WINFLEX 2006

Mechanistic-Empirical Overlay Design System
for Flexible Pavement

Technical Background for Program Development

Final Report of Project No. KLK492
ITD Contract No. SPR-0010 (028), RP 121

Prepared for
Idaho Transportation Department

By

Fouad M. Bayomy
Principal Investigator

NIATT

Center for Transportation Infrastructure (CTI)
National Institute for Advanced Transportation Technology (NIATT)
University of Idaho

WINFLEX 2006

A Mechanistic-Empirical Overlay Design System
For Flexible Pavement

Final Submittal

The final submittal of this project includes:

1. CD for the Software, which includes the WINFLEX 2006 software setup package, help manual, and set of design examples,
2. Two DVD's for video presentations on program training; and
3. This report on the program documentation**.**

UI Research Team

Fouad M. Bayomy, PhD, PE
Professor of Civil Engineering, and
Principal Investigator,
National Institute for Advanced Transportation Technology (NIATT)
University of Idaho
Moscow, ID 83844-1022
Bayomy@uidaho.edu

Steve J. Taylor
Programmer Analyst
National Institute for Advanced Transportation Technology (NIATT)
University of Idaho
Moscow, ID 83844-0901
Staylor@uidaho.edu

ITD Project Coordinator

Michael J. Santi, PE
Assistant Materials Engineer
Idaho Transportation Department
PO Box 7129
Boise, ID 83707-1129
Mike.Santi@itd.idaho.gov

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Chapter 1 - Introduction

1.1 General

The purpose of this brief report is to document the technical background of the development of the WINFLEX 2006 software. It describes the engineering principals used in the development of the mechanistic-empirical overlay design system that is implemented in the WINFLEX software.

1.2 Project History

The development of this computer program was performed through a series of contracts with ITD. The first contract (Research Project RP 121, Agreement No. 95-60) dealt with the system development and its implementation in computer software. The first version of the software was DOS-based due to the fact that Fortran computer language was only available in the DOS environment. The first version of the program was named FLEXOLAY. It was developed using two computer languages - Fortran 77 and Visual Basic for DOS. It was released in 1996. Shortly after Microsoft release of the Fortran Power Station 4.0 for Windows, an upgrade of the FLEXOLAY program to operate under Windows was requested by ITD. Hence, the first windows-based program (WINFLEX 97) was developed under ITD project RP 121 Phase. The upgrade included not only the transfer to a new computer environment, but also included new design features in the program. For example, FLEXOLAY could only design an overlay for a single pavement section, while WINFLEX 97 can design overlay for multiple pavement sections at the same run. The next release of WINFLEX was developed under Windows 2000 operating system. The WINFLEX 2000 was developed under NIATT project No. KLK456 and has been included in the ITD materials manual. It contained two main codes using two computer languages - Visual Basic 6.0 and Fortran Power Station 4.0.

The latest version is the WINFLEX 2006, which was initiated under NIATT project No. KLK492. It built on the WINFLEX 2000 and addressed many programming bugs that were discovered during the previous several years.

1.3 Project Objective

The main objective of this project was to upgrade the WINFLEX 2000 software to add features and resolve many bugs that were discovered in the 2000 version.

In addition, a training workshop was developed and delivered to ITD. A set of two video DVD’s were also developed for training purpose.

Chapter 2 – Background of the Overlay Design Procedure in WINFLEX 2006

2.1 General

The mechanistic-empirical (M-E) design concept is not new to pavement design engineers and has been addressed in hundreds of publications over decades. A list of slected references is provided in Appendix A. [Ref 1 to 31]. The M-E overlay design procedure requires the determination of critical stresses, strains and deflections in the pavement by some mechanistic methods such as multi-layer elastic theory. Then, empirical models are used to evaluate the pavement accumulated damage or failure in various distress modes. The design decision would be based on some empirical failure criteria.

To implement this methodology in overlay design, the condition of the existing pavement must be evaluated first to assess the bearing capacity and the structural condition of the existing pavement section. Based on the anticipated future traffic and the adopted failure criteria, the remaining life of the exiting pavement is assessed. Hence, a decision is made on whether an overlay is needed and how much overlay thickness is then determined.

There are several features and tools are incorporated in the design software that allow for versatility and flexibility of the program use. For example, in WINFLEX, a user can select form alist of failure models in fatigue and rutting. Also, the program incorporates a seasonal variation module that allows the design engineer to select seasonal shift factors to adjust the pavement layer moduli values for various seasons. While the seasonal shift factors in the WINFLEX database were developed for specific Idaho zones, the program provides the flexibility for the user to input other shift factors that might be more appropriate to the design case under consideration.

In this chapter, a description of the various elements of the mechanistic procedures is provided. The following steps would be required for developing a mechanistic overlay design:

1. Modeling the pavement structure.
2. Identifying the design inputs.
3. Evaluating the response of the pavement to loading.
4. Evaluating the allowable load that a pavement can carry based on specified failure criteria.
5. Performing a damage analysis.

2.2 Pavement Structure Model

The pavement is regarded as a multi-layered elastic system. The application of the multi-layer elastic theory in pavement analysis involves several assumptions [3]:

1. Material in the pavement layers is assumed to be elastic, homogenous and isotropic.
2. All layers, except the bottom one, are finite in depth and the bottom layer (subgrade) is assumed to be infinite depth.
3. All layers are assumed to be infinite in extent in the lateral direction.
4. The applied loads are static and load imprints are assumed to be circular.
5. Pavement materials are characterized by a modulus of elasticity and Poisson's ratio.
6. Full friction is assumed to have developed between layers at each interface.

These assumptions may be found to be unrealistic for actual pavement conditions. However, the existing mechanistic procedures showed that applying the multi-layered elastic theory gave acceptable results [1, 23, 24, 25, 26, 27, and 29]

2.3 Design Inputs

Design inputs can be divided into three categories: material properties, traffic and loading, and environmental factors. Each input category is described below.

2.3.1. Material Properties

Since the pavement has been regarded as a multi-layered elastic system, the elastic moduli and Poisson ratios must be specified. The Poisson ratio is defined as the ratio of the lateral strain to the axial strain measured by laboratory testing. Because it has a relatively small effect on the pavement response, it is customary to assume reasonable value for design rather than to determine it from actual tests [4]. Table 1 shows typical Poisson ratios for paving materials.

Table 1. Poisson ratios for paving materials [Ref. 5]

Material	**Range**	**Typical**
Hot mix asphalt	0.30 – 0.40	0.35
Portland cement concrete	0.15 – 0.20	0.15
Untreated granular materials	0.30 – 0.40	0.35
Cement-treated granular materials	0.10 – 0.20	0.15
Cement-treated fine grained soils	0.15 – 0.35	0.25
Lime-flyash mixtures	0.10 – 0.15	0.15
Loose sand or silt sand	0.20 – 0.40	0.30
Dense sand	0.30 – 0.45	0.35
Fine-grained soils	0.30 – 0.50	0.40
Saturated soft clay	0.40 – 0.50	0.45

The layer moduli values can be obtained by performing resilient modulus tests on cores taken from the pavement. This operation disturbs and destroys the pavement components and may be costly. Another alternative technique for determining the layer moduli values is Non-

Destructive Testing (NDT) such as Benkleman Beam, Dynaflect, Road Rater and Falling Weight Deflectometer (FWD). The FWD is becoming the most widely used device since it applies impulse loading, which better simulates the actual traffic loading. Pavement layer moduli are predicted from deflection data using backcalculation techniques. Several programs have been developed that perform the backcalculation [6 and 7].

A study by Bayomy and Shah [8] was performed on selected backcalculation programs including MODULUS 4.0 and EVERCALC 3.3. The authors developed some recommendations and guidelines to be followed when using these programs in order to minimize layer moduli prediction errors. This study uses the Modulus 4.0 software for backcalculating layer moduli values of existing pavements.

It is well known that granular materials and subgrade soils are nonlinear, with the resilient modulus varying with the level of stresses. A simple but more popular relationship between the resilient modulus (M_r) of granular materials and the state of stresses can be expressed as [9]:

$$M_r = K_1 \theta^{k2} \quad (1)$$

In which k_1 and k_2 are experimentally derived constants and θ is the bulk stress, which is the sum of the principal stresses, $\theta = \sigma_1 + \sigma_2 + \sigma_3$.

For fine-grained soils, the stress dependent behavior can be described as [10]:

$$M_r = K \sigma^n_d \quad (2)$$

In which k and n are experimentally derived constants and σ_d is the deviatoric stress, $\sigma_d = \sigma_1 - \sigma_3$.

Some design procedures (e.g. Asphalt Institute DAMA program) consider the subgrade as linear elastic. This is a reasonable approximation because the variation of modulus due to change of subgrade stresses is usually quite small [4 and 5].

In the proposed design procedure, all layers are assumed to be linear elastic with constant elastic modulus, unless indicated otherwise. In the nonlinear elastic case, these layers and the required parameters must be identified.

In the nonlinear elastic case, these layers and the required parameters must be identified. An iterative procedure is used, in which the moduli of nonlinear layers are adjusted as the stress varies, while moduli of linear layers remains the same. A constant set of moduli is computed based on stresses obtained from the previous iteration. The process is repeated until the moduli converge to a specified tolerance.

2.3.2. Traffic Data

Traffic is a major input parameter in the pavement design process. The consideration of traffic should include both loading magnitude and configuration, and number of load repetitions. Traffic is estimated in 18-kip equivalent single axle loads (ESALs).

The wheel configuration used in the design procedure is based on a single axle load supported by dual tires. The required loading magnitude is based on one tire on one side (e.g. for 18 kip ESAL, the input wheel load is 4.5 kip). To account for the dual tire action, it is also necessary to specify the tire spacing from center to center. The tire pressure is used to determine the radius of the contact area between the tire and the pavement; 80 psi is a typical value.

2.3.3. Environmental Effects

The key parameter that was selected to reflect the environmental effects is the layer elastic modulus. The elastic modulus of a flexible layer changes with the surrounding environment. While an asphalt layer may be more sensitive to temperature, a clayey soil layer will be less sensitive to temperature variation but more affected by the change in moisture. Thus, the environmental parameters that are considered to affect the variation of the pavement properties are: temperature (for asphalt bound layers) and moisture (for unbound materials). For layers that are subjected to freezing conditions, the moduli values become extremely large. In this condition, an upper frozen value would be suggested [4 and 5].

The effect on the elastic modulus or modulus of resilience value of a pavement layer may be represented by a multiplying factor, called “Seasonal Adjustment Factor, SAF” with an equation:

$$E_{ij} = F_{ij} * E_{in} \qquad (3)$$

Where:

E_{ij} = Elastic Modulus value of layer i in season j,
F_{ij} = Seasonal Shift Factor for layer i in season j, and
E_{in} = Elastic Modulus value of layer i during the normal season.

The normal modulus of a layer, E_{in}, is considered the layer elastic modulus at which the pavement was tested. It becomes a reference value from which the shift is made at different seasons. It is typically considered the value of summer season.

Equation (3) is applicable for unbound layers. For asphalt bound layers, a continuous function where the E value is a function of temperature can always be developed.

2.3.3.1. Subgrade Layer

The environment plays an important role in establishing subgrade resilient modulus. The modulus of soils decreases substantially when moisture content increases. Temperature cycling can alter the modulus. Frozen subgrade may exhibit an increase in the resilient modulus compared to the condition where the subgrade is considered normal. The thawing process substantially reduces the resilient modulus compared to the condition where the subgrade is considered normal.

A study conducted by Hardcastle [11] resulted in proposing a method for estimating seasonal adjustment factors, SAF, of resilient moduli of subgrade soils found in Idaho. The study has identified the following:

1. Idaho pavement operation climate zones.
2. The various season in an average year, and most importantly, the time boundary of each season.
3. Adjustment coefficients to account for seasonal variations in subgrade resilient modulus.

The state of Idaho was divided into six pavement climate zones. These are based on six geographic areas, each having approximately equal climate parameters such as the annual air temperature and precipitation, and equal climate indices such as Thornthwaite Moisture Index (TMI) and Freezing Index (FI). The zone boundaries and their characteristics as presented by Hardcastle [11] are shown in Figure 1. The climate zones and their characteristics are used to determine the magnitude of the expected moisture changes for the various soil groups as a function of location, and to define the duration and onset dates of the possible operating periods.

For each period there are corresponding subgrade conditions and resilient moduli values. In zone 1, 2, 4, and 5, which experience significant subgrade frost penetration, an average year in a pavement's life is divided into four periods:

- Winter (Frozen) Period
- Spring-Thaw Recovery
- Summer (Normal) Period
- Freezing Transition Period

In zone 3 and 6, which do not experience significant subgrade frost penetration, the average year is divided into three periods:

- Winter-Spring (Wet) Period
- Summer (Normal) Period
- Wet Recovery Period

The calculation of duration, and onset date of each operating period were performed on six representative locations, Driggs (Zone 1), Idaho Falls 46W (Zone 2), Twin Falls (Zone 3), Powell (Zone 4), McCall (Zone 5), and Moscow (Zone 6). The environmental changes in various climatic zones in Idaho are summarized in Table 2.

