Accelerated Pavement Testing on Foamed Asphalt Base Materials

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ABSTRACT: This paper documents accelerated pavement testing (APT) results obtained from three full-scale APT test sections constructed and tested at the Louisiana Pavement Research Facility. In general, each section includes three layers and shares a common layer thickness configuration: 50.8 mm asphalt layer, 216 mm base layer and 305 mm subbase layer. The only difference was among the base layers: one section with a crushed stone base and the other two with different foamed-asphalt (FA) treated recycled materials. The two FA bases were designed strictly based on a standard design manual and supposedly would have a potential application in lieu of a stone base in a flexible pavement structure design. However, the APT results indicated that the two foamed asphalt base materials did not perform as expected. In fact, both field performances were found inferior to that of a crushed stone base when tested under an increased (heavier) APT wheel load. Forensic investigation revealed that one FA base was failed mainly due to its severe water susceptibility, while the other possessed both moisture and over-asphalting problems.

KEYWORDS: APT, foamed asphalt, pavement performance, stone base

1 INTRODUCTION

Foam asphalt treatment is a process that combines hot asphalt and small quantity of cold water in a chamber to produce asphalt foams that are incorporated into a base material. Foamed asphalt has been used sporadically in the United States since the late 1960s. The benefits of using foamed asphalt in pavement stabilization may be summarized as follows [9]: (a) an increase in strength over unbound materials, (b) a quick construction method, (c) lower cost than reconstruction, (d) immediate trafficking, and (e) improved durability and material resistance to moisture infiltration.

Initially satisfactory performance of using a foamed asphalt stabilized base material has been reported in many literatures (Csanyi, 1957, Roberts et al. 1984, Marquis, 2009, Mohammad et al. 2003). However, the long-term performance of using this type of base material is not certain. The Maine Department of Transportation recently published a report on using foamed asphalt as a stabilizing agent in a full depth reclamation project (Marquis, 2009). From the first five-year performance results (i.e. rut depth, cracking, IRI and structural number), a section containing 76-mm hot mix asphalt (HMA) and 203-mm foamed asphalt stabilized full-depth reclamation base ("Foamed section") did performed slightly better than a section with 101.6-mm HMA and full-depth reclamation base without foamed asphalt treatment ("Regular section"). The cracking data also showed that the "Foamed section" had significantly less amount of cracking than the "Regular section" during the first four years. However, the transverse, longitudinal, and load cracking on "Foamed section" increased to about the same level as the "Regular section" during the fifth year. However, the reason for such a rapid increase in cracking in the fifth year in the foamed asphalt section was not investigated. Another study indicated that a foamed asphalt treated base material could have severe moisture susceptibility problem that caused a premature pavement failure due to extensive surface distresses (e.g. rutting and cracking) for a warranty project in Texas (Chen et al. 2006).

This paper is intended to document the performance of two foamed asphalt treated reclaimed asphalt pavement (RAP) base materials under an APT experiment.

2 FULL-SCALE ACCELERATED PAVEMENT TESTING

2.1 Pavement Structures, Materials, and Instrumentation

Three full-scale pavement sections (each 33.0-m long by 4.0-m wide) were constructed in this APT experiment at the Pavement Research Facility (PRF) of the Louisiana Transportation Research Center (LTRC). Figure 1 presents the corresponding pavement structures of test sections. Section 4-2B consisted of a 50-mm HMA wearing course, and 216-mm crushed stone base course, and 305-mm soil treated with 8% cement subbase (hereafter referred as the "stone" section). Section 4-3A consisted of a 50-mm HMA wearing course, and 216-mm foamed asphalt of a blend of 50% RAP and 50% recycled soil cement (SC) base course, and 305-mm cement soil subbase (hereafter referred as the "FA/50RAP/50SC" section). Section 4-3B included a 50-mm HMA wearing course, and 216-mm foamed asphalt of 100% RAP, and 305-mm cement soil subbase (hereafter referred as the "FA/100RAP" section).

