World Academy of Science, Engineering and Technology
International Journal of Civil and Environmental Engineering
Vol:9, No:4, 2015

Moisture Variations in Unbound Layers in an Instrumented Pavement Section

Md R. Islam, Rafiqul A. Tarefder

***Abstract*—**This study presents the moisture variations of unbound layers from April 2012 to January 2014 in the Interstate 40 (I-40) pavement section in New Mexico. Three moisture probes were installed at different layers inside the pavement which measure the continuous moisture variations of the unbound layers. Data show that the moisture contents of unbound layers are typically constant throughout the day and month unless there is rainfall. Moisture contents of all unbound layers change with rainfall. Change in ground water table may affect the moisture content of unbound layers which has not been investigated in this study. In addition, the Level 3 predictions of moisture contents using the Pavement Mechanistic-Empirical (ME) Design software were compared and found quite reasonable. However, results presented in the current study may not be applicable for pavement in other regions.

***Keywords*—**Asphalt pavement, moisture probes, resilient modulus, climate model.

I. Introduction

ENVIRONMENTAL changes (such as moisture content) have a direct impact on the structural property of pavement and consequently, its performance. For example, moduli of unbound layers of pavement change with moisture content. The modulus value is the greatest at the optimum moisture content and decreases with change in saturation level. This is why, accurate measurement or prediction of moisture content is very important for accurate determination of layer modulus. Pavement design guide such as the Pavement Mechanistic-Empirical (ME) Design Guide (previously known as the Mechanistic-Empirical Pavement Design Guide (MEPDG)) considers the resilient modulus (M_R) of unbound layer affected by the in-situ moisture content. For example, the Pavement ME Design Guide uses the following model to determine the variation in M_R of unbound layer with moisture [1]:

$$\log\left(\frac{M_R}{M_{Ropt}}\right) = a + \frac{b-a}{1+\exp\left[\ln\frac{-b}{a} + k_m(S-S_{opt})\right]} \quad (1)$$

where M_{Ropt} = resilient modulus at optimum moisture content; a = minimum of $\log(\frac{M_R}{M_{Ropt}})$; b = maximum of $\log(\frac{M_R}{M_{Ropt}})$; k_m = regression parameter; $(S-S_{opt})$ = variation in degree of saturation expressed in decimal. Typically, for fine-grained materials, a, b and k_m are -0.5934, 0.4 and 6.1324, respectively. For course-grained materials, a, b and k_m are -0.3123, 0.3 and 6.8157, respectively.

M. R. Islam is with the University of New Mexico, Albuquerque, NM 87131 USA (phone: 505-363-6902; e-mail: mdislam@unm.edu).
R. A. Tarefder is with the University of New Mexico, Albuquerque, NM 87131 USA (phone: 505-277-6083; e-mail: tarefder@unm.edu).

To understand the effect of moisture variation on M_R value, (1) has been plotted in Fig. 1 for both course and fine grained materials. The vertical axis is the ratio between the resilient modulus (M_R) at any degree of saturation and the resilient modulus at the optimum saturation level (M_{Ropt}). Fig. 1 shows that any deviation from the optimum moisture content leads to the decreases in M_R for unbound material. For example, M_R decreases by 47% for course-grained and 67% for fine-grained material due to change in degree of saturation by 40%.

