



INFLUENCE OF VARIABILITY IN FLEXIBLE PAVEMENT PARAMETERS ON BACKCALCULATED MODULI

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ABSTRACT

Many researchers recommended Falling Weight Deflectometer (FWD) to be use for the purpose of stiffness profile determination of existing pavement. Several sources of uncertainties contribute to the inaccuracies in moduli obtained in this manner. these include: 1) the measured parameters (deflection basin and FWD load), 2) the back calculation model, and 3) the pavement parameters, such as Poisson's ratio and thickness of each pavement layer .

In the present study the influence of the variation in the thickness and other pavement parameters on the backcalculated moduli are investigated .Theoretical deflection basins were generated for different pavement structure using program Mich-pave. Mich-back program was then utilized to backcalculate the moduli from these theoretical basins. To assess the influence of the variability in thickness, Poisson's ratio, FWD load and deflection, a Monte Carlo simulation process was employed.

Results show that the backcalculation of the layer moduli is greatly influence by the variability of the combined pavement. A sensitivity analysis showed that the uncertainties in thicknesses are the major contributor to variations of the backcalculated Moduli.

الخلاصة:

يوصي الكثير من الباحثين باستخدام جهاز (FWD) لغرض ايجاد قيم معاملات الصلادة (Stiffness) للتبليط الحالي بالرغم من ان بعض المصادر تشكل في حساب دقة المعاملات فيما لو استخدمت هذه الطريقة و التي تشمل:

1-المعاملات التي تم حسابها (الهبوط وكذلك احمال جهاز FWD) 2-النموذج (الموديل) الخاص بطريقة الحساب العكسي
3-معاملات التبليط (نسبة بواسان وكذلك سمك طبقات التبليط)

في الدراسة المقدمة فان تأثير التغييرات في السمك وكذلك بقية معاملات التبليط في الحساب العكسي للمعاملات قد تم التحري عنها. ان القيم النظرية للهبوط قد تم توليدها لانواع مختلفة من التبليط باستخدام برنامج Mich-Pave. بينما تم استخدام برنامج Mick-Back للحساب العكسي لقيمة المعاملات (Stiffness) حسب مقدار الهبوط النظري التي تم ذكره.

لتقدير مقدار تأثير التغييرات في قيم معاملات التبليط المرنة على السمك للطبقات ونسبة بواسان ومقدار الحمل الخاص بجهاز (FWD) وكذلك الهبوط فقد تم استخدام طريقة (Monte Carlo) لتمثيل هذه التأثيرات.

لقد اوضحت النتائج بانه الحساب العكسي للمعاملات الخاصة بطبقات التبليط تتأثر بشكل كبير بالمتغيرات الخاصة بالتبليط. وقد اظهرت نتائج التحليل الحساس (Sensitivity Analysis) بانه سمك طبقات التبليط هو العامل الرئيسي المؤثر في التغييرات الحاصلة بالحسابات العكسية للمعاملات.

KEY WORDS:

Flexible pavement Parameters, Backcalculation Moduli, Mich-pave, Mich-back, Sensitivity Analysis, and Monte Carlo Simulation.

INTRODUCTION

Back-calculation is a process for estimating the elastic layer modulus in pavement structures that represent in situ conditions under a test load. Back-calculation gets its name from the fact that a load of known size and shape is applied to the pavement and deflections are measured by sensors at known distances from the load. Theoretical predictions are made of the deflections, assuming certain layer properties, and those properties (usually elastic layer modulus) are adjusted until the calculated deflections match the measured deflections within a reasonable error (goodness-of-fit between the measured and calculated deflection basins).

The falling weight Deflectometer (FWD) device is strongly recommended to use throughout the world to determine the stiffness profiles of existing pavements. Surface deflections created by dropping a weight on the pavement are measured by seven sensor of the device. These deflections are then used to backcalculate the modulus of layer within a multi-layer pavement system. From a pavement management point of view, understanding and quantifying how the uncertainties in the pavement parameters affect the backcalculated Moduli are very important. The design of a new pavement system or an overlay, and the calculated Moduli.

If the results of the Moduli are overestimated, thinner pavement layers will be design. Resulting in a lower life expectancy. The initial construction cost would decrease but the maintenance cost would increase or a complete rehabilitation would be necessary sooner than desired. Conversely, if the moduli are underestimated, thicker pavement layer would be designed.

This would increase the life expectancy of the pavement and at the same time; increase the cost of construction.

