INFLUENCE OF AMBIENT TEMPERATURE ON STIFFNESS OF ASPHALT PAVING MATERIALS

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ABSTRACT

Asphalt pavement properties in Iraq are highly affected by elevated summer air temperatures. One of these properties is stiffness (resilient modulus).To explain the effect of air temperatures on stiffness of asphalt concrete, it is necessary to determine the distribution of temperatures through the pavement asphalt concrete layers. In this study, the distribution of pavement temperatures at three depths (2cm ,7cm, 10cm) below the pavement surface is determined by using the temperature data logger instrument .

A relationship for determining pavement temperature as related to depth and air temperature has been suggested.

To achieve the objective of this thesis,the prepared specimens have been tested for indirect tension in accordance with ASTM D4123, using the pnuematic repeated load apparatus , in order to determine the values of resilient modulus at three different temperatures (10, 25, 40) °C.

From results of testing, it is observed that the resilient modulus decreases with increase in test temperature by a rate of 8.78×10^3 Psi/C° for asphalt concrete wearing courses.

An increase in optimum asphalt content by 0.1% (by weight of total mixture) causes a decrease in resilient modulus by 22% at a temperature of 40C°.

A statistical model for the prediction of resilient modulus has been developed depending on mixture variables of: asphalt content , asphalt binder viscosity , surface area of combined aggregates , air voids of compacted mixture and test temperature.

Key words: Ambient temperature , Stiffness

الخلاصه

خواص التبليط الاسفلتي في العراق تتأثر بدرجة كبيرة بدرجات حرارة الهواء المرتفعة خلال فصل الصيف,وانه أحد هذه الخواص هو معامل الجساءة و لبيان تأثير درجات حرارة الهواء على معامل الجساءة للخرسانة الاسفلتية فانه من الضروري تحديد توزيع درجات الحرارة خلال طبقات الخرسانة الاسفلتية للتبليط.

في هذه الدراسة توزيع درجات حرارة التبليط على ثلاثة اعماق(2سم ،7سم ،10 سم) تحت سطح التبليط تم تحديده بأستخدام جهاز تسجيل بيانات درجات الحرارة.

لقد تم اقتراح علاقة رياضية لتحديد درجة حرارة التبليط نسبة الى العمق ودرجة حرارة الهواء.

و لتحقيق الهدف من هذا البحث العينات المحضرة تم فحصها للشد الغير مباشر وفقا (ASTM D4123)بأستخدام جهاز الاحمال المتكررة لأيجاد معامل المرونة بثلاث درجات حرارة مختلفة هي (10, 25 ،40) درجة مئوية.

ومن نتائج الفحص لوحظ ان معامل المرونة يتناقص بزيادة درجة حرارة الفحص بنسبة 8.78×10^3 Psi/C° للطبقات السطحية للخرسانة الاسفلتية.

وأن الزيادة في محتوى الاسفلت المثالي بمقدار 0.1% من وزن الخلطة الكلية يسبب نقصان في معامل المرونة بمقدار 22% عند درجة حرارة 40 مئوي.

وقد تم تطوير علاقة احصائية لتنبأ معامل المرونة وفقا لمتغيرات الخلطة الاسفلتية: محتوى الاسفلت ' لزوجة الاسفلت 'المساحة السطحية للركام 'نسبة الفجوات الهوائية للخلطة المرصوصة ودرجة حرارة الفحص.

INTRODUCTION

Asphalt concrete pavements are physical structures responding in a complex way to the influence of many factors (i.e., loads, material, variables, environmental conditions, etc.) and their interactions.

Temperature is one of the most important environmental factors affecting the design, performance, and distress of pavement structures.
Temperature affects many physical properties in asphalt concrete pavement including material stiffness. Generally, the stiffness (resilient modulus) of a pavement is a measure of materials performance and their ability to spread the applied traffic loading over a specified area.

The resilient modulus Mr, is defined as the elastic modulus based on the recoverable strain under repeated Loading:

$$Mr = \frac{\sigma}{\varepsilon_r}$$

σ: Repeated diametral stress

ε_r: Vertical resilient strain

Because the applied load is usually small, the resilient modulus test is considered as a nondestructive test and the same sample can be used for other tests.

The resilient modulus is a major parameters in design of pavement structures, overlay thickness determination, and for the assessment of other rehabilitation needs. In design, the properties of materials must be specified, so that the response of the pavement, such as stresses, strains, and displacements, in the critical components, can be determined (Huang, 1993).

REVIEW OF LITERATURE

Increase in the temperature of asphalt layer is one of the major factors of failure in asphalt pavements in tropic zones. In these areas, high air temperature and severe radiation of solar ray cause increase in asphalt layer temperature. It has been shown that the modulus of elasticity can strongly depend on the temperature **Figure (1).**
The surface of the pavement varies with time during the day, which in turn changes the temperature in the pavement section. For instance, temperature variation in a flexible pavement section in Los Angeles (**Ongel and Harvey 2004**) is shown in **Figure (2).**
Thus, to determine in-situ strength characteristics of flexible pavement, it is necessary to predict the temperature distribution within the HMA layers. There exist several developed models for the prediction of the pavement temperature based on air temperature in the literature (**Witczak, 1972; Fatani et al. (1990),SHRP, 1994**) are shown in eq. (1) and (2), (3)respectively.

$$T_{pave} = T_{air}(1+\frac{76.2}{Z+304.8}) - \frac{84.7}{Z+304.8} + 3.3 \quad (1)$$

Where:
Tpave = pavement temperature (°C)
Tair = air temperature (°C)
Z= depth below the pavement surface (cm)

$$T(d) = 3.714 + 1.006\,T(a) - 0.146\,d \quad (2)$$

Where:
T(d) = pavement temperature at depth d, °C
T(a) = air temperature, °C
d = depth from pavement surface, cm

$$T_{pave} = [T_{air} - 0.00618\,(latitude\,)^2 + 0.22891\,(latitude\,) + 42.2]0.9594 - 17.78 \quad (3)$$

Where:
Tpave = pavement temperature at the 2 cm depth below the surface (°C)
Tair = air temperature (°C)

Diefenderfer et al. (2003) linear models are developed for predicting daily maximum and minimum temperatures based on data collected at the Virginia Smart Road. Data are used from three depths within the pavement for model development: 0.038, 0.063, and 0.188m below the surface.
The model is developed to predict maximum daily pavement temperatures, Tpmax , is as follows:

$$Tpmax = 3.2935 + 0.6356Tmax + 0.1061Y - 27.7975Pd \quad (4)$$

The RMSE for this model is 3.54 and the adjusted R^2 value is 91.36%. The model is developed to predict minimum daily pavement temperatures, Tpmin, is as follows:

$$Tpmin = 1.6472 + 0.6504Tmin + 0.0861Y + 7.2385Pd \quad (5)$$

The RMSE for this model is 2.79 and the adjusted R^2 is found to be 91.41%. These values indicate that the model for predicting the minimum daily pavement temperature is slightly more accurate than the model for predicting the maximum daily pavement temperature. **Figure (5)** presents the actual maximum daily pavement temperature and the predicted maximum daily pavement temperature at a depth of 0.038m for this model validation time period. **Figure(6)** presents the actual minimum daily pavement temperature and the predicted minimum daily pavement temperature at a depth of 0.038m for this model validation time period.