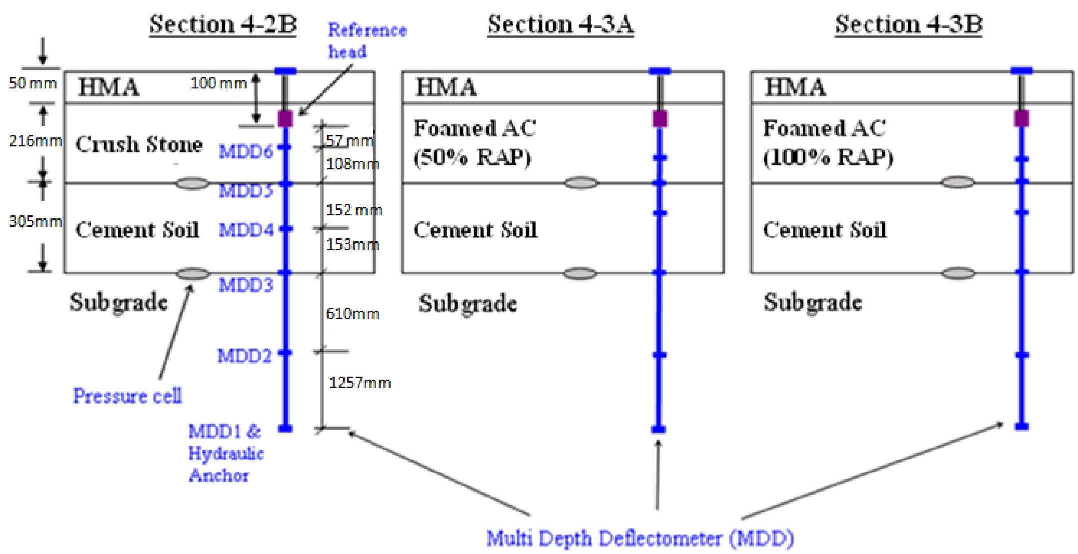


Figure 1: Pavement structures and instrumentation layout of APT test sections

Note that all three sections were built on top of a silty clay soil embankment. The HMA wearing course mixture was a 19-mm Superpave mix designed at 100 gyrations with a 4.4% PG76-22M binder (Wu et al. 2009). The two foamed-asphalt treated bases were designed according to the Wirtgen's foamed asphalt design procedure (Wirtgen 1998) and used different percentages of RAP and recycled soil cement (SC) mixtures. Table 1 presents a design summary for the two foamed-asphalt RAP materials.

The stone layer in Section 4-2B was a regular crushed stone base specified as Class-II base course in Louisiana road design specification (LADOTD, 2006). The cement soil subbase was an in-place treated soil with 8 percent cement by volume. The treated soil was a silty clay, the same soil used for the embankment, which may be classified as an A6 soil type according to the AASHTO soil classification (Wu et al. 2009).

Table 1: Design data of foamed-asphalt RAP bases

Property	FA/100RAP	FA/50RAP/50SC
Asphalt Type	PG58-22	PG58-22
Expanded Asphalt Cement added (%)	2.5	2.8
ITS—Dry (min), kPa	365.5	322.2
ITS—Wet (min), kPa	345.5	256.6
Retained ITS (%) min	94.5	82.4
Selected moisture content	6	8
Bulk Relative Density (Mg/m^3)	2	1.88
Air Voids (%)	15.3	20.3

Figure 1 also presents the instrumentation layout of this experiment. For each section, two Geokon 3500 pressure cells were embedded at two depths directly under the center path. In addition, one multi-depth deflectometer (MDD) with six potentiometers (deformation measurement sensors) was installed on each test section along the centerline. More details about instrumentation of this experiment may be referred to elsewhere (Wu et al. 2009).

2.2 APT Loading and Field Measurements

The loading device used is called the accelerated load facility (ALF), which is a 33-m long accelerated loading device. The ALF wheel assembly models one half of a single axle with dual tires moving repetitively in one direction at a speed of 16.8 km/hr. In this experiment, the beginning ALF load was 43.4 kN in weight. The load was then raised by adding two more steel plates (each weighs 10.2 kN) onto the ALF to accelerate the APT testing of test sections.