At least three major sources of uncertainty contribute to inaccuracies in the back calculated moduli. These uncertribute are associated with: 1) error in measured parameters (deflection and impact load).2) simplification and assumption used in backcalculation process and (3) random deviations of pavement Parameters form those assumed or specified.

Several investigators (Hudson et al., 1986 and Bentsen et al., 1989) have attempted to quantify the uncertainties in measured parameters. Their result shows that deflection and load are know within an accuracy of 2 to 5 percent.

The uncertainties associated with the model depend on the algorithm used and the nature of the pavement structure (Lyton.1989).These uncertainties can be determine by calibrating results cases or form past experience.

In this study the influence of random deviation in layer thickness, Poisson's ratio, FWD load and deflection on the backcalculates moduli are determined. Layer thickness usually deviate form those specified in the construction plans. Poisson's ratios vary due to variation in material consistency and compaction method. The impact load and deflection are known to be affected by measurement error. To assess the influence of the uncertainty of these parameters on back calculated moduli, Monte Carlo simulation technique was formulated and applied to three selected (three-layered) pavement. These are designated as P1, P2, and P3 their sections are shown in Fig's (1a, 1b and 1c respectively).The deflection basins associated with each determine using program Mich-Pave.

The procedure followed to quantify uncertainties the moduli for the pavement sections consisted of: (1) layer thickness of the AC and base layer Poisson's ratio of the AC, base and sub grade layers, the FWD load and the measured deflection were assumed to be random variable, (2) a Monte Carlo simulation technique was utilized to generate several sets if values of these variables for each pavement section, (3) each set was input into program Mich-back to backcalculate the modulus of each layer, and (4) the resulting samples of moduli were then statistically analyzed to determine the influence of the random variable on the predicated moduli. Details of the methodology utilized are discussed next.

METHODOLOGY

Pavement models

Three selected flexible (three-layer) pavement systems were studied. These pavement systems are shown in Fig.1. The thickness of the top layer was 3.0 in. or 5.0 in. Thinner layer were not considered because of the limitations with the backcalculation process used. The thickness of the second layer, which is either 6.0 in. or 12.0 in., is representative of the thickness of base layer usually used. The last was considered 240 in. as recommended by Bush (1980). The thinnest pavement structure Fig. (1a) corresponds to a low-volume road and the thickest one Fig. (1c) represent a major highway.

The actual Moduli and Poisson's ratios for each layer were kept constant in all pavement systems .The modulus of the AC, base and sub grade were assumed to be 450, 35, and 10 Ksi, respectively. These values are poisons ratios were assumed to be equal to 0.35, 0.40, and 0.45 for the AC, base and sub grade, respectively.

Determination of Deflection Basins

To eliminate the effects of the site relates and device related parameters on the back calculated moduli, it was necessary to determine the deflection basins theoretically .To obtain these deflection program Mich-Pave (Harichandran, and Baladi, 1993) was used. Deflection from program Mich-Pave was considered to be the representative field measurements.

<p>ASPHALT T1=3in E1=450000psi V1=0.35</p>	<p>ASPHALT T1=3in E1=450000psi V1=0.35</p>	<p>ASPHALT T1=5in. E1=450000psi V1=0.35</p>
<p>BASE T2=6in E2=35000psi V2=0.40</p>	<p>BASE T2=12in E2=35000psi V2=0.40</p>	<p>BASE T2=12in. E2=35000psi V2=0.40</p>
<p>SUBGRADE T3=240in E3=10000psi V3=0.45</p>	<p>SUBGRADE T3=240in. E3=10000psi V3=0.45</p>	<p>SUBGRADE T3=240in E3=10000psi V3=0.45</p>
1a	1b	1c

Fig. (1) Pavement sections.

The deflection basin for each pavement section studied comprises of seven deflections at 12 in. intervals. A9000-1b load was used as the FWD load input. As Mich-pave is based upon linear-

elastic theory, selection of such a value would not affect the generality of the results presented in this research.

Backcalculation process

Program Mich-back (Harichandran, R. S. et, 1995) was used to backcalculated the modulus of each layer. The required input pavement parameters to the program are: the thickness, Poisson's ratio, and resilient modulus for each layer. In addition, minimum and maximum acceptable moduli have to be defined. These values were assumed as 0.1 and 10 time that of the actual modulus, respectively. This insures that the only criterion for back calculating moduli was the closeness of the theoretical and the actual deflection.