(Algibury,2008) develops two models to predict the resilient modulus of asphalt pavement layers (surface, binder, base) layers.R^2 for model no. (6) and model no.(7) are 0.957 , 0.955 .

$$M_r=322342.7-47368.7(T^{0.310683}+P_8{}^{0.310683})-4341.74P_s+8913.09P_{200}+11055.16\sin(-577.43Av-28.083) \quad (6)$$

$$M_r=10249376-38888.4(T^{0.365504}+P_8{}^{0.365504})-5996.61P_s+11115.29P_{200}-0.000181EXP(0.000122Av+24.72744) \quad (7)$$

Where:
Mr : Resilient Modulus (psi)
T : Test Temperature (°C)
Av : Percent Air Voids
P_S : Percent Volume of Effective Asphalt
P_8 : Percent Passing Sieve No. 8
P_{200} : Percent Passing by weight of Filler Content

EXPERIMENTAL WORK

Indirect Tension Repeated Load Test

The indirect tension repeated load test specified by **ASTM D4123** "Standard Test Method for Indirect Tension Test for Resilient Modulus of Bituminous Mixtures ", are conducted by using the pneumatic repeated load system (PRLS), (Al-Bayati, 2006). In these tests, repetitive diametral loading is applied to the specimen and the resilient vertical strain is measured under load repetitions. Diametral loading is applied with a constant loading frequency of 60 cycles per minute and loading sequence of 0.1 sec load duration and 0.9 sec rest period .Three temperatures 10C , 25C , 40C are used in the tests, and the applied stress level is 20 psi.

The IDT repeated load test procedures used in this study is summarized as follows:

- Place the specimen in the testing chamber for two hours at the desired testing temperature to bring it to test temperature and to allow for a uniform temperature distribution within the specimen.
- The LVDT (Linear Variable Differential Transformer) is set to zero reading after completion of the specimen "setup" in the testing equipment. The pressure actuator is adjusted to the specified stress level. The timer (both loading port and rest port) is also set to the required load and rest durations.
- The experiment is commenced by application of repeated indirect tensile stress and the resilient strain is measured.
- The test is completed after number of load repetitions when the resilient strain reading is reached to its suitable value or small difference between two readings that can be neglected.

Figure (8) shows the IDT test apparatus. The resilient strain (ε_r) and resilient modulus (Mr) are calculated as follows:

Resilient strain:

$$\varepsilon_r = (rd*Fc)/h \qquad (8)$$

Where:

ε_r: Vertical resilient strain (mm/mm).
rd: Reading of LVDT for voltage in volt unit.

Fc= calibration factor to convert the reading of LVDT from voltage in (volt unit) to distance in (mm) unit . Shown in Figure(9)
h: specimen diameter (mm).

Resilient modulus:

$$Mr = \frac{\sigma}{\varepsilon_T} \qquad (9)$$

Where:
Mr: Resilient modulus (psi).
σ: Repeated diametral stress (psi).

Predictive Model for Resilient Modulus

The resilient modulus is a key parameter in the pavement design and performance prediction system, so it is desirable to have a statistical model capable for the prediction of the resilient modulus of asphalt concrete.

Linear regression is used to develop model for prediction the resilient modulus of asphalt concrete as a function of mixture properties(asphalt content , viscosity at 135C° , air voids, surface area) and test temperature.

This model has an R^2 value of 0.849 .

$$MR=763480.93-173341.49AC+16835.719\eta-3793.643Av-8778.963T+88084.523S.A \qquad (10)$$

Where:
MR : Resilient Modulus (psi)
T : Test Temperature (°C)
Av : Percent Air Voids
%AC: Percent by Weight of Effective Asphalt
D= Viscosity of binder at 135°C (Pa.sec)
S.A=Surface Area (m^2/kg)

Field Measurements

In this study,the **µlogger 4R** - For measuring Temperature with a thermistor or resistance is used. This model of µlogger (pronounced micro-logger) has four resistance channels; usually for connecting to our high quality thermistor based temperature sensors but can be connected to any sensor that produces a 100 - 50k Ohm output.

The supplied software allows the µlogger to be configured before leaving it at the logging site. At the end of the logging period your data is offloaded and can be displayed and analysed using the same software.
Three metal sensors are embedded in the pavement at the depths of 2, 7 and 10 cm, representing the depth of the first three layers of asphalt concrete. One sensor is seperated from three sensors collects the air temperature data.

Model Development

Linear regression is used to develop model for prediction of pavement temperature as a function of the air temperature and the depth below the pavement surface. The developed statistical model is shown below in equation (11). This model has an R^2 value of 0.923 and SE of 2.7725. The figures (13) to (15) show the relationships between air temperatures and pavement temperatures at three depths below the pavement surface.
$T_{Pave}=3.17\ 5+0.0\ 4866Z+0.946\ T_{air}$ (11)

Where :
T_{Pave} = Pavement Temperature °C
Z =Depth below the pavement surface (cm)
T_{air}= Air Temperature °C

Based on the diagnostic plots shown in figures (16) to (18), the model is rational. The residual plots of this model do not indicate any unusual pattern and normally distributed.

