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INNOVATIVE DESIGN STRATEGY INCORPORATING TEMPERATURE EFFECT ON THE PENNSYLVANIAN PAVEMENTS

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ABSTRACT

The objective of this research is to develop an innovative design strategy capable of handling the temperature variations in the asphalt concrete layers. This strategy handles weak soils specific to Pennsylvania using a wide variety of variables consisting of standard deviations, traffic, MR, Delta PSI, surface course, base course. and subbase materials. For all designs, the surface course, and the base course contain minimum thicknesses as a function of traffic. The efficacy of expansive soil-limestone as subbase material was evaluated by designing and estimating flexible pavement thicknesses. The modified strength coefficients were used for designing the pavement sections in Pennsylvania. Based on this paper, it can be concluded that the subbase thickness has (i) a linear relationship with the structural number, and (ii) a nonlinear relationship with the change in serviceability index and the resilient modulus. In this innovative design strategy, the effect of temperature is built into the structural number. This is achieved by appropriately modifying the strength coefficient for the asphalt concrete layer.

KEYWORDS: *Expansive Soil, Innovative Strategy, Pavement Performance, Regression Analysis, Temperature, Effect*

Article History

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INTRODUCTION

Expansive soil is one of the difficult soils faced by civil engineers during construction of highways. It expands significantly with increase in its moisture content and shrinks when the moisture content is decreased. Severe damages occur to pavements and roads constructed with expansive soil because of this type of behavior (Sakai 1978). Excessive permanent deformation is one of the worst problems due to expansive soils. This in turn causes hydroplaning leading to severe accidents involving causalities and economic losses (Horne, 1963).

The state of Pennsylvania has a diverse geology. As a result, a wide variety of soils are present across the state. These include soils that have low bearing capacities such as soft clays as well as soils with high bearing capacity such as stiff clays. In addition, the state also has expansive soils that are capable of volumetric strains due to moisture fluctuations.

The objective of this research is to develop an innovative design methodology capable of handling the temperature variations coupled with additive working in tandem with the weak soils specific to Pennsylvania.

More Specifically, the Following are the Objectives

- To determine the effect of temperature on the asphalt concrete stiffness.
- To develop an innovative design procedure and design pavement structures covering a wide variety of variables consisting of standard deviations, traffic, MR, Delta PSI, surface course, base course, and subbase materials.

The designs capable of handling the temperature variations coupled with additive working to improve the weak soils performance in Pennsylvania and the critique on the results are new contributions from this research.

BRIEF LITERATURE REVIEW

Distress caused to the highway structure when constructed on expansive soils is significant and is well recognized by the research community (Brooks and Udoeyo, 2011) (Chen, 1988) (Pedarla, 2011). Among several additives, lime is the most extensively being used additive, and expansive soil stabilization with this additive is the common traditional practice being followed (Thompson, 1969). Lime stabilization is a widely used means of chemically converting unstable soils into structurally sound construction materials. Lime stabilization enhances engineering properties in soils, including improved strength; improved resistance to fracture, fatigue, and permanent deformation and also improved resilient. AI-Azzo (2009) had studied the stabilizing effect of crushed limestone on engineering properties of expansive clayey. The structural capacities of flexible pavements are greatly influenced by the stiffness of the asphalt concrete layer. The asphalt layer stiffness is a function of temperature. As the temperature of the asphalt increases, its stiffness decreases, leaving it less able to withstand wheel loads. A decrease in asphalt concrete stiffness results in higher stresses. For the pavement design engineer, temperature-induced fluctuations in structural capacity over time mean that pavement damage does not occur uniformly throughout the design life of the pavement (Inge, 1995). To design more cost-effective flexible pavements, these temperature effects must be considered in the design process (Tayebali, 1994). The latest AASHTO design procedure does not account for this variable. This is one of the highlights of this study.

Bituminous layers have properties which are dependent on the time of loading and temperature. Solutions have been given for cases where pavement materials possess simple viscoelastic behavior. (Freudenthal & Lorsh, 1957; Pister & Monismith, 1960; Pister & Westmann, 1963; Hoskin & Lee, 1959). Elastic analysis has been extensively used to find stresses in bituminous mixtures by assigning appropriate stiffness corresponding to the particular time of loading and temperature. Monismith & Secor (1963) and Coffman et al. (1964) used equivalent time-dependent modulus for the asphaltic courses in the corresponding elastic analysis. Seed et al. (1961) used resilient moduli from repeated load tests and used the elastic layered theory.