Statistical simulation .

To compute the variability of the estimated back calculated Moduli, a Monte Carol simulation approach was used (Ang. and Tang, 1984) .In general, the method consists of: (1) numerically drawing a number of sets of observation of the input variable used by Mich-back using the statistical distribution of each variable ;(2) evaluating the random samples of backcalculated Moduli; (3) using these sample, statistical parameters and distributions of the Backcalculated Moduli were determined. A flow diagram of this process is shown in Fig.2.

For the simulation of the input parameters, the mean value of the layer thickness and Poisson's ratio were taken as those specified and given in Fig. (1). The mean value of the FWD load was assumed to be 9000-lb and mean values of the deflection were assumed to be these obtained for program Mich-Pave.

Coefficients of variation of 0.2 and 0.1 were assumed for the thickness of the layer and Poisson's ratio, respectively. These values were considered to reflect the uncertainty associated with the determination of these pavement parameters in practice. However, further work is required to validate this assumption. A Coefficient of variation of 0.05 was set of the FWD load and 0.02 for the deflection value, as previously discussed in the introduction.

All variables were tested to be independent and to follow a normal distribution. However, the distributions for the Poisson's ratios were truncated at a lower bound of 0.15 and an upper bound of 0.45. This account for the practical impossibility of having pavement materials with Poisson's ratio outside of these bounds.

Sample size.

The results of the Monte Carlo simulation are influenced by the size of the sample. In general, the larger the sample the highly accuracy is obtained.

In order to determine the sample size for this study, several calibration runs were performed using sample of 10, 50, 100, 500, and 1000. For these calibration runs only the thickness of layer 1 and 2 were considered to be random variables with mean values of 5 in. and 12 in. respectively.