Three seasonal adjustment factors, SAF, relative to the summer resilient modulus, E_n, have been used in the proposed overlay design procedure. These factors are used for adjusting summer resilient modulus for freezing, thawing, and wet conditions. Adjustments for freeze-thaw conditions are required in pavement operating climate zones 1, 2, 4, and 5, which experience significant subgrade frost penetration. Pavement operating climate zones 3 and 6 do not experience significant frost penetration. Thus, an adjustment is required to account for the temporary increase in subgrade water content during wet periods.

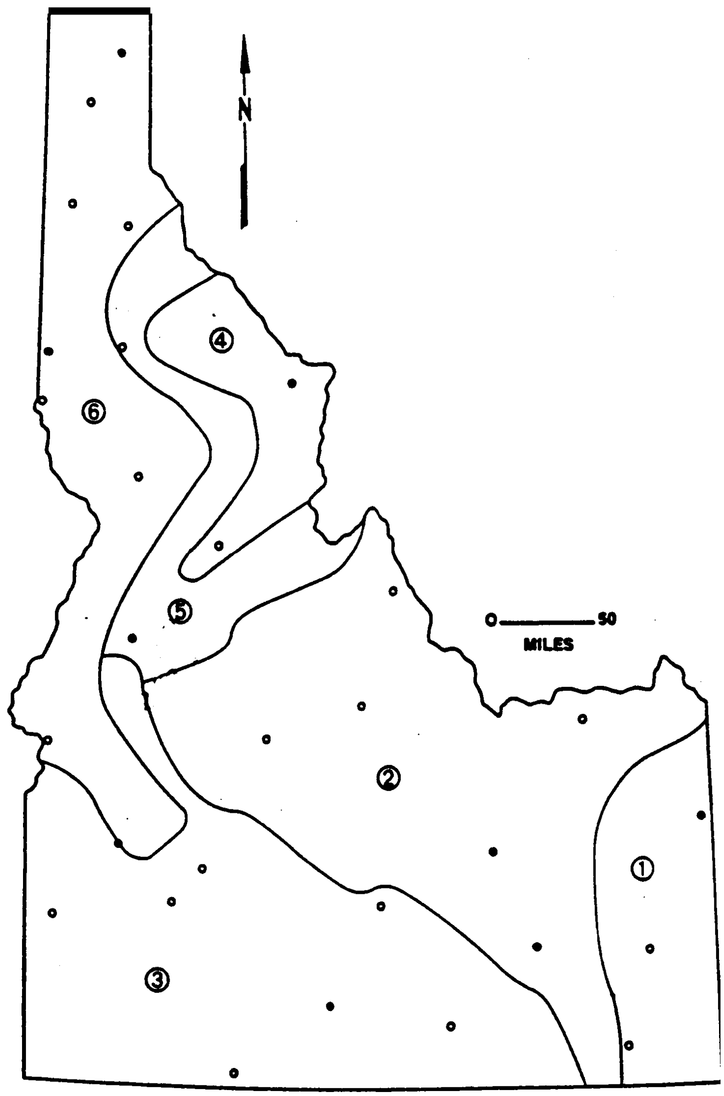


Figure 1. Idaho Pavement Climate Zones [Ref. 11]

Table 2. Environmental Parameters Representing Climatic Zones in Idaho (Ref. 11, 14 and 16)

a) Representative Air Temp. (C)*

Season and Condition	Zone 1 Driggs	Zone 2 Idaho Falls	Zone 3 Twin Falls	Zone 4 Powell	Zone 5 McCall	Zone 6 Moscow
Winter – Freeze	-0.6	0.0	6.7	0.6	0.6	8.9
Spring – Thaw	13.3	14.4	14.4	11.7	13.3	15.0
Summer – Normal	16.1	18.3	18.9	16.7	15.6	18.3
Fall/Winter – Normal	1.1	0.6	2.2	2.2	1.7	1.1

* Shown values are the 68^{th} percentile

b) Climatic Parameters

Climatic Parameter	Zone 1 Driggs	Zone 2 Idaho Falls	Zone 3 Twin Falls	Zone 4 Powell	Zone 5 McCall	Zone 6 Moscow
Frost Depth, mm	1321	1372	660	940	1067	559
Freezing Index, Degree-days	1507	1587	543	873	1062	442
Thaw Index, Degree-days	395	415	---	230	279	---
Freezing Transition Period, days	15	9	---	44	24	---
Onset of Frozen, Period	10-Jan.	3-Jan	1-Feb	10-Feb	30-Jan	15-Feb
Frozen Period*, days	120	126	90	82	110	90
Frozen Period, % time of the year	33%	35%	25%	22%	30%	25%
Onset of Thaw Period	10-May	9-May	1-May	3-May	16-May	16-May
Thaw Period**, days	38	36	15	27	24	30
Thaw Period, % time of the year	10%	10%	4%	7%	7%	8%
Normal Period, days	192	194	260	212	207	245
Normal Period, % time of the year	53%	53%	71%	58%	57%	67%

* Calculated based on Thaw Index of 24 degrees-days
** Calculated based on Thaw Index = 4.154+0.259 (AFI)

For freezing conditions, the increase in resilient modulus due to freezing is largest for fine-grained soils that already contain substantial amounts of water and therefore have low resilient moduli (E_n) in the unfrozen condition. Figure 2 shows the inverse relationship between E_n and the freezing adjustment factor, F_f. The resilient modulus of the subgrade, E_f, applicable during frozen periods is computed from the equation:

$$E_f = F_f * E_n \quad (4)$$

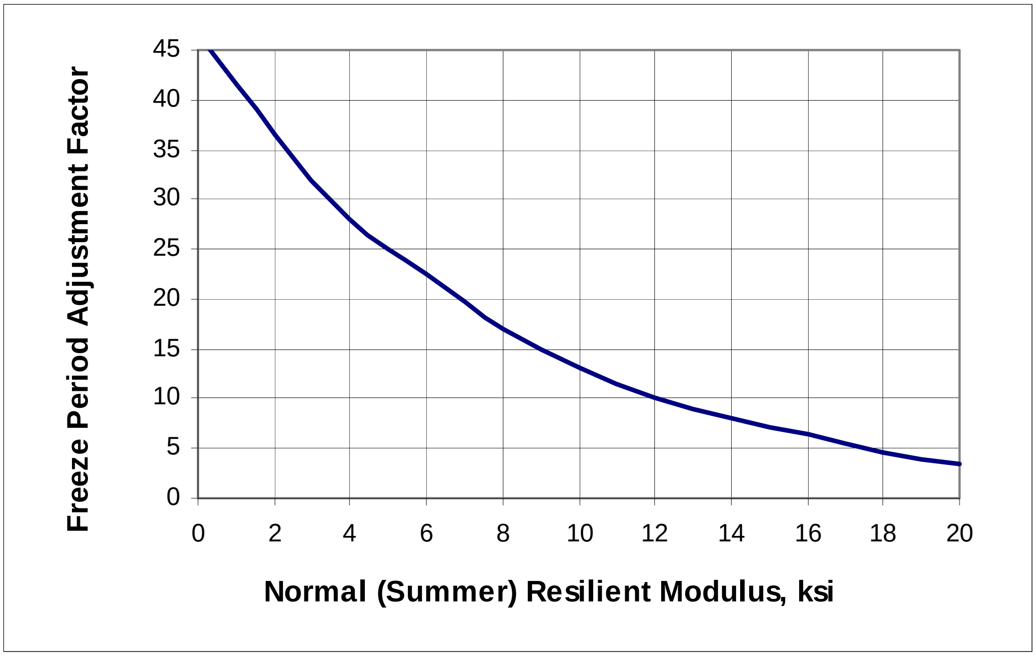


Figure 2. Adjustment Factor for Subgrade Freezing [Ref. 11]

A second adjustment factor, F_t, is used to account for the thaw-softening effect observed to occur in medium to fine-grained soils immediately following thawing. The mechanisms by which the stiffness of frozen and thawed granular mineral aggregates is first reduced and then caused to recover with time and the application of dynamic loads are not completely understood [11]. It believed, however, that the effect is most pronounced for fine-grained soils, which exhibit the largest amount of freezing-induced stiffening. These are also the soils that generally have the lowest values of the normal period resilient modulus, E_n. For this reason, the thaw-softening factor, F_t, has also been inversely related to the normal, Summer, operating resilient modulus, E_n, as shown in Figure 3. The thaw-reduced resilient modulus, E_t is calculated as follows:

$$E_t = F_t * E_n \quad (5)$$

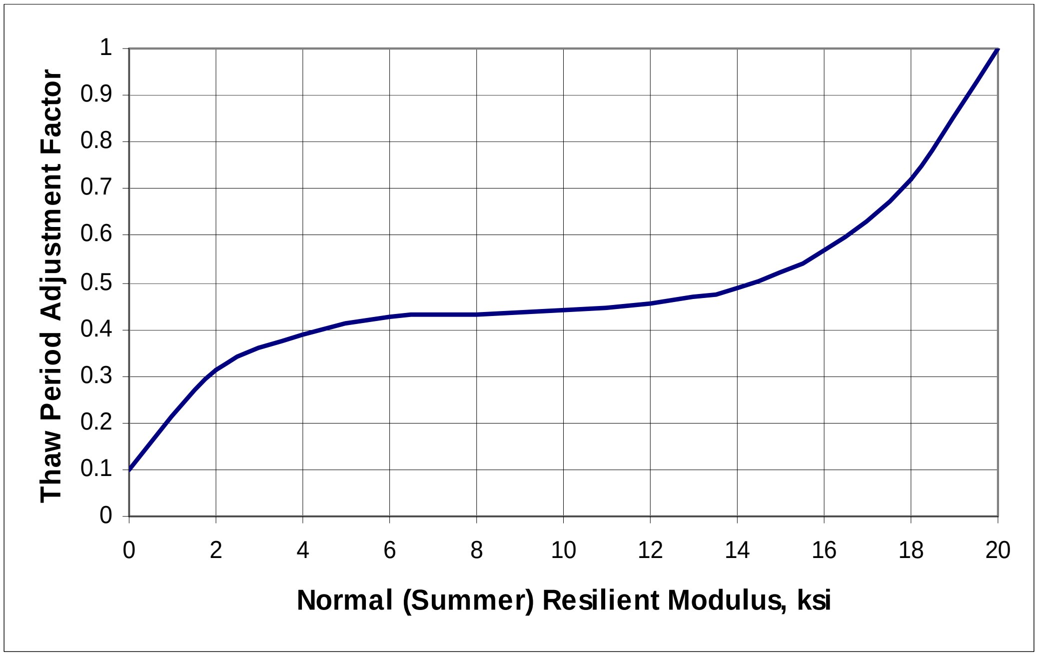


Figure 3. Adjustment Factor for Subgrade Thawing [Ref. 11]

The last condition assumed for subgrade soils in Idaho is a winter-spring wet condition for zones 3 and 6. This condition is necessary to account for the possibly short duration but significant seasonal (temporary) increases in moisture content of subgrade soils which may occur in areas where complete freezing and thawing of the subgrade does not occur. Like the factor used to account for post-construction changes in the long-term average annual water content, the factor for significant temporary moisture content increases depends on the climate zone and the soil type.

