BACK

Foamed Asphalt Stabilized Reclaimed Asphalt Pavement: A Promising Technology for Mid-Western Roads

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ABSTRACT

Recycling of the materials obtained from the milling of asphalt pavements, known as RAP (Reclaimed Asphalt Pavement), involves mixing RAP with asphalt cement/emulsion and aggregates in definite proportions to produce a new asphalt concrete mix or cold-in place recycled mixture. However, in many cases, the RAP is unusable because it is not uniform (i.e. it may originate from different sources) or the underlying pavement does not provide adequate structural support. One solution to this inadequate support problem is construction of a base with full depth reclamation (FDR) materials stabilized with foamed asphalt. The process is also suitable for moist materials since the moisture is needed to accomplish base compaction. A research project was initiated at Kansas State University to estimate the structural contribution of the foamed asphalt stabilized bases in a typical pavement structure. Four pavement test sections, three with foamed asphalt stabilized bases and one with conventional crushed stone base, were constructed at the Civil Infrastructure Systems Laboratory (CISL). Falling Weight Deflectometer (FWD) tests were conducted before accelerating loading of these test sections. The layer moduli were backcalculated from the FWD deflection data and the structural layer coefficients were estimated following 1993 AASHTO Design Guide and other methodologies. The results show that the estimated structural layer coefficient of the foamed asphalt stabilized FDR base materials is 0.18. This indicates the promise of this recycled base material in pavement construction.

Key words: asphalt pavement—cold-in-place—foamed asphalt

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INTRODUCTION

Cold-in-place recycling is gaining recognition and popularity worldwide as a cost effective method of rehabilitating distressed asphalt pavements (*1*). In-place recycling requires the use of specially designed recycling machines with a mixing chamber. While the milling operation is taking place in the front part of the machine, the milled material passes through a mixing chamber where it is mixed with the stabilizing agent (lime, fly ash, bitumen emulsion, foamed bitumen or cement slurry). The mixture is then placed on the milled pavement and compacted. The process is carried out in a single-pass operation. The use of foamed bitumen as a stabilizing agent is not a new idea. Csanyi (1956) investigated the possibility of using the foamed asphalt as a binder for soil stabilization (*2*). Figure 1 shows the schematic of the asphalt foaming process. Foaming of the asphalt reduces its viscosity considerably and has shown to increase adhesion properties making it well suited for mixing with cold and moist aggregates. No chemical reaction is involved, only the physical properties of the asphalt are temporarily altered. When the cold water comes into contact with the hot asphalt, it turns into steam and then gets trapped in the asphalt as thousands of tiny bubbles. After a few minutes, the asphalt will regain its original properties once the steam evaporates.

The first reported use of foamed asphalt dates back to 1957 on an Iowa county road. Several other field applications were also reported including projects in Arizona (1960) and in Nipawin, Canada (1960-1962). The original process consisted of injecting high-pressure steam, at controlled pressure and temperature, into heated penetration-grade asphalt cement. This required special equipment on the job site, such as, a boiler and was not very practical. In 1968, Mobil Oil Australia modified the original process by adding cold water rather than steam, into a stream of hot asphalt in a low-pressure system (*4*). This made the process much more practical and economical. The foam was created within an expansion chamber after which it was dispersed through a series of nozzles, onto the aggregate mass. However, the nozzles were prone to blockage, and the manufacturer could not control the foam characteristics. Recently, Wirtgen GmbH of Germany, Soter of Canada, and CMI of Oklahoma City have developed new equipment for producing foamed asphalt.

