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Effectiveness of Open-Graded Base Layer on Subgrade Moisture Regime and Overall Pavement Performance

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Since the mid-1960s, it has been common practice in the state of Idaho to place a 1- or 2-ft-thick layer of shot rock as a cap over the subgrade in highway pavement construction. Much of the new pavement construction in Idaho required significant rock excavation, making the shot rock an economical method of improving the subgrade soil. In the 1970s, the rock layer was being screened to limit the maximum size, reduce the fines, and improve drainage. Because this shot rock layer was first used as a cap on the subgrade, it became known as rockcap (*1*).

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Because most of the rockcap material was obtained either within or adjacent to the roadway prism, the cost was attractive—approximately half that of the conventional aggregate base. The cost of the rockcap material could be greater than that of the aggregate base if hauled from quarries far away from the job site. The rockcap materials also have higher drainage properties compared with the aggregate base, which may help in reducing the amount of rainwater entering the subgrade soil through the surface. The gradation range of the rockcap materials is presented in Table 1.

The Idaho Transportation Department (ITD) sponsored a research project to quantify the environmental impacts on pavement performance and to include its effects in the design process of new and rehabilitated pavements. The outcomes of this part are published elsewhere (*2–5*). Another objective of the ITD project was to investigate the effectiveness of placing a rockcap layer under the pavement surface (instead of the conventional aggregate base layer) on the moisture regime of the underlying subgrade and the overall pavement performance, which is the main focus of this paper.

Time domain reflectometry (TDR) technique in moisture measurement has been widely used by several agencies recently, especially the nationwide Long-Term Pavement Performance Program (LTPP). The TDR moisture measurements of the LTPP sites are now available on the DataPave website (*6*, *7*). The moisture data of some of the LTPP sites were used by Richter and Witczak to evaluate the moisture prediction capabilities of the Enhanced Integrated Climatic Model [EICM, (*8*)]. The EICM is the main component of the new design guide for seasonal moisture prediction and is still under calibration using LTPP data (*9*).

OBJECTIVE

The main objective of this study was to evaluate the impacts of the presence of a rockcap layer on the subgrade moisture variation under rockcap and aggregate base layers. It also estimated the effectiveness of placing a rockcap on the overall pavement performance.

STUDY APPROACH

The approach adopted in this study has two parts: first, measure the subgrade moisture content using the TDR technique under (adjacent) identical pavement sections constructed by rockcap and aggregate base layers, and, second, measure the pavement structural capacity using the falling weight deflectometer (FWD) and use the data to predict the expected pavement life.

TABLE 1 Rockcap Gradation Range

Sieve Size	% Passing
2.5 in. (63 mm)	100
1.5 in. (37.5 mm)	65–80
¾ in. (19 mm)	15–30
½ in. (12.5 mm)	5–15
No. 4 (4.75 mm)	0–5

TABLE 2 Layer Thickness, Subgrade Soil Characterization Tests, and Probe Anchors to Pavement Surface for Different Sites

	Moscow		Weiser	
Test	A	B	A	B
Layer thickness and construction year				
Construction year	96	96	99	99
AC surface thickness, in.	4.8	4.8	6	6
Aggregate base thickness, in.	6	27.6	6	12
Rockcap thickness, in.	21.6	0	6	0
Subgrade properties				
% Pass #40	100	100	100	100
% Pass #200	98	98	70	70
LL, %	30.3	30.3	39.8	39.8
PI, %	8	8	9.6	9.6
AASHTO classification	A-4	A-4	A-4	A-4
Unified Soil Classification System	CL	CL	ML	ML
Probe anchors to the pavement surface (Figure 1)				
d1, in.	16	16	7	7
d2, in.	40	40	42	36
d3, in.	19	19	12	11
d4, in.	22	22	12	11

METHODOLOGY

Site Selection

The original plan of the ITD project was to select, if possible, sites where two adjacent pavement sections, one with rockcap and the other with ¾-in. aggregate base, were available. This was to allow for the comparison of the effectiveness of the rockcap base on the moisture regime under the pavement. New construction was available with two adjacent sites at two different locations: Moscow in the northern region and Weiser in the southern region.

The Moscow sites are located on ID-8 (Pullman Moscow Road) at Milepost 1.06. The pavement section is a new construction on subgrade soil with at least a 12-in. rockcap base. A 100-ft section was constructed with ¾-in. aggregate base to replace the rockcap. Site A was installed in the rockcap section, and Site B was in the ¾-in. aggregate base section. Cable conduits were installed during construction, and no trenches were cut in the pavement.

The Weiser sites are located on US-95 in downtown Weiser at the intersection with Park Street. Similarly to Moscow, two adjacent installations were made. The pavement section was a new construction with a 6-in. rockcap base. A 100-ft section was constructed with ¾-in. aggregate base to replace the rockcap. Site A was installed in the rockcap section, and Site B was in the ¾-in. aggregate base section. Cable conduits were installed during construction, and no trenches were cut in the pavement.

The construction year, the thickness of each of the pavement layers, and the subgrade soil characterization tests for both sites are presented in Table 2.

Site Instrumentation

Instrumentation at each site was the same, in that each site instrumentation contained three types of probes: a moisture probe (TDR), a temperature sensor (MRC type), and a resistivity sensor manufactured by ABF Manufacturing, Inc.

Two TDR probes were installed on top of each other, with the first segment in the base layer. The MRC temperature and the ABF resistivity sensors also were installed so that the top of the sensor was in the base layer. During the installation, soil samples were collected at approximately every foot, and the moisture content was determined. To check equipment operation, preliminary data collection was made on completion of the installation at each site.

Figure 1 shows a schematic of the typical probe installation at all sites. The anchored dimensions shown in the figure are probe anchors to the pavement surface. These dimensions for each site are provided in Table 2.