Conclusions

Within the limitations of materials and testing program used in this work, the following principal conclusions are made based on the findings of the investigations:

1. Based on the indirect tensile test results employing the pneumatic repeated load apparatus, a model is developed to predict the resilient modulus of the asphalt concrete for different test conditions and mix properties, in the following form:

$$M_R=763480.93-173341.49AC+16835.719\eta-3793.643Av-8778.963T+88084.523S.A$$

2. The resilient modulus values of the two types of asphalt paving mixtures used in local specifications for wearing and Leveling courses (mid gradation limit, 40-50 grade binder, optimum asphalt content) are as shown at different temperatures:

Asphalt Concrete Layers	**Resilient Modulus (psi) at Temperatures**		
	10C°	**25C°**	**40C°**
Wearing course	342328	210643	78959
Leveling course	346891	215206	85522

3. The average rate of decrease in resilient modulus as affected by increase in temperature is equal to 8.78×10^3 Psi/C° for wearing course and 8.72×10^3 Psi/C° for Leveling course.
4. The resilient modulus is adversely affected by change in asphalt cement content from optimum value. An increase in asphalt content by 0.1% (by weight of total mixture) causes a decrease in resilient modulus by : 5.1% at 10 C°, 8.3% at 25 C° and 22% at 40 C°.
5. From Local field work , using the temperature data logger instrument the following model is developed according to air temperatures and depths below the pavement surface:-

$$T_{Pave}=3.175+0.04866Z+0.946\ T_{air}$$

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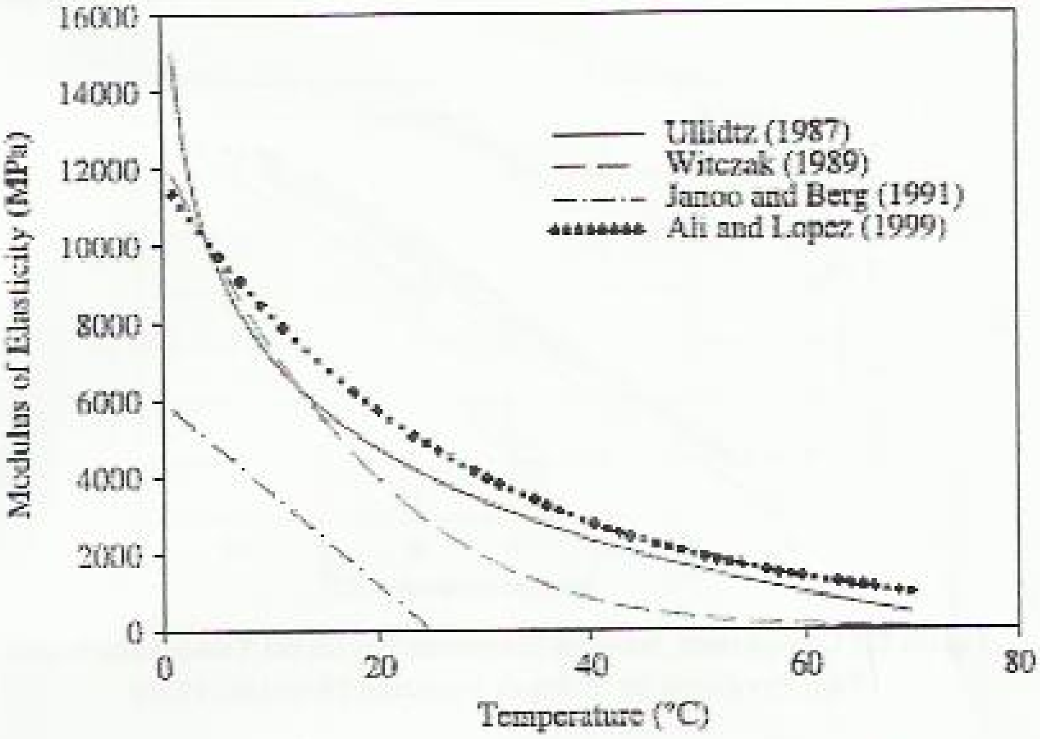


Figure (1) Resilient Modulus vs. Temperature (Alkasawneh et.al ,2007)

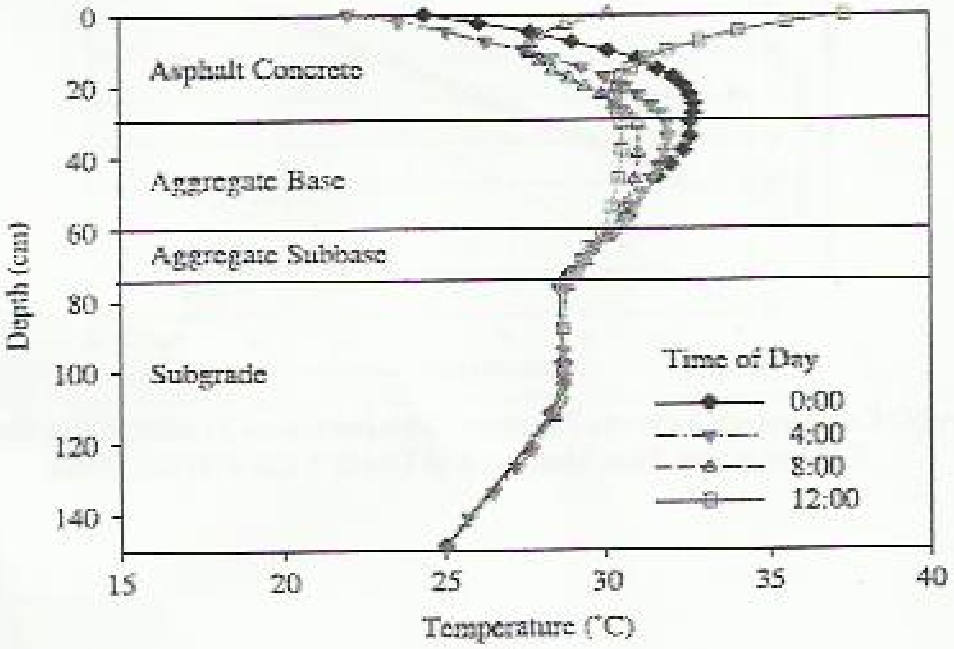


Figure (2) Daily Temperature Variation (modified by Ongel and Harvey 2004)

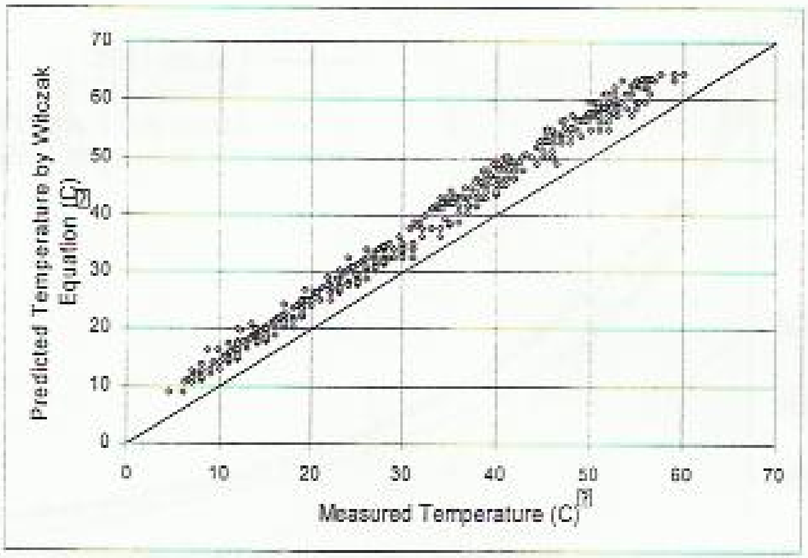


Figure (3) Comparison between Measured Pavement Temperature and That Predicted By Witczak Equation (Witczak, 1972)