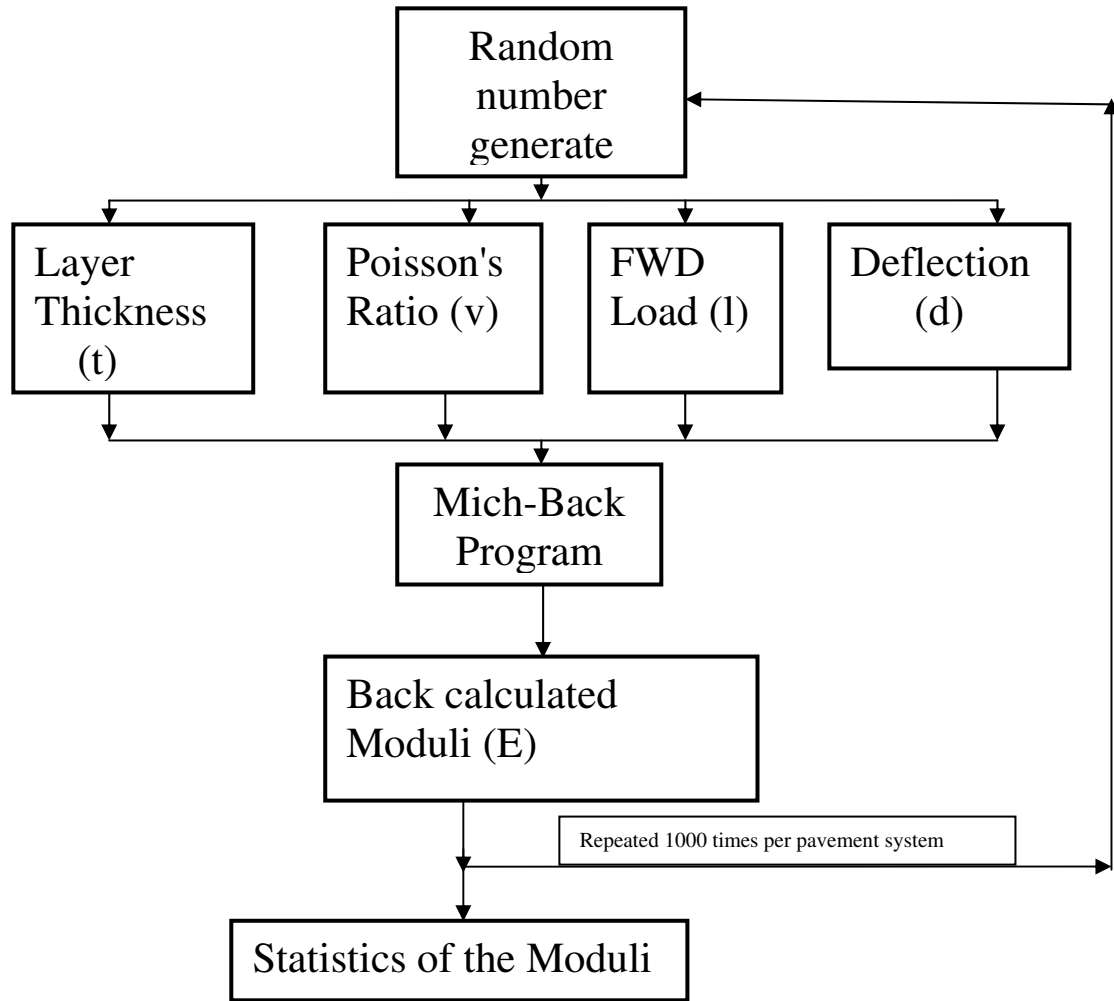


Fig. (2)- Statistical simulation of Backcalculated Moduli.

Table 1- Influence of sample size.

Number of simulations	Mean E1 (ksi)	Std. Dev.E1 (ksi)	Mean E2 (ksi)	Std. Dev.E2 (ksi)	Mean E3 (ksi)	Std. Dev.E3 (ksi)
10	766	1154	24.4	5.3	10.6	0.1
50	680	654	25.5	7.8	10.6	0.1
100	595	394	24.9	7.1	10.6	0.1
500	612	384	25.4	7.8	10.6	0.1
1000	605	406	26.1	8.9	10.6	0.1

A coefficient of variation of 0.1 was assumed for both variables. All other variables were assumed known as given in Fig.1. Results of the calibration runs are shown in Table 1. This table shows the computed means and standard deviation of the backcalculated moduli for each sample size. The relative error between the results of the 100 and the 1000 simulations are small enough to suggest that the approximation optioned with a minimum sample size of 100 values provides degree of accuracy on the statistical parameters estimated.

RESULTS AND DISCUSSION

Combined Random Variables.

The Monte Carlo simulation was performed for all pavement sections shown in Fig. 1 considering all parameters, (thickness of AC and base, Poisson's ratio of AC, Base and sub grade, load and deflection) to be random variables. These results are shown in Tables 2 through 4 in the row entitled "All Variables" In all three pavement sections, the variability induced by the combined random variables on the back calculated moduli of layer 1 and 2 (i.e. the AC layer and base layer) is much greater than that for the backcalculated moduli of the sub grade. The computed coefficients of variation of the moduli for layer 1 and 2 ranged from 0.8 to 1.4. While the computed coefficients of variation for the moduli of layer 3 were either 0.06 or 0.07. These results indicate that the variability of the pavement parameters do not significantly influence the backcalculated Moduli of the sub grade.

The coefficient variation for the AC layer moduli in pavement sections P1 (3"AC layer thickness) and P2 (3"AC layer and 12" base layer) are similar, 1.08 and 1.15, respectively However, a greater difference exists between the coefficient of variation of the base layer moduli for the pavement section P1 and that of P2 (0.81). Similar results are obtained when comparing pavement section P3 (5"AC layer and 12" base layer). These results indicate that the variability of backcalculated Moduli in thinner pavement structure is more sensitive to the variability of the pavement parameters than those of thicker pavement structures. It is also evident from the results in Table 2 through 4 that the variability in the moduli are much larger for section P1, a secondary road design, than for section P3, an interstate highway design. The larger variabilities associated with thinner pavement section might be due to existing limitation of Mich-Back in estimating the backcalculated Moduli.

The variation of variables of the backcalculated Moduli of each pavement section and each pavement layer are show in Fig. 3 through 5. The variation distribution of variables of backcalculated moduli are plotted against the normalized moduli. A normalized modulus of 1.0 represents the design or mean value of each layer.

It should be noted that the y-axis scale of the graphs are different for the normalized modulus of layer 3 than for the other two layers.

Sensitivity Analysis. In order to identify the influence that each variable has on the backcalculated Moduli, a stochastic sensitivity analysis was performed. This was accomplished by keeping all input variable, except one. Constant at their mean values as in Fig.1 the remaining parameter was considered to be random variable on which the Monte Carlo simulation was performed 100 times. The only exception to one variable being considered random at a time was the effect variations in the measured parameters were determined.

