125 103  69  31 12474  7.49  6.47  5.79  4.91  4.04  2.70  1.20
 786 190 164 146 124 103  70  32 12482  7.49  6.44  5.76  4.90  4.04  2.74  1.25
'F
S  45.400D50 7      4  4  D3101845  38  39  Heights ..........................
 762 166 146 134 116 100  74  39 12100  6.54  5.74  5.26  4.57  3.94  2.89  1.55
 761 166 146 133 116 100  73  39 12088  6.54  5.73  5.24  4.56  3.92  2.88  1.54
 759 166 145 133 115  99  73  39 12057  6.55  5.72  5.22  4.54  3.91  2.88  1.54
'F
S  45.272D50 7      4  4  D3101945  38  39  Heights ..........................
 769 230 205 187 160 135  96  48 12220  9.04  8.07  7.35  6.31  5.31  3.79  1.90
 770 229 204 187 160 135  97  48 12235  9.02  8.04  7.34  6.31  5.32  3.81  1.89
 769 229 204 186 160 135  97  48 12220  9.03  8.03  7.33  6.28  5.31  3.80  1.88
'F
S  45.200D50 7      4  5  D3102045  39  41  Heights ..........................
 769 363 319 285 240 199 133  57 12223 14.30 12.56 11.21  9.46  7.85  5.24  2.26
 768 363 319 284 240 199 133  58 12208 14.28 12.54 11.20  9.46  7.85  5.25  2.27
 769 363 319 284 240 199 133  57 12212 14.30 12.54 11.18  9.46  7.84  5.23  2.25
'C,T/S
S  45.100D50 7      4  5  D3102245  39  41  Heights ..........................
 771 175 154 142 124 108  80  40 12243  6.89  6.05  5.57  4.89  4.26  3.16  1.56
 771 175 154 142 124 107  79  39 12251  6.88  6.05  5.57  4.88  4.23  3.13  1.53
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 771 174 152 142 124 107  80  39 12255  6.86  6.00  5.57  4.89  4.20  3.15  1.53
'C
S  45.000D50 7      5  5  D3102345  40  41  Heights ..........................
 770 186 174 163 148 131 102  57 12239  7.31  6.85  6.43  5.83  5.16  4.03  2.25
 770 186 174 163 147 131 102  57 12227  7.32  6.85  6.42  5.80  5.17  4.03  2.24
 771 186 174 163 148 131 102  57 12243  7.30  6.83  6.41  5.81  5.15  4.02  2.24
'C,T/S
S  44.898D50 7      5  5  D3102545  41  40  Heights ..........................
 767 143 127 118 104  91  68  36 12188  5.63  5.02  4.63  4.09  3.59  2.67  1.41
 767 142 127 117 105  91  68  35 12188  5.59  5.01  4.62  4.12  3.57  2.66  1.37
 766 142 127 117 104  91  68  36 12164  5.60  5.00  4.61  4.08  3.57  2.66  1.40
'C
S  44.799D50 7      5  6  D3102645  41  43  Heights ..........................
 765 172 157 146 132 118  90  51 12160  6.76  6.17  5.76  5.20  4.64  3.54  2.02
 766 171 157 146 132 116  90  51 12168  6.74  6.16  5.75  5.18  4.58  3.53  2.02
 767 172 157 146 131 117  91  54 12192  6.77  6.17  5.75  5.17  4.59  3.57  2.13
'GR
S  44.700D50 7      6  6  D3102745  42  43  Heights ..........................
 755 143 129 120 107  95  73  41 11997  5.62  5.07  4.72  4.22  3.75  2.88  1.61
 757 143 128 120 108  96  74  41 12033  5.61  5.04  4.73  4.24  3.78  2.91  1.62
 756 142 128 120 107  96  74  41 12013  5.61  5.03  4.72  4.22  3.80  2.91  1.63
'GR
S  44.600D50 7      6  6  D3102945  42  42  Heights ..........................
 753 190 158 141 119 101  71  34 11965  7.48  6.24  5.55  4.69  3.96  2.78  1.35
 755 190 158 141 119 100  71  34 11993  7.47  6.22  5.55  4.69  3.95  2.80  1.34
 754 189 158 141 119 100  71  34 11981  7.44  6.20  5.53  4.68  3.93  2.78  1.32
'GR
S  44.500D50 7      6  6  D3103045  43  43  Heights ..........................
 764 119  96  83  70  54  32  11 12144  4.67  3.79  3.28  2.76  2.13  1.26  0.45
 764 118  96  83  71  54  32  12 12132  4.64  3.78  3.26  2.78  2.12  1.28  0.48
 764 118  96  83  70  54  32  12 12144  4.63  3.76  3.25  2.77  2.11  1.27  0.48
'C
S  44.400D50 7      6  6  D3103145  43  42  Heights ..........................