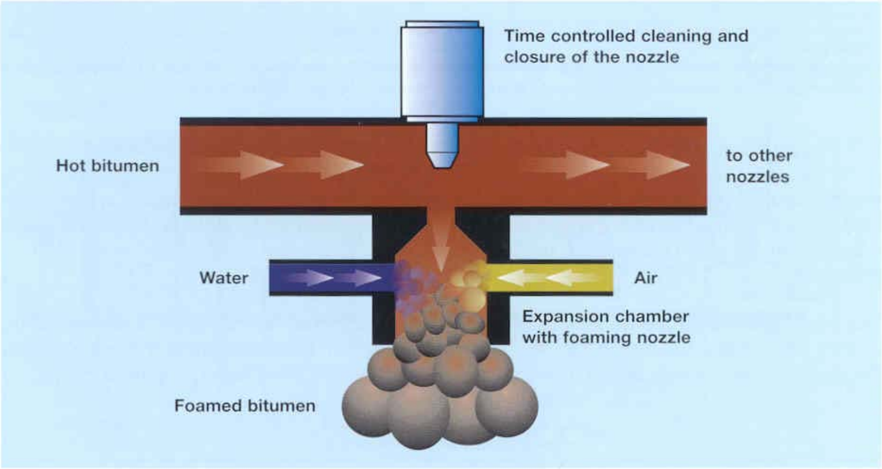

FIGURE 1. Schematic of the Foamed Asphalt Production (*3*)

Stabilization of RAP material with foamed asphalt has been tried in the United States and abroad. Roberts et al. (*5*) compared the performance of stabilized RAP material with foamed asphalt with those treated with cut-back asphalt and asphalt emulsion in the laboratory. Macaronne (*6*), Lancaster (*7*) and Ramanujam (*8*) reported successful stabilization with foamed asphalt of RAP material, both in-plant and in-place, in Australia. Van der Walt (*9*) have reported the use of foamed asphalt to stabilize RAP material in South Africa. Van Wijk (*10*) reported the successful use of foamed asphalt stabilization of the RAP material on two road sections in Indiana. The RAP material was obtained by milling only the top five inches of a distressed asphalt pavement and was, therefore, not contaminated with aggregates or soil.

In full-depth reclamation (FDR) of asphalt pavements, the salvaged material would contain not only RAP, but also aggregates from the granular base and in some case, soil from the subgrade. Thus it would be useful to determine if the foamed-asphalt stabilization is effective for the FDR materials, and what are the structural properties of this new material as bases in a pavement system.

OBJECTIVES

The goal of this research was to evaluate the structural performance of foamed asphalt stabilized base layers obtained from full-depth reclamation of an existing asphalt pavement. The objective was accomplished by doing structural testing on the flexible pavements with foamed asphalt stabilized bases.

MIX DESIGN

The laboratory mix design for the foamed asphalt stabilized base materials was done at the IADOT Central Materials Laboratory in Ames, Iowa. Sample aggregates, reclaimed asphalt pavement (RAP), soil, and the PG binder to be used in this project were shipped to IADOT to develop the mixture design. A Wirtgen Foamed Bitumen Laboratory Plant (WLB 10) was used in the mix design process. The optimum water content for foaming was found to be at 3% water injection rate at a binder temperature of 160˚C (320˚F). The added asphalt content at which the soaked indirect tensile strength of the mixture was maximum was taken as the design asphalt content. For this mixture, the design asphalt content was found to be 3%. Details of the mixture design can be found elsewhere (*11*).

TEST SECTION LAYOUT AND CONSTRUCTION

The test bed at CISL consists of two six feet deep pits, the North Pit (approx. 15 x 20 feet square) and the South pit (approx. 20 x 20 feet square). Four pavement sections were constructed in the pits, two in the North pit ((FDR-6 & FDR-9) and two in the South pit (FDR-12 & AGG-9). Figure 2 shows the schematic of the pavement cross sections. The existing subgrade material was silty clay. After removal and drying, the subgrade soil was recompacted in the pit to a density greater than 90% of the maximum dry density (MDD). Lane AGG-9 was constructed with a nine-inch granular base. The material used in this base is classified as an AB-3 by the current KDOT specifications and consists of crushed limestone materials. The material has an MDD of 128 pcf at optimum moisture content of 10%. The granular base was compacted in three lifts, each having a thickness of three inches. Compaction was done using the vibratory plate compactor and very high densities were obtained.