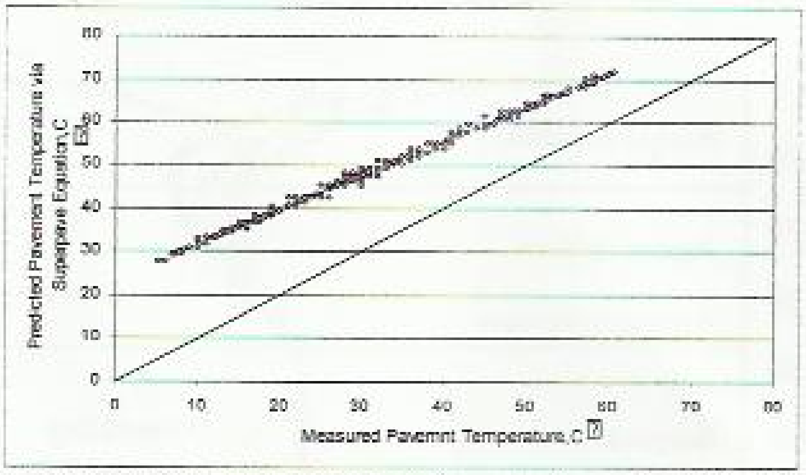


Figure (4) Comparison between Pavement Temperatures Predicted Via Superpave Equation and That Measured at Depth 2 Cm (SHRP, 1994)

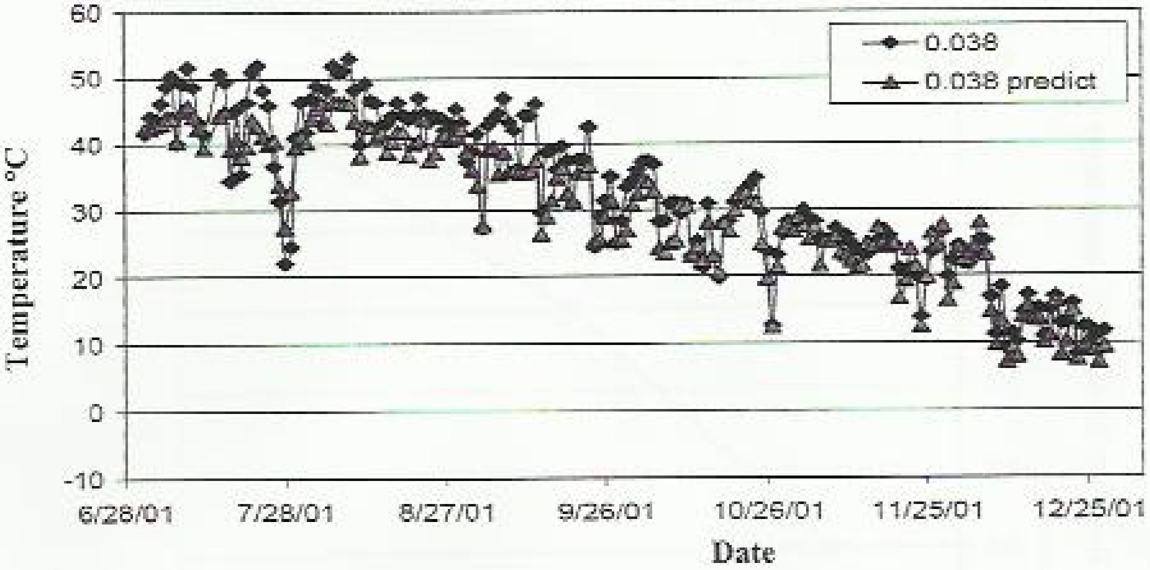


Figure (5) Maximum Daily Pavement Temperature Utilizing Day of Year at 0.038m Depth (Diefenderfer et al. 2003)

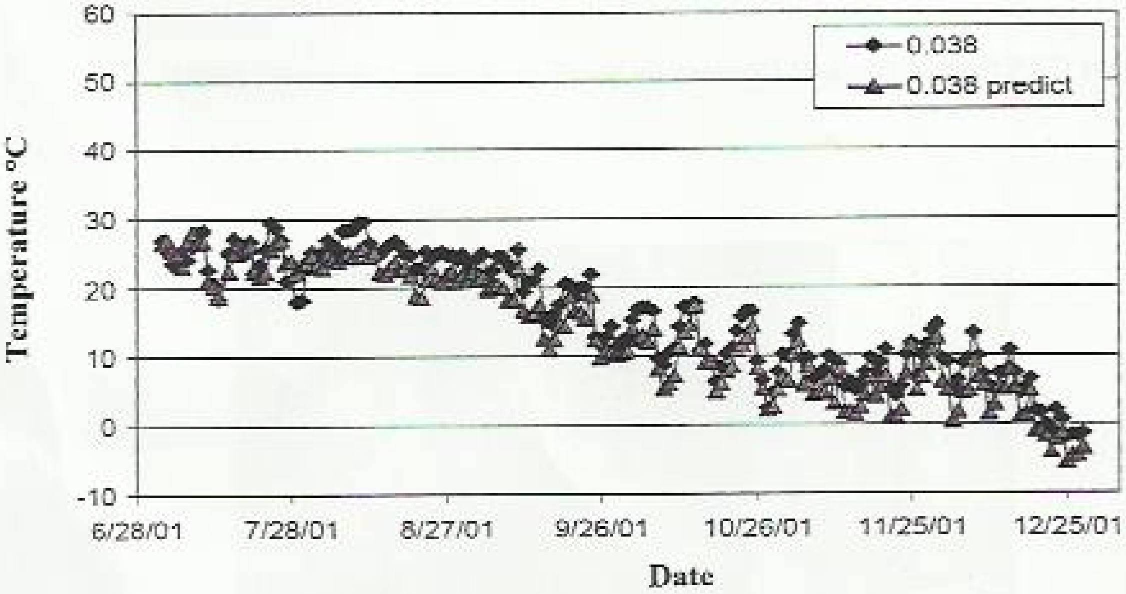


Figure (6) Minimum Daily Pavement Temperature Utilizing Day of Year at 0.038m Depth (Diefenderfer et al. 2003)