 761 238 191 168 141 118  81  38 12096  9.37  7.50  6.63  5.56  4.63  3.18  1.48
 761 237 190 168 141 117  80  37 12096  9.32  7.48  6.60  5.54  4.60  3.16  1.44
 760 236 189 167 140 117  80  37 12080  9.30  7.46  6.59  5.52  4.59  3.16  1.46
'GR,L/S
S  44.300D50 7      6  6  D3103345  43  42  Heights ..........................
 753 152 137 125 112  96  73  36 11957  5.99  5.39  4.91  4.41  3.76  2.88  1.41
 753 153 137 124 112  96  73  36 11965  6.02  5.40  4.90  4.41  3.76  2.86  1.42
 754 152 136 125 111  95  71  36 11973  5.98  5.37  4.91  4.37  3.74  2.81  1.40
'GR
S  44.200D50 7      6  5  D3103445  43  40  Heights ..........................
 757 174 158 148 135 121  97  56 12021  6.83  6.21  5.81  5.33  4.76  3.82  2.22
 757 173 158 147 135 120  96  56 12033  6.82  6.20  5.79  5.31  4.74  3.80  2.21
 757 174 158 147 136 120  96  56 12025  6.85  6.21  5.78  5.35  4.73  3.76  2.22
'C
S  44.094D50 7      7  6  D3103545  44  43  Heights ..........................
 751 216 191 175 154 135 103  59 11930  8.49  7.51  6.89  6.07  5.30  4.06  2.31
 748 215 189 174 154 134 103  60 11886  8.46  7.44  6.83  6.07  5.28  4.04  2.34
 748 214 189 173 154 134 103  60 11882  8.43  7.43  6.83  6.06  5.28  4.06  2.34
'C
S  44.000D50 7      6  6  D3103745  43  43  Heights ..........................
 752 160 134 120 106  88  63  26 11941  6.28  5.27  4.70  4.16  3.45  2.48  1.01
 751 160 134 120 104  87  62  26 11933  6.29  5.27  4.73  4.11  3.44  2.45  1.01
 752 159 134 120 104  87  62  26 11949  6.26  5.26  4.72  4.10  3.44  2.44  1.01
'C
S  43.899D50 7      7  6  D3103845  44  43  Heights ..........................
 747 184 166 154 138 122  93  51 11862  7.23  6.52  6.07  5.44  4.81  3.65  2.01
 744 183 166 154 139 120  92  49 11826  7.22  6.52  6.06  5.46  4.74  3.62  1.94
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 746 183 165 154 138 121  92  51 11858  7.20  6.50  6.05  5.43  4.76  3.61  1.99
'C
S  43.793D50 7      7  6  D3103945  45  43  Heights ..........................
 757 217 194 177 153 131  93  47 12025  8.56  7.62  6.96  6.02  5.14  3.66  1.85
 757 217 193 176 153 130  93  47 12033  8.53  7.60  6.94  6.01  5.13  3.66  1.85
 756 216 193 176 152 130  93  48 12009  8.51  7.61  6.94  6.00  5.13  3.66  1.87
'C
S  43.698D50 7      8  6  D3104045  45  43  Heights ..........................
 748 219 189 171 150 131  96  56 11878  8.62  7.43  6.75  5.91  5.14  3.79  2.20
 748 218 188 171 150 129  96  54 11886  8.59  7.40  6.72  5.91  5.08  3.76  2.12
 747 217 187 170 149 129  96  55 11862  8.56  7.37  6.70  5.87  5.08  3.76  2.17
'C,PATCH
S  43.599D50 7      8  6  D3104245  45  43  Heights ..........................
 749 167 149 136 120 104  76  36 11902  6.56  5.86  5.37  4.71  4.09  2.98  1.42
 749 167 149 137 120 104  76  37 11906  6.56  5.85  5.37  4.70  4.10  3.00  1.44
 748 166 148 136 119 103  76  36 11886  6.53  5.83  5.35  4.70  4.07  2.98  1.41
'GR
S  43.500D50 7      8  7  D3104345  45  45  Heights ..........................
 746 176 154 142 122 106  77  38 11854  6.93  6.08  5.57  4.82  4.17  3.02  1.50
 746 176 154 141 122 105  77  38 11850  6.93  6.07  5.56  4.81  4.13  3.03  1.49
 744 175 154 141 122 105  77  39 11826  6.91  6.06  5.55  4.80  4.13  3.02  1.53
'GR
S  43.400D50 7      8  6  D3104545  46  43  Heights ..........................