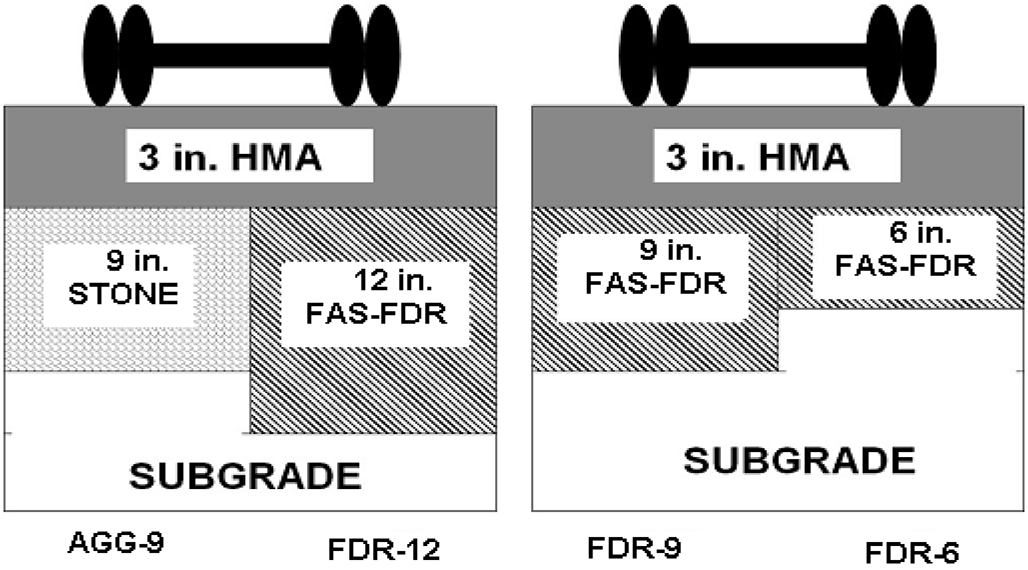

FIGURE 2. Cross Section of the Pavement Sections

Production of Foamed Asphalt Stabilized Material

The foamed asphalt stabilized base material was produced on the grounds of CISL in a portable plant of Wirtgen GmbH. of Germany. The plant consisted of a two-bin aggregate blending system and a chamber for mixing foamed asphalt with the full depth reclamation material blend. The RAP, aggregate and soil were stockpiled at the site. The soil and the aggregate were preblended, and then that mixture and RAP were fed with a front-end loader. The whole process was carefully controlled with a control panel on the plant. The produced material was collected on a dump truck and stockpiled for later use.

Construction of Foamed Asphalt Stabilized Base

The stockpiled stabilized material was transferred into the pit in the CISL with a bucket. Enough material was transferred at a time so that, after compaction, a three-inch layer of compacted FAS-FDR material will result. The material was raked to have a plane surface, and then compaction was done with a jumping jack-type compactor. The in-place density was monitored with a nuclear gage and was found to be satisfactory.

Construction of the Asphalt Concrete Surface Layer

The 3-inch asphalt layer above the base was placed in one lift on all lanes in two pits. The compaction was done with a steel-wheeled vibratory roller. The asphalt layer consisted of a ½ in. (12.5 mm) nominal maximum size Superpave mixture. The combined aggregate gradation (dry) of this mixture, designated as SM-12.5B in Kansas, passes below the maximum density line in the sand sizes.

Falling Weight Deflectometer (FWD) Testing

FWD testing was performed by KDOT personnel on two separate dates before loading began on these sections. The tests were performed at six stations on each test lane as shown in Figure 3.

For stations 1, 2 and 3 the geophones were oriented toward the East. For stations 4, 5 and 6 the geophones were oriented toward the West. Stations 3 and 4 were at the same location, in the center of the lane, but the geophones were directed to the East for station 3 and to the West for station 4. The FWD testing sequence consisted of three drops at 6,000 lbs load level followed by five drops at 9,000 lbs load level. The seven geophones were placed at 0, 8, 12, 18, 24, 36 and 60 inches from the center of the FWD loading plate. The deflections recorded for the last drop at 6,000-lb load level and the last two drops at the 9,000 lb-load level were used to backcalculate the elastic moduli of the pavement layers.