MATERIALS

The scope of this research contains a study of the larger selection of pavement materials (than mentioned in the literature review) specifically suitable for Pennsylvanian conditions.

Soil

The bulk soil samples used were obtained from borrow pits at three separate sites in Pennsylvania. The three soils are classified as lean clay (CL) according to the Unified Soil Classification System (USCS) and as A-7-6 according to the AASHTO system.

Limestone Dust (LSD)

The limestone dust used was the AASHTO #10 LSD, obtained from Rohrers Quarry, Inc., in Lititz, Pennsylvania. The LSD was the hydrated commercial grade.10 % LSD gave the best performance results from the PI, CBR, and Swell tests.

The three soils have high clay content. The subbase course materials are lime treated clay with a strength coefficient of 0.16 and sandy gravel with a strength coefficient of 0.11. It is important to note that when treated with LSD (strength coefficient 0.16), the weak clay becomes stronger than untreated sandy gravel (strength coefficient 0.11).

Asphalt Concrete Mix

12.5 mm SUPERPAVE surface mix has been used for its high stability with the PG 64-22 binder. The aggregate gradation is AASHTO dense gradation.

TESTS

Three identical control sample (untreated natural) soil were prepared for comparison purposes. The following are the tests that were conducted adhering to the ASTM standards: Atterberg limits, Compaction, California bearing ratio (CBR), Unconfined Compressive Strength (UCS), and Swell.

METHODOLOGY

Different percentages of crushed limestone dust added were 2,4,6,8, and 10%. It was found that there was a reduction in the plasticity of the clay and significant decrease in the expansion (Little, 2000).

In this research 95% liability is selected. This is suitable for the design of interstate highways. The variations in the design parameters are accounted by 4 standard deviations of 0.2, 0.35, 0.5 and 0.6. In order to handle the busy highways of the commonwealth of Pennsylvania 10 traffic values are chosen: 0.05, 0.1, 0.3, 0.5, 1, 3, 5, 10, 30, and 50 million standard axels. The following 5 resilient modulus values determined by the laboratory tests represent the stiffness characteristics of soils in Pennsylvania: 4.5, 6, 8.3, 10.5, and 14.5 Ksi. The loss of serviceability index due to the usage of pavement is represented by the following 6 values: (0.05, 1, 1.5, 2, 2.5, and 3). Two surface course and two base course materials were used. The surface course materials are hot mix asphalt and recycled in place asphalt. The base course materials are crushed stone and lime-treated base.

The surface course materials are Hot Mix Asphalt with a strength coefficient of 0.44 and in place-recycled mixture with a strength coefficient of 0.2

The base course materials are crushed stone with a strength coefficient of 0.14 and lime-treated base with strength coefficient of 0.22.

The subbase course materials are lime treated clay with a strength coefficient of 0.16 and sandy gravel with a strength coefficient of 0.11.

The AASHTO design procedure is based on fulfilling the following structural number equation.

$SN = a_1D_1 + a_2D_2 + a_3D_3$ Where:

- a_1, a_2, a_3 = structural-layer coefficients of the wearing surface, base, and subbase layers, respectively.

- D_1, D_2, D_3 = thickness of the wearing surface, base, and subbase layers in inches, respectively.

The design started with determining the effect of the LSD as an additive to the subbase material. Subsequently, the effect of the temperature variation on the surface course and its effect on changing the stiffness coefficient for HMA and recycled mix in place were determined.

Asphalt Concrete

The following method is used to determine the effect of temperature on the surface course stiffness.

Step 1: Experimental Data for MAT and MPT

Three pits of asphalt concrete layer of 2 inches deep and 1.5-inch diameter were selected in Philadelphia. The pavement temperatures at 2 inches deep were recorded for a selected 9 values of air temperatures.

Repeatability

For the known air temperature (Independent variable) three pavement temperatures (dependent variable) were measured. It is confirmed that the repeatability of the dependent variable is within the acceptable limits of accuracy of 1%.

Table 1: Shows the Experimental Data Containing 27 Values for the Pair of Air and Pavement Temperatures Measured at the Three Pits.

Table 1: Air and Pavement Temperature at Pits 1, 2 and 3.

Air Temp. °F	Pit 1	Pit 2	Pit 3
	Pavement Temp. °F @2" Depth	Pavement Temp. °F @2" Depth	Pavement Temp. °F @2" Depth
83.1	99.3	99.1	99.5
82.4	98.4	98.6	98.2
83.6	99.9	99.5	100.4
75.9	90.5	90.9	90.1
75.2	89.7	90.3	89.2
76.4	91.2	90.7	91.6
72.2	86.1	86.1	86.2
71.5	85.2	85.5	85
72.7	86.7	86.5	86.9

Step 2: Development of Regression Equation between MAT and MPT

The following regression equation was developed using the experimental data shown in Table 1.