Data Collection Procedures

Different types of data were collected regularly on a monthly basis for almost 3 years at the Weiser sites and 4 years at the Moscow sites (where installations were made earlier). The volumetric moisture data were collected by the moisture point instrument (Milepost-917). A detailed description of the instrument and its basic operation is provided in the instrument manual, Milepost-917 (*10*). The moisture point technology is based on TDR. In addition to moisture measurements, the resistivity was measured by the ABF probes, and the pavement temperature was measured at various depths with MRC sensors. In addition, the groundwater table was determined by atmospheric piezometers. Climatic data were imported from nearby weather stations.

To evaluate the pavement structure capacity at the different Idaho sites, the FWD testing was conducted with Dynatest equipment. The test was conducted once a year during the summer for 4 years (1999, 2000, 2001, and 2002). For each site, the test was conducted at five different stations using two different loads (8,000 lb and 12,000 lb). The radial distances between the centerline of the applied load and each of the seven sensors were 0, 8, 12, 18, 24, 36, and 60 in. The plate radius on which the load was applied was 5.91 in. The pavement temperature was recorded during the test, and the resulting deflection is used for backcalculating the pavement layers' moduli.

DATA ANALYSIS

Impact of Rockcap Base Layer on Moisture Regime in Underlying Subgrade

The main objective of this paper was to determine the effectiveness of having a rockcap base layer on the moisture regime under

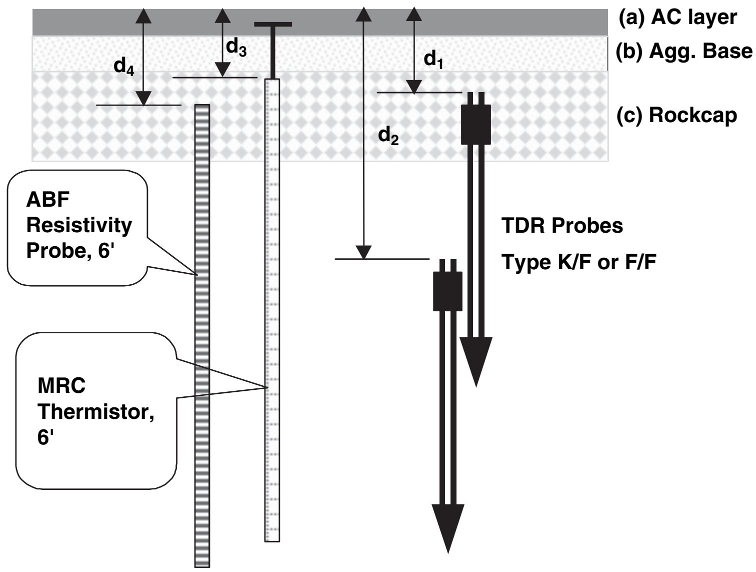


FIGURE 1 Schematic for probe installation at all sites.

pavement. Two sites (Moscow and Weiser) had installations with two identical pavement sections constructed adjacent to each other, with the base layer of one being a rockcap and the other being a ¾-in. aggregate base. The moisture data were collected regularly on a monthly basis for almost 3 years, as previously stated. The moisture content data were analyzed for these two sites, and the subgrade moisture content profiles with depth under rockcap and base layers are presented in Figure 2 for both Moscow and Weiser sites. For each site, the figure shows two curves: Installation A for subgrade soil moistures under a pavement having rockcap layer and Installation B for subgrade soil moisture under a pavement with aggregate base layer.

Figure 2 shows the volumetric moisture content versus depth from the pavement surface at some selected months representing differ-

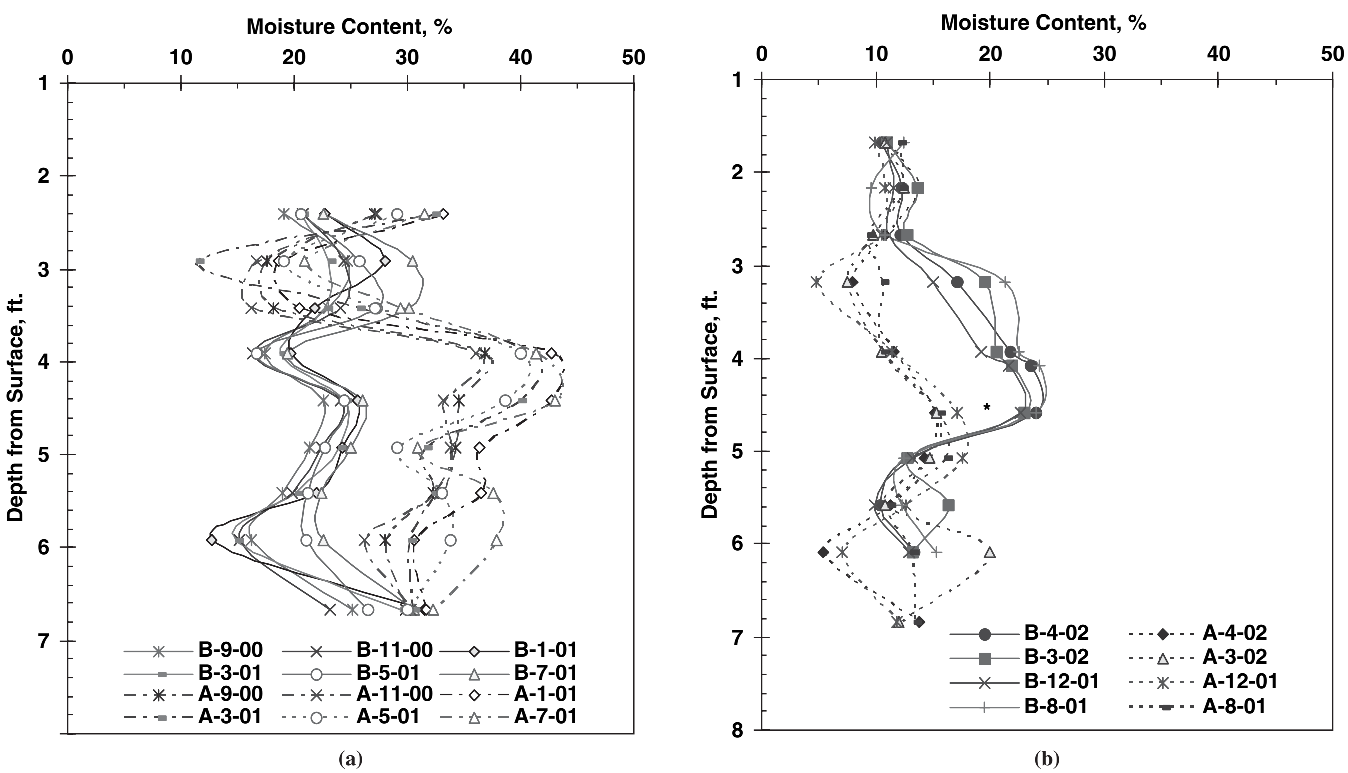


FIGURE 2 Subgrade moisture content profile at different months for (*a*) Moscow and (*b*) Weiser sites (A = rockcap, B = aggregate base layer).

ent seasons. For example, the curve noted as B-9-00 is for subgrade soil moisture under the aggregate base layer measured during September 2000. The figure indicates that there is some significant change in the subgrade moisture under the aggregate base and rockcap at the shallow depths just below the base or rockcap layer. It could be observed that the subgrade moisture content under the rockcap layer is, as expected, smaller than the moisture content under the aggregate base layer because of the higher drainage properties of the open-graded rockcap layer, whereas the opposite was noticed at the Moscow site. There, the moisture content under the rockcap layer was greater than the moisture content under the aggregate base layer. This could have occurred because the site at Moscow was confined (had no adjacent daylight ditch drain) and the groundwater coming from rainfall had no exit. Conversely, the rockcap at the Weiser site continued to the shoulder and water in the rockcap had an exit to the adjacent daylight ditch drain. Thus, if the pavement section has daylight drainage layer (open to a side ditch), the rockcap shows its effectiveness in draining the water out of the system. In a closed system like the one at Moscow, the water may seep vertically and cause an increase in subgrade moisture.

Figure 2 indicates that at greater depths (6.5 ft at the Moscow site and 5.5 ft at the Weiser site), there is no significant difference in the subgrade moisture content under both rockcap and base layers. This finding shows that the moisture increase is noticed only in the upper part of the subgrade just below the rockcap layer.

Figure 3 shows the average subgrade moisture content from the upper TDR sensors (just below the subgrade) versus time for both the Moscow and Weiser sites. The figure shows higher fluctuation in the moisture content for the early time period just after construction, especially at the Weiser sites, and then the moisture content moves toward long-term equilibrium with little seasonal fluctuation. This observation agrees with a similar study by Halliburton on subgrade soils beneath both rigid and asphalt concrete pavement (*11*).

Figure 3 provides two observations:

- In general, the subgrade moisture content at the Moscow sites is greater than those at the Weiser sites and
- The seasonal fluctuation in the subgrade moisture content at both Moscow sites is greater than those at the Weiser sites.

These observations support the authors' opinion in that the presence of the daylight ditch drain at the Weiser site helped in preventing the rainwater from entering the subgrade soil, thus there was no seasonal fluctuation and smaller subgrade moisture content. Conversely, because there is no daylight ditch drain at the Moscow sites, the water coming from rain penetrates to the subgrade soil, and, therefore, the moisture content showed seasonal fluctuation according to the rainy seasons.

This also can be confirmed from the data presented in Figures 4 and 5. The figures present the relationship between the average monthly moisture content and the average monthly rainfall. It could be observed that the seasonal variation in the subgrade moisture content almost has the same trend as the seasonal variation in the monthly rainfall. Conversely, there is no trend between the moisture content and the rainfall at the Weiser sites, because the water coming from

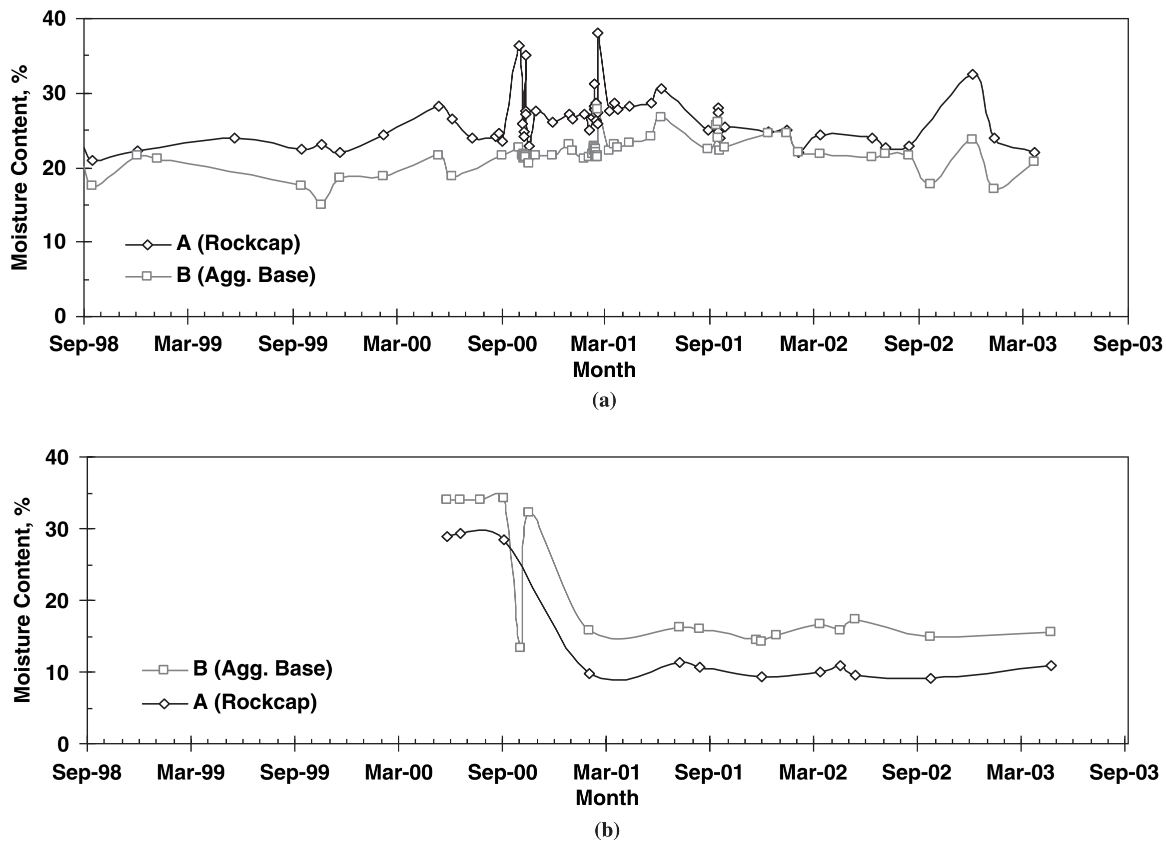
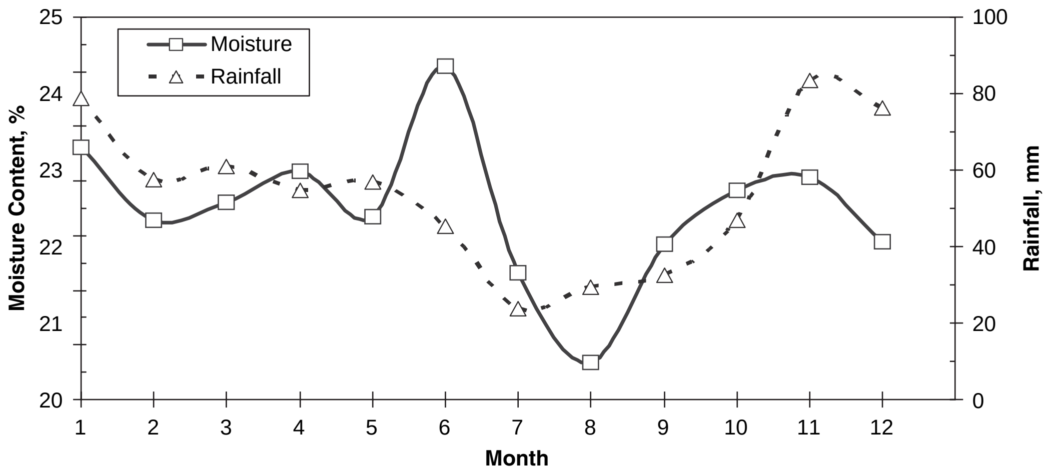


FIGURE 3 Average subgrade moisture content from upper two TDR sensors versus time for (*a*) Moscow and (*b*) Weiser sites.



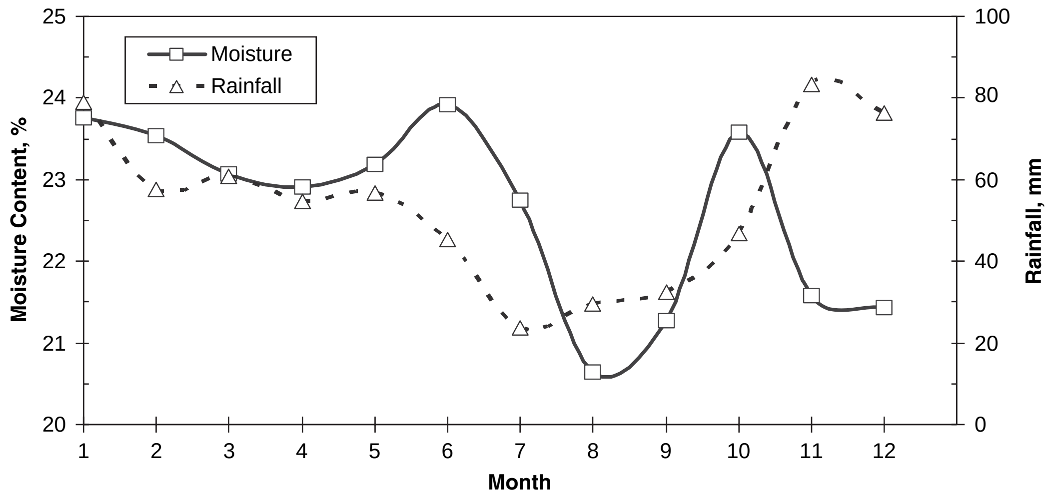


FIGURE 4 Average moisture content versus rainfall for Moscow sites: (*a*) rockcap and (*b*) aggregate base layer.

rainfall usually goes to the drainage system and does not penetrate to the subgrade as discussed before.

Impact of Rockcap Base Layer on Pavement Structural Capacity

The previous analysis showed that the presence of the rockcap layer in a closed pavement system like the one at Moscow may increase the subgrade moisture content. However, the contribution of the rockcap (because of its high modulus and no-freeze potential) is significant. The expected reduction in subgrade modulus, if any, caused by moisture increase under the rockcap layer could be superseded by the high modulus of the rockcap layer compared with aggregate base. Consequently, reduction of thickness is likely with pavements with rockcap base. This section discusses the effect of the rockcap layer on the pavement structural capacity using the results of FWD tests performed at both Moscow and Weiser sites.

Figure 6 shows the FWD vertical deflection at the Moscow sections with rockcap and aggregate bases during 4 different years. The figure presents the vertical deflections measured at various distances from the applied load. The figure shows that the recorded deflections at the pavement section with rockcap layer are less than at the other section with aggregate base for the 4 years. This indicates that the pavement section with rockcap layer is always stronger than the section with aggregate base, even though the subgrade moisture content under the rockcap layer was greater.

Figure 7 show the same relationship for the Weiser sites for 3 different years. The figure also shows that the pavement section with rockcap layer is stronger than the section with aggregate base.

Multilayer Elastic Analysis

The MODULUS 5.1 software was used to backcalculate the layers' moduli for each of the pavement sections on the basis of the FWD deflections (*12*). The tensile strain at the bottom of the asphalt concrete (AC) layer and the compressive strain at the top of the subgrade soil, for both sections, were computed using the KENLAYER program (*13*). The strains were computed on the basis of the backcalculated layers' moduli and assuming the standard 18-kip axle load with 13.5-in. dual spacing and 80-psi tire pressure.

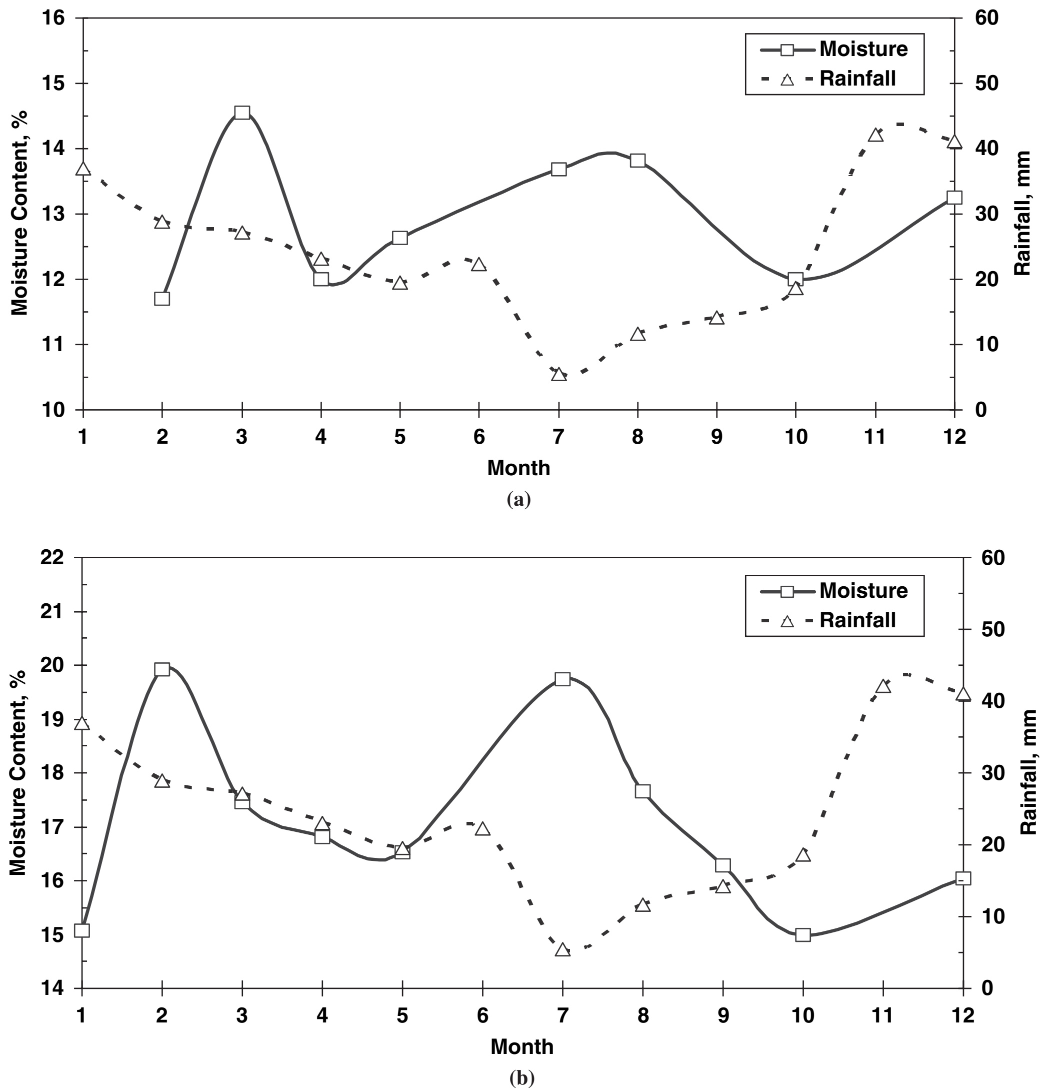


FIGURE 5 Average moisture content versus rainfall for Weiser sites: (*a*) rockcap and (*b*) aggregate base layer.

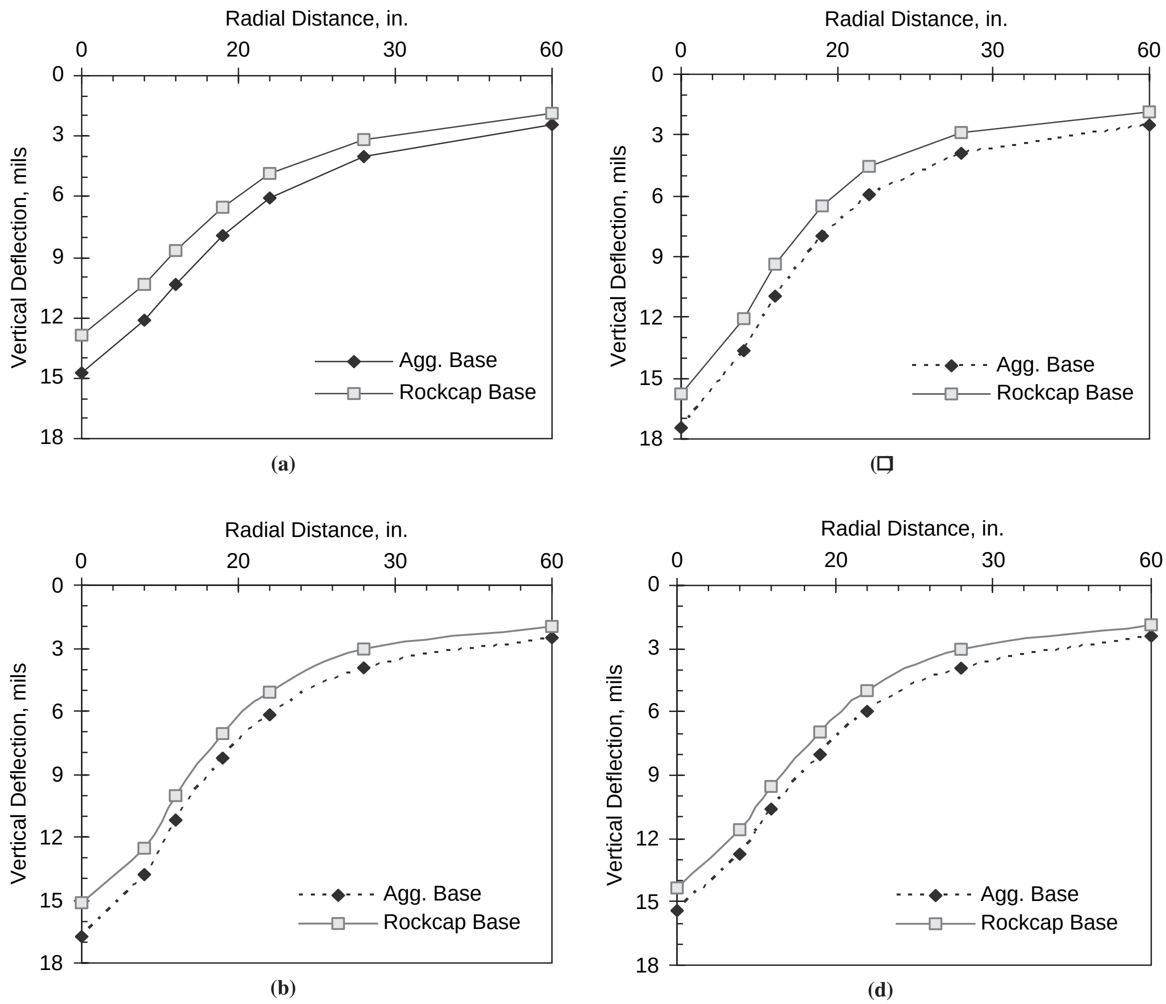


FIGURE 6 Vertical FWD deflection for Moscow sections with rockcap and aggregate bases: (*a*) October 1999, (*b*) September 2000, (*c*) September 2001, and (*d*) August 2002.

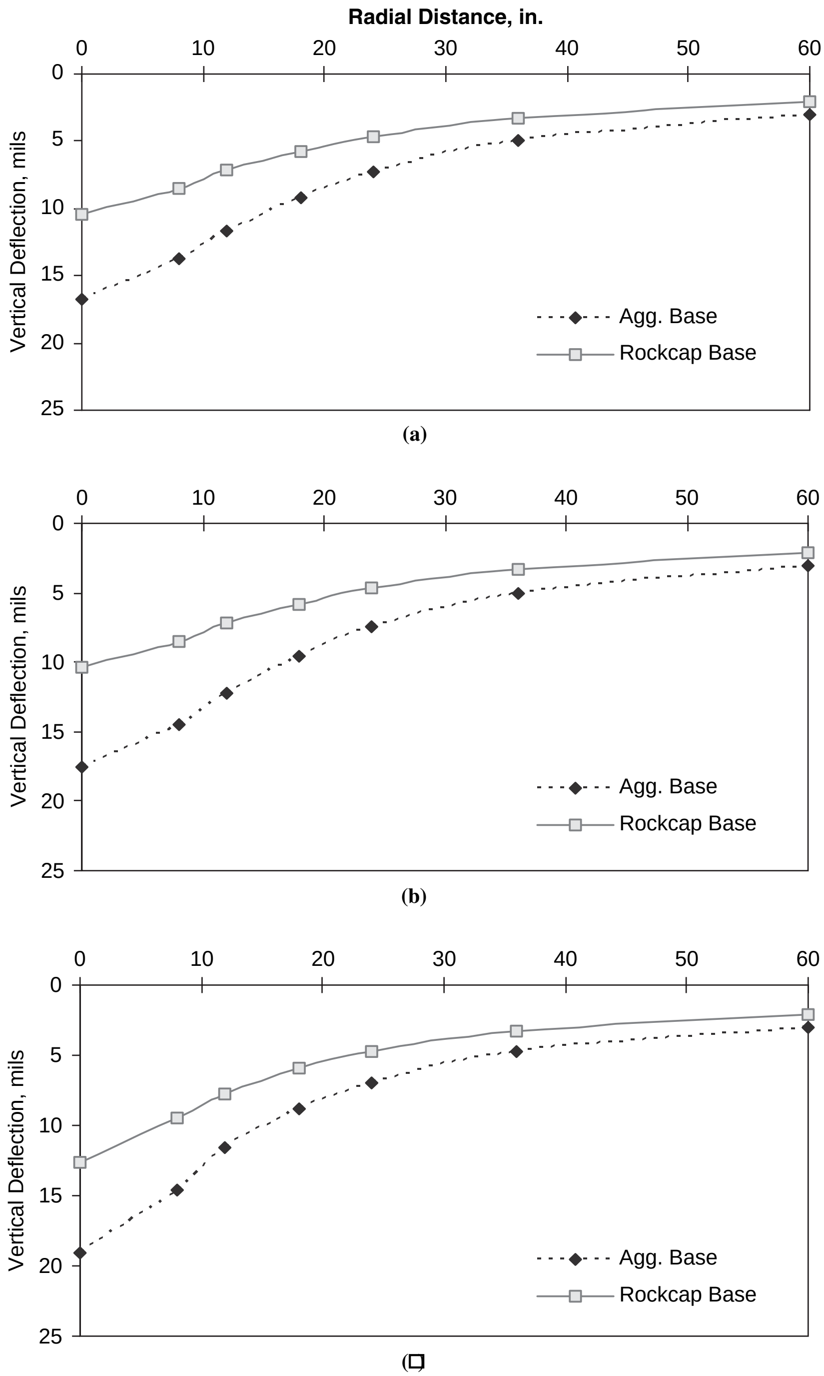


FIGURE 7 Vertical FWD deflection for Weiser sections with rockcap and aggregate bases: (*a*) October 2000, (*b*) November 2001, and (*c*) May 2002.

Figure 8 shows the computed tensile and compressive strains for the Moscow and Weiser sites. The figure indicates that the tensile strains are slightly smaller when rockcap is used rather than aggregate base. Conversely, the figure shows that the compressive strain at the top of the subgrade layer is highly reduced when the rockcap layer is used. The reason is that the contribution of the rockcap–aggregate base modulus is greater when the compressive strain on the surface of the subgrade is calculated, whereas the AC tensile strains are mainly affected by the AC modulus, which is almost the same for both sections.

Estimating Allowable Pavement Life for Sections With and Without Rockcap Layers

The mechanistic–empirical design methods for flexible pavements were based on the assumption that the pavement life is inversely proportional to the magnitude of the traffic-induced pavement strains. Two competing failure mechanisms were typically assumed to be related to the pavement design. These two failure mechanisms are the cracking caused by fatigue of the asphalt bound pavement layers and

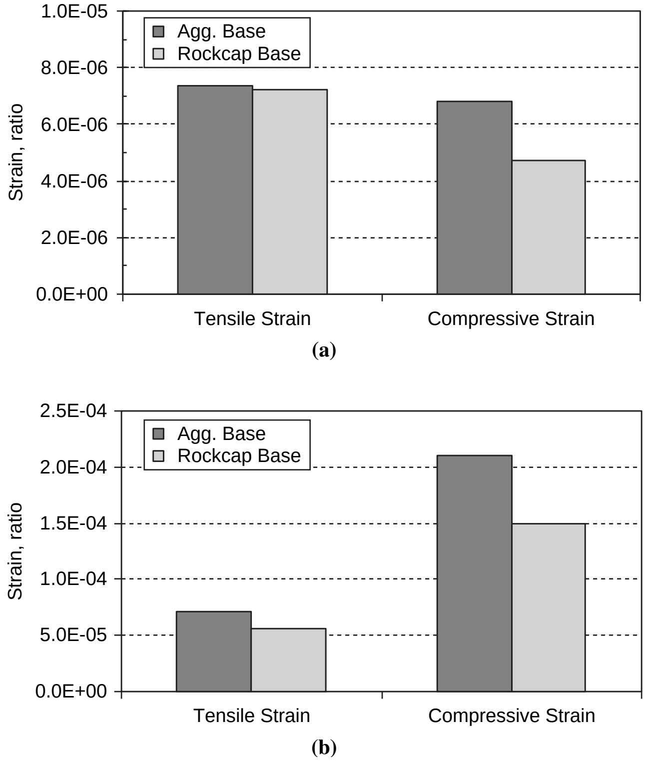


FIGURE 8 Computed tensile and compressive strains for (*a*) Moscow and (*b*) Weiser sections with rockcap and aggregate bases.

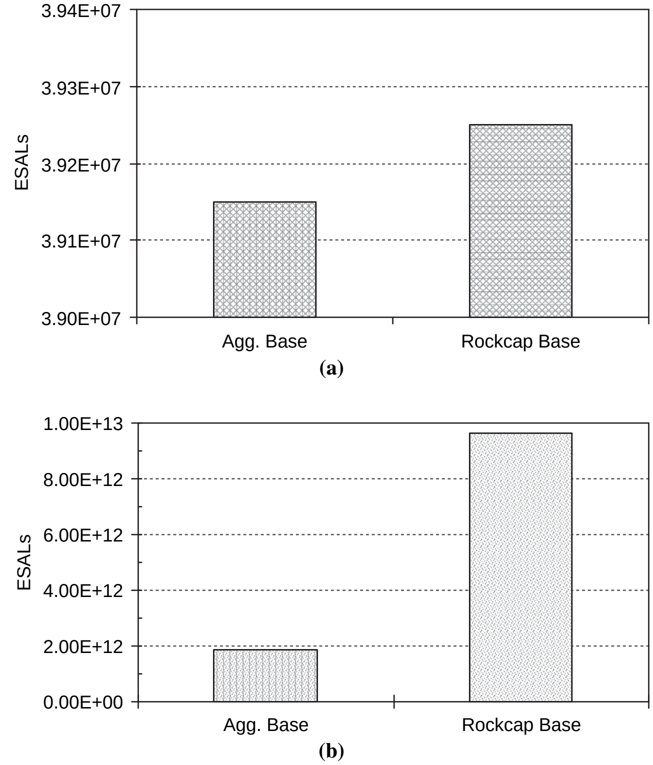


FIGURE 9 Predicted pavement life in equivalent single-axle loads for Moscow sections with rockcap and aggregate bases: (*a*) fatigue life and (*b*) rutting life.

the rutting caused by accumulated permanent deformations at the top of the subgrade soil.

Several models are available in the literature to predict the pavement performance on the basis of the predicted rutting fatigue failures. The performance models considered in this analysis were those included in the Asphalt Institute design manual (*14*). For fatigue cracking, the manual suggested the following performance model for standard AC mixes with an asphalt volume of 11% and air void volume of 5%:

$$N_f = 0.0796\, \epsilon_t^{-3.291}\, E^{-0.854} \tag{1}$$

where

N_f = allowable number of load applications,
ϵ_t = tensile strain at the bottom of AC layer, and
E = elastic modulus of the asphalt mixture (psi).

The rutting model incorporated in the Asphalt Institute design manual is given by the following equation:

$$N_{f2} = 1.365 \times 10^{-9}\ \epsilon_c^{-4.477} \tag{2}$$

where N_{f2} is the number of load repetitions to failure and ϵ_c is the compressive strain at the top of the subgrade. The predicted pavement life (number of repetitions to failure) is considered to be the lower of the number of repetitions to failure obtained from either the fatigue or the rutting models.

Figure 9 shows the predicted pavement life, in equivalent single-axle loads, for both sections of the Moscow site. The upper part of the figure indicates that there is no great difference in the predicted allowable fatigue life when rockcap or aggregate bases are used because the fatigue life is affected mainly by the AC modulus. However, the bottom part of the figure indicates that the rutting life is greatly increased (approximately five times) when the rockcap layer is used.

Figure 10 shows the predicted pavement life for the Weiser sites with rockcap and aggregate base layers. The upper part of the figure indicates that using rockcap layer increases predicted fatigue life to approximately 1.7 times that of the aggregate base. Conversely, the bottom part of the figure shows that the rutting life is greatly increased (approximately five times) when the rockcap layer is used.

CONCLUSIONS

On the basis of results of this study, the following conclusions can be drawn:

- The presence of open-graded rockcap base layer under the asphalt surface that serves as a drainage layer in the pavement system has shown two opposite effects on the subgrade moisture regime under the pavement. It helps in reducing the subgrade moisture content in pavements with daylight ditch drains as it facilitates water escape laterally to the side drains. However, the reverse may occur such that the subgrade moisture may increase if the rockcap layer is not continued to the edge drains. In this case, surface moisture entrapped in the rockcap layer will seep vertically and cause an increase in subgrade moisture.

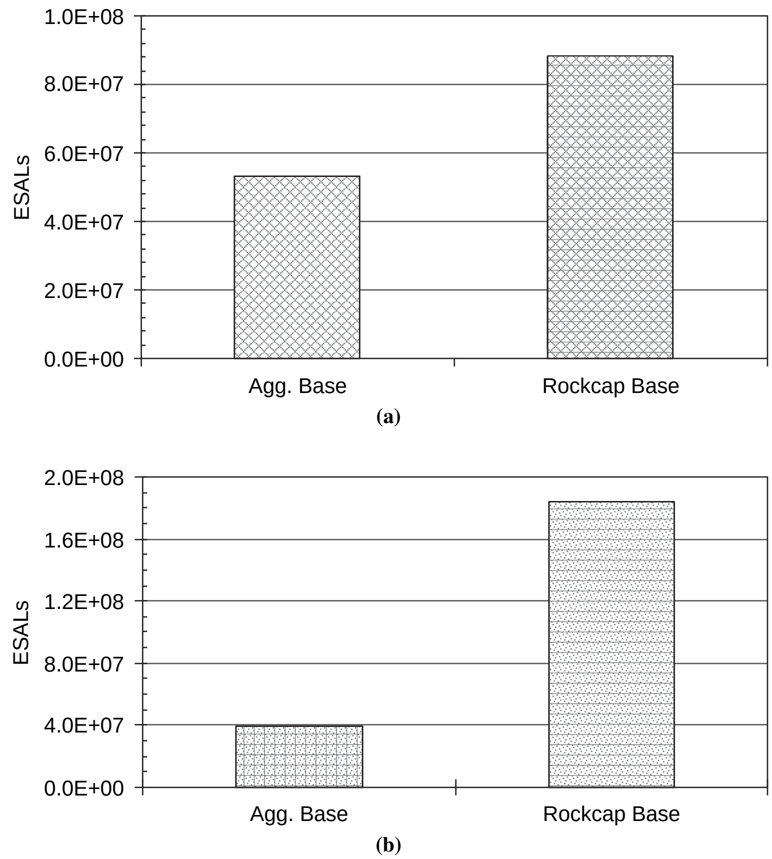


FIGURE 10 Predicted pavement life in equivalent single-axle loads for Weiser sections having rockcap and aggregate bases: (*a*) fatigue life and (*b*) rutting life.

- The rockcap base layer, however, contributes a great deal to the structure support of the pavement system and results in great increase in the pavement service lives. The performance analysis of the pavement sections having rockcap and aggregate base layers showed that the sections with rockcap layer were always stronger than the other sections with aggregate base even in the case where the subgrade moisture content under rockcap layer was greater. The predicted rutting life, for the pavement sections with rockcap layer, was approximately five times greater than for the other sections with aggregate base.

REFERENCES

1. Smith, R. M. *Open-Graded Rock Base Asphalt and Portland Cement Concrete Pavement.* Idaho Transportation Department, Boise, 1998.
2. Salem, H. M. *Quantification of Environmental Impacts on the Performance of Asphalt Pavements.* PhD dissertation, University of Idaho, Moscow, 2004.
3. Salem, H. M., F. M. Bayomy, M. G. Al-Taher, and I. H. Genc. Using Long-Term Pavement Performance Data to Predict Seasonal Variation in Asphalt Concrete Modulus. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1896,* Transportation Research Board of the National Academies, Washington, D.C., 2004, pp. 119–128.
4. Aly Salem, H. M., F. M. Bayomy, and M. G. Al-Taher. Prediction of Seasonal Variation of Subgrade Resilient Modulus Using LTPP Data. Presented at 82nd Annual Meeting of the Transportation Research Board, Washington, D.C., 2003.
5. Bayomy, F. M., H. M. Salem, R. Smith, M. Santi. Using LTPP Data to Assess the Impacts of Seasonal Variation of Subgrade Resilient Modulus on Overlay Mechanistic Design. Presented at the International Conference on Highway Pavement Data, Analysis and Mechanistic Design Applications, Columbus, Ohio, September 7–10, 2003.
6. DataPave 3.0. FHWA Document No. FHWA-RD-01-148. U.S. Department of Transportation, Washington, D.C., 2003.
7. DataPave. www.datapave.com. Accessed July 30, 2004.
8. Richter, C. A., and M. W. Witczak. Application of LTPP Seasonal Monitoring Data to Evaluate Volumetric Moisture Predictions from Integrated Climatic Model. Presented at 80th Annual Meeting of the Transportation Research Board, Washington, D.C., 2001.
9. Larson, G., and B. J. Dempsey. Enhanced Integrated Climatic Model Version 3.0. Applied Research Associates/ERES Division Staff, for upgrade with results from NCHRP 1-37 A, the 2002 Guide Development, 2003.
10. *MP-917 Technical Brief.* www.esica.com/_docs/tb01.pdf. Accessed June 23, 2006.
11. Halliburton, T. A. *Subgrade Moisture Variations.* Final Report, Research Project 64-01-3. School of Civil Engineering, Oklahoma State University, Stillwater, 1970.
12. Texas Transportation Institute. MODULUS 5.1 Software for Backcalculation of Pavement Layer Properties. Texas A&M University System, College Station, 1990.
13. Huang, Y. H. *Pavement Analysis and Design.* Pearson & Prentice Hall, Upper Saddle River, N. J., 2004.
14. Asphalt Institute. *Research and Development of the Asphalt Institute Thickness Design Manual* (MS-1), 9th ed. Research Report 82-2. Asphalt Institute, Lexington, Ky., 1982.

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