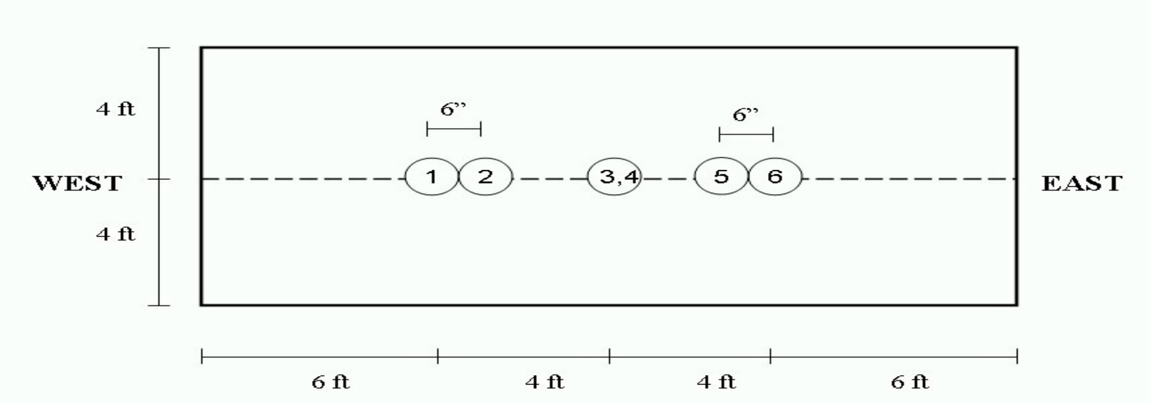

FIGURE 3. Location of the FWD Test Stations

Backcalculation of Layer Moduli from the FWD Deflections

The backcalculation analysis was performed using MODULUS 4.0 backcalculation program. The backcalculated asphalt layer moduli were not corrected to the standard temperature of 68°F since the temperature at the bottom of the asphalt layer varied only between 67°F and 72° F during FWD tests. The average values of the backcalculated moduli, backcalculated at the 9,000-lbs load level, for the six FWD stations are plotted for each pavement layer in Figure 4. Figure 4 indicates that the backcalculated asphalt layer moduli had large variabilities for the six FWD test stations. Moduli are also quite different for the four pavement sections, despite the fact that the same HMA mix was used in paving. This large variation can be attributed to the fact that the asphalt layer thickness of the constructed pavements varied along the pavement sections. Some variabilities between the test drops were also observed. Figure 4 also indicates that the backcalculated modulus for the foamed asphalt stabilized FDR material is always higher that the backcalculated moduli for the AB-3 granular base material. This indicates that the stiffer foamed asphalt stabilized FDR material base may assure a better protection to the soil subgrade than the conventional AB-3 granular base. The average backcalculated subgrade soil modulus is close to 15,000 psi for lanes FDR-6, FDR-9 and AGG-9. Higher values of around 20,000 psi were obtained for the lane FDR-12.