Calculating the resilient modulus during wet periods for zone 3 and 6 requires the determination of the expected temporary increase in subgrade water content during this period from Figure 4. Once the temporary increase in water content is determined, the temporary reduced resilient modulus, E_w, for the spring-wet period is computed by applying the adjustment factor, F_w, obtained from Figure 5 to the normal, Summer, operating value of resilient modulus, E_n as follows:

$$E_w = F_w * E_n \qquad (6)$$

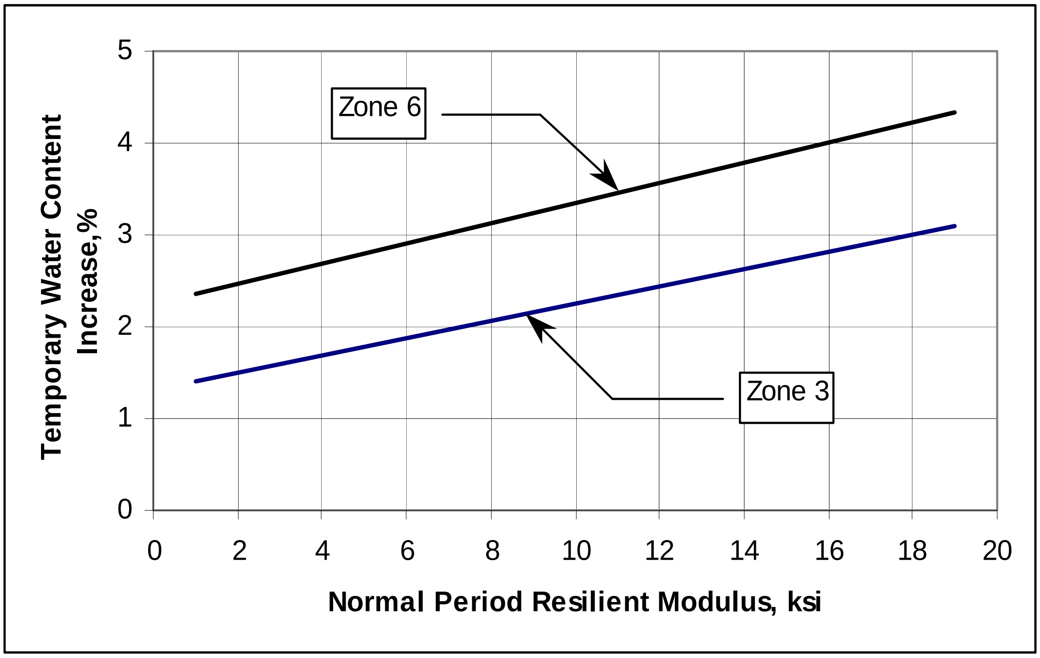


Figure 4. Winter-Spring Temporary Water Content Increase [Ref. 11]

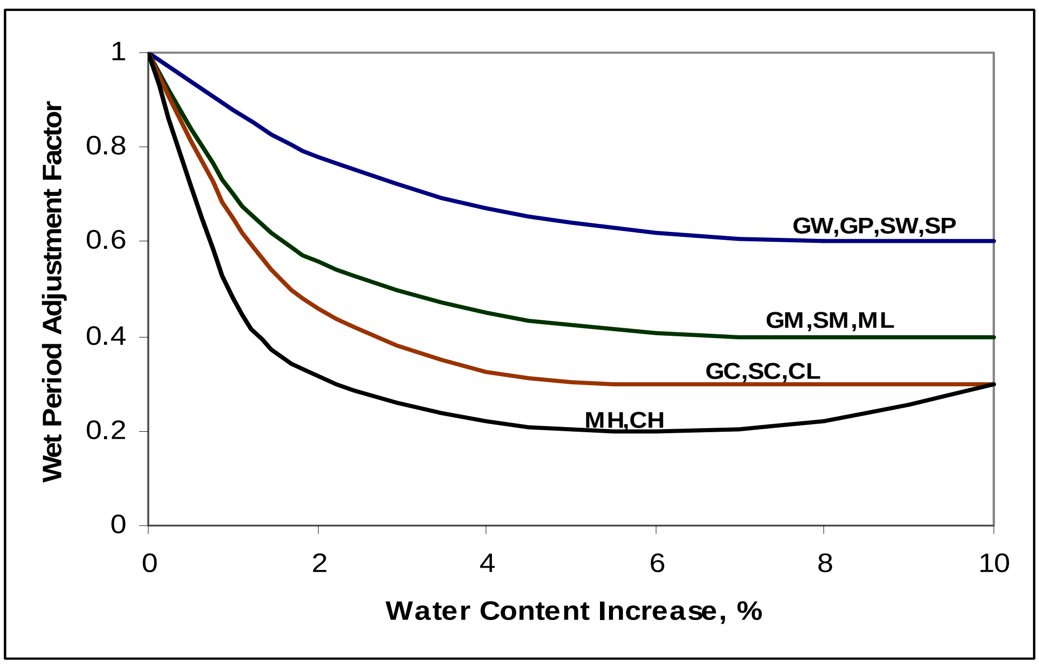


Figure 5. Adjustment Factors for Post-Construction W.C. Increase [Ref. 11]

Figure 6 shows a graphical representation of the annual distribution of the resilient moduli values for the various pavement operation climate zones found in Idaho. For proposed overlay design procedure, the analysis year was divided into four separate seasons.

For zones 1, 2, 4 and 5, winter season represents the frozen period, with subgrade resilient modulus equal to the average of E_n and E_f. E_f is computed from equation (4). The freezing Adjustment factor, FR_f, is determined from Figure 2 or from the following equation, which is used in the proposed overlay design procedure:

$$FR_f = 45 \times (0.8838^{E_n}) \qquad (7a)$$

Then an average value of E_f and E_n is used to represent the average modulus during the frozen season.

$$E_f = \frac{FR_f E_n + E_n}{2} \qquad (7b)$$

$$E_f = \left(\frac{45 \times (0.8838^{E_n}) + 1}{2}\right) E_n \qquad (7c)$$

Thus the Seasonal Adjustment Factor for the frozen season equals to:

$$F_f = \frac{45 \times (0.8838^{E_n}) + 1}{2} \qquad (7d)$$

Equation 7d is used in the Winflex program to calculate the average SAF for frozen season.

Spring season represents the thaw recovery period for zones 1, 2, 4, and 5 with subgrade resilient modulus equal to the average of E_t and E_n. E_t is computed from equation (5) and the thawing adjustment factor, F_t, is determined from Figure 3. In the proposed overlay design procedure, Figure 3 is divided into three stages according to the normal resilient modulus, E_n, and these stages are written in the program for computing the adjustment factor, F_t, as following:

If $0 < E_n \leq 6$, then

$$F_t = (0.002778 + 0.012549 \times E_n)^{\frac{1}{3}} \qquad (8)$$

If $6 < E_n \leq 20$, then

$$F_t = 0.43127 + 0.00000000884 \times (E_n)^6 \qquad (9)$$

If $E_n > 20$, then

$$F_t = 1.0 \qquad (10)$$

For climate zones 3 and 6, winter-spring season represents the wet period with subgrade resilient modulus equal to E_w. Spring period represents the wet recovery period with subgrade resilient modulus equal to the average of E_w and E_n. E_w is computed from equation (6) and the thawing adjustment factor, F_w, is determined from Figure 4 and Figure 5. In the overlay design procedure, the percent of temporary water content increase, Wc, according to Figure 4 is computed from the following equations:

For Zone 3:

$$Wc = 1.3125 + 0.09375\ E_n \quad (11)$$

For Zone 6:

$$Wc = 2.2857 + 0.1071\ E_n \quad (12)$$

Finally, Figure 5 is divided into three stages, according to the soil type, for computing the thawing adjustment factor, F_w,:

For soil type GW, GP, SW, SP:

If $0 \le Wc \le 2$, then	$F_w = 1 - 0.1\ Wc$	(13)
If $2 < Wc \le 6$, then	$F_w = 0.963\ (0.91)^{Wc}$	(14)
If $Wc > 6$, then	$F_w = 0.66$	(15)

For soil type GM, SM, ML:

If $0 \le Wc \le 1$, then	$F_w = 1 - 0.3\ Wc$	(16)
If $1 < Wc \le 4$, then	$F_w = 0.786\ (0.869)^{Wc}$	(17)
If $Wc > 4$, then	$F_w = 0.41$	(18)

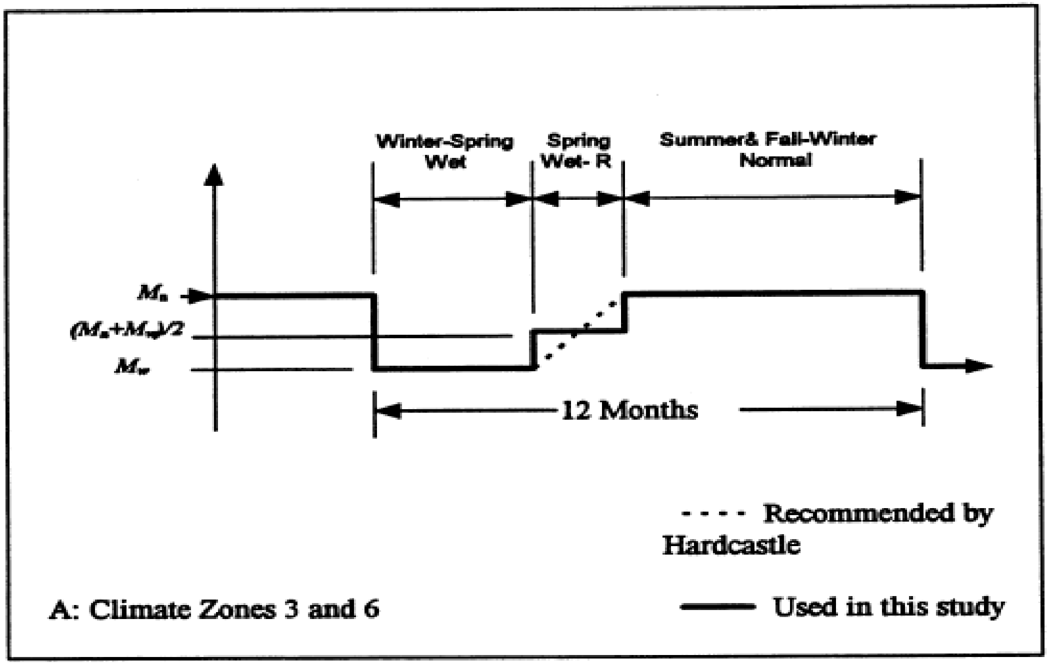
For soil type GC, SC, CL:

If $0 \le Wc \le 1$, then	$F_w = 1 - 0.4\ Wc$	(19)
If $1 < Wc \le 4$, then	$F_w = 0.735\ (0.798)\wedge^{Wc}$	(20)
If $Wc > 4$, then	$F_w = 0.3$	(21)

For soil type MH, CH:

If $0 \le Wc \le 1$, then	$F_w = 1 - 0.5\ Wc$	(22)
If $1 < Wc \le 4$, then	$F_w = 0.535\ (0.7962)\wedge^{Wc}$	(23)
If $Wc > 4$, then	$F_w = 0.22$	(24)

Summer and fall-winter seasons together in all zones represent the normal period with subgrade resilient modulus equal to E_n.



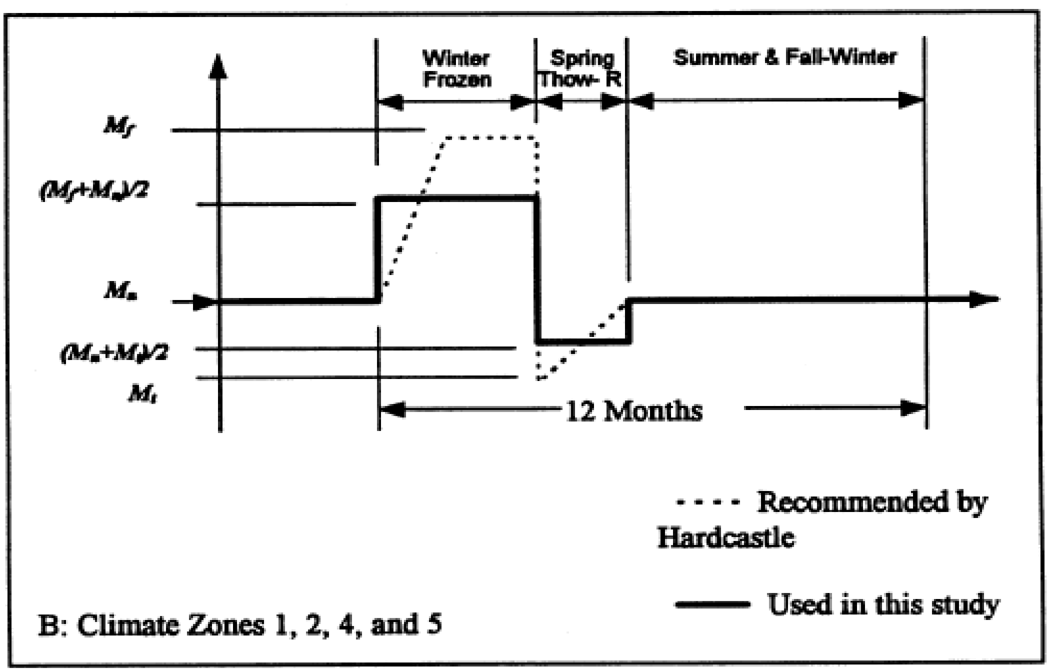


Figure 6. Graphical Representation of Subgrade Modulus Variations Throughout the Year for Pavement Climate Zones in Idaho

2.3.3.2. Granular Bases and Subbases

Like subgrade soils, the environment can affect granular base and subbase resilient modulus. Base and subbase layers are expected to have higher resilient modulus than the subgrade beneath. From the inspection of Figure 2, which shows an inverse relationship between normal resilient modulus, E_n, and the freezing factor, F_f, it is safe to assume that the effect of freezing on the base and subbase is negligible. This means that in pavement climate zones 1, 2, 4, and 5, the winter (frozen) period resilient modulus for granular layers is the same as the summer (normal) resilient modulus.