Instrumentation responses (i.e. the MDD and pressure cell readings) were collected at roughly every 8,500 ALF load repetitions. Note that the responses were recorded under a left tire of the ALF dual tire assembly when the left tire of the dual tires was directly positioned on the top of an instrumentation device (i.e., pressure cell and MDD). Field measurements including surface deflections (measured using both Dynaflect and falling weight deflectometer (FWD)) as well as surface rut depths and crack mappings were conducted after each 25,000 ALF load repetitions (Wu et al 2009).

3 DISCUSSIONS OF TEST RESULTS

For the APT experiment, a test section would consider to have failed when pavement condition meets one of the following failure criteria, whichever comes first: (1) the average rut depth reaches up to 12.5 mm among eight measurement stations within the trafficked area of a section; (2) 50 percent of the trafficked area of a section develops visible cracks (e.g. longitudinal, transverse, and alligator cracks) more than 5 m/m^2.

3.1 Accelerated Loading Results

All three test sections had a rutting failure according to failure criteria set for this experiment. Some severe localized cracks were observed on all sections after the APT test. It should note that those localized cracks were directly resulted from large surface rut depths developed nearby.

Figure 2 presents mean measured rut depths with the number of load repetitions for the three sections tested. Each point in the figure represents an average value from eight measurement stations under the loading paths. As shown in the figure, for the first 175,000 load repetitions when the load level was at 43.4 kN, it is apparent that the two foamed asphalt sections (4-3A and 4-3B) performed similarly or even slightly better than the stone section. The mean rut depth at 175,000 repetitions was 3-mm for the FA/50RAP/50SC section, 6-mm for both the FA/100RAP and stone sections. Subsequently, as the load level increased to a higher load magnitude, both foamed asphalt sections exhibited a significantly higher rutting accumulation rate than the stone section. In the end, the stone section (4-2B) reached to the rutting limit (i.e. an average rut depth of 12.5-mm) at 282,000 repetitions, whereas, the FA/100RAP section reached at 230,000 repetitions, and the FA/50RAP/50SC section at 228,000 repetitions.