 757 148 132 121 106  92  67  35 12021  5.81  5.18  4.78  4.18  3.61  2.64  1.37
 754 147 131 121 106  92  67  35 11985  5.79  5.17  4.77  4.17  3.61  2.64  1.37
 755 147 132 121 106  92  67  35 11989  5.79  5.18  4.76  4.18  3.61  2.64  1.37
'GR
S  43.300D50 7      9  8  D3104645  47  45  Heights ..........................
 755 184 158 143 122 104  73  34 11997  7.24  6.22  5.61  4.81  4.10  2.89  1.35
 752 184 158 142 122 104  73  34 11941  7.22  6.21  5.60  4.80  4.09  2.88  1.35
 754 184 158 142 122 104  73  34 11985  7.22  6.21  5.61  4.82  4.08  2.88  1.35
'GR
S  43.198D50 7      9  7  D3104745  47  45  Heights ..........................
 743 176 147 129 108  91  64  33 11810  6.91  5.78  5.08  4.24  3.57  2.53  1.30
 742 175 147 129 107  91  64  34 11794  6.88  5.77  5.07  4.23  3.57  2.52  1.33
 744 175 146 129 107  91  64  33 11814  6.87  5.76  5.07  4.22  3.56  2.51  1.30
'GR
S  43.098D50 7      9  6  D3104945  47  42  Heights ..........................
 753 197 157 139 118  98  66  29 11969  7.74  6.17  5.49  4.65  3.84  2.60  1.13
 753 195 156 139 118  97  66  29 11965  7.69  6.15  5.47  4.64  3.83  2.60  1.13
 752 196 157 139 118  98  66  29 11949  7.72  6.17  5.49  4.65  3.85  2.60  1.14
'GR
S  43.000D50 7      8  6  D3105045  46  43  Heights ..........................
 747 159 145 134 118 102  76  39 11866  6.27  5.70  5.26  4.63  4.02  2.99  1.55
 746 159 145 133 118 102  75  39 11858  6.25  5.70  5.25  4.63  4.00  2.96  1.55
 748 159 145 134 118 103  76  40 11878  6.25  5.70  5.26  4.63  4.04  2.98  1.56
'GR
S  42.900D50 7      9  6  D3105145  48  42  Heights ..........................
 739 219 196 178 154 132  95  47 11747  8.64  7.70  6.99  6.07  5.20  3.74  1.85
 740 220 196 178 155 133  95  47 11755  8.64  7.70  7.00  6.09  5.22  3.74  1.85
 740 219 195 178 155 132  95  47 11751  8.63  7.69  7.00  6.10  5.18  3.73  1.84
'GR
S  42.800D50 7      9  7  D3105345  48  45  Heights ..........................
 744 216 196 182 161 141 105  56 11814  8.50  7.70  7.15  6.35  5.53  4.15  2.19
 742 216 196 182 161 140 105  56 11790  8.50  7.70  7.15  6.35  5.53  4.14  2.19
 744 217 195 181 161 140 105  56 11818  8.53  7.69  7.14  6.34  5.52  4.15  2.20
'GR
S  42.700D50 7      9  7  D3105445  47  45  Heights ..........................
 737 144 128 123 117  91  71  40 11715  5.65  5.02  4.84  4.62  3.59  2.78  1.56
 737 144 127 123 119  91  72  40 11715  5.68  5.00  4.84  4.67  3.57  2.81  1.59
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 736 144 127 122 117  93  73  40 11687  5.65  5.00  4.81  4.62  3.65  2.85  1.59
'GR
S  42.599D50 7      9  7  D3105645  47  44  Heights ..........................
 755 154 137 124 108  91  65  32 12001  6.04  5.38  4.89  4.27  3.59  2.56  1.26
 755 153 136 123 107  91  65  32 11989  6.02  5.35  4.86  4.22  3.58  2.57  1.25
 758 153 136 124 108  91  65  32 12037  6.01  5.35  4.86  4.25  3.59  2.57  1.25
'GR
S  42.499D50 7      9  7  D3105745  48  44  Heights ..........................
 743 207 181 168 152 133 104  60 11810  8.13  7.13  6.62  5.99  5.22  4.08  2.36
 742 205 181 168 151 133 104  60 11783  8.08  7.11  6.60  5.94  5.23  4.09  2.36
 743 205 181 168 151 133 103  59 11802  8.06  7.11  6.59  5.96  5.23  4.07  2.34
'GR
S  42.399D50 7      9  8  D3105845  48  46  Heights ..........................