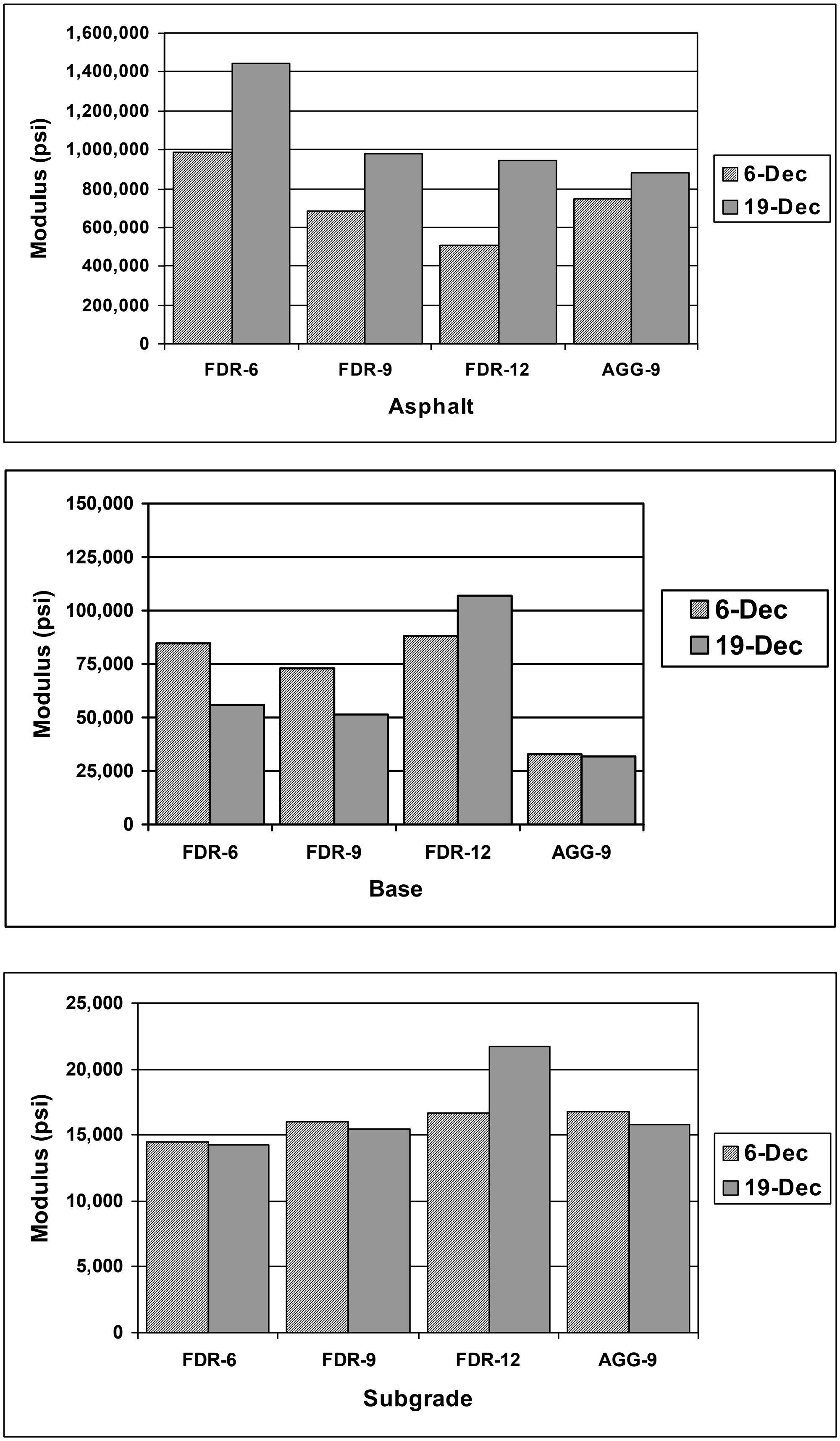

FIGURE 4. Backcalculated Layer Moduli

BASE LAYER STRUCTURAL PERFORMANCE EVALUATION

Currently, there is no standard method for the determination of layer coefficients. Several methods have been used by different investigators to determine layer coefficients for certain paving materials (*12*, *13*, *14*). In this study, the AASHTO Design Method (*15*) and the Equal Mechanistic Approach were followed to determine the structural layer coefficient of the foamed asphalt stabilized FDR materials for base. In both approaches, backcalculated layer moduli values were used to determine the layer coefficient values.