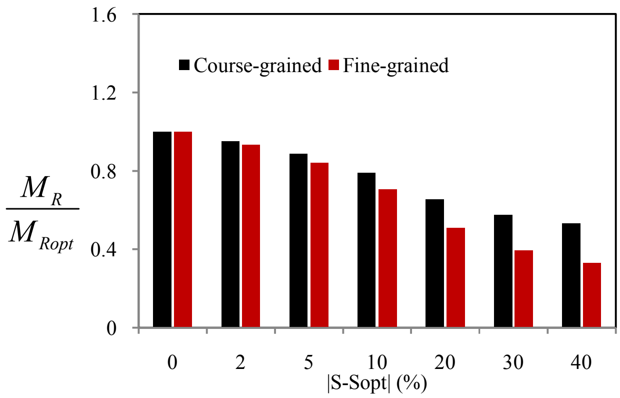

Fig. 1 Effect of moisture on the resilient modulus

It is essential to measure the in-situ moisture content to understand the moisture content variations in pavement layers and calculate the deviation of moisture content from the optimum moisture content of the material. The available literature does not provide good information regarding the moisture variations in pavement layers. For example, [2] showed that the moisture content of one of the studied section varied from 50% to 70%, which is so high for real pavement. This study presents and discusses the results obtained from an instrumented pavement section. The section is located on Interstate 40 (I-40) east bond lane at mile post 141 near the city of Albuquerque in the state of New Mexico, USA.

Several factors may affect the moisture contents of unbound layers. Bayomy and Salem [2] reported that daily solar radiation, Relative Humidity (RH), pavement temperature and rainfall may affect the moisture content of unbound layers. However, no study, till this date, has investigated the effects of these factors. Such effects are investigated in the current study.

In the second part of the current study, the Level 3 subroutine used in the Pavement ME Design software to calculate the moisture content of the unbound layers has been evaluated. This method determines the volumetric moisture content (θ_w) of unbound layers using the gradation of material and Plasticity Index (PI) of the material as input. These inputs are used to calculate soil-water characteristic curve parameters (i.e., a_f, b_f, c_f and h_r) and saturated volumetric moisture content (θ_{sat}). The model is shown in (2):

$$\theta_w = [1 - \frac{\ln(1+\frac{h}{h_r})}{\ln(1+\frac{1.45x10^5}{h_r})}]*[\frac{\theta_{sat}}{\{\ln[\exp(1)+\left(\frac{h}{a_f}\right)^{bf}]\}^{cf}}] \quad (2)$$

The volumetric moisture content (θ_w) can be converted into gravimetric moisture content (W_g) using (3):

$$W_g = \theta_w \frac{\gamma_w}{\gamma_d} \quad (3)$$

where γ_w and γ_d are the unit weights of water and dry unit weight of the corresponding material respectively. Typically, it is very difficult to calibrate these subroutines used to calculate these parameters and hence, the default Pavement ME Design subroutines are very often used. However, these may lead to erroneous moisture content and consequently, incorrect M_R value. This study compares the moisture variations predicted by the Pavement ME Design software (Level 3) and the measured data.

II. Objectives and Methodology

The main objective of this study is to measure the change in moisture contents of unbound layers of an instrumented flexible pavement using the installed moisture probes. Specific objectives are:

a) Determining the effects of daily solar radiation, RH and pavement temperature on the moisture contents of unbound layers.
b) Determining the effects of rainfall on the moisture contents of unbound layers.
c) Determining the seasonal trend of the moisture contents.
d) Compare the measured moisture content data with the Pavement ME Design software prediction (Level 3).

To fulfill the objectives, three moisture probes were installed at different depths of the pavement. Continuous voltage reading are recorded and converted into gravimetric moisture content using the calibration factor. From the daily moisture variation, the effects of solar radiation, RH and pavement temperature are determined. The effects of rainfall on the moisture contents of base and subbase layers are determined by analyzing the data before and after the rainfall.

To fulfill the last objective, the Pavement ME Design software Level 3 subroutines have been used to calculate (manually; the guide does not show the moisture value) the moisture contents of the unbound layers. These predictions were compared with the measured data from the I-40 instrumented pavement section.

III. Installation of Moisture Probes

Three moisture probes were installed on the I-40 instrumentation section. The sensors are located at middle of the base and subbase (also called, Process Place and Compact (PPC)) layers and 200 mm (8 in.) below the subgrade layer. The elevations of the sensors are presented in Fig. 2. There was no moisture probe in the Hot-Mix Asphalt (HMA) layer.