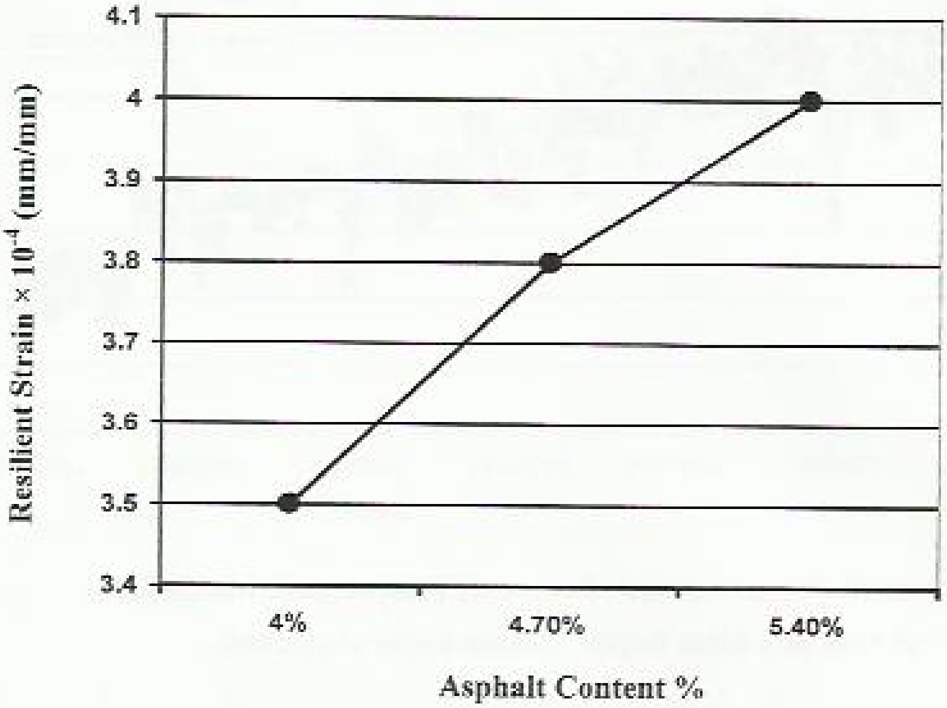


Figure (7) Effect of Asphalt Content on Resilient Strain (Algibury, 2008)

Figure (8) Indirect Tension Test Apparatus

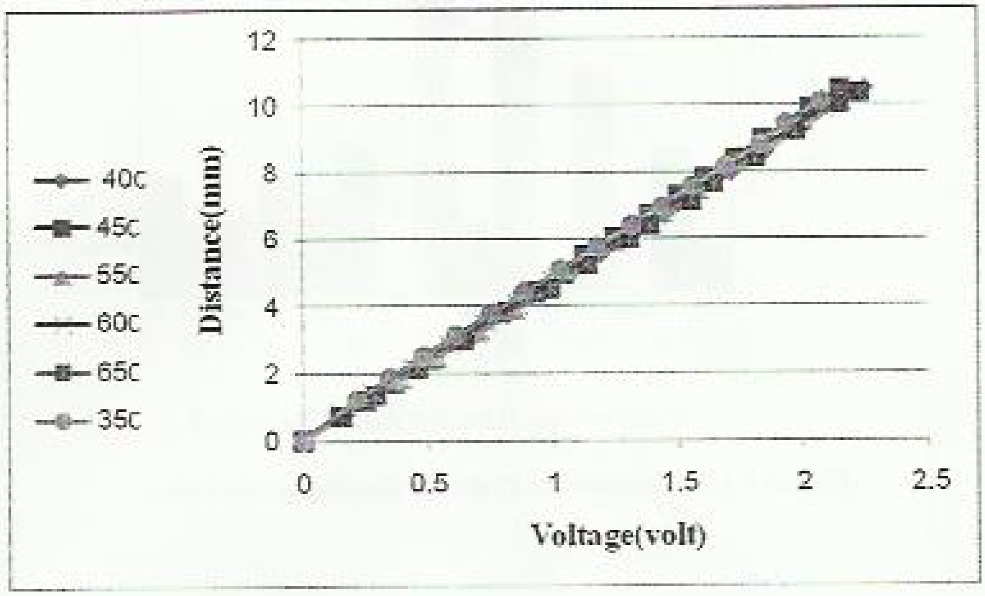
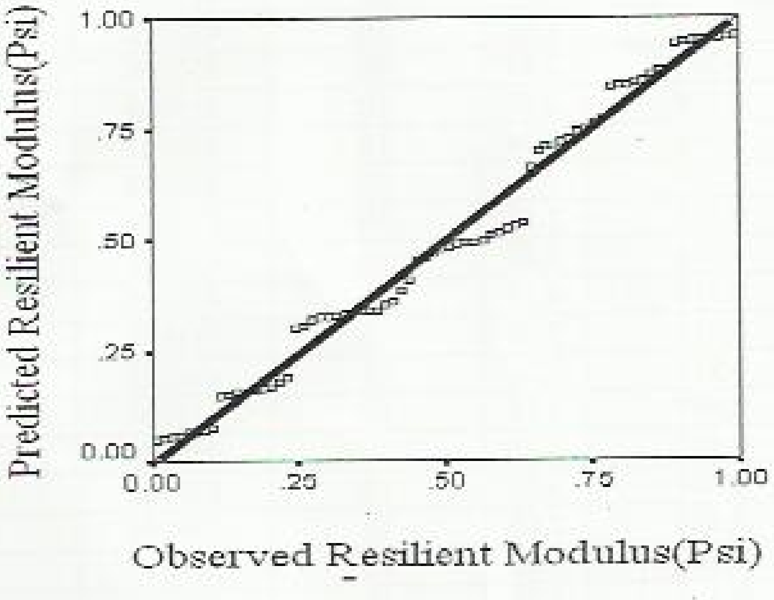


