FEASIBILITY OF DETECTING DEBONDING OF HOT MIX ASPHALT LAYER WITH SONIC/SEISMIC AND IMPULSE METHODS

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ABSTRACT

The lack of interface bonding between asphalt layers may lead to several premature distresses of which slippage, cracking, delamination and distortion are most prominent. Undetected delamination can ultimately result in the peeling away of thin asphalt overlays from the surface of the roadway. Further progression of delamination may result in stripping of the lower layers due to the intrusion of moisture. Many NDT methods, which included the Ground Penetrating Radar, Thermography, sonic/seismic and impulse response, are evaluated for different pavement problems.

To determine delamination, several debonding agents were placed between asphalt lifts at predetermined locations to simulate different degrees of debondingin this study. From those locations sonic/seismic and impulse methods and their results are discussed in this paper.

Keywords: Pavement, NDT methods, Sonic/seismic methods, Impact methods, Delamination

1 INTRODUCTION

A poor bond between pavement layers may lead to several premature distresses of which slippage, cracking, delamination and distortion are most prominent. The delaminated layers and their associated cracks may require frequent maintenance, and may lead to premature need for major rehabilitation. For those reasons, rapid detection of delamination with nondestructive test (NDT) devices is highly desirable. NDT methods provide quick acquisition of test data which are reliable and consistent test technique and with a number of data sets provide statistical reliability.

In this paper, the feasibility of estimating the presence and extent of hot mix asphalt (HMA) delamination with two NDT methods are presented. NDT methods were evaluated on a pavement section specifically constructed to simulate different degrees of debonding. The applicability of NDT methods and their detection potentials were evaluated and summarized in this study.

2 NDT METHODS USED IN THIS STUDY

Several NDT technologies have been developed that could potentially be employed for detection of delamination within HMA layers [1]. Since most of these technologies have been developed for detecting the delamination in concrete slabs, several complications, such as thinner HMA lifts, more material heterogeneity, presence of tack coats and changes in temperature, are encountered when applying these methods to HMA. The five most promising methods are described below.

Ground Penetrating Radar (GPR): GPR uses electromagnetic pulses to characterize subsurface materials based on changes in electromagnetic properties of the layers. The application of GPR in detecting delamination has been previously found to be questionable [2]. Even at frequencies of 1 to 2 GHz, the GPR wavelengths in asphalt are too long to resolve the thin delamination. Numerical modeling of the GPR signals for the case of delaminated asphalt was carried out by Smith and Scullion [3]. The results indicated that the detection of an air-filled delamination of 0.5 cm or water-filled delamination of 0.25 cm and larger at a minimum depth of 5 cm may be detected using a 2.5 GHz GPR antenna. The maximum speed for data acquisition suggested was 16.09 km/h.

Impulse Response (IR): An impulsive loading is applied to the pavement surface with an instrumented hammer and the vertical displacement with a geophone is measured. If structural distresses are present in the form of loss of adhesion between layers, this is reflected in the dynamic response of the pavement structure. Using a simple modal analysis [4], the bonding condition of two adjacent layers can be obtained. Kruntcheva[5] successfully implemented IR for detection of debonding in controlled test sections.

Thermography: Infrared Thermography measures temperature distributions across the surface of the pavement to detect the presence of shallow subsurface flaws in HMA. Stroup-Gardiner [6] showed its effectiveness for large area inspections, but also its limitations.

Ultrasonic Surface Waves (USW): USW is a seismic-based methodology, in which a dispersion curve (variation in the velocity with wavelength) is obtained. In the USW method, the surface or Rayleigh wave velocity of the top layer is measured without an inversion algorithm that can be converted to modulus [7]. This method has been successfully used to detect HMA stripping [8]. *The Portable Seismic Property Analyzer (PSPA)* that applies the USW in real time was used in this study.

Falling Weight Deflectometer (FWD): The FWD device consists of an impact loading mechanism and a set of sensors to measure vertical surface displacements at the load location and at specified offsets from the load. The loading component delivers a transient load to the pavement surface and the sensors measure the surface deflection at the specified locations. A number of studies have been carried out to assess the suitability of the FWD for assessing the delamination of HMA layers. Intuitively, higher deflections are expected, if poor bond between asphalt layers exists. A new backcalculation process for assessing the bond condition between the HMA layers using FWD deflections has shown some promising results [9].

3 CASE STUDY

Ten different 2.7 m by 3 m sections were constructed (see Figure 1a). Three transition zones were also incorporated to minimize the construction variability. The pavement cross-section consisted of a sandy-silt subgrade covered with a 200 mm thick HMA placed in three lifts. The bottom lift consisted of about 75 mm of a coarse mix whereas the middle lift consisted of 63 mm of a fine mix. The top lift of Sections 1 through 5 consisted of a coarse mix and Sections 6 through 10 a fine mix. The plan view of each section with prepared debonded areas and test locations are shown in Figure 1b. For this study, the focus was more on the large 1.2 m by 2.7 m debonded areas. Shear tests were conducted on prepared HMA specimens to select different materials to be used as debonding agents (see [1] for details). Clay slurry, talcum powder, grease and thin paper soaked in motor oil were considered. A tack coat at a rate of 0.7 liter/m^2 was used as a control section. A severely debonded area was reproduced in the transition area by placing a 1.2 m by 1.2 m piece of thick corrugated cardboard and a thick layer of clay slurry of 1.2 m by 1.8 m as shown in Figure 1a. Shallow and deep debondings correspond to the debonding between the top two lifts (at a depth of 63 mm) and bottom two lifts (a depth of 125 mm), respectively.

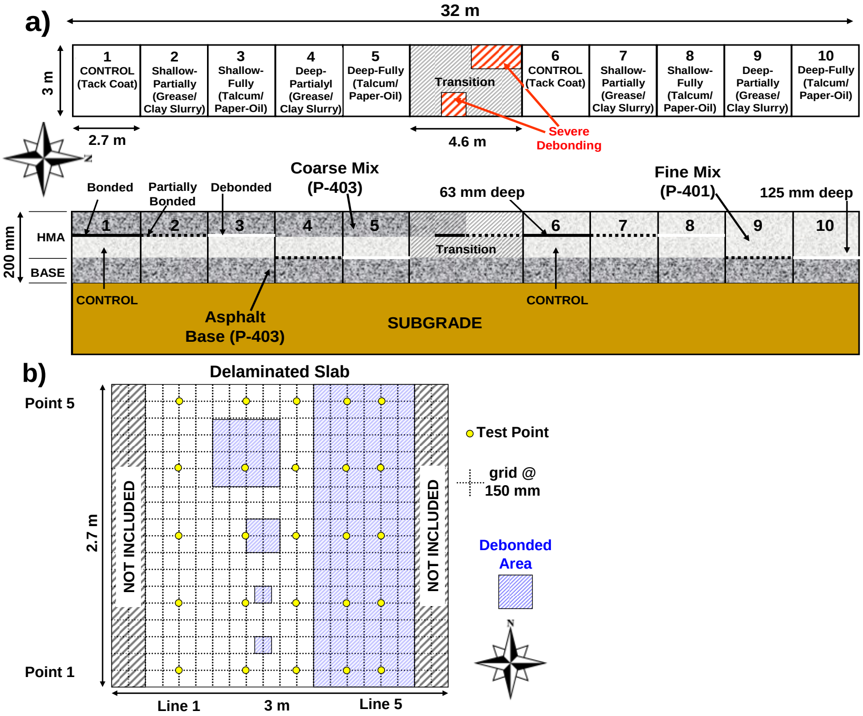