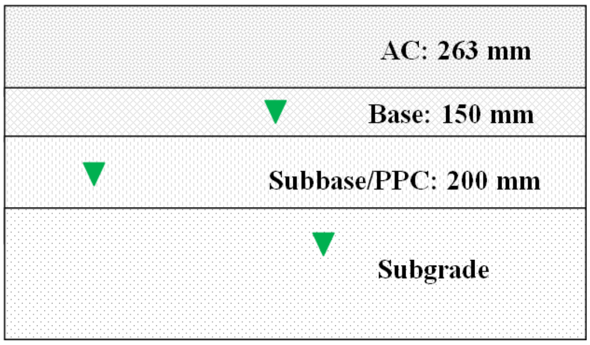

Fig. 2 Elevations of the installed moisture probes

To install the moisture sensors a hole was drilled first as shown in Fig. 3. After inserting the sensor, some sieved soil passing #8 sieve was gently pressed around the probe. The probes were calibrated using the materials collected from the site. The probe installed on I-40 is an EC-5 probe supplied by Decagon Devices Inc. It measures the dielectric constant of surrounding soil. The dielectric constant of soil and aggregate are much smaller than moisture. This sensor determines the volumetric moisture content of the surrounding soil using the measured dielectric constant. The details of the instrumentation procedure have been described in [5].

Fig. 3 Installation of a moisture probe

IV. Results and Discussion

From the moisture content data, two findings were sought. First, examine whether the daily pavement temperature variations, RH of air and solar radiation affect the moisture of unbound layers or not. Secondly, investigate whether rainfall causes a change in the moisture content of unbound layers or not.

To examine the first issue data were gathered from a day and a month when there was no rainfall. The gravimetric moisture variations at different times of a day (October 1, 2012) for base, subbase and subgrade are shown in Fig. 4. It can be seen that the gravimetric moisture contents on that day were 7.94%, 7.99% and 9.65% for the base, PPC and subgrade layers respectively. It can be seen that the moisture variation at different times of a day is pretty constant provided no precipitation occurs. That means the daily temperature variations; RH and solar radiation do not affect the moisture variations in unbound layers.

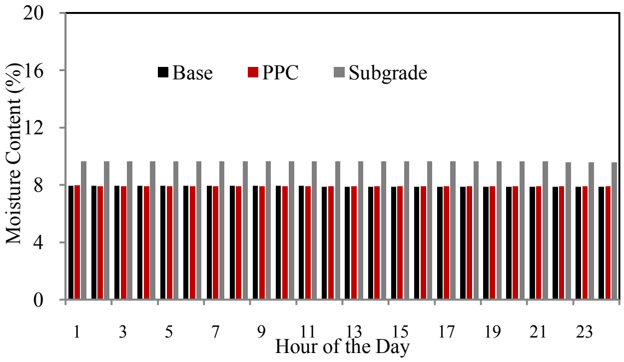

Fig. 4 Moisture variations in subgrade on October 1, 2012

The moisture variation in June 2012 is shown in Fig. 5. It shows that the moisture content of base layer varies from 7.4% to 8%, of subbase layer varies from 7.7% to 8.7% and of subgrade layer varies from 7.6% to 7.94%. The values have an increasing trend with day although the degree of increase in very low. It is mentionable that no precipitation was measured during this month. Therefore, this increasing trend is not due to rainfall. This may be due to increase in water table level. It can be said from this data that daily temperature variations, RH and solar radiation do not affect the moisture variations so much.