 749 171 152 141 126 111  87  51 11902  6.73  6.00  5.54  4.95  4.37  3.44  2.02
 753 172 153 141 126 112  87  51 11957  6.76  6.02  5.55  4.96  4.39  3.44  2.02
 750 170 153 141 126 111  88  51 11918  6.70  6.01  5.55  4.95  4.38  3.44  1.99
'F
S  42.300D50 7      9  7  D3110045  47  45  Heights ..........................
 740 181 169 157 139 121  92  48 11751  7.14  6.66  6.17  5.48  4.78  3.61  1.91
 737 181 169 156 139 121  92  49 11715  7.13  6.64  6.15  5.46  4.76  3.60  1.93
 740 181 169 156 139 121  91  49 11759  7.13  6.63  6.15  5.46  4.76  3.59  1.91
'F
S  42.199D50 7      9  8  D3110145  48  45  Heights ..........................
 750 183 165 152 133 114  85  47 11918  7.19  6.48  5.99  5.24  4.49  3.33  1.83
 749 182 164 152 132 113  84  46 11906  7.17  6.45  5.96  5.21  4.46  3.32  1.80
 749 182 164 152 133 113  84  46 11902  7.16  6.46  5.98  5.23  4.46  3.32  1.82
'F
S  42.097D50 7      10 8  D3110245  49  45  Heights ..........................
 744 222 191 176 155 136 102  55 11814  8.73  7.50  6.94  6.12  5.36  4.02  2.15
 743 221 190 175 155 136 102  55 11802  8.70  7.48  6.91  6.09  5.34  4.00  2.15
 744 221 190 176 156 135 101  54 11818  8.71  7.47  6.91  6.12  5.33  3.98  2.13
'F
S  42.000D50 7      9  6  D3110445  48  43  Heights ..........................
 725 247 200 174 163 133 101  47 11524  9.74  7.89  6.86  6.41  5.24  3.96  1.83
 725 244 200 173 162 131  99  46 11516  9.62  7.88  6.80  6.37  5.14  3.91  1.82
 722 244 199 174 160 136 102  47 11477  9.59  7.84  6.86  6.30  5.33  4.02  1.85
'C,PATCH
S  41.900D50 7      9  9  D3110645  47  47  Heights ..........................
 749 121 106  97  86  76  58  32 11898  4.78  4.16  3.81  3.39  2.98  2.29  1.24
 747 121 105  96  86  75  58  31 11874  4.76  4.15  3.80  3.40  2.96  2.27  1.22
 747 121 105  97  86  75  58  31 11866  4.75  4.15  3.80  3.39  2.97  2.28  1.23
'F
S  41.800D50 7      9  8  D3110745  47  45  Heights ..........................
 733 181 164 155 143 125 100  56 11643  7.13  6.44  6.10  5.63  4.93  3.94  2.19
 733 181 162 155 144 125 101  57 11647  7.13  6.37  6.08  5.66  4.91  3.97  2.23
 734 180 163 154 144 125 100  56 11655  7.09  6.41  6.08  5.67  4.91  3.93  2.20
'C
S  41.700D50 7      9  8  D3110845  48  45  Heights ..........................
 739 218 200 187 170 151 117  62 11747  8.60  7.88  7.36  6.67  5.93  4.61  2.45
 739 220 202 188 171 152 119  65 11747  8.66  7.93  7.41  6.74  5.98  4.69  2.54
 743 220 202 188 171 152 119  65 11802  8.66  7.94  7.42  6.74  5.99  4.67  2.55
'C
S  41.600D50 7      9  8  D3111045  48  46  Heights ..........................
 747 187 167 155 139 121  91  49 11862  7.37  6.57  6.10  5.45  4.74  3.59  1.94
 745 186 167 155 139 121  92  50 11842  7.31  6.57  6.10  5.45  4.78  3.61  1.96
 745 186 167 155 139 121  92  50 11842  7.32  6.58  6.11  5.47  4.76  3.61  1.95
'C
S  41.500D50 7      9  8  D3111145  47  45  Heights ..........................