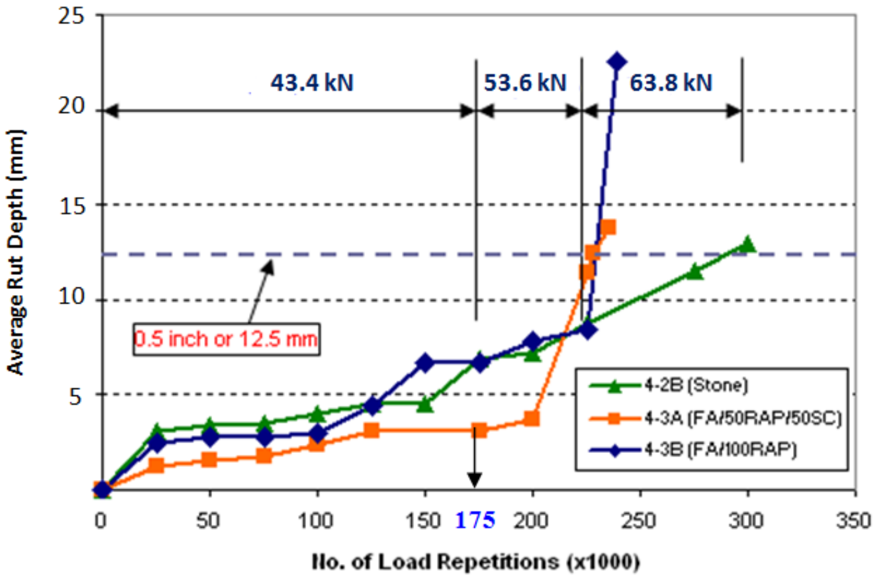


Figure 2: Measured rut depths on test sections

Such drastic increase in the rate of rutting for the two foamed asphalt test sections may be explained by the stress-dependence of pavement base materials based on the Shakedown theory (Sharp and Booker 1984). The Shakedown theory indicates that most pavement materials are stress-dependent and have a self-specific threshold stress level called the “shakedown load”. When limiting the stress level in a pavement material below its threshold stress, it will eventually respond in a resilient (elastic/shakedown) manner as the load repetitions increase. On the other hand, when continuously increasing the stress level and passing its threshold stress, the material will first go to plastic creep stage and eventually to a stage of incremental collapse. Obviously, the drastic increase in the rutting rates indicates that both foamed asphalt materials had gone into a stage of incremental collapse due to increase of the load magnitudes. Since both foamed asphalt base materials had an excellent early performance up to 175,000 repetitions when the load level was at 43.4-kN, it may be reasonably assumed that if the load level was kept at 43.4-kN, both foamed asphalt materials would possibly have performed equally well or even better than the stone base course.

3.2 FWD Test Results

Figure 3 presents variation of average FWD center deflections (D0s) measured at different load repetitions for the three test sections considered. Due to the excessive surface rutting, FWD results after 225,000 repetitions were not included. Noted that the measured D0s were first normalized to a load level of 40-kN and then temperature-corrected to 25 ^{o}C based on the BELL3 model (Lukanen et al. 2000). FWD center deflections are usually considered as an indicator related to an overall composite stiffness of a pavement structure, and a low D0-value is indicative of a potentially stiffer pavement structure.

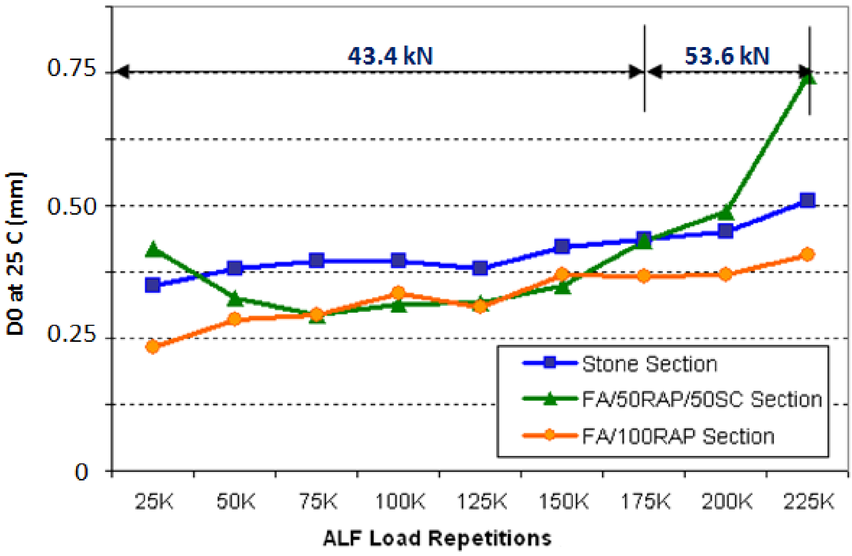


Figure 3: FWD center deflection results

As seen in Figure 3, all three sections showed an increasing D0 trend as load repetitions increased except those in first 50,000 repetitions on section 4-3A. Up to 150,000 repetitions, the two foamed asphalt test sections still had a lower D0 value than the stone section. Subsequent to 150,000 repetitions, the D0s on the FA/50RAP/50SC section started to take off and increased rapidly, indicating a fast deterioration inside the pavement structure of this section. In general, the D0 results are consistent with the measured rut depths in Figure 2 up to 225,000 repetitions.

Figure 4 presents backcalculated modulus values for the three base materials considered. EVERCALC, a FWD backcalculation computer program developed by the Washington

Department of Transportation (Pierce and Mahoney 1996), was used in the analysis. As shown Figure 4, the modulus values for both foamed asphalt materials decreased rapidly as the load repetitions increased. The rapid decrease of modulus is indicative of internal stiffness degradation or internal damages, which could be load-induced (e.g. shakedown failure) or environmentally-induced (e.g. the moisture effect), although partially due to the temperature effect. On the other hand, the moduli for the stone base seemed not very sensitive to either the load repetitions or load magnitudes. In addition, both foamed asphalt bases had a higher backcalculated modulus than the stone base up to 150,000 load repetitions, which is consistent with the D0 results.