AASHTO provides the following general equation for Structural Number (SN) reflecting relative structural contribution (using coefficients (a_i) and thickness (D_i)) and assuming no effect of drainage:

$$SN = a_1 D_1 + a_2 D_2 + a_3 D_3 + a_4 D_4 \quad (1)$$

Because the pavements structures in this study had only two layers on top of the subgrade soil, the Structural Number can be computed as:

$$SN = a_1 D_1 + a_2 D_2 \quad (2)$$

Assuming that the asphalt concrete layer had a thickness of h1= 3 inches, and a typical structural layer coefficient for the asphalt concrete would be 0.42 (i.e. a1=0.42), the structural layer coefficient for the base layer material can be computed as:

$$a_2 = [SN_{eff} - 0.42 * 3.0] / D_2 \quad (3)$$

where

a_2 - the structural layer coefficient for the base layer material;
SN_{eff} - the effective structural number; and
D_2 - the thickness of the base layer, in inches

The effective structural number (SN_{eff}) can be computed from the following equation given in the 1993 AASHTO Design Guide (*15*):

$$SN_{eff} = 0.0045 * D * E_p^{1/3} \quad (4)$$

where

D = total thickness of all pavement layers above subgrade (inch), and
E_p = effective modulus of the pavement layers above subgrade (psi)

In equation (4), E_p is determined after computing the backcalculated subgrade modulus (M_r) value. The AASHTO algorithm for determining M_r suggests that M_r be calculated from a single deflection measurement at a distance sufficiently large enough so that the point falls outside the stress bulb at the subgrade-pavement interface and the measured deflection is solely due to the subgrade deformation. The following equation is used to calculate the M_r value:

$$M_r = (0.24 P) / (d_r)*r \quad (5)$$

where

M_r = backcalculated subgrade resilient modulus;

P = applied load;
d_r = deflection at a distance r from the center of the load; and
r = distance from the center of the load.

To use a particular sensor deflection for estimating the subgrade resilient modulus, the sensor location must be far enough so that it corresponds to the deflection of the subgrade only, but also be close enough so that it is not too small to be measured accurately. AASHTO further suggests that the minimum distance be determined by the radius of the stress bulb (a_e) at the subgrade-pavement interface. This is accomplished by choosing the 3rd or 4th sensor arbitrarily and checking whether it falls outside a radial distance of $0.7a_e$ from the center of the load or not.

The calculated M_r value is used to calculate the equivalent pavement modulus, E_p that satisfies the equation:

$$d_0 = 1.5 * p * a * \left\{ \frac{1}{M_r*[1+(D/a*(E_p/M_r)^{1/3})^2\,]^{0.5}} + \frac{1 - 1 / \tilde{}\,[1+(D/a)^2]}{E_p} \right\} \tag{6}$$

where
d_0 = the temperature corrected (68˚F) central deflection, in inches;
p = load pressure, in psi;
a = load plate radius, in inches; and
M_r = subgrade resilient modulus, in psi.

The deflections used in the calculations for the base layer structural coefficients are those measured corresponding to the last drop at the 9,000 lbs load level, on December 6 and 19, 2001, before any loading was applied. The estimated structural layer coefficients of the base layer material for all FWD test stations were computed and then averaged for each lane. The average value of the layer coefficient for the foamed asphalt stabilized FDR base material is: FDR-6 – 0.16; FDR-9 – 0.15; and FDR-12 – 0.217. The overall average computed for the three lanes with foamed asphalt stabilized FDR material, $a_2 = 0.1756$.

The average value of the computed structural layer coefficient for the AB-3 granular base is 0.137, almost same as the value of 0.14 used by KDOT for the AB-3 granular base for the structural design of flexible pavements in Kansas. It is then reasonable to apply a simple linear correction to estimate the structural layer coefficient for the foamed asphalt stabilized FDR base material:

$$a_2 = 0.1756 \text{ x } (\ 0.14 / 0.137\ ) = 0.179 \tag{5}$$

Thus, the Falling Weight Deflectometer tests performed on the constructed pavements resulted in recommended structural layer coefficient for the foamed asphalt stabilized FDR base material of **0.18**.

CONCLUSIONS

Based on this study following conclusions can be made:

1. The foamed asphalt stabilized FDR material is a uniform material that can be placed and compacted easily, and can be efficiently used as base material in flexible pavements.

2. The effective structural number computed from the FWD deflections measured on the as-constructed pavements suggested a structural layer coefficient of 0.18 for the foamed asphalt stabilized FDR base material.

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