 738 193 174 160 142 125  94  51 11731  7.60  6.86  6.31  5.57  4.91  3.70  2.02
 737 193 173 160 141 124  94  50 11707  7.59  6.82  6.30  5.56  4.89  3.69  1.98
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0	90	45.500	D	12482	7.49	6.44	5.76	4.90	4.04	2.74	1.25
0	90	45.400	D	12057	6.55	5.72	5.22	4.54	3.91	2.88	1.54
0	90	45.272	D	12220	9.03	8.03	7.33	6.28	5.31	3.80	1.88
0	90	45.200	D	12212	14.30	12.54	11.18	9.46	7.84	5.23	2.25
0	90	45.100	D	12255	6.86	6.00	5.57	4.89	4.20	3.15	1.53
0	90	45.000	D	12243	7.30	6.83	6.41	5.81	5.15	4.02	2.24
0	90	44.898	D	12164	5.60	5.00	4.61	4.08	3.57	2.66	1.40
0	90	44.799	D	12192	6.77	6.17	5.75	5.17	4.59	3.57	2.13
0	90	44.700	D	12013	5.61	5.03	4.72	4.22	3.80	2.91	1.63
0	90	44.600	D	11981	7.44	6.20	5.53	4.68	3.93	2.78	1.32
0	90	44.500	D	12144	4.63	3.76	3.25	2.77	2.11	1.27	0.48
0	90	44.400	D	12080	9.30	7.46	6.59	5.52	4.59	3.16	1.46
0	90	44.300	D	11973	5.98	5.37	4.91	4.37	3.74	2.81	1.40
0	90	44.200	D	12025	6.85	6.21	5.78	5.35	4.73	3.76	2.22
0	90	44.094	D	11882	8.43	7.43	6.83	6.06	5.28	4.06	2.34
0	90	44.000	D	11949	6.26	5.26	4.72	4.10	3.44	2.44	1.01
0	90	43.899	D	11858	7.20	6.50	6.05	5.43	4.76	3.61	1.99
0	90	43.793	D	12009	8.51	7.61	6.94	6.00	5.13	3.66	1.87
0	90	43.698	D	11862	8.56	7.37	6.70	5.87	5.08	3.76	2.17
0	90	43.599	D	11886	6.53	5.83	5.35	4.70	4.07	2.98	1.41
0	90	43.500	D	11826	6.91	6.06	5.55	4.80	4.13	3.02	1.53
0	90	43.400	D	11989	5.79	5.18	4.76	4.18	3.61	2.64	1.37
0	90	43.300	D	11985	7.22	6.21	5.61	4.82	4.08	2.88	1.35
0	90	43.198	D	11814	6.87	5.76	5.07	4.22	3.56	2.51	1.30
0	90	43.098	D	11949	7.72	6.17	5.49	4.65	3.85	2.60	1.14
0	90	43.000	D	11878	6.25	5.70	5.26	4.63	4.04	2.98	1.56
0	90	42.900	D	11751	8.63	7.69	7.00	6.10	5.18	3.73	1.84
0	90	42.800	D	11818	8.53	7.69	7.14	6.34	5.52	4.15	2.20
0	90	42.700	D	11687	5.65	5.00	4.81	4.62	3.65	2.85	1.59
0	90	42.599	D	12037	6.01	5.35	4.86	4.25	3.59	2.57	1.25
0	90	42.499	D	11802	8.06	7.11	6.59	5.96	5.23	4.07	2.34
0	90	42.399	D	11918	6.70	6.01	5.55	4.95	4.38	3.44	1.99
0	90	42.300	D	11759	7.13	6.63	6.15	5.46	4.76	3.59	1.91
0	90	42.199	D	11902	7.16	6.46	5.98	5.23	4.46	3.32	1.82
0	90	42.097	D	11818	8.71	7.47	6.91	6.12	5.33	3.98	2.13
0	90	42.000	D	11477	9.59	7.84	6.86	6.30	5.33	4.02	1.85
0	90	41.900	D	11866	4.75	4.15	3.80	3.39	2.97	2.28	1.23
0	90	41.800	D	11655	7.09	6.41	6.08	5.67	4.91	3.93	2.20
0	90	41.700	D	11802	8.66	7.94	7.42	6.74	5.99	4.67	2.55
0	90	41.600	D	11842	7.32	6.58	6.11	5.47	4.76	3.61	1.95
0	90	41.500	D	11731	7.59	6.85	6.25	5.54	4.91	3.70	2.06

I 90D004S.SUM
EVERCALC

BACKCALCULATION BY EVERCALC VERSION 3.3
==========

Route: I 090YYD MP 45.500 - 41.500 Tested on 10/16/