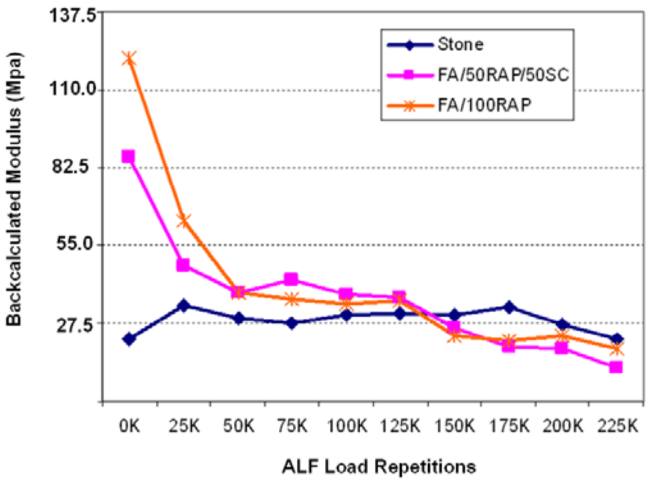


Figure 4: Backcalculated moduli for base materials

3.3 Instrument Responses to ALF Wheel Loading

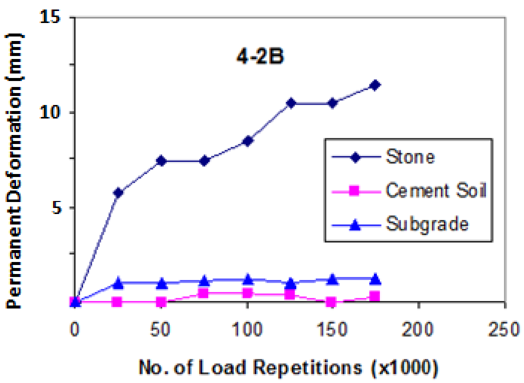
Table 2 presents a statistical summary for the pressure cell measurements in this experiment. Note that the results in Table 2 were up to 175,000 load repetitions only. Unfortunately, after 175,000 repetitions several pressure cells started to malfunction.

Table 2: Results of measured vertical compressive stresses

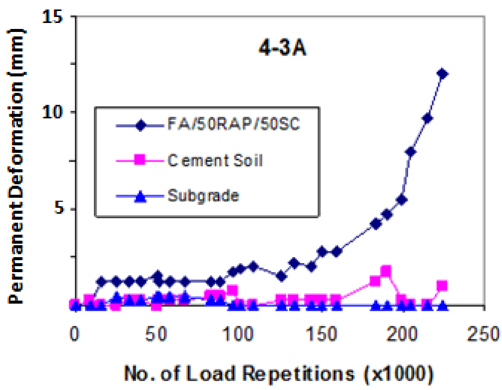
Section	Statistics	Vertical Stress (kPa)	
		At Bottom of Base	At Top of Subgrade
Stone	Avg	128.3	4.8
	Std	2.8	0.4
	COV	2.2%	7.7%
FA/50RAP/50SC	Avg	70.3	2.8
	Std	8.6	0.5
	COV	12.2%	18.5%
FA/100RAP	Avg	66.2	2.1
	Std	10.4	0.2
	COV	15.7%	9.7%

As shown in Table 2, the average vertical stresses developed at the bottom of base layers under an ALF dual-tire load of 43.4-kN were 128.3-, 70.3- and 66.2- kPa for the stone, the FA/50RAP/50SC, and the FA/110RAP sections, respectively; meanwhile, the corresponding average stress values on the top of subgrades were 4.8-, 2.8 and 2.1- kPa, respectively. In addition, the coefficients of variation (COV) of stress measurements were found generally higher for the two foamed asphalt sections than for the stone section, possibly due to: (1) a foamed asphalt base layer is temperature sensitive, (2) the moduli of the foamed asphalt layers were kept decreasing under the ALF load repetitions, Figure 4. In general, vertical stress measurements indicate that a higher vertical stress distribution generally exists within the stone section (4-2B) than those within the two foamed asphalt sections. This implies that, under a load of 43.4-kN, the stone layer in section 4-2B possesses a lower modulus value (which results in a higher stress) than both foamed asphalt base materials. This observation confirmed the FWD backcalculated results shown in Figure 4.