The FWD load, with a mean of 9000-lb, and the 7 deflection values, with means generated by Mich-Pave were randomly simulated at the same time. The variation of each variables plots of the back calculated Moduli generated for each case are shown in Fig.'s 3 through 5. Also, to facilitate the comparison of results. The coefficients of variation are summarized in Tables 2 through 4. A large coefficient of variation indicates that variability in the parameter has a major influence on the variability of the calculated moduli. Conversely, small coefficients of variation suggest that the variability of the moduli is insensitive to the given parameter.



Individual Random Variables; In all three pavement sections, the variability of the Poisson's ratio of the AC and base layers (v_1 and v_2) had very little effect on the backcalculated Moduli of all three layers. The small variability in the moduli is shown in the figures by variation of each variables plot. Then results also show that the Modulus of layer 3, in all three pavement, is not significantly influenced by any the variability of any of the input variables.

Table 2-Coefficient of variation.

Pavement section P1

Variable(s)	E1	E2	E3
V1	0.0273	0.0073	0.0000
V2	0.0082	0.0196	0.0022
V3	0.5094	0.3221	0.0483
T1	0.9193	0.1380	0.0022
T2	0.4656	0.8663	0.0066
L & d	0.3511	0.3402	0.0493
All variables	1.0840	1.3163	0.0727

Table 3-Coefficient of Variation.

Pavement section P2

Variable(s)	E1	E2	E3
V1	0.0333	0.0024	0.0003
V2	0.0084	0.0165	0.0036
V3	0.1856	0.1041	0.0361
T1	0.9672	0.0483	0.0023
T2	0.8521	0.7853	0.0023
L & d	0.2387	0.0862	0.0491
All variables	1.1464	1.8082	0.0661

Table 4-Coefficient of Variation

Pavement section P3

Variable(s)	E1	E2	E3
V1	0.0240	0.0186	0.0002
V2	0.0091	0.0343	0.0021
V3	0.2151	0.4185	0.0410
T1	0.8647	0.3273	0.0035
T2	0.1262	0.8813	0.0023
L & d	0.2503	0.3038	0.0551
All variables	0.9382	1.3706	0.0716

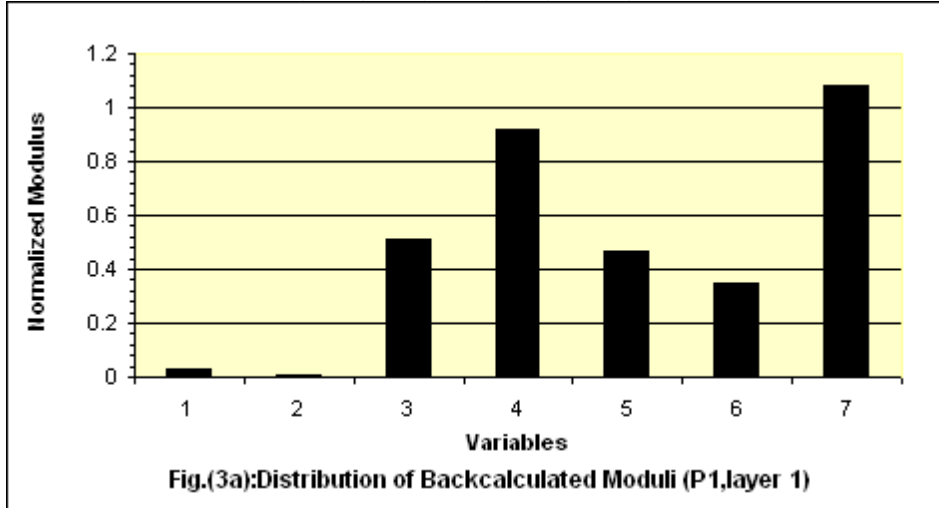
The remaining individual parameter influence the modulus of the AC layer and the base layer differently depending on the pavement section considered. In general the variability of the moduli for the first two layer of each pavement is greatly influenced by the uncertainty in the thickness of the layers. This result agrees with engineering intuition. For all pavement section, the variability in the measured deflection and load also has an important influence on the variability of the moduli. For thinner pavement this importance is large than for thicker ones. This highlights the necessity of improving the accuracy in measuring the thickness of the layer and in determining the deflection. An interesting result is the large influence that Poisson's ratio of the sub grade layer has on the variability of the moduli when compared with the influence of the variability of the moduli when compared with the influence of the Poisson's ratio of the layers. A possible explanation is that the mass of the sub grade is much greater than that of the other two layers and therefore its properties dominate the measured deflection basin. This is confirmed by the fact that the influence of this variable is larger for thinner pavement than thicker.