							Sensor Readings							
STN	Load	EAD	E(1)	E(2)	E(3)	E(4)	1	2	3	4	5	6	7	ARMS
45.500	12482.0	175.2	666.9	150.0	15.3	1000.0	7.49	6.44	5.76	4.90	4.04	2.74	1.25	4.9
45.400	12057.0	272.7	1038.1	150.0	18.3	1000.0	6.55	5.72	5.22	4.54	3.91	2.88	1.54	4.1
45.272	12220.0	135.0	514.0	150.0	12.8	1000.0	9.03	8.03	7.33	6.28	5.31	3.80	1.88	3.6
45.200	12212.0	169.1	643.7	10.0	10.0	1000.0	14.30	12.54	11.18	9.46	7.84	5.23	2.25	7.7
45.100	12255.0	267.6	1018.6	150.0	13.9	1000.0	6.86	6.00	5.57	4.89	4.20	3.15	1.53	4.5
45.000	12243.0	594.5	2263.4	10.0	16.2	1000.0	7.30	6.83	6.41	5.81	5.15	4.02	2.24	3.1
44.898	12164.0	388.2	1478.0	150.0	18.7	1000.0	5.60	5.00	4.61	4.08	3.57	2.66	1.40	4.1
44.799	12192.0	702.1	2672.8	10.0	20.5	1000.0	6.77	6.17	5.75	5.17	4.59	3.57	2.13	2.7
44.700	12013.0	482.0	1834.8	142.8	18.7	1000.0	5.61	5.03	4.72	4.22	3.80	2.91	1.63	3.1
44.600	11981.0	179.9	684.7	150.0	15.5	1000.0	7.44	6.20	5.53	4.68	3.93	2.78	1.32	5.8
44.500	12144.0	359.8	1369.8	150.0	22.6	1000.0	4.63	3.76	3.25	2.77	2.11	1.27	.48	8.9
44.400	12080.0	111.0	422.7	150.0	13.6	1000.0	9.30	7.46	6.59	5.52	4.59	3.16	1.46	5.4
44.300	11973.0	326.8	1244.0	150.0	15.7	1000.0	5.98	5.37	4.91	4.37	3.74	2.81	1.40	4.7
44.200	12025.0	716.2	2726.7	10.0	18.4	1000.0	6.85	6.21	5.78	5.35	4.73	3.76	2.22	2.3
44.094	11882.0	353.2	1344.6	63.8	15.3	1000.0	8.43	7.43	6.83	6.06	5.28	4.06	2.34	3.0
44.000	11949.0	271.1	1031.9	150.0	13.5	1000.0	6.26	5.26	4.72	4.10	3.44	2.44	1.01	6.2
43.899	11858.0	283.5	1079.1	150.0	15.2	1000.0	7.20	6.50	6.05	5.43	4.76	3.61	1.99	3.3
43.793	12009.0	167.0	635.7	131.7	13.9	1000.0	8.51	7.61	6.94	6.00	5.13	3.66	1.87	3.6
43.698	11862.0	271.1	1032.2	85.0	16.9	1000.0	8.56	7.37	6.70	5.87	5.08	3.76	2.17	3.0
43.599	11886.0	262.0	997.4	150.0	13.8	1000.0	6.53	5.83	5.35	4.70	4.07	2.98	1.41	4.3
43.500	11826.0	228.9	871.6	150.0	15.6	1000.0	6.91	6.06	5.55	4.80	4.13	3.02	1.53	4.1
43.400	11989.0	330.1	1256.9	150.0	18.4	1000.0	5.79	5.18	4.76	4.18	3.61	2.64	1.37	4.0
43.300	11985.0	195.2	743.0	150.0	14.6	1000.0	7.22	6.21	5.61	4.82	4.08	2.88	1.35	4.7
43.198	11814.0	189.9	722.9	150.0	19.9	1000.0	6.87	5.76	5.07	4.22	3.56	2.51	1.30	6.0
43.098	11949.0	159.5	607.2	150.0	14.6	1000.0	7.72	6.17	5.49	4.65	3.85	2.60	1.14	6.1
43.000	11878.0	299.4	1139.8	150.0	16.6	1000.0	6.25	5.70	5.26	4.63	4.04	2.98	1.56	3.6
42.900	11751.0	141.9	540.3	150.0	12.4	1000.0	8.63	7.69	7.00	6.10	5.18	3.73	1.84	3.3
42.800	11818.0	244.3	930.0	99.6	12.9	1000.0	8.53	7.69	7.14	6.34	5.52	4.15	2.20	3.1
42.700	11687.0	421.1	1603.0	142.9	18.0	1000.0	5.65	5.00	4.81	4.62	3.65	2.85	1.59	3.7
42.599	12037.0	284.0	1081.2	150.0	16.9	1000.0	6.01	5.35	4.86	4.25	3.59	2.57	1.25	4.6