Figure 5 shows MDD measured permanent deformations versus the number of load repetitions for each pavement layers on sections 4-2B and 4-3A. MDD results of section 4-3B are not presented since they were similar to those of section 4-3A. As shown in Figure 5, the load-deformation curves for the two types of base materials differed significantly each other. The crushed stone base (Figure 5a) was found to develop significantly large permanent deformation during the first 25,000 ALF repetitions, and then the rate of change started to slow down till the end of the MDD measurements at 175,000 ALF passes. As shown in Figure 5b, the foamed asphalt layer on section 4-3A (FA/50RAP/50SC) initially developed very small amounts of permanent deformation for the first 100,000 ALF loading repetitions, and then picked up rapidly after 175,000 passes when the ALF load was increased (i.e. the shakedown failure). Based on the MDD permanent deformation results, it was found that the crushed stone had a Range B shakedown response, while the FA/50RAP/50SC base had a Range C shakedown response. More details can be referred to elsewhere (Tao et al. 2009).



(a)



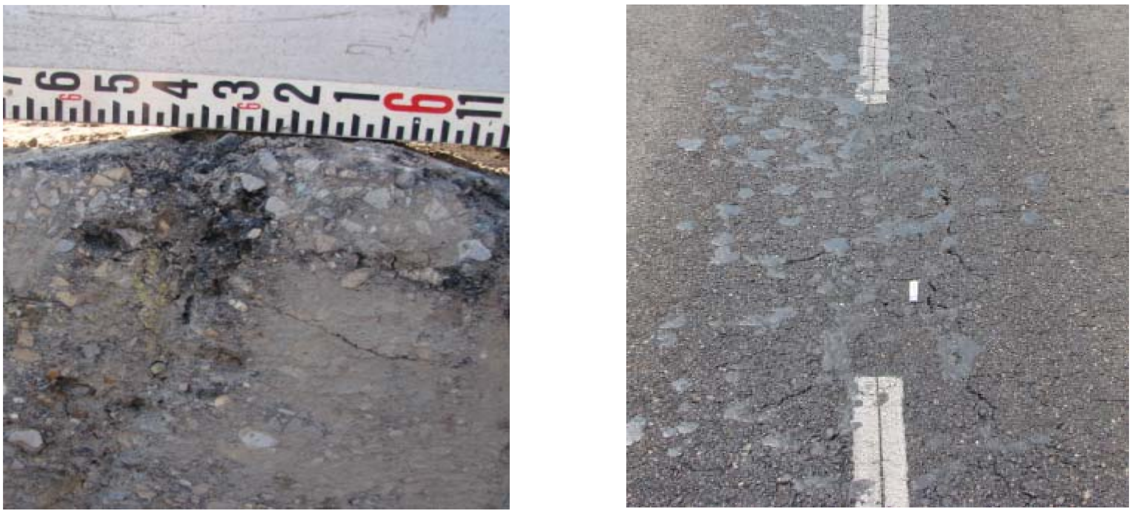
(b)

Figure 5: MDD measured permanent deformations

3.4 Failure Analysis of Foamed Asphalt Base Materials

The aforementioned Shakedown theory indicates that both foamed asphalt treated RAP bases seemed to have a smaller shakedown stress than the crushed stone base evaluated, which would be the reason for the early failure found in both foamed asphalt sections when the ALF load levels increased. However, it is still not known why those asphalt bounded materials (e.g. foamed asphalt treated) could possibly have a lower shakedown stress (that indicates a lower load carrying capacity) than a unbound crushed stone material.