Figure (9) The Average Calibration Factor for LVDT at Different Temperatures



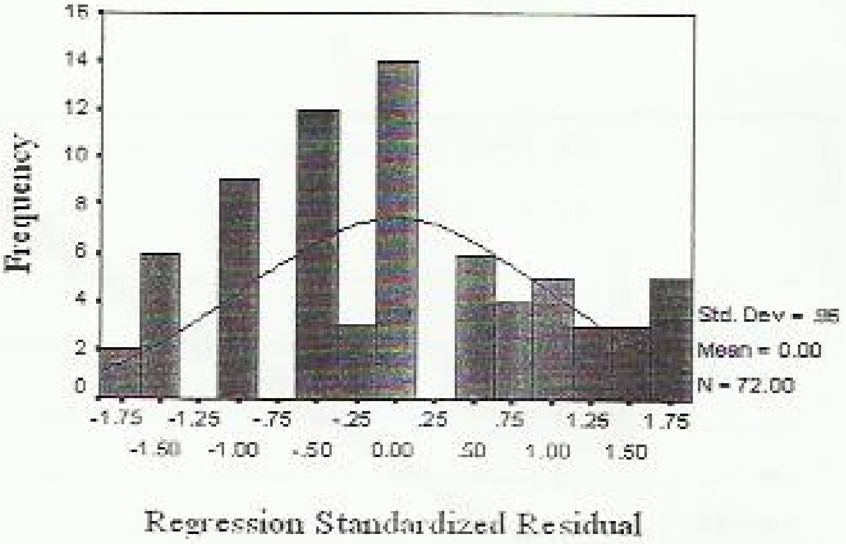


Figure (10) Diagnostic Plots for Resilient Modulus

Table (1) Indirect Tensile Test Data

%AC	Viscosity(Pa.s)	AV	Temperature C^O	MR (psi)	S.A(m^2/kg)
4.9	0.516	4.84	10	430108	5.97
5.2	0.516	4.08	10	215054	5.97
4.6	0.516	3.47	10	430385	5.97
4.9	0.516	2.67	10	430108	5.97
5.2	0.516	2.47	10	215054	5.97
4.6	0.516	2.94	10	430385	5.97
4.9	0.516	3.9	10	430108	5.98
5.2	0.516	2.31	10	215054	5.98
4.6	0.516	3.47	10	430385	5.98
4.9	0.516	4.19	10	430108	5.98
5.2	0.516	3.26	10	215054	5.98
4.6	0.516	5.23	10	430385	5.98
5.2	0.400	4.54	10	215054	5.97
4.6	0.400	3.81	10	430385	5.97
4.9	0.400	3.62	10	430108	5.97
4.9	0.400	2.96	10	430108	5.97
5.2	0.400	4.00	10	215054	5.97
4.6	0.400	3.72	10	430385	5.97
4.9	0.400	4.27	10	430108	5.98
5.2	0.400	3.05	10	215054	5.98
4.6	0.400	5.07	10	430385	5.98
4.9	0.400	2.63	10	430108	5.98
5.2	0.400	3.92	10	215054	5.98
4.6	0.400	2.5	10	430385	5.98
4.9	0.516	3.08	25	215031	5.97

5.2	0.516	2.84	25	143369	5.97
4.6	0.516	3.59	25	215054	5.97
4.6	0.400	4.46	25	215054	5.97
4.9	0.400	4.19	25	215031	5.97
5.2	0.400	3.26	25	143369	5.97
4.6	0.400	3.97	25	215054	5.97
4.9	0.400	2.79	25	215031	5.97
5.2	0.400	2.72	25	143369	5.97
4.6	0.400	2.95	25	215054	5.98
4.9	0.400	2.75	25	215031	5.98
5.2	0.400	5.49	25	143369	5.98
4.6	0.400	3.72	25	215054	5.98
4.9	0.400	2.01	25	215031	5.98
5.2	0.400	4.70	25	143369	5.98
4.6	0.516	3.8	25	215054	5.97
4.9	0.516	3.45	25	215031	5.97
5.2	0.516	2.51	25	143369	5.97
4.6	0.516	4.25	25	215054	5.98
4.9	0.516	2.87	25	215031	5.98
5.2	0.516	3.50	25	143369	5.98
4.6	0.516	4.49	25	215054	5.98
4.9	0.516	2.3	25	215031	5.98
5.2	0.516	4.37	25	143369	5.98
4.9	0.516	4.27	40	86014	5.97
5.2	0.516	3.63	40	85837	5.97
4.6	0.516	5.07	40	107538	5.97
4.6	0.400	4.95	40	107538	5.97
4.9	0.400	3.20	40	86207	5.97
5.2	0.400	2.48	40	86014	5.97
4.6	0.400	4.3	40	86022	5.97
4.9	0.400	2.34	40	86014	5.97
5.2	0.400	2.81	40	86003	5.97
4.6	0.400	3.93	40	107527	5.98
4.9	0.400	2.47	40	86014	5.98
5.2	0.400	4.91	40	85837	5.98
4.6	0.400	4.99	40	107518	5.98
4.9	0.400	3.12	40	86014	5.98
5.2	0.400	4.99	40	85837	5.98
4.6	0.516	4.94	40	107538	5.97
4.9	0.516	4.31	40	107527	5.97
5.2	0.516	4.40	40	86014	5.97
4.6	0.516	4.21	40	107527	5.98
4.9	0.516	3.69	40	86014	5.98
5.2	0.516	3.09	40	85837	5.98
4.6	0.516	5.47	40	107538	5.98
4.9	0.516	3.08	40	107516	5.98
5.2	0.516	3.13	40	86022	5.98

Figure (11) The µlogger 4R (Temperature Data Logger)