Conclusions

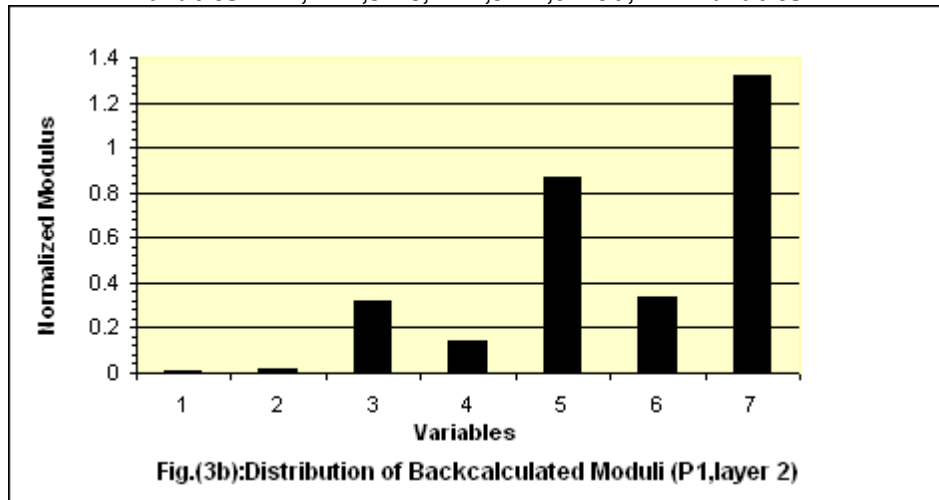
A Monte Carlo simulation approach has been proposed to study the influence of random deviations in the parameter that define a pavement structure on the backcalculated Moduli. Results are shown in terms of coefficients of variation and distribution of moduli. The results show that the sub-grade modulus is not significantly influenced by the variability of any of the parameters. The moduli of the first two layers of thinner structures are more influenced by the variability of the pavement parameters. The parameters with major influence on the variability of the AC layer and the base are: the thickness of the AC and base layer, the Poisson's ratio of the sub grade and the combined effects of the measured FWD load and deflection basin.



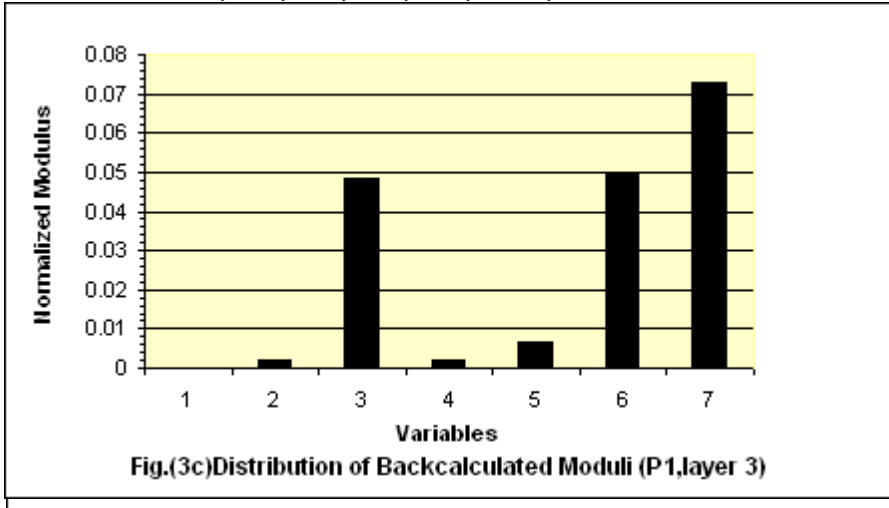
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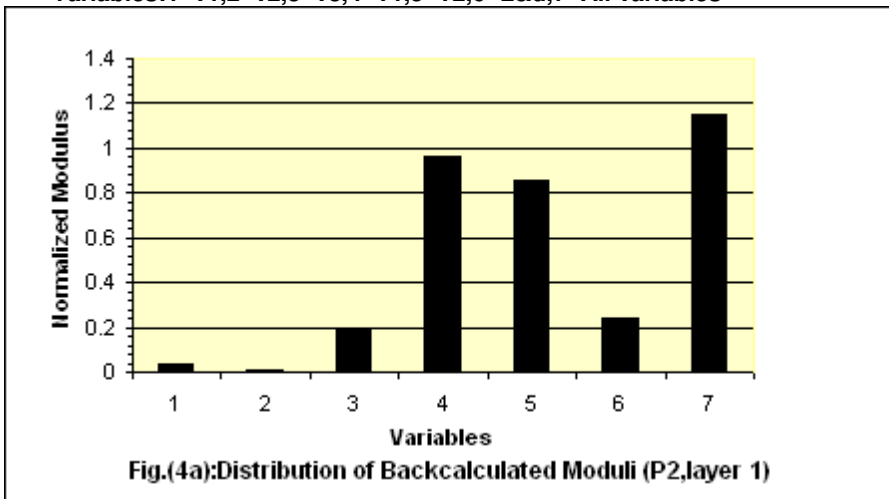
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Variables:1=v1,2=v2,3=v3,4=T1,5=T2,6=L&d,7=All variables