42.499	11802.0	440.0	1675.1	42.5	15.1	1000.0	8.06	7.11	6.59	5.96	5.23	4.07	2.34	2.5
42.399	11918.0	481.0	1831.3	84.1	17.2	1000.0	6.70	6.01	5.55	4.95	4.38	3.44	1.99	3.4
42.300	11759.0	319.1	1214.9	101.1	14.4	1000.0	7.13	6.63	6.15	5.46	4.76	3.59	1.91	3.6
42.199	11902.0	280.8	1069.1	118.1	16.7	1000.0	7.16	6.46	5.98	5.23	4.46	3.32	1.82	3.8
42.097	11818.0	186.4	709.6	141.2	13.6	1000.0	8.71	7.47	6.91	6.12	5.33	3.98	2.13	2.6
42.000	11477.0	126.4	481.1	150.0	10.0	1000.0	9.59	7.84	6.86	6.30	5.33	4.02	1.85	5.9
41.900	11866.0	530.6	2020.0	150.0	21.3	1000.0	4.75	4.15	3.80	3.39	2.97	2.28	1.23	5.3
41.800	11655.0	615.9	2344.8	10.0	15.4	1000.0	7.09	6.41	6.08	5.67	4.91	3.93	2.20	2.7
41.700	11802.0	467.2	1778.6	10.0	13.3	1000.0	8.66	7.94	7.42	6.74	5.99	4.67	2.55	2.8
41.600	11842.0	290.3	1105.1	124.8	14.7	1000.0	7.32	6.58	6.11	5.47	4.76	3.61	1.95	3.1
41.500	11731.0	343.0	1305.9	80.9	15.6	1000.0	7.59	6.85	6.25	5.54	4.91	3.70	2.06	3.3

Note: STN = Station ID
Load = FWD load (lbs)
EAD = AC layer moduli adjusted for temperature (ksi)
E(i) = Modulus of i-th layer (ksi)
i = i-th sensor reading (mils)
ARMS = Average RMS error at this station (%)

(3) 73.out

TTI MODULUS ANALYSIS SYSTEM (SUMMARY REPORT) (Version 4.0)

District: 0
County: 90
Highway/Road:

JT90D0045

ARPenter A.

	Thickness(in)	MODULI RANGE(psi) Minimum	Maximum
Pavement:	9.60	100,000	1,750,000
Base:	8.40	10,000	100,000
Subbase:	0.00	0	0
Subgrade:	119.80	20,000	

Station	Load (lbs)	Measured Deflection (mils): R1	R2	R3	R4	R5	R6	R7	Calculated Moduli values (ksi): SURF(E1)	BASE(E2)	SUBB(E3)	SUBG(E4)	Absolute ERROR/Sens.	Depth to Bedrock
45.500	12,481	7.49	6.44	5.76	4.90	4.04	2.74	1.25	981.	65.0	0.0	21.2	1.51	99.87
45.400	12,056	6.55	5.72	5.22	4.54	3.91	2.88	1.54	1441.	100.0	0.0	17.8	2.10	141.61 *
45.272	12,219	9.03	8.03	7.33	6.28	5.31	3.80	1.88	955.	62.4	0.0	14.1	1.65	124.29
45.200	12,211	14.30	12.54	11.18	9.46	7.84	5.23	2.25	550.	20.6	0.0	11.3	1.21	103.41
45.100	12,254	6.86	6.00	5.57	4.89	4.20	3.15	1.53	1395.	97.7	0.0	17.0	0.40	108.92
45.000	12,242	7.30	6.83	6.41	5.81	5.15	4.02	2.24	1518.	38.9	0.0	15.2	6.53	169.91 *
44.898	12,163	5.60	5.00	4.61	4.08	3.57	2.66	1.40	1750.	100.0	0.0	20.1	2.28	130.02 *
44.799	12,191	6.77	6.17	5.75	5.17	4.59	3.57	2.13	1669.	43.6	0.0	16.7	6.31	224.54 *
44.700	12,012	5.61	5.03	4.72	4.22	3.80	2.91	1.63	1750.	27.1	0.0	23.5	9.22	160.67 *
44.600	11,980	7.44	6.20	5.53	4.68	3.93	2.78	1.32	854.	100.0	0.0	19.7	1.53	106.13 *
44.500	12,143	4.63	3.76	3.25	2.77	2.11	1.27	0.48	1278.	50.0	0.0	49.6	2.11	71.67
44.400	12,079	9.30	7.46	6.59	5.52	4.59	3.16	1.46	543.	100.0	0.0	17.7	1.32	104.91 *