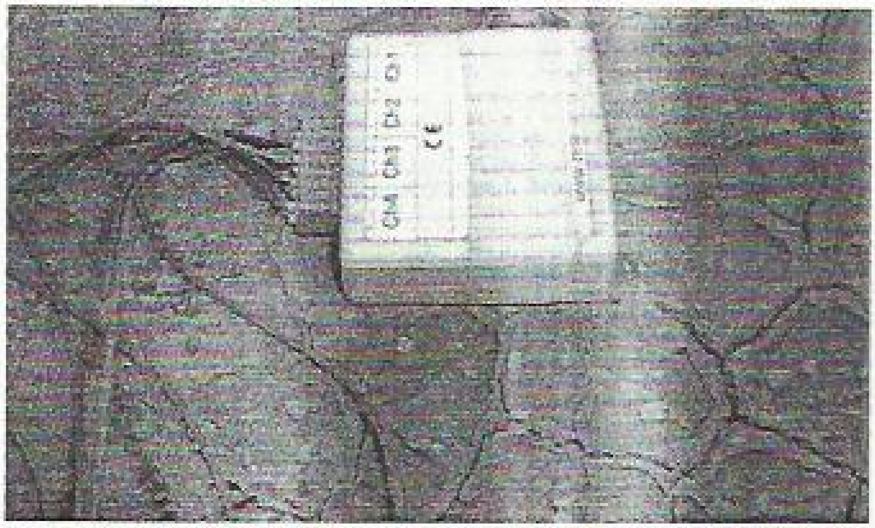


Figure (12) The µlogger 4R with Four Channels

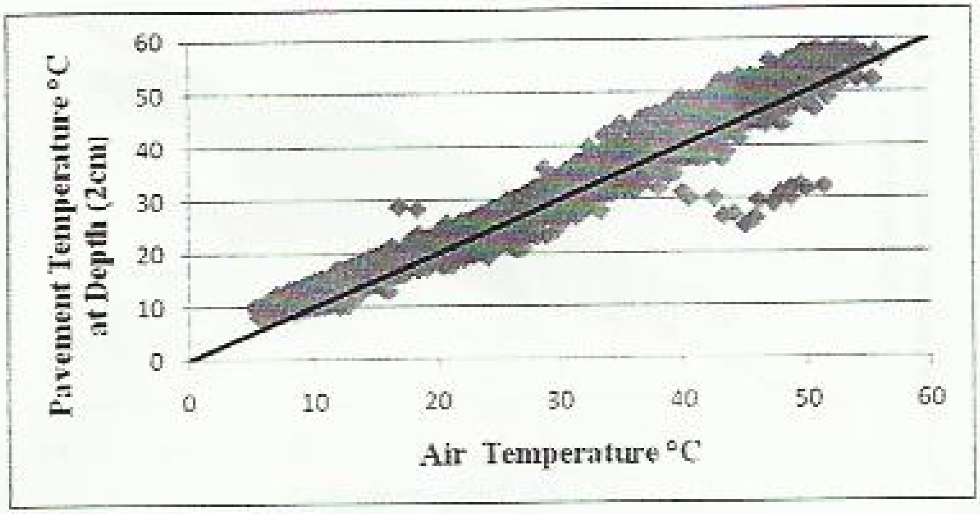


Figure (13) Effect of Air Temperature on Pavement Temperature at Depth 2cm

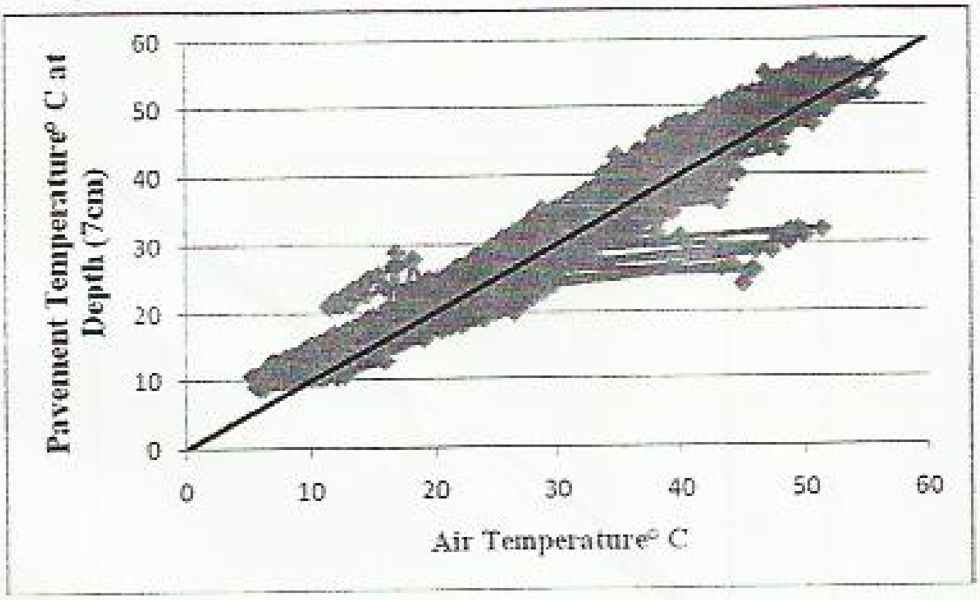


Figure (14)Effect of Air Temperature on Pavement Temperature at Depth 7cm

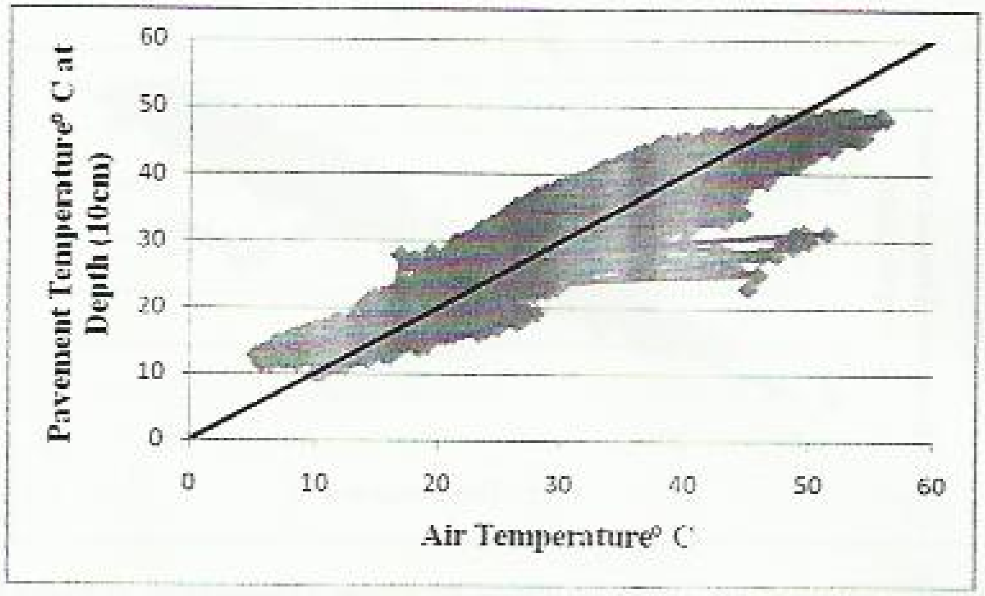


Figure (15) Effect of Air Temperature on Pavement Temperature at Depth 10cm

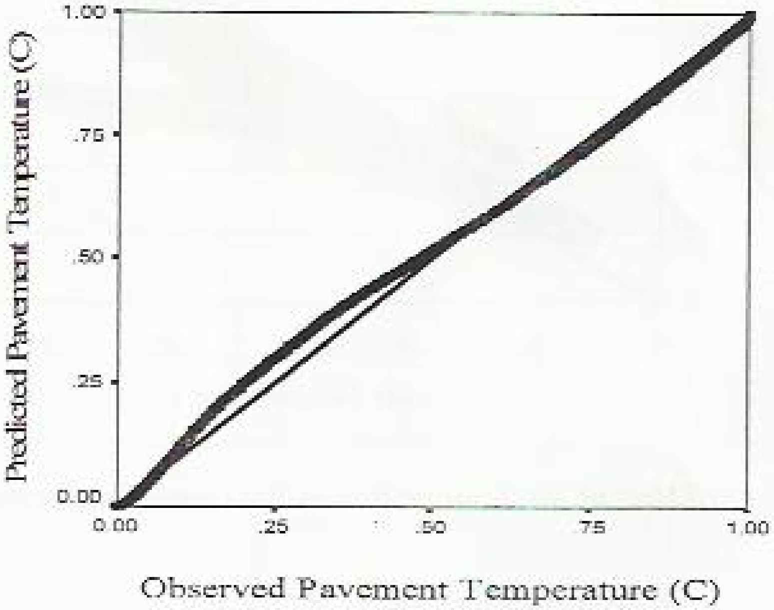


Figure (16) Predicted Versus Observed Pavement Temperature

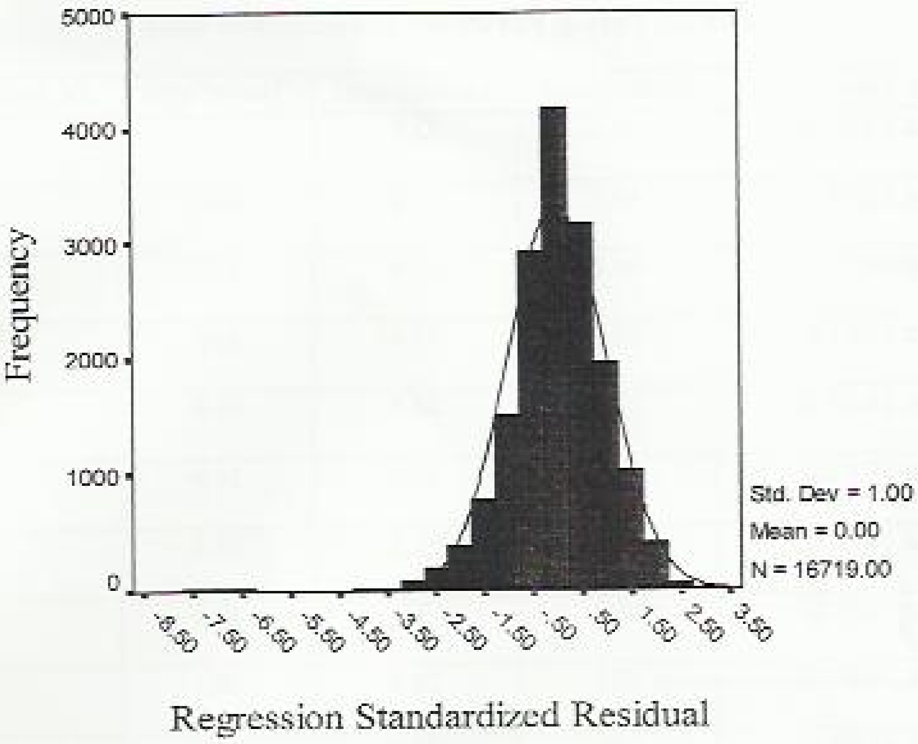


Figure (17) Frequency Versus Regression Standardized Residual for Pavement Temperature Model

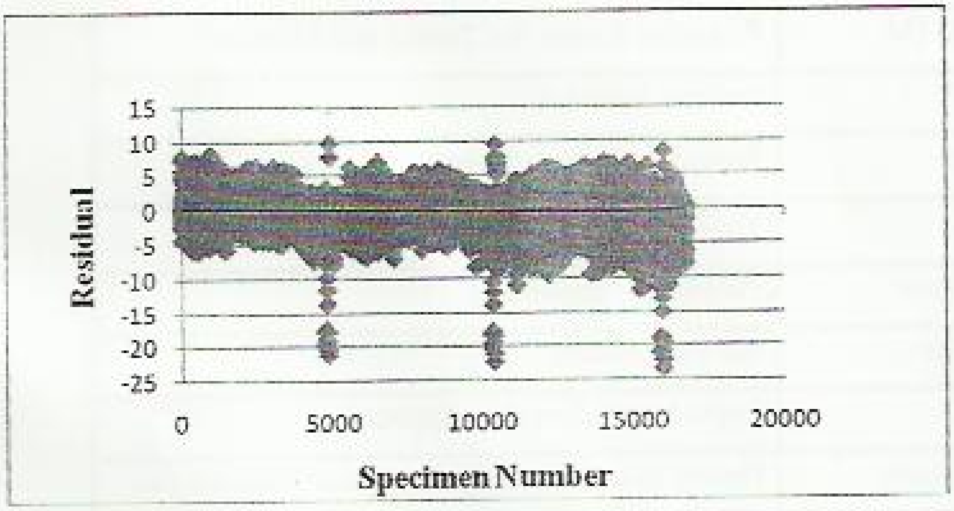


Figure (18) Residual Versus Specimen Number for Pavement Temperature Model

Table (2) Part of Pavement Temperature Data

Date and Time	Tpave(2cm)	Tpave(10cm)	Tpave(7cm)	air temperatures C°
Mon 27 of Apr at 12:07:23 2009	43.3	32.9	41.1	34.6
Mon 27 of Apr at 13:07:23 2009	44.7	34.6	42.6	37.7
Mon 27 of Apr at 14:07:23 2009	44.1	35.6	42.8	35
Mon 27 of Apr at 15:07:23 2009	42.2	35.4	40.8	36.2
Mon 27 of Apr at 16:07:23 2009	37.1	34.5	36.9	35.5