Mean Pavement Temperature = 1.21*MAT – 1.29

Step 3: Calculations

Room Temp. = 68 F = AASHTO design-based temperature.

The corresponding Mean Pavement Temperature = 1.21*68 – 1.29 =81.0 = 27.2 C

A loading time of 0.1 sec. is selected. Using the graph, Figure 1 (Shell International, 1978) showing the relationship between loading time and stiffness, stiffness values are determined for the selected pavement temperatures shown in step1 and Table 1.

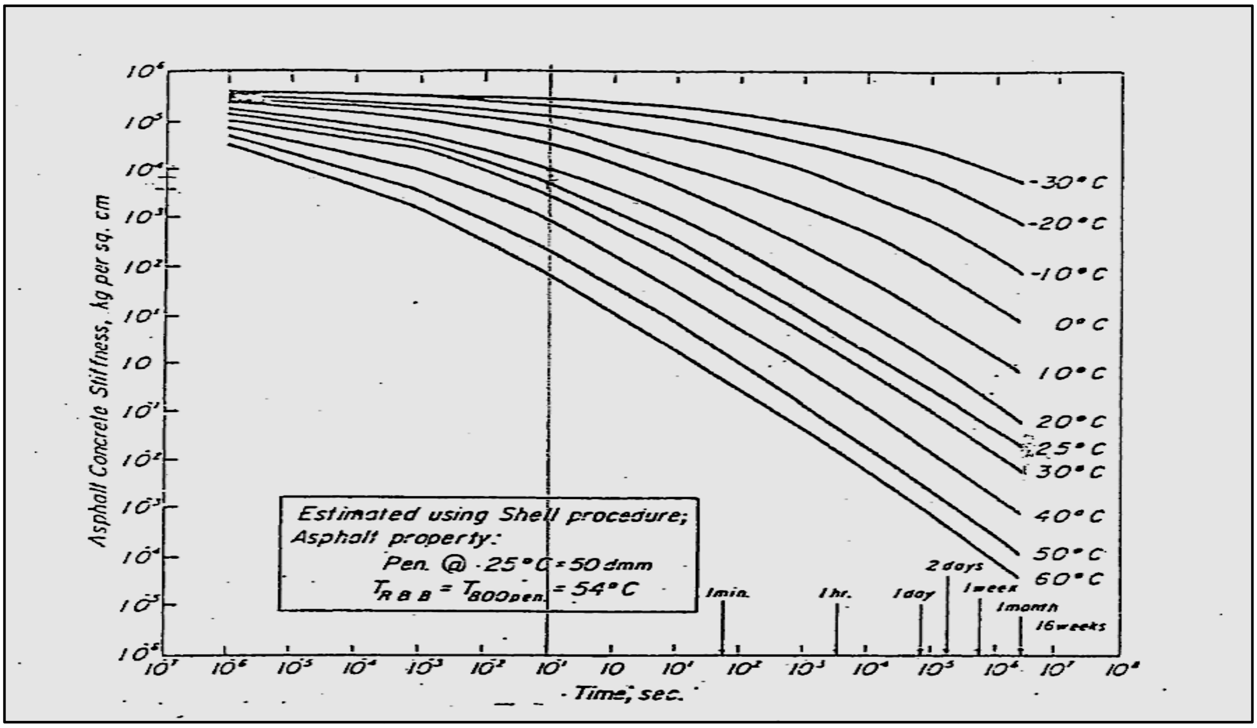

Figure 1: Variation of Asphalt Stiffness with Time and Temperature (Shell International, 1978)

From the graph Stiffness is equal to 4,800 Kg/cm^2 = 68,272 Psi.

Step 4: Correction of AASHTO strength coefficients for asphalt concrete

Table 2 shows the average air temperature for the hottest three months in Pennsylvania (NOAA - National Weather Service). This contains the worst-case scenario representing the temperature effect of the entire year on the pavement.

Table 2: Mean Monthly Air Temperature in PA for June, July and August 2018.