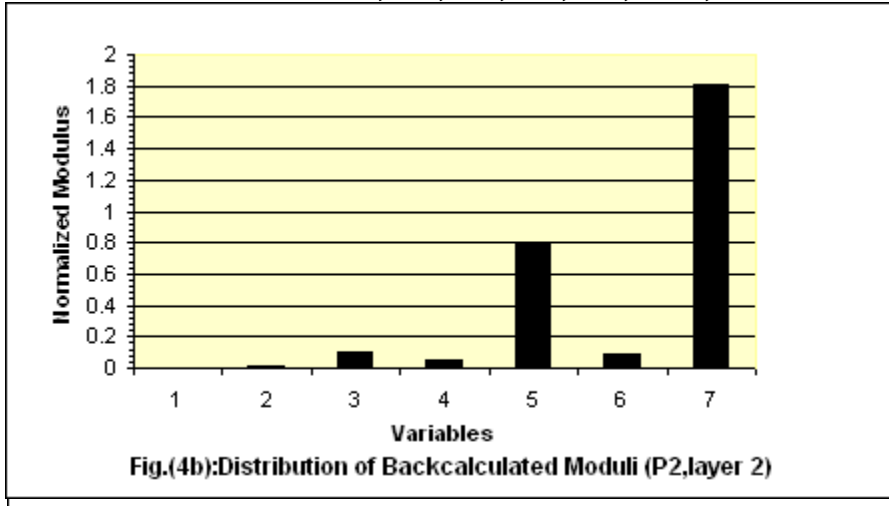


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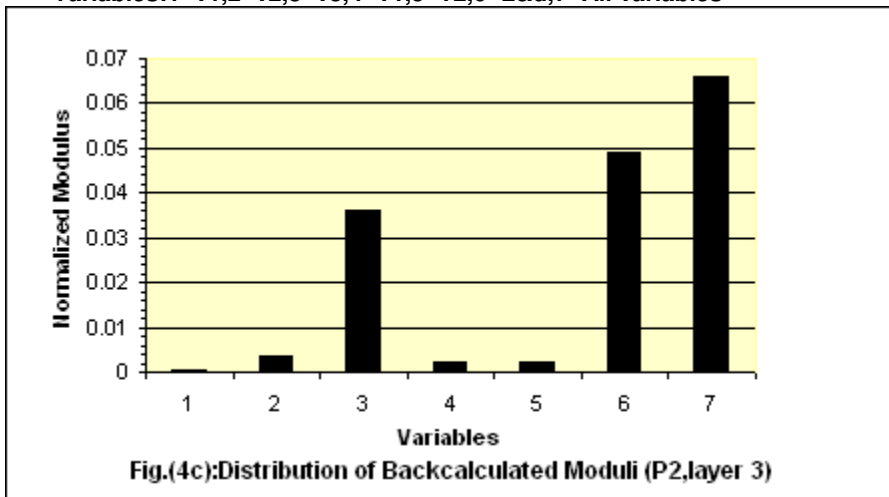