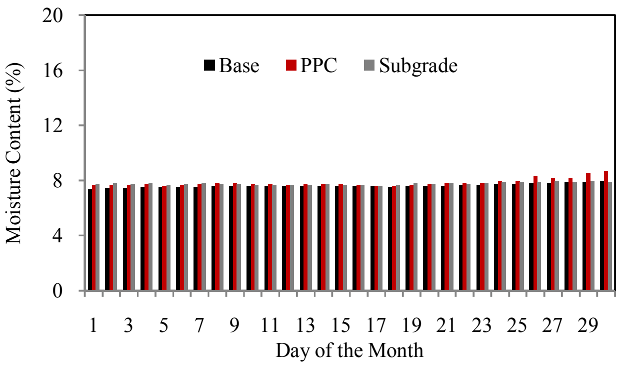

Fig. 5 Moisture variations in June, 2012

Now, data before and after the rainfall are analyzed to find out the rainfall's effect. The moisture and rainfall variations in July 2012 are shown in Figs. 6 and 7, respectively. Fig. 6 shows that there is a jump in the moisture content of unbound layers on the 4th July 2012. In addition, Fig. 7 shows that there was rainfall on that day. Therefore, this jump in moisture content may be due to the rainfall. The precipitation infiltrates inside the pavement and the moisture contents of unbound layer increases accordingly. Fig. 7 shows that there was some rainfall on the August 26, 2012 and the moisture contents also jumps on that day (Fig. 6).

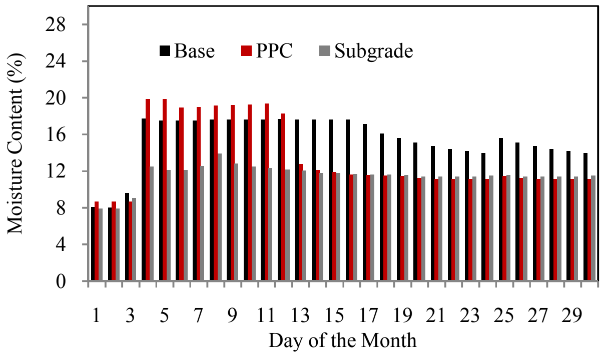

Fig. 6 Moisture variations in a month (July, 2012)

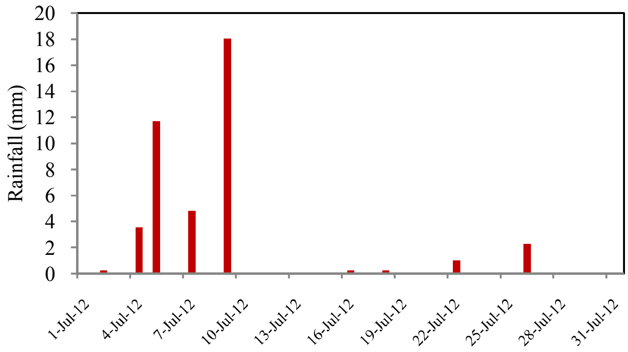

Fig. 7 Rainfall in July 2012

To examine the yearly variations, the moisture variation from April 2012 to January 2014 is shown in Fig. 8. It shows that the moisture contents in unbound layers are not constant over the year. It varies between 5.4% and 15.6% in base layer, 5.45% and 16.31 in subbase layer and 7.2% and 12.9% in subgrade layer. The variation is due to the precipitation. The rainfall data at the test site is shown in Fig. 9. It shows that most of the rainfall occurs in July. In 2013, there was heavy rainfall in September (Fig. 9); the moisture contents are also increased in this month (Fig. 8).

Comparing moisture content data (Fig. 8) and rainfall (Fig. 9) data it can be said that the increases in moisture content is due to the rainfall. The rainwater infiltrates through the HMA and causes an increase in moisture content of the unbound layers. Note that the permeability of the HMA layer was measured to be an average value of $2.85x10^{-2}$ cm/s with a standard deviation of $0.8 x10^{-2}$ cm/s which is very high [3].

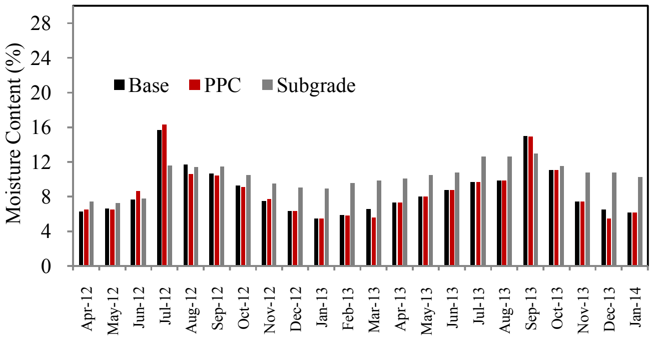

Fig. 8 Moisture variations from 2012 to 2014)