A study conducted by Rutherford [31], involving seasonal pavement response, proposed reducing the Freeze-thaw period resilient modulus of granular soils by OR TO-important distinction 25 to 50 percent of their normal values. Values in this range were used by some agencies [25 and 26]. In this study, an adjustment factor of 0.65 is applied to the normal period resilient modulus to determine the freeze-thaw period resilient modulus in zones 1, 2, 4, and 5 for base and subbase layers. It is assumed that Figure 4 and Figure 5 can be applied to granular bases and subbases in zones 3 and 6. Knowing that the normal modulus of these layers may exceed 20 ksi, it is clear that a value of 0.65 may be a reasonable adjustment factor to account for water content increase during the wet period for zones 3 and 6. The adjustment factor for the wet-recovery period is taken as the average of the wet and the normal period resilient modulus. The adjustment factor to account for the wet condition is 0.65, as mentioned previously. By adding this value to the one for normal condition and dividing by two to get the average, the adjustment factor for the wet-recovery period was determined to be 0.85.

The results were used to establish seasonal shift or adjustment factors for the pavement layer moduli for each season of the year. The corresponding seasonal adjustment factors (F_{ij} in Eqn. 3) for different layers are summarized in Table 3. It is important to note that the data presented in Table 3 are for the average conditions that may be found in the state.

2.3.3.3. Asphalt Concrete Material

For asphalt mixtures, temperature would be the factor affecting the variation of the layer moduli. Asphalt concrete is quite temperature sensitive, exhibiting modulus increase at lower temperatures and modulus decrease at higher temperatures. The determination of seasonal moduli values of asphalt concrete materials requires selection of a representative seasonal pavement temperature and then evaluation of the asphalt concrete modulus at that temperature. A model developed by Witczak [12] that is incorporated in the Asphalt Institute's pavement design DAMA program [5] relates the mean pavement temperature, T_p and mean monthly air temperature, T_a as:

$$T_P = T_a\left(1+\frac{1}{z+4}\right)-\frac{34}{z+4}+6 \qquad (25)$$

In which z is the depth below surface. It is usually calculated to the mid-depth of the asphalt layer. To determine the seasonal mean air temperature, maximum and minimum daily air temperature data files for the representative locations of each climate zone were collected for the past 10 years from Idaho State Climatologic. These data files were loaded in spreadsheet software and analyzed. A summary of the mean air temperatures determined for each season is presented in Table 2(a). Summer season duration was obtained by considering the hottest months in the year that follow the thaw period (spring) for zones 1, 2, 4, and 5 and the wet-recovery period (spring) for zones 3 and 6.

The modulus of asphalt concrete depends on its material characteristics and testing conditions (loading time and temperature). It can be estimated using SHRP's equation [13]:

$$\begin{aligned}\log_{10}\left[E_{ac}\right] &= 0.553833 + 0.28829 * P_{200} * f^{-0.17033} - 0.03476 * V_a + 0.070377 * \eta_{70,10^6} \\ &+ 0.000005 * \left[t_p^{(1.3+0.498251*\log(f))} * P_{ac}^{0.5}\right] - 0.00189 * \left[t_b^{(1.3+0.49825*\log(f))} * P_{ac}^{0.5} * f^{-1.1}\right] \\ &+ 0.931757 * f^{-0.02774} \end{aligned} \quad (26)$$

Where;

E_{ac} = AC modulus, x 10^5

V_a = Percent air voids in mix

F = Test frequency

T_p = Mid depth AC layer temperature (F)

P_{200} = Percent Aggregate weight passing # 200 sieve

$\eta_{70,106}$ = Asphalt viscosity at 70 F

P_{ac} = Percent asphalt content by volume of mix

Table 3. Seasonal Adjustment Factors (SAF) for Idaho Climatic Zones [Ref. 16]

(A: Zones 1, 2, 4 and 5)

Climate Zone	Seasonal Adjustment Factors, SAF				
		Winter Frozen	Spring Thaw	Summer Normal	Fall Normal
Zone 1	Subgrade	Eqn. 7	Eqn. 8,9,10	1	1
	Base/Subbase	1	0.65	1	1
	Traffic	User Input			
	Temperature, F	31	55	62	34
	Period, Months	4	1.5	3.5	3
Zone 2	Subgrade	Eqn. 7	Eqn. 8,9,10	1	1
	Base/Subbase	1	0.65	1	1
	Traffic	User Input			
	Temperature, F	32	58	65	33
	Period, Months	4	1.5	3.5	3
Zone 4	Subgrade	Eqn. 7	Eqn. 8,9,10	1	1
	Base/Subbase	1	0.65	1	1
	Traffic	User Input			
	Temperature, F	33	53	62	36
	Period, Months	3	1	4	4
Zone 5	Subgrade	Eqn. 7	Eqn. 8,9,10	1	1
	Base/Subbase	1	0.65	1	1
	Traffic	User Input			
	Temperature, F	33	56	60	35
	Period, Months	4	1	4	3

(B: Zones 3 and 6)

Climate Zone	Seasonal Adjustment Factors, SAF					
		Subgrade Classification	Winter Wet	Spring Wet	Summer Normal	Fall Normal
Zone 3	Subgrade	GW,GP,SW,SP	Eqn. 13,14,15	Eqn. 13,14,15	1	1
		GC,SC,CL	Eqn. 16,17,18	Eqn. 16,17,18	1	1
		GM,SM,ML	Eqn. 19,20,21	Eqn. 19,20,21	1	1
		MH,CH	Eqn. 22,23,24	Eqn. 22,23,24	1	1
	Base/Subbase		0.65	0.85	1	1
	Traffic		User Input			
	Temperature, F		44	58	66	36
	Period, Months		3	1	4	4
Zone 6	Subgrade	GW,GP,SW,SP	Eqn. 13,14,15	Eqn. 13,14,15	1	1
		GC,SC,CL	Eqn. 16,17,18	Eqn. 16,17,18	1	1
		GM,SM,ML	Eqn. 19,20,21	Eqn. 19,20,21	1	1
		MH,CH	Eqn. 22,23,24	Eqn. 22,23,24	1	1
	Base/Subbase		0.65	0.85	1	1
	Traffic		User Input			
	Temperature, F		48	59	65	34
	Period, Months		3	1	4	4

The most sensitive variable in this equation is the temperature. To avoid the use of this cumbersome equation, a graphical representation of the equation (26) was prepared by Bayomy et al. [8] for average conventional asphalt mixes, as shown in Figure 7. From this figure a simplified equation (27) was developed.

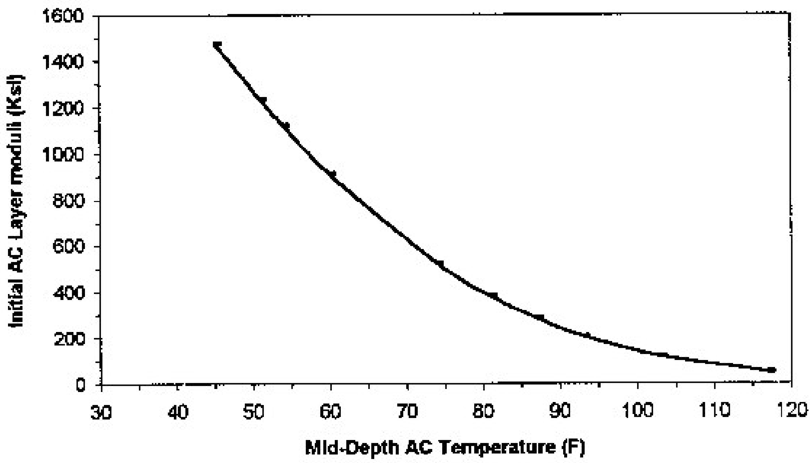


Figure 7. SHRP’s Equation for Conventional Asphalt Mixes

$$E_{AC} = \left(15.018 - 0.12692 * T_p\right)^{\frac{1}{0.35}} \qquad (27)$$

Equation (27) represents the SHRP’s equation with slope equal to 0.12692 for average conventional asphalt mixes. To adjust for a modulus value determined at a certain temperature, the modulus value is plotted on the graph against the temperature. Then a parallel curve is drawn to the mix characteristic curve of the SHRP’s equation. The new curve is the temperature-adjusting curve for the pavement layer. Figure 8 shows a schematic of the shifting procedure.

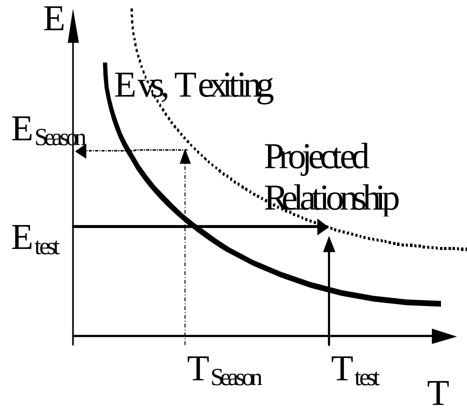


Figure 8. Schematic of the Modulus-Temperature Adjustment

The proposed overlay design procedure uses this schematic for the AC Modulus-Temperature adjustment and equation (27) as SHRP's equation. Equation (27) can be written as equation (28a), with the same slope to be used in the design procedure as a default, where F_{cept} is the intercept. To adjust for a modulus value determined at a certain temperature, the modulus value is plotted against the temperature. Then, the intercept, F_{cept}, of the new curve can be determined by using equation (28b), and the asphalt modulus at any season can be determined from equation (29).

$$E_{AC} = \left(F_{cept} - 0.12692 * T_p\right)^{\frac{1}{0.35}} \tag{28a}$$

$$F_{cept} = \left(E_{test}\right)^{0.35} + 0.12692 * T_{test} \tag{28b}$$

$$E_{season} = \left(F_{cept} - 0.12692 * T_p\right)^{\frac{1}{0.35}} \tag{29}$$

Equation (29) assumes that the asphalt mix will follow the behavior as suggested by SHRP equation (27). However, if it is believed that the mix for the design case in consideration does not follow such trend of E vs. Temp relationship, then laboratory evaluation of the new mix is required.

From lab data develop a plot for the E vs. Temp curve. Then fit an equation with the general form as given by equation (30) to the lab data.

$$E^n = \left(F_{cept} - slope * T_p\right) \tag{30}$$

The exponent (n) defines the shape of the (E vs. Temp) function. It can be referred to as a function shape factor. One needs to pre-select this shape factor prior to applying regression analysis on the data. Then the Intercept and slope can be determined from linear regression between the E value raised to the power n and temperature to reach the best R-square value. By using data from LTPP database, it was found out that the exponent (n) that best fit the E-T function would be in the range of 0.2 to 0.4. The default exponent (n) in WINFLEX is 0.35, which is typical for conventional asphalt mixes.

The WINFLEX 2006 allows the user to choose a new equation where the exponent (n) and the slope can be entered. The actual Intercept can then be calculated based on the provided E-value at the test temperature for the design case in consideration as described earlier.

2.3.3.4. Cement Treated Bases

The modulus of cement treated bases ranges from approximately 1,000,000 to 3,000,000 psi [4]. However, in most cases this modulus will have decreased considerably towards the end of the service life of the pavement structure, as determined by evaluation measurements (i.e. backcalculated from FWD data). Therefore, it is generally assumed that the cement base has become unbound material [29]. In this study, the cement treated base is treated as unbound material and is always stress-independent.

2.4 Pavement Response

Each material used in the pavement system has a specific tensile strength, compressive strength and shear strength. When the strength of a material is exceeded through repeated or single loading conditions, the material will fail. It is crucial to know precisely where stresses or strains will be at their maximum value and what that maximum value will be.

In flexible pavement the critical tensile strains are located at the bottom of the asphalt layers. The repetition of this strain as a result of the repeated traffic loading progressively damages the asphalt concrete until cracking begins. As the pavement is subjected to additional traffic, a fatigue crack is propagated upward. The critical compressive strains are located at the top of the subgrade. Each load application produces some permanent deformation through consolidation of the subgrade material, causing a distress called rutting.

The magnitude of stresses and strains induced in a pavement can be calculated using graphical solutions or computer programs, although any calculation for more than one or two layers becomes fairly complicated. Several computer programs have been developed (e.g. CHEVRON, BISAR, ELSYM5 and WES5) to provide solutions for the analysis of multi-layered elastic systems. This study adopted the CHEVRON program, which was developed by the Chevron research company [15] as a routine to handle the calculations of critical stresses and strains. A principal reason for its use is that the software is in the public domain [16, 17 and 18].