44.300	11,972	5.98	5.37	4.91	4.37	3.74	2.81	1.40	1693.	99.2	0.0	18.4	0.68	113.02
44.200	12,024	6.85	6.21	5.78	5.35	4.73	3.76	2.22	1605.	44.2	0.0	16.0	7.60	209.54 *
44.094	11,881	8.43	7.43	6.83	6.06	5.28	4.06	2.34	1303.	55.4	0.0	13.0	3.52	204.93 *
44.000	11,948	6.26	5.26	4.72	4.10	3.44	2.44	1.01	1148.	82.1	0.0	23.6	1.13	82.23
43.899	11,857	7.20	6.50	6.05	5.43	4.76	3.61	1.99	1547.	42.6	0.0	15.5	3.86	165.60 *
43.793	12,008	8.51	7.61	6.94	6.00	5.13	3.66	1.87	1022.	71.8	0.0	14.1	1.67	136.35
43.698	11,861	8.56	7.37	6.70	5.87	5.08	3.76	2.17	1050.	100.0	0.0	12.9	3.11	214.19 *
43.599	11,885	6.53	5.83	5.35	4.70	4.07	2.98	1.41	1750.	23.9	0.0	19.7	1.37	104.83 *
43.500	11,825	6.91	6.06	5.55	4.80	4.13	3.02	1.53	1225.	100.0	0.0	16.8	1.17	123.69 *
43.400	11,988	5.79	5.18	4.76	4.18	3.61	2.64	1.37	1750.	68.8	0.0	20.4	1.94	127.41 *
43.300	11,984	7.22	6.21	5.61	4.82	4.08	2.88	1.35	989.	93.3	0.0	18.7	0.70	104.58
43.198	11,813	6.87	5.76	5.07	4.22	3.56	2.51	1.30	948.	100.0	0.0	21.3	3.56	129.12 *
43.098	11,948	7.72	6.17	5.49	4.65	3.85	2.60	1.14	685.	100.0	0.0	21.6	0.77	93.24 *
43.000	11,877	6.25	5.70	5.26	4.63	4.04	2.98	1.56	1704.	84.5	0.0	17.0	1.32	134.56 *
42.900	11,750	8.63	7.69	7.00	6.10	5.18	3.73	1.84	1011.	62.1	0.0	13.8	1.23	123.68
42.800	11,817	8.53	7.69	7.14	6.34	5.52	4.15	2.20	1314.	37.0	0.0	13.1	2.41	151.57 *
42.700	11,686	5.65	5.00	4.81	4.62	3.65	2.85	1.59	1750.	35.0	0.0	20.5	8.10	300.00 *
42.599	12,036	6.01	5.35	4.86	4.25	3.59	2.57	1.25	1750.	10.0	0.0	29.6	4.14	109.12 *
42.499	11,801	8.06	7.11	6.59	5.96	5.23	4.07	2.34	1350.	50.6	0.0	13.5	4.62	199.71 *
42.399	11,917	6.70	6.01	5.55	4.95	4.38	3.44	1.99	1681.	45.2	0.0	16.8	5.47	187.06 *
42.300	11,758	7.13	6.63	6.15	5.46	4.76	3.59	1.91	1504.	49.4	0.0	15.0	2.73	146.29 *
42.199	11,901	7.16	6.46	5.98	5.23	4.46	3.32	1.82	1590.	47.3	0.0	15.9	2.52	160.07 *
42.097	11,817	8.71	7.47	6.91	6.12	5.33	3.98	2.13	1348.	36.9	0.0	13.5	2.72	156.14 *
42.000	11,476	9.59	7.84	6.86	6.30	5.33	4.02	1.85	666.	100.0	0.0	13.0	1.97	103.99 *
41.900	11,865	4.75	4.15	3.80	3.39	2.97	2.28	1.23	1750.	31.6	0.0	30.2	10.38	130.11 *
41.800	11,654	7.09	6.41	6.08	5.67	4.91	3.93	2.20	1487.	43.3	0.0	14.9	7.33	166.89 *
41.700	11,801	8.66	7.94	7.42	6.74	5.99	4.67	2.55	1212.	44.6	0.0	12.1	5.48	168.02 *
41.600	11,841	7.32	6.58	6.11	5.47	4.76	3.61	1.95	1507.	49.7	0.0	15.1	2.87	153.15 *
41.500	11,730	7.59	6.85	6.25	5.54	4.91	3.70	2.06	1487.	37.5	0.0	14.9	3.57	176.51 *
Mean:		7.35	6.46	5.91	5.21	4.48	3.31	1.72	1329.	62.2	0.0	18.2	3.27	137.75
Std. Dev:		1.63	1.41	1.27	1.09	0.95	0.73	0.44	363.	28.1	0.0	6.6	2.52	39.68
Var Coeff(%):		22.14	21.85	21.41	21.01	21.27	21.96	25.74	27.	45.2	0.0	36.2	77.08	28.81