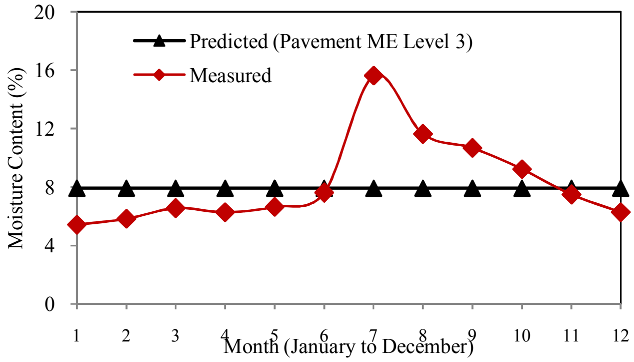

Fig. 10 Measured and predicted moisture data in base layer

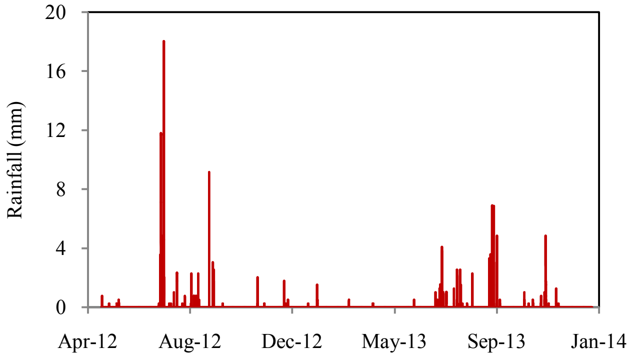

Fig. 9 Rainfall from 2012 to 2014

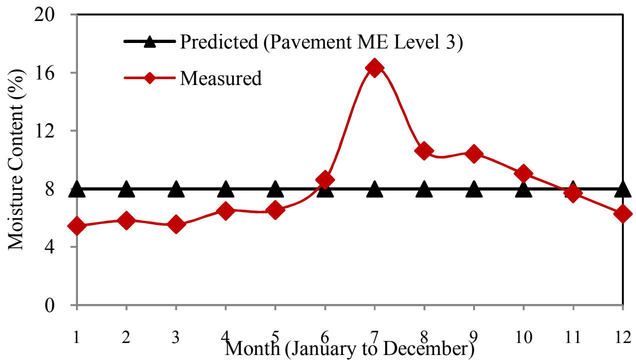

Fig. 11 Measured and predicted moisture data in subbase layer

In this part, the measured moisture data are compared with the Pavement ME Design predictions. The moisture contents for the base layer and the Pavement ME Design predicted moisture contents are presented in Fig. 10. The measured data is collected from April 2012 to March 2013. After inserting the gradation, PI and Ground Water Table (GWT), the soil-water characteristic curve parameters, a_f, b_f, and c_f are obtained to be 3.124, 2.2253, and 0.7182 respectively; the h_r is found to be 115 psi and θ_{sat} is found to be 61.2%. The GWT is considered to be 100 ft which is reasonable for the test site [4]. Fig. 10 shows that the predicted moisture content (7.9%) is close to the measured values except in July (there was heavy rainfall in July 2012). The predicted moisture content is also called the predicted equilibrium moisture content of that layer. It is important to mention that the optimum moisture content of the base layer is 6.9%.

The measured moisture contents and the Pavement ME Design predicted moisture contents for the subbase layer using the EICM model are presented in Fig. 11. The measured data is collected from April 2012 to March 2013. The soil-water characteristic curve parameters, a_f, b_f, and c_f are obtained to be 16.582, 0.6352, and 3.4048 respectively; the h_r is found to be 186 psi and θ_{sat} is found to be 70.6%. Fig. 11 shows that the predicted moisture content (8%) is close to the measured values except in July (there was heavy rainfall in July 2012). It is important to mention that the optimum moisture content of the subbase layer is 7.1%.