The critical strains are calculated by applying the superposition principal for the dual tire action. This calculates the strain at the required depth under the center of one tire and the strain at the required depth under a point located at a distance equal to the dual tire spacing.

The presence of stress dependent layers requires the calculation of the principal stresses, $\sigma 1$, $\sigma 2$, and $\sigma 3$ in order to estimate their resilient modulus from the relationships described earlier (e.g. Eqn. 1 for granular soils and Eqn. 2 for fine soils). It should be noted that the use of a layered system for non-linear analysis is an approximate approach. Thus, the following has been decided for non-linear layers:

- The principal stresses are calculated at a point on the axis of symmetry for a single tire
- Because most granular materials cannot take any tension, the point at which the principal stresses are calculated for non-linear granular base and subbase is located in the upper quarter and the upper third of the layer. Because the point is in the upper part of the layer, the chance of negative θ is rare [4]. If θ turns out to be negative, a minimum modulus is assigned.
- Because the variation of modulus due to the change of subgrade stresses is usually quite small [5], the depth at which the stresses are calculated for the stress-dependent subgrade is assumed to be 1.5 times the total thickness of the pavement.

2.5 Allowable Traffic and Failure Criteria

Research and field-testing have shown that the performance of flexible pavements can be related to certain failure mechanisms. From a structural capacity point of view, flexible pavement may experience two kinds of failure: fatigue, which shows as excessive alligator cracking; and rutting, which shows as permanent deformations along the wheel path.

2.5.1. Fatigue Failure

Several investigations have shown that fatigue failure is best related to the horizontal tensile strain, ε_t, at the bottom of the asphalt layers [11,19,20,21]. Most of the transfer functions, found in the literature, have the following forms for fatigue failure:

$$N_f = f_1 \, \varepsilon_t^{-f2} \, E_1^{-f3} \qquad (31)$$

Where N_f is the allowable number of load repetitions to prevent fatigue cracking from reaching certain limits defined by the agency, ε_t is the tensile strain at the bottom of the asphalt layer, E_1 is the modulus of the asphalt layer, and f_1, f_2 and f_3 are coefficients which can be determined from fatigue tests. Because the term E_1 has less effect on N_f than ε_t, some agencies neglect the E_1 term; hence equation (5) is reduced to:

$$N_f = f_1 \, \varepsilon_t^{-f2} \qquad (32)$$

The laboratory model developed by Monsmith et al. [22] shown in equation (7) has been used by various agencies as the base case fatigue model, which has been calibrated by means of fatigue shift factors to correlate with field conditions.

$$N_f = 0.00432\,(\varepsilon_t)^{-3.3291}\,(E_1)^{-0.854} \qquad (33)$$

Finn, et al. [15] modified the above equation by applying a shift factor of 18.4 to provide an indication of approximately 20 percent or greater fatigue cracking (based on total area) in selected sections of the AASHO Road Test.

The Asphalt Institute adopted the Finn model and modified it to reflect the effect of percent air void volume, V_a, and percent asphalt volume, V_b, [5]. The final form of the equation used by the Asphalt Institute is:

$$N_f = 10^M\,(18.4)\,(0.00432)\,(\varepsilon_t)^{-3.291}\,(E_{ac})^{-0.854} \qquad (34)$$

Where

$$M = 4.84\left[\frac{V_b}{V_a + V_b} - 0.69\right] \qquad (35)$$

In WINFLEX, all the available published models listed in Table 4 are available to the user. These available models are plotted in Figure 9.

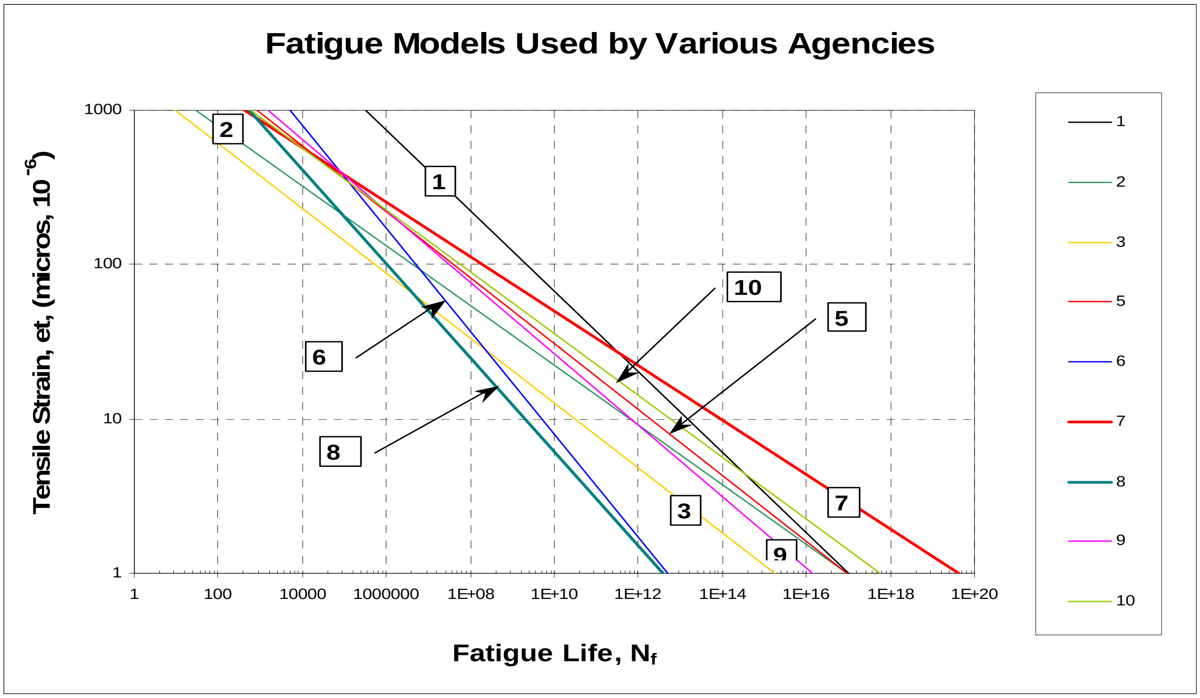


Figure 9. Fatigue Models Used by Various Agencies
Plotted for asphalt temperature of 70F (E_1 = 400 ksi)

Table 4. Fatigue and Rutting Coefficients Used by Various Agencies

		Fatigue Coefficients			Rutting Coefficients		
No.	**Reference Agency Name**	f_1	f_2	f_3	f_4	f_5	**Ref.**
1	Arizona DOT	9.33E-07	3.84	0	(Not Available)	(Not Available)	23
2	Austin Research Engineers (ARE)	9.73E-15	5.16	0	(Not Available)	(Not Available)	24
3	Belgian Road Research Center (BRRC)	4.92E-14	4.76	0	3.05E-09	4.35	4
4	CHEVRON (Not Available)	(Not Available)	(Not Available)	(Not Available)	1.34E-09	4.484	25, 26
5	Federal Highway Administration	7.56E-12	4.68	0	(Not Available)	(Not Available)	27
6	Illinois DOT	5.00E-06	3	0	(Not Available)	(Not Available)	28
7	SHELL Research	0.0685	5.671	2.363	6.15E-07	4	29
8	The Asphalt Institute (AI)	4.32E-03	3.291	0.854	1.37E-09	4.477	5
9	Transport and Road Research Laboratory	1.66E-10	4.32	0	1.13E-06	3.57	4
10	U.S. Army Corps of Engineers	497.156	5	2.665	1.81E-15	6.527	1

2.5.2. Rutting Failure

Permanent deformation or rutting in flexible pavements has been modeled by various agencies as:

$$N_d = f_4 \, \varepsilon_c^{-f5} \qquad (36)$$

Where N_d is the allowable number of load repetitions to limit rutting from reaching certain limits defined by the agency, ε_c is the compressive strain on the top of the subgrade and f_4 and f_5 are coefficients, which can be determined from lab testing. Values of f_4 and f_5 used by several agencies are shown in Table 4 and plotted in Figure 10.

2.6 Damage Analysis

Since different loading conditions for each season will be encountered, some method of combining the effects of different loading conditions must be considered. Miner's Hypothesis is the one most often used, which allows an accumulation of damage from the various load conditions to be combined into one damage number [15].

2.6.1. For Fatigue

For fatigue, the damage ratio is calculated by the following equation:

$$SDR_{future} = \sum_{i=1}^{4} \frac{N_{(future)_i}}{N_{(allow)_i}} \leq 1.0 \tag{37}$$

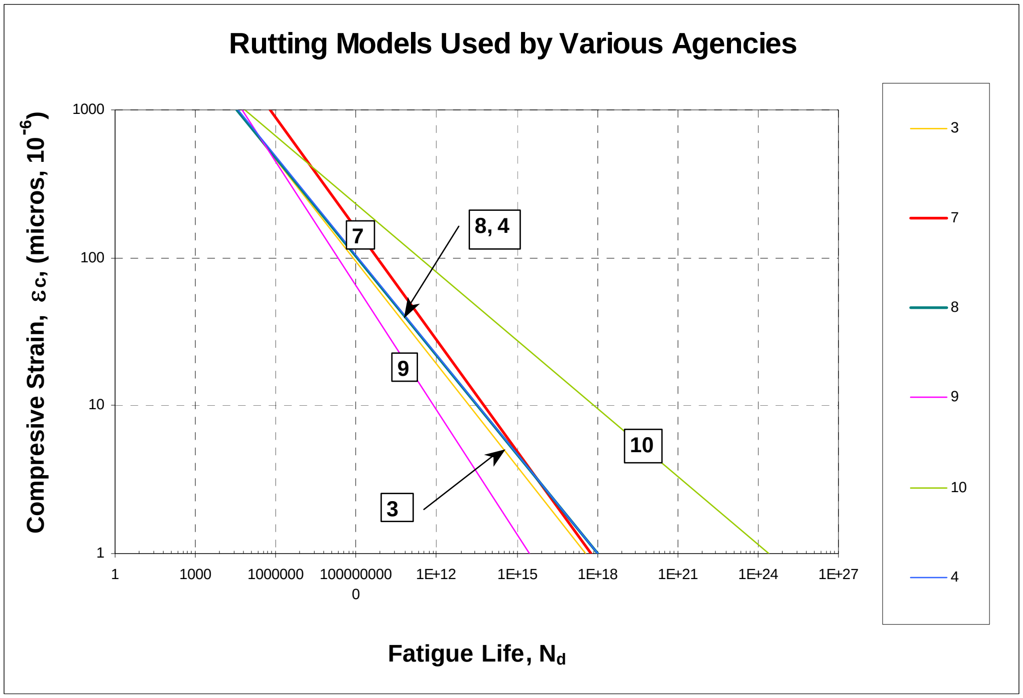


Figure 10. Rutting Models Used by Various Agencies
Plotted for asphalt temperature of 70F (E_1 = 400 ksi)

The overlay thickness is determined such that SDR_{future} for the overlay does not exceed unity. Where $N_{(allow)i}$ is determined from Eqn. (31) with tensile strain value at the bottom of the overlay layer and/or at the bottom of the existing pavement.

2.6.2. For Rutting

Since rutting is of more concern at the surface of the overlay, it can be assumed that the existing rut, if any, will be filled and that the development of rutting will only be a function of the future traffic to be applied on the "new" pavement structure with the overlay. As with fatigue, the sum of damage ratio can be determined as follows:

$$SDR_{(rutting)} = \sum_{i=1}^{4} \frac{N_{(future)_i}}{N_{(allow)_i}} \tag{38}$$

Where the allowable number of ESAL applications is determined using Eqn. (36) with the compressive strain determined on the top of the subgrade layer. The final overlay thickness is the one that satisfies both fatigue and rutting requirements.

Chapter 3 – Description of WINFLEX User Interface

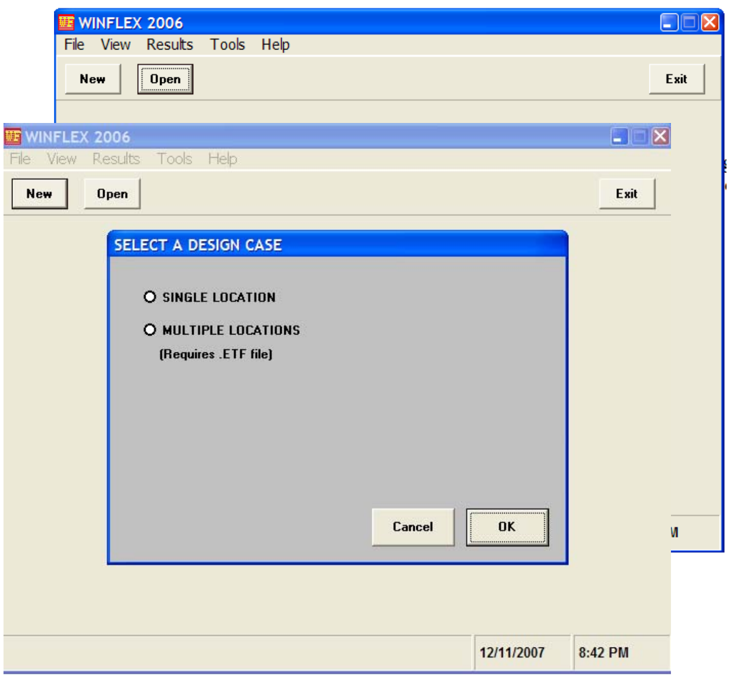
3.1 General

The user interface program that was written in Visual Basic 6 code has been totally revised. However, the developers did their best to maintain the "old" screen looks to facilitate the transition from 2000 version to 2006 version. There have been some differences in the screen menus but those differences will be picked up quickly by the user. For instance, the design traffic (ESALs) was moved from the general screen to the Pavement screen. Also the fatigue shift factors were moved to the Models screen. Also, new buttons are now created in the main opening screen to provide maneuverability and quick transition from one screen to another. The buttons also show flags if the data in certain module (or Form) is not complete. In the following sections, brief descriptions of the program screen are provided for the document completion. The reader can follow this section along with the program to best understand the flow of the various program menus. It is important to note that while the following description follows a certain sequence, the user can actually navigate through screens in any order he wishes to follow.
The design calculations in the FORTRAN code were minimally changed to solve the bugs that were encountered in the 2000 version. For example, the 2000 version failed to include a design case that has full depth asphalt. This and other (found) bugs have been fixed.

3.2 WINFLEX Screens

Main Screen

Upon the launch of WINFLEX the main screen appears as shown below (back screen). In this screen the user selects to "Open" a pre-existing design case or start a "New" one.



With the selection of new design case, the user is prompted to either single location or multiple locations. The single location considers the design of an overlay for a pavement section at one location or for average section properties over a pavement length. The Multiple Location, allows for designing an overlay for every station at FWD drop.

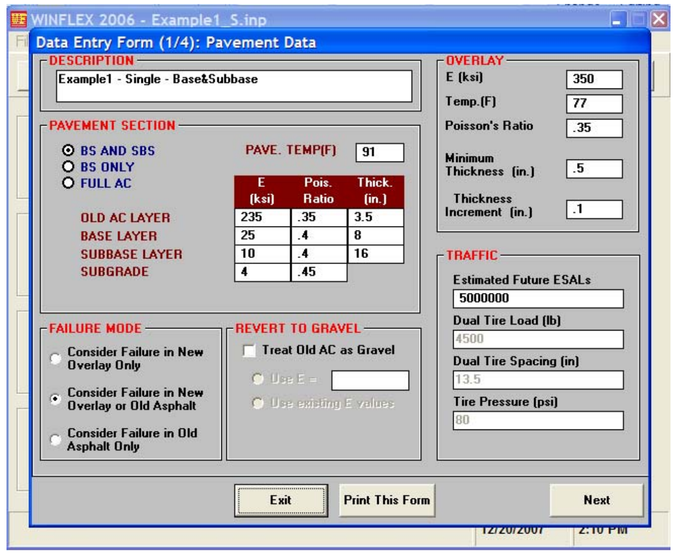
If the user "Open" an existing design case, the program will open the data entry forms directly.

Single Location Design

Data is entered in 4 consecutive forms as described below:

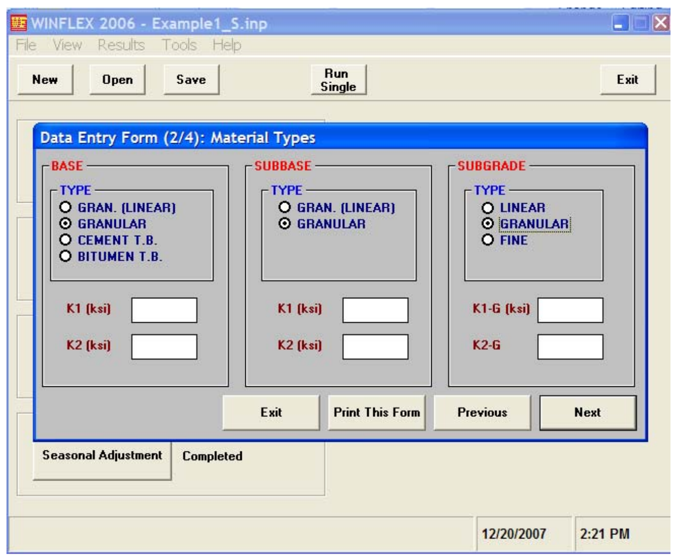
Form 1/4 Pavement Data

Once the choice of single location design is chosen, the first data entry form (Pavement Data) will appear. The form will be blank if new design case is selected. Upon completion of the data entry in this form, the user clicks next to move to the next data entry form (2/4), Materials Types. It is to be noted that the program will post a message if any data is missing.



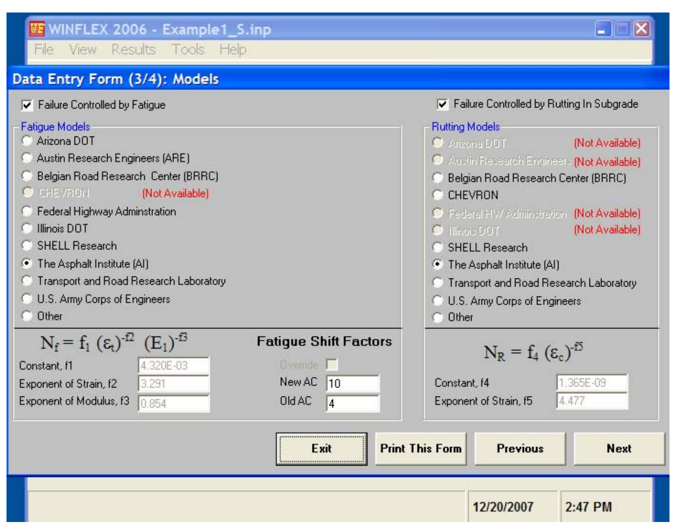
Form 2/4 Material Types

In this data entry form, the material types for various layers are selected. Based on the type of the layer, additional information may be needed. For example, the non-linear coefficients for granular layers may be needed if the design selects non-linear analysis.
Upon the completion of this form, click next for the "Models" screen.

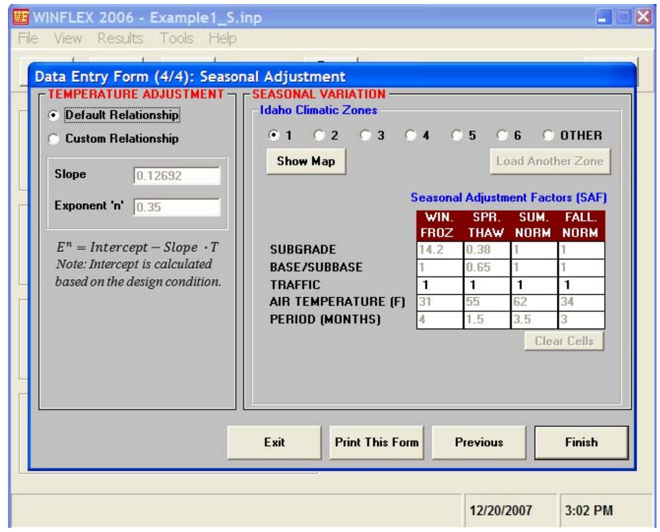


Form 3/4 Models

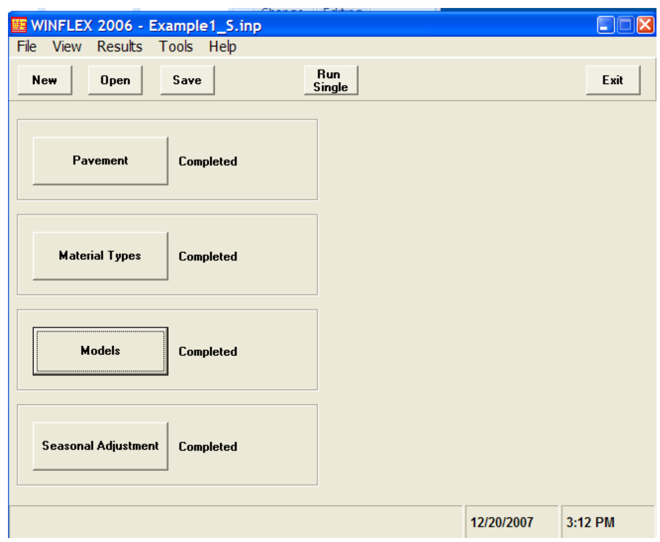
In this Form, the user can select the design criteria, rutting or fatigue or both, and select the appropriate performance models. WINFLEX 2006 has set of models that have been identified from the literature. However, the user can select "Other" and enter the model parameters of his choice. However, the model has to be in the form shown by the equation displayed on the screen. Also, fatigue shift factors for old and new pavements are also entered here.



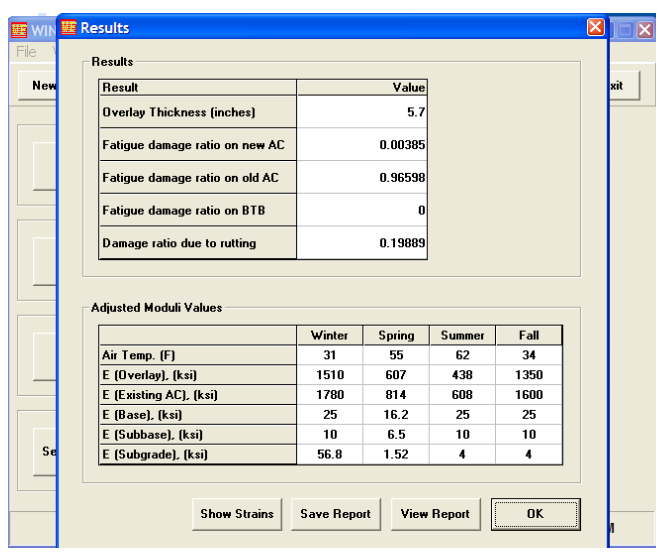
Form 4/4 Seasonal Adjustment
In this form, the user enters seasonal adjustment factors (SAFs) and the moduls-temperature relationship for the asphalt mix. Six climatic zones have been established for Idaho, where their SAFs are built in the program. The user also can choose “other” and enter new SAFs for his location, and save it a new zone that can be used later. Similarly a temperature shift function is built in the program and also the user can select a new relationship by entering other equation parameters, in the form displayed by the program.



Run Single
Upon completion of data entry form 4, click on “finish” button. The Main screen appears with flags showing completed data forms. The **Run Single** button will now be active. Once the **Run Single** is clicked, the program will process the design and show the output on the “Results” screen.



Results
The Results screen will display the overlay thickness along with the damage factors that were calculated for the various design criteria. The highest actor is the one that controlled the design. It also displays the calculated moduli values based on the considered seasonal shift factors, and temperature adjustments for asphalt layers.
The screen also displays new buttons to allow the user to save a report, view a report on screen and to show the critical stains that were used in the final design for the given loads.

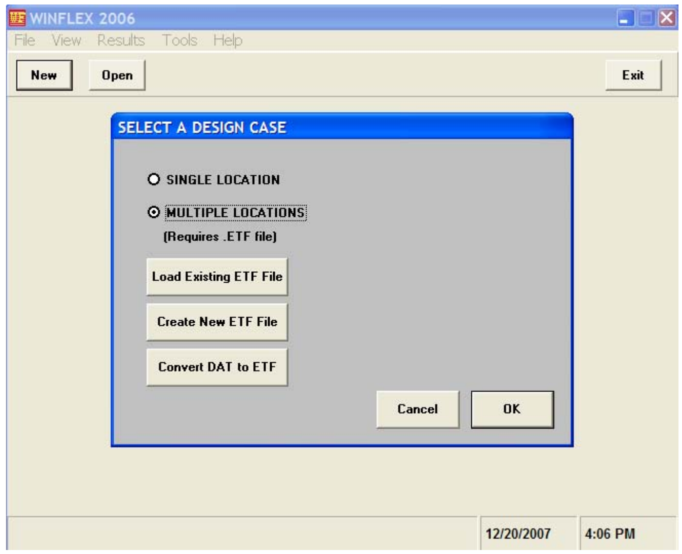


Note on Help
Throughout the program, the user can click F1 to access the help menu for any subject related to the cursor location.