Temp. in F / Month	June	July	August	Average
High Temp.	83	87	85	85
Low Temp.	69	69	68	68.7
Average	76.0	78	76.5	76.8

The Mean hottest 3 months (June, July, August) Air Temperate MAT for Pennsylvania State in 2018 = 76.8 F. the corresponding mean pavement temperature: The corresponding Mean Pavement Temperature = 1.21*MAT – 1.29

MPT in Pennsylvania = 1.21*76.8 – 1.29 = 91.6 F = 33.1 C

From graph 1, Stiffness is equal to 2,000 Kg/cm2 = 28,446Psi

Change in stiffness = (4,800 – 2,000)/4800 = 2,800 / 4,800 = 58.33 % Reduction

The corrected AASHTO strength coefficient for HMA = 0.44 *58.33% = 0.257

The corrected AASHTO strength coefficient for Recycled Mix = 0.2 *58.33% =0.117

The corrected strength coefficients were used for designing the pavement sections in Pennsylvania representing a wide variety of conditions described in the Methodology section. The following are the detailed steps for designing the pavement sections. To affirm the validity of the procedure for the determination of asphalt concrete stiffnesses, 9 diametral tests were conducted at room temperature following the ASTM standard D- 6931.

The lab stiffnesses changes confirmed the stiffnesses changes obtained in this procedure within the accuracy of 2%.

RESULTS

All the designs are tailor-made for the construction of highways on the in-situ weak soils of PA covering a wide variety of traffic, weather, and material conditions.

For all the eight designs, the surface course and the base course contain minimum thicknesses as a function of traffic. The eight designs are designed minimizing the cost of construction.

The efficacy of expansive soil-limestone as subbase material was evaluated by designing and estimating flexible pavement thicknesses.

A graph showing the influence of structural number on subbase thickness. A linear relationship is shown with the equation (y = 6.25x – 5.10). The relationship is based on the following values: Reliability 0.95, Standard Deviation 0.2, traffic 0.05 million standard axles, Subbase MR 4.5 Ksi, Delta PSI 0.05, HMA surface course 1 inch, crushed stone base course 4 inches.

A graph showing the influence of the change in the serviceability index on subbase thickness. A nonlinear relationship is shown with the equation. The relationship is based on the following values: Reliability 0.95, Standard Deviation 0.2 traffic 1.0 million standard axles, MR 4.5 Ksi, HMA surface course 3 inches, crushed stone base course 6 inches.

A graph showing the influence of resilient modulus of subbase on subbase thickness. A nonlinear relationship is shown with the equation. The relationship is based on the following values: Reliability 0.95, Standard Deviation 0.5 traffic 5.0 million standard axles, Delta PSI 0.05, HMA surface course 3.5 inches, crushed stone base course 6 inches.