Mon 27 of Apr at 17:07:23 2009	34.6	33.3	34.4	35.6
Mon 27 of Apr at 18:07:23 2009	31.7	32.2	32.2	29.8
Mon 27 of Apr at 19:07:23 2009	29.1	31	29.9	26.9
Mon 27 of Apr at 20:07:23 2009	27.2	29.8	28.1	25.5
Mon 27 of Apr at 21:07:23 2009	26	28.8	26.9	24.4
Mon 27 of Apr at 22:07:23 2009	24.9	28	25.8	23.3

NOMENCLATURE

ASTM	American Society for Testing and Materials
Mr	resilient Modulus
σ	Repeated Diametral Stress
ε_r	Vertical Resilient Strain
Tpave	Pavement Temperature
Tair	Air Temperature
Z	Depth below Pavement Surface
Tpmax	Predict Maximum Daily Pavement Temperatures
Tpmin	Predict Minimum Daily Pavement Temperatures
Tmax	Maximum Daily Ambient Temperature
Tmin	Minimum Daily Ambient Temperature
Y	Day of Year
Pd	Depth Within The Pavement

T	Test Temperature
Av	Percent Air Voids
P_s	Percent Volume of Effective Asphalt
P_8	Percent Passing Sieve No. 8
P_{200}	Percent Passing by weight of Filler Content
PRLS	Pneumatic Repeated Load System
rd	Reading of LVDT
Fc	Calibration Factor
h	Specimen Diameter
LVDT	Linear Variable Differential Transformer
%AC	Percent by Weight of Effective Asphalt
D	Viscosity of Binder
S.A	Surface Area