The measured and the Pavement ME Design predicted moisture contents for the subgrade layer are presented in Fig. 12. The measured data is collected from April 2012 to March 2013. The soil-water characteristic curve parameters, a_f, b_f, and c_f are obtained to be 4.7124, 3.1651 and 0.8523 respectively; the h_r is found to be 100 psi and θ_{sat} is found to be 48.7%. Fig. 12 shows that the predicted moisture content (5.1%) is less than the measured values.

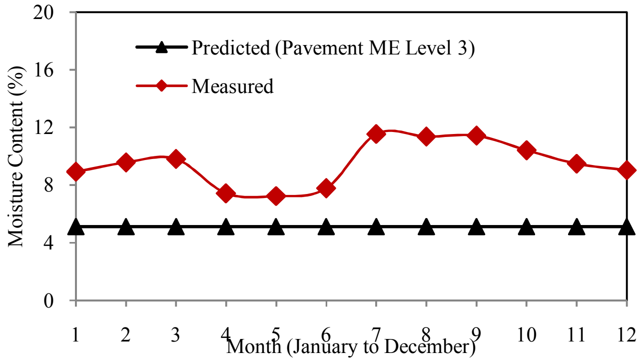

Fig. 12 Measured and predicted moisture data in subgrade layer

V. Conclusions

This study is based on a single instrumentation section in New Mexico. The results presented in the study cannot make a general conclusion. However, the results presented in the study are useful to understand the moisture variations in unbound layers. Accurate predictions of moisture variations in unbound layers are important as the resilient moduli of unbound layers are dependent of moisture. Finally, several conclusions can be made from the I-40 study:

a) The moisture contents of unbound layers are typically constant through the day and month unless there is rainfall. The temperature changes inside the unbound layers, RH of air and solar radiations do not affect the moisture contents. However, change in ground water table may affect the moisture content of unbound layers which has not been investigated in this study.
b) The moisture contents in unbound layers change sharply with rainfall.
c) The Pavement ME Level 3 (nationally calibrated subroutines) prediction to determine the moisture content of is close to the measured data for base and subbase layers; however, way less in the subgrade.

ACKNOWLEDGMENT

This study is funded by the New Mexico Department of Transportation (NMDOT). The authors would like to express their sincere gratitude and appreciation to Mr. Jeff Mann, Pavement Management and Design Bureau Chief, NMDOT, for being the advocate of this project. The authors appreciate the valuable suggestions and time of the Project Manager Mr. Virgil Valdez, Research Bureau, NMDOT and project technical panel member, Mr. Parveez Anwar, State Asphalt Engineer, NMDOT and Mr. James Gallegos, Materials Bureau Chief, NMDOT. Finally, the authors would like to appreciate the help of Dr. David Timm from the Auburn University to install the sensors on the I-40.

REFERENCES

[1] AASHTO, *Mechanistic-Empirical Pavement Design Guide*. A Manual of Practice, July 2008, Interim Edition, American Association of State Highway and Transportation Officials, Washington D. C., 2008.
[2] F. Bayomy and H. Salem, Monitoring and Modelling Subgrade Soil Moisture for Pavement Design and Rehabilitation in Idaho, Phase III: Data Collection and Analysis." Final Report, Project No. ITD Project SPR 0010 (025) 124), 2005, submitted to Idaho Transportation Department (ITD), Boise, Idaho 83707.
[3] R. A. Tarefder and M. Ahmad, "Addressing Permeability of Superpave Mixes in New Mexico." Final Report, NM11MSC-02, 2013, New Mexico Department of Transportation (NMDOT), Albuquerque, NM 87199.
[4] C. Heywood, D. Galloway, and S. Stork, "Ground Displacements Caused by Aquifer-System Water-Level Variations Observed Using Interferometric Synthetic Aperture Radar near Albuquerque, New Mexico." Water-Resources Investigations Report 02-4235, 2002, City of Albuquerque, Albuquerque, New Mexico.
[5] R. A. Tarefder and M. R. Islam, "Study and Evaluation of Materials Response in Hot Mix Asphalt Based on Field Instrumentation." Final Report, NM11MSC-03, 2015, New Mexico Department of Transportation (NMDOT), Albuquerque, NM 87199.