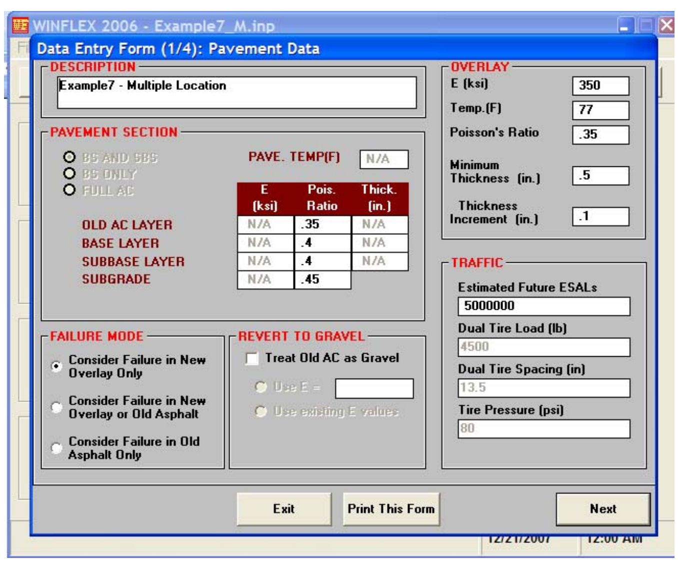
Save

The save button appears on the main screen top bar. Clicking it will invoke a dialog for saving the input file in a folder of the user's choice. The input file shall be saved with the extension (.inp). When the **Open** button is clicked, the program looks for input files with .inp extension. This will allow opening the file later and making the necessary changes in the data entry based on the user's selection. The button also works as a "Save as" button where the user can save a file under a different file name. The **New**, **Open** and **Save** file features can also be accessed from the "File" menu from the program menu bar.

Multiple Location Design



If the user selects the multiple location design option, the program assumes that the pavement section properties (thickness and moduli values at test temperatures) are available in a separate file, referred to as ETF (E vs Temp File). The WINFLEX 2006 provides a tool to prepare this file from data of the backcalculated moduli, regardless of the backcalculation software.

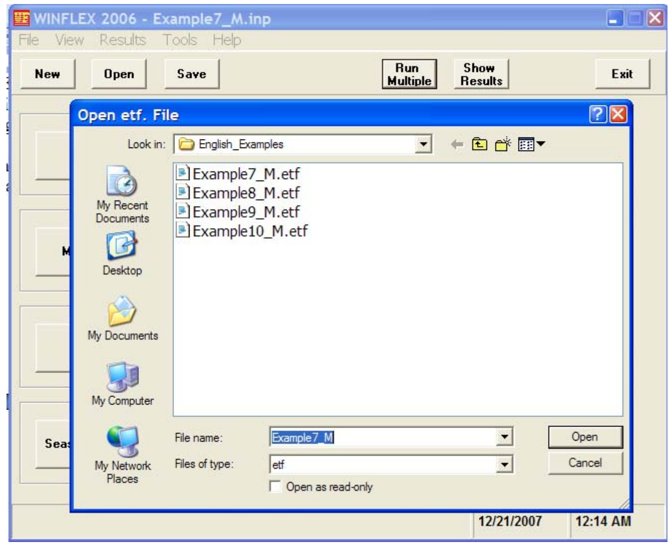


The Multiple Location design screen will prompt the user to identify where is the ETF file. The user chooses to either load a pre-exiting ETF file or create a new one for the design case.

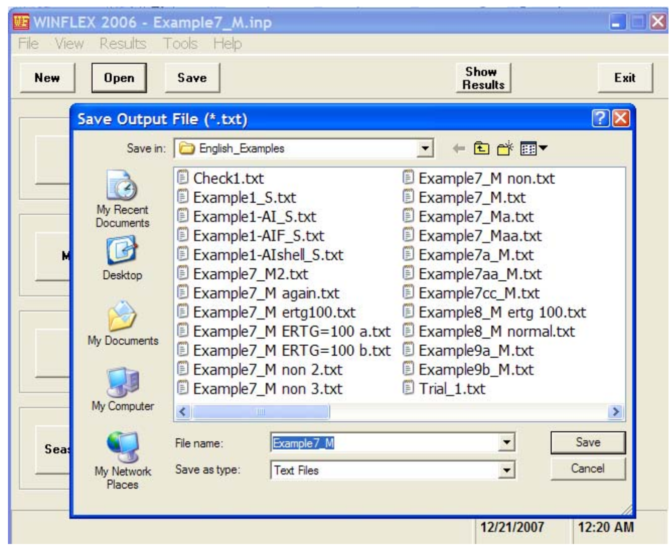
The next screen will be the first data entry form (Form 1/4). But in this case, the cells for the moduli and thickness in the Pavement Section block will be inactive since they are imported from the ETF file. The form is then completed similar to that of the single location design case.

The rest of the forms (Material Types, Models and Seasonal Adjustment) are completed similar to those of the single location design case.

Once the data entry is completed, the program will return to the main screen, and in this case, the **Run Multiple** button appears. Upon clicking the Run Multiple button, the program will open a dialog box to load the associated ETF file for the design case.

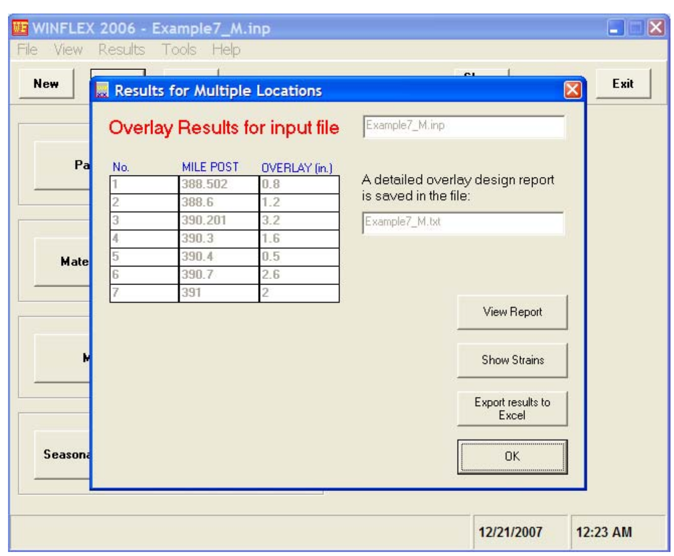


Upon the completion of the calculation, a dialog box for saving the output file in text format is opened.

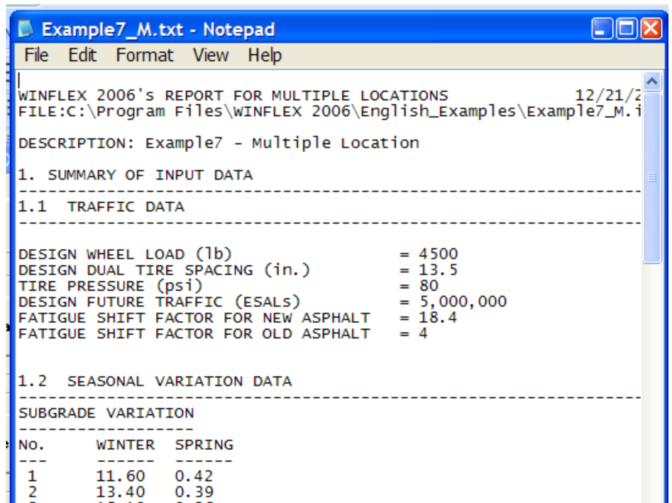


The results are also displayed in a limited form. The detailed results are stored in the saved output text file.

The results screen also displays buttons for: View Report, Show strains, and Export Results to Excel

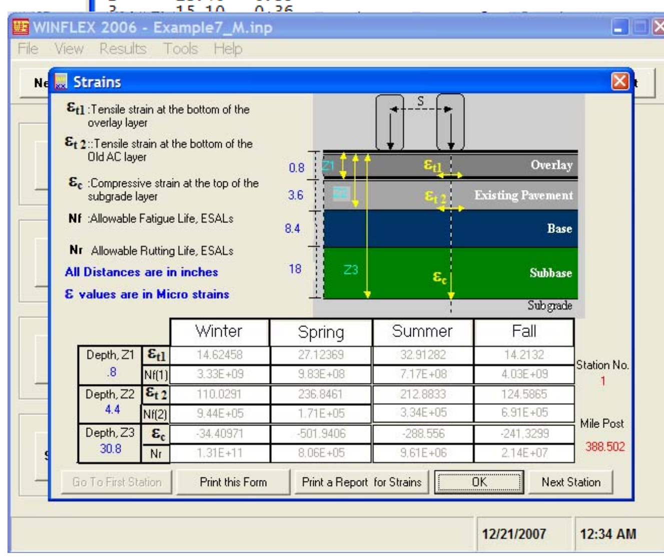


View Report
The design report is saved in a text file that can be viewed on screen, and printed using normal text editor. The report contains the details of the design case.

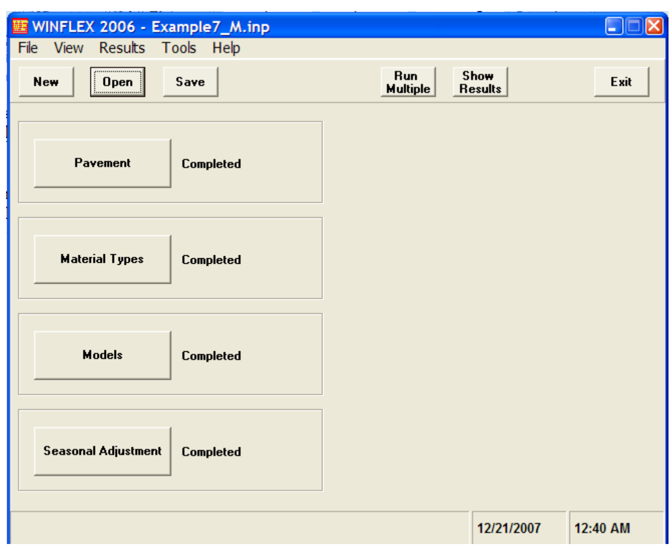


Show Strains
This tool allows the user to view the critical strain values that were used in the calculations of the fatigue and rutting lives.

The show strains screen allows for scrolling through all stations and printing a report for all strains.



Finally, the program returns to the main screen indicating that all data forms are completed. From this screen, the results can be shown again, or modifications to the data form can be made, and re-Run of the design case can be made.



The file is saved in an input file with extension .inp as was done in the single location design.

Design Examples:
The program is released with set of examples that allows the user to practice several design cases for both single and multiple locations.

Appendix A – References

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Appendix B – Description of Forms and Modules in WINFLEX 2006

General Notes about WINFLEX 2006 forms and modules

WINFLEX has gone through many development cycles. There is a lot of old code, and a lot of new code. The development of WINFLEX 2006 ran short of time, and not all of the old unused code was removed. When doing future bug testing or development, edit code with great care and make sure you are editing the correct code. There may be old code that *looks* like it controls what you want to change, but really there may be another similar piece of code someplace else is the real active code. Set breakpoints in the code and step through the debugger first to make sure you are editing the correct code.

Lots of old code means lots of old controls. Before you delete a control, you really must search the ENTIRE project for references to that control. Pay close attention to potential side effects of removing old controls.

General WINFLEX 2006 Forms

Form1

Form1 contains all the common dialog boxes (e.g., file selection dialog boxes) used in WINFLEX. The actual form is never shown to the user. This form should not need modifications.

Form2

Form2 is the form that offers an option to export to Excel during a multiple case. It is displayed if the user clicks “Results->Excel Summary” in the main form.

frm_EAdjusted

frm_EAdjusted shows the adjusted E values. It is currently not used in WINFLEX 2006 but it remains to maintain dependencies.

frm_Idaho_zones

frm_Idaho_zones is a map of the Idaho state climactic zones. It has almost no code or functionality; it is just for visual reference for the user.

frm_Output_M

This is the results form for a multiple design case.

frm_strains*

There are many strains forms. They are unchanged in WINFLEX 2006.

frm_Zones

Unused but has not been checked for references, so it has not been removed.

frmAbout

This is the WINFLEX 2000 about screen. It is not used in WINFLEX 2006.

frmAboutWinflex

This is the WINFLEX 2006 about screen. It is all static text except for the version number in the lower left corner.

frmDatToETF

This form is the DAT to ETF parser that was written by ITD. A few minor modifications were done to integrate it into WINFLEX.

frmedit

This form is shown when a user creates a new ETF file through the WINFLEX ETF file editor. The user enters a description and number of layers for the new file.

frmEdit_Open

This is the main form of the ETF file editor.

FRMINPUT

This is the form that is shown when the user chooses to create a new design case. Its main purpose is to distinguish between a single or multiple design case.

FRMResult

This is the result form that is shown after running a single design case. There are old elements remaining from WINFLEX 2000 that are still on the form, but not visible during runtime. **Do NOT** delete these controls. The new flexgrid controls get some values directly from the old controls. This is hardly ideal, but it was done to save time.

Main User Forms

Main1

This is the main screen in WINFLEX 2006. It is the first form to be shown. There is an imagelist control and a common dialog control. They may be unused, but do not delete without checking for references first.

frmpave

This is the Pavement Data form, data entry form 1 of 4.

frmmat

This is the Material Types form, data entry form 2 of 4.

frmmodels

This is the Models form, data entry form 3 of 4.

FRMGEN

This is the seasonal adjustment form, data entry form 4 of 4.

Navigation Buttons

The data entry screens have navigations buttons such as “Next”, “Previous”, and “Exit” that are used to move back and forth between forms. There are also buttons on the main form that allow the user to jump directory to any form. Because the user is not forced to click through all four forms, it is vitally important that the navigation buttons only change the currently displayed form, and do NOT change any other state information. There should be NO variable assignments and NO changes to the forms made in the navigation button subroutines for these forms. Similarly no state changes should occur in the form’s “Activate” subroutine. You cannot assume a user will look at a form before running a design case.

Reset

Each of these five forms have a “Reset” subroutine. When called, the reset subroutine will reinitialize the form to its initial “clean” state.

isCompleted

Each of the four data entry functions has an “isCompleted” function that returns a Boolean value. The function checks to see if the user has completed all of the necessary inputs on that form. If so, it returns true, otherwise it returns false. The main form calls all of the other form’s “isCompleted” functions to determine which forms, if any, to mark as incomplete. It also prevents a user from running calculations a design case that has incomplete data (malformed or incomplete data is one of the most common bugs in WINFLEX, because the Fortran library is very trusting and does not handle invalid input in a robust manner).

updateUnits

The updateUnits subroutine was designed to do the switch between English/Metric units. WINFLEX 2006 no longer supports metric units, but the updateUnits functions still perform some formatting functions, so they should not be removed.

WINFLEX 2006 Modules

Controller

The controller module contains wrapper (get, set) functions that control access to some global variables. Its primary purpose was to handle unit conversion. It also keeps track of the “isDirty” flag. If an open file is “dirty” that means it has changed and the user should be prompted to save before they try to exit the program. A clean file has not changed from the last time it was saved. The global variables that are wrapped in the controller module should NOT be accessed directly. Use the included get/set functions.

Conversions

This module contains functions that implement unit conversion formulas (e.g., in. to cm). Even though WINFLEX 2006 no longer support metric, some of these functions are still referenced, so this module should remain.

GLOBAL

The global module contains a large mix of old and new code. It contains definitions for the rather astounding number of global variables WINFLEX uses. It also includes the majority of enumerations and constants. Most of the default values are defined here. For example if you wanted to change the default slope of the temperature adjustment function, you would not go to the seasonal adjustment form code, you would go to the global module and change the defined constant “defaultSlope”.

The global module also includes some global functions such as the single design case report generation and export to excel functions.

Report

The report module contains code that was designed to create HTML reports. It was never fully completed and it remains unused.

START

The start module contains the entry point into the program. Basically it just defines the location of the help file, sets the units to English, then shows the main form.

Appendix C – Examples of Output Reports

Example of Output of a Single-Location Design

```
WINFLEX 2006, REPORT FOR SINGLE LOCATION, 12/21/2007  1:04:48 AM
Input File: Example1_S.inp

Description: Example1 - Single - Base&Subbase

1. SUMMARY OF INPUT DATA
--------------------------------------------------------------------------------

1.1  TRAFFIC DATA
----------------------------------------------------------------------
DESIGN WHEEL LOAD (lb)                 = 4500
DESIGN DUAL TIRE SPACING (in)          = 13.5
TIRE PRESSURE (psi)                    = 80
DESIGN FUTURE TRAFFIC (ESALs)          = 5,000,000
FATIGUE SHIFT FACTOR FOR NEW ASPHALT   = 10
FATIGUE SHIFT FACTOR FOR OLD ASPHALT   = 4


1.2  SEASONAL VARIATION DATA
----------------------------------------------------------------------
                           WINTER SPRING SUMMER FALL
SUBGRADE VARIATION         14.20  0.38   1.00   1.00
BASE/SBASE VARIATION       1.00   0.65   1.00   1.00
TRAFFIC VARIATION          1.00   1.00   1.00   1.00
TEMPERATURE VARIATION(F)   31.00  55.00  62.00  34.00
PERIOD (MONTHS)            4.00   1.50   3.50   3.00


1.3  PAVEMENT DATA
----------------------------------------------------------------------
CLIMATIC ZONE:                 1  (Idaho Zone)
TEMPERATURE AT FWD TEST (F):  91


                           MODULUS      POISSON      THICKNESS
                            (ksi)        RATIO         (in.)
OLD AC LAYER                235    0.35    3.5
BASE LAYER                  25     0.40    8
SUBBASE LAYER               10     0.40    16
SUBGRADE                    4      0.45    SEMI-INFINITE


SUBGRADE TYPE:      LINEAR
BASE TYPE:   LINEAR
SUB-BASE TYPE:      LINEAR

1.4  OVERLAY DATA
----------------------------------------------------------------------
OVERLAY MODULUS(ksi)   = 350  AT TEMPERATURE (F) = 77
POISSON'S RATIO        = 0.35
MINIMUM THICKNESS(in.) = 0.5


2.  RESULTS
--------------------------------------------------------------------------------
```

2.1 PAVEMENT SEASONAL DATA

VARIATION OF LAYER MODULUS FOR OVERLAY (ksi)

	WINTER	SPRING	SUMMER	FALL
Air Temp.(F)	31	55	62	34
E (ksi)	1510	607	438	1350

VARIATION OF LAYER MODULI VALUES FOR EACH LAYER AND SEASON (ksi)

	WINTER	SPRING	SUMMER	FALL
E1	1780	814	608	1600
E2	25	16.2	25	25
E3	10	6.5	10	10
E4	56.8	1.52	4	4

E1 = Modulus for Old Pavement, E2= Modulus for Base
E3 = Modulus for Subbase, E4= Modulus for Subgrade

2.2 OVERLAY RESULTS

OVERLAY(in.)	DAMA1	DAMA2	DAMA3	DAMA4
5.7	0.00385	0.96598	0	0.19889

DAMA1 = FATIGUE DAMAGE ON OVERLAY
DAMA2 = FATIGUE DAMAGE ON OLD AC
DAMA3 = FATIGUE DAMAGE ON BTB
DAMA4 = RUTTING DAMAGE

Fatigue Model: The Asphalt Institute (AI)
Rutting Model: The Asphalt Institute (AI)

Example of Output of a Multiple-Location Design

```
WINFLEX 2006's REPORT FOR MULTIPLE LOCATIONS            12/21/2007  12:20:56 AM
FILE:C:\Program Files\WINFLEX 2006\English_Examples\Example7_M.inp

DESCRIPTION: Example7 - Multiple Location

1. SUMMARY OF INPUT DATA
--------------------------------------------------------------------------------
1.1  TRAFFIC DATA
----------------------------------------------------------------------

DESIGN WHEEL LOAD (lb)                 = 4500
DESIGN DUAL TIRE SPACING (in.)         = 13.5
TIRE PRESSURE (psi)                    = 80
DESIGN FUTURE TRAFFIC (ESALs)          = 5,000,000
FATIGUE SHIFT FACTOR FOR NEW ASPHALT   = 18.4
FATIGUE SHIFT FACTOR FOR OLD ASPHALT   = 4


1.2  SEASONAL VARIATION DATA
----------------------------------------------------------------------
SUBGRADE VARIATION
------------------
No.    WINTER SPRING
---    ------ ------
 1     11.60  0.42
 2     13.40  0.39
 3     15.10  0.36
 4     13.40  0.39
 5     11.50  0.42
 6     14.90  0.36
 7     12.80  0.40

                           WINTER SPRING SUMMER FALL
                           ------ ------ ------ ----
SUBGRADE VARIATION                       1.00   1.00
BASE/SBASE VARIATION       1.00   0.65   1.00   1.00
TRAFFIC VARIATION          1.00   1.00   1.00   1.00
TEMPERATURE VARIATION(F)   31.00  55.00  62.00  34.00
PERIOD (MONTHS)            4.00   1.50   3.50   3.00


1.3  PAVEMENT DATA
----------------------------------------------------------------------
CLIMATIC ZONE :                1  (Idaho Zone)

                 POISSON'S RATION
OLD AC LAYER          0.35
BASE LAYER            0.40
SUBBASE LAYER         0.40
SUBGRADE              0.45


SUBGRADE TYPE:  LINEAR
BASE TYPE:     LINEAR
SUB-BASE TYPE:    LINEAR


MODULI AND THICKNESSES DATA (From ETF FILE:Example7_M)
--------------------------------------------------------------------
***************************************************************
```

No.	MILE POST	TEMP. (F)	E1(ksi)	E2(ksi)
1	388.502	81	271	46
2	388.6	83	242	57
3	390.201	85	303	27
4	390.3	81	351	35
5	390.4	90	222	50
6	390.7	82	358	35
7	391	85	289	25

MODULI AND THICKNESSES DATA (Cont'd)

No.	E3(ksi)	E4(ksi)	H1(in.)	H2(in.)	H3(in.)
1	10.1	5.7	3.6	8.4	18
2	12.8	4.5	3.6	8.4	18
3	10	3.5	3.6	8.4	18
4	14.3	4.5	3.6	8.4	18
5	14.1	5.8	3.6	8.4	18
6	12.7	3.6	3.6	8.4	18
7	11.3	4.9	3.6	8.4	18

1.4 OVERLAY DATA

OVERLAY MODULUS(ksi) = 350 AT TEMPERATURE (F) = 77
POISSON'S RATIO = 0.35
MINIMUM THICKNESS(in.)= 0.5

2. RESULTS

2.1 PAVEMENT SEASONAL DATA

VARIATION OF MODULUS FOR OVERLAY (ksi)

	WINTER	SPRING	SUMMER	FALL
Air Temp.(F)	31	55	62	34
E (ksi)	1510	584	401	1350

PAVEMENT SEASONAL DATA (Cont'd)

VARIATION OF MODULUS FOR OLD PAVEMENT , E1 (ksi)

No.	WINTER Temp. 31 F	SPRING Temp. 55 F	SUMMER Temp. 62 F	FALL Temp. 34 F
1	1460	578	415	1300
2	1460	597	430	1300
3	1730	757	561	1560
4	1690	733	541	1520
5	1690	704	518	1510
6	1760	771	572	1620
7	1690	732	540	1520

VARIATION OF MODULUS FOR BASE , E2 (ksi)

No.	WINTER Factor= 1	SPRING Factor= 0.65	SUMMER Factor= 1	FALL Factor= 1
1	46	29.9	46	46
2	57	37.1	57	57
3	27	17.6	27	27
4	35	22.8	35	35
5	50	32.5	50	50
6	35	22.8	35	35
7	25	16.2	25	25

Factor = Seasonal Variation Factors

VARIATION OF MODULUS FOR SUBBASE , E3 (ksi)

No.	WINTER Factor= 1	SPRING Factor= 0.65	SUMMER Factor= 1	FALL Factor= 1
1	10.1	6.57	10.1	10.1
2	12.8	8.32	12.8	12.8
3	10	6.5	10	10
4	14.3	9.3	14.3	14.3
5	14.1	9.17	14.1	14.1
6	12.7	8.26	12.7	12.7
7	11.3	7.35	11.3	11.3

Factor = Seasonal Variation Factors

VARIATION OF MODULUS FOR SUBGRADE , E4 (ksi)

No.	WINTER Factor= 12.8	SPRING Factor= 0.4	SUMMER Factor= 1	FALL Factor= 1
1	66.1	2.39	5.7	5.7
2	60.3	1.75	4.5	4.5
3	52.9	1.26	3.5	3.5
4	60.3	1.75	4.5	4.5
5	66.7	2.44	5.8	5.8
6	53.6	1.3	3.6	3.6
7	62.7	1.96	4.9	4.9

2.2 OVERLAY RESULTS

No.	OVERLAY(in.)	DAMA1	DAMA2	DAMA3	DAMA4
1	0.8	0.00348	11.59241	0	0.98569
2	1.2	0.00221	6.27974	0	0.97408
3	3.2	0.00081	3.50661	0	0.98574
4	1.6	0.00062	6.40679	0	0.97515
5	0.5	0.00047	8.47233	0	0.76633
6	2.6	0.00045	3.53755	0	0.95769
7	2	0.0009	7.26253	0	0.9399

DAMA1 = FATIGUE DAMAGE ON OVERLAY
DAMA2 = FATIGUE DAMAGE ON OLD AC
DAMA3 = FATIGUE DAMAGE ON BTB
DAMA4 = RUTTING DAMAGE

The fatigue model used was 'Asphalt Institute'
The Rutting model used was 'Asphalt Institute'