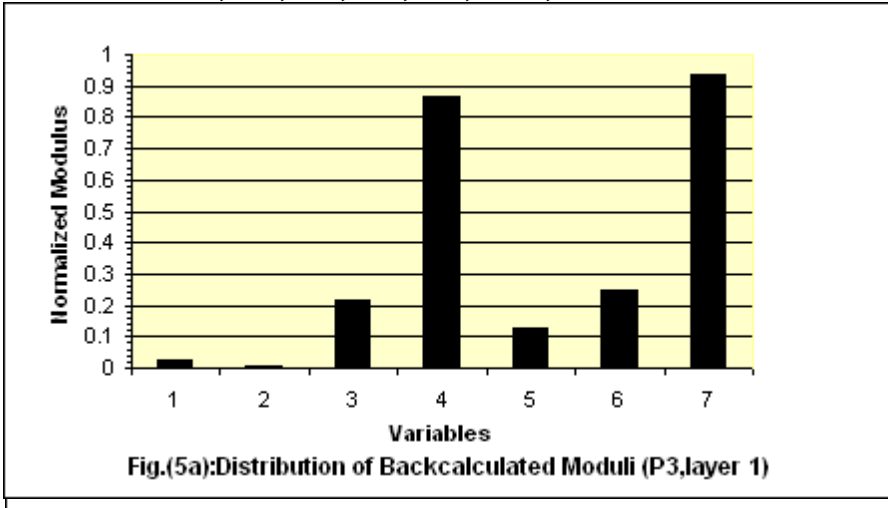
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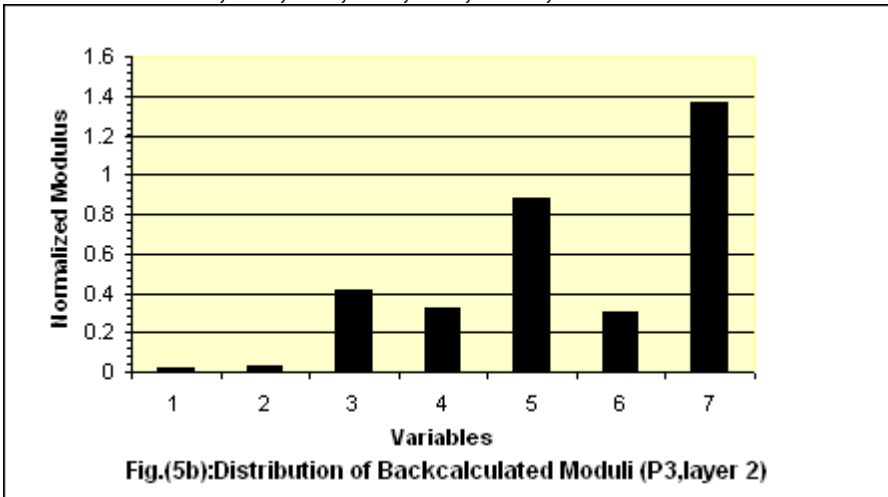
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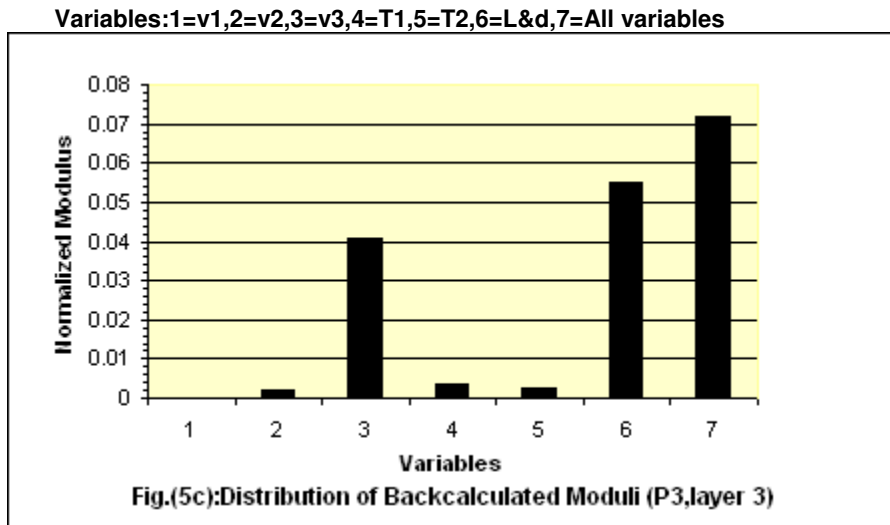


Variables:1=v1,2=v2,3=v3,4=T1,5=T2,6=L&d,7=All variables



Variables:1=v1,2=v2,3=v3,4=T1,5=T2,6=L&d,7=All variables





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