Laboratory Hamburg rut tests did showed that both foamed asphalt materials exhibited low water resistance when tested in a submerged condition, and the FA/50RAP/50SC of section 4-3A exhibited even greater moisture susceptibility than the FA/100RAP of section 4-3B. A closer field survey further indicated that section 4-3A was failed primarily due to a large shear flow developed inside the foamed asphalt base layer (Figure 6a), whereas, the failure of section 4-3B was due to both shear deformations and excessive surface cracks (Figure 6b). In fact, it was noticed several months after construction (as shown in Figure 6b) that small droplets of asphalt binder material had seeped up through the surface of both foamed asphalt test sections and these droplets were much more noticeable on section 4-3B than 4-3A.



(a) shear flow in section 4-3A

(b) Surface cracks with asphalt droplets on section 4-3B

Figure 6: Failure photos taken from the two foamed asphalt sections

Further lab results indicated that the droplet binder material belongs to the asphalt emulsion material from the foaming of these test sections that had bled through the surface. Based on laboratory and field observations, the following hypothesis was made to explain why the two foamed asphalt treated RAP materials failed prematurely in this APT study:

The early failure of section 4-3A could be attributed to both water susceptibility and the weak aggregate skeleton of the FA/50RAP/50SC base mixture. First, free moistures could have entered into the FA/50RAP/50SC base layer through the surface cracks around the MDD of this section. Second, this mixture consisted of 48.6 percent RAP and 48.6 percent recycled soil cement. The design air voids was 20.3 percent (Table 1). The high percentage of recycled soil cement material had potentially produced a weak structural skeleton for the FA/50RAP/50SCmixture (i.e. too much soil particles). Therefore, only 2.8 percent foamed asphalt content may be not able to bond the weak aggregate skeleton effectively. Consequently, when high load-induced stresses transformed to this material under a moisture rich pavement condition, it lost its strength and started to develop a shear failure, Figure 6a.

The early failure on Section 4-3B could be attributed to both water susceptibility and over-asphalting of the FA/100%RAP mixture. The construction record showed that a MC-250 cutback asphalt was used as a prime coat on top of both foamed asphalt layers with a measured 0.25 gallons per square yard. Knowing that the FA/100% RAP mixture contained 97.5 percent RAP and 2.5 percent foamed asphalt. The aged RAP binders plus the foamed asphalt cement could have prevented the foamed asphalt mixture from absorbing the additional prime coat materials. Consequently, under the daily temperature change (especially during a summer), the free asphalt materials started to seep up through the top HMA layer. Such "seep-up" action not only caused a cosmetic problem, but also created many tiny crack paths inside the HMA mixture. Subsequently, free surface moistures could have entered into the base layer through the cracks and gradually weakened the strength of the material, eventually caused a premature shear failure.

4 CONCLUSIONS

The overall APT results indicated that all three test sections had a rutting failure. For the first 175,000 repetitions when the load level was at 43.4-kN, the two foamed asphalt sections: one with a foamed asphalt treated 50 percent RAP and 50 percent recycled soil cement base (FA/50RAP/50SC) and the other with a foamed asphalt treated 100 percent RAP base (FA/100RAP) were observed to perform similarly or even better than a crushed stone base section. However, as load levels increased, both foamed asphalt sections exhibited faster deterioration rates of rutting than the stone base. The Shakedown theory indicates that both foamed asphalt base materials seemed to have a lower shakedown stress than the stone base.

Forensic investigation indicated that the early failure on the FA/50RAP/50SC section could be attributed to both the water susceptibility and weak aggregate skeleton of the FA/50RAP/50SC mixture, whereas, the premature failure on the FA/100RAP section was due to the combination of poor water resistance and over-asphalting.

Since laboratory Hamburg test results confirmed that both foamed asphalt treated RAP mixtures had high water susceptibilities, although many studies have indicated that foamed asphalt treated bases showed satisfactory field performance, more research on the design of foamed asphalt treated RAP and other recycled materials is still warranted. Furthermore, the use of a tack coat layer on top of a foamed asphalt treated RAP layer should be cautioned.

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