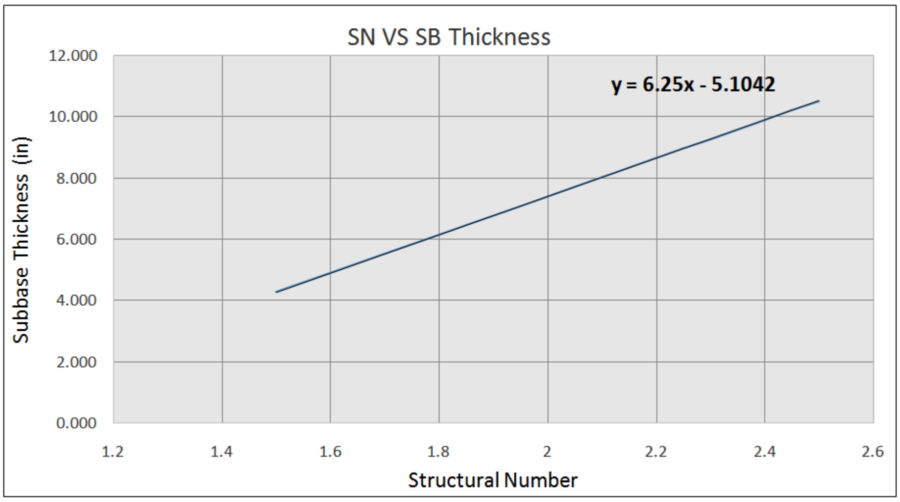

Figure 2: Influence of Structural Number on the Subbase Thickness

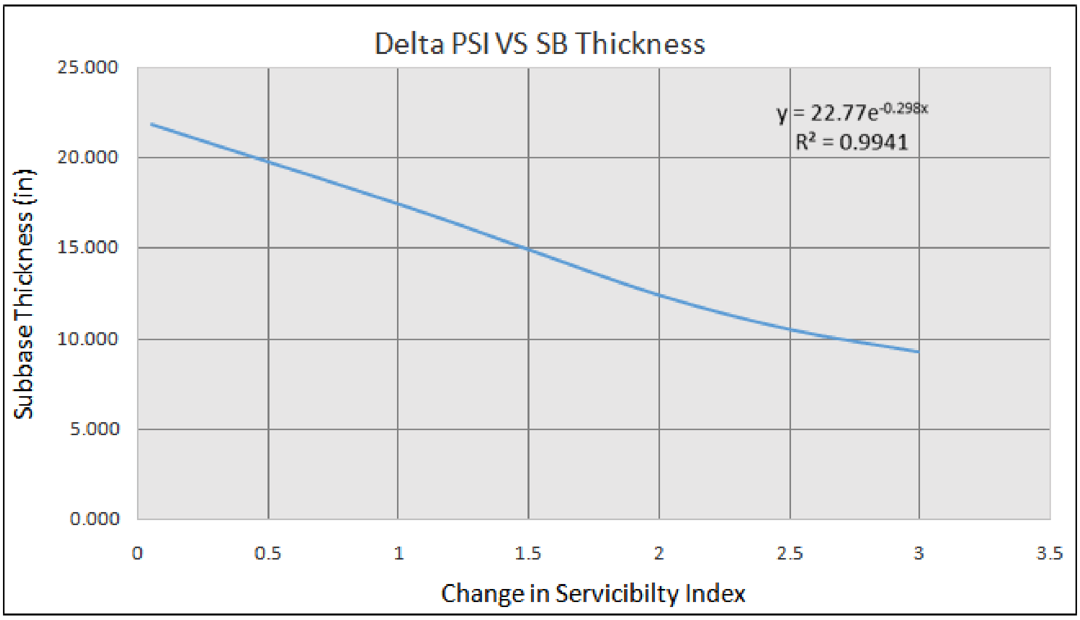

Figure 3: Influence of Serviceability Index Changeon the Subbase Thickness

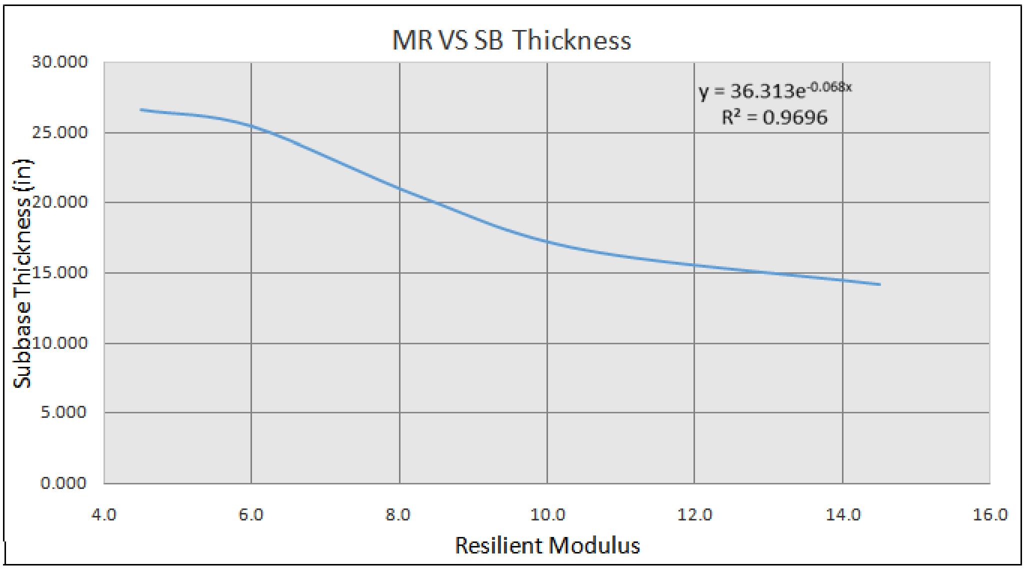

Figure 4: Influence of Resilient Modulus on the Subbase Thickness

CONCLUSIONS

The Following are the Conclusions

- In this innovative design strategy, the effect of temperature is built into the structural number. This is achieved by appropriately modifying the strength coefficient for the asphalt concrete layer.
- The subbase thickness has a linear relationship with the structural number with the following regression equation: $y = 6.25x - 5.1042$
- Subbase thickness has a nonlinear relationship with the change in serviceability index. This is described by the regression equation: $y = 22.77\ e^{-0.298x}$

- Subbase base thickness has a nonlinear relationship with the resilient modulus. The following regression equation quantifies the relationship: $y = 36.313e^{-0.068x}$

Disclaimer

The purpose of the paper is limited to research and education only. The paper must not be used in any form to design real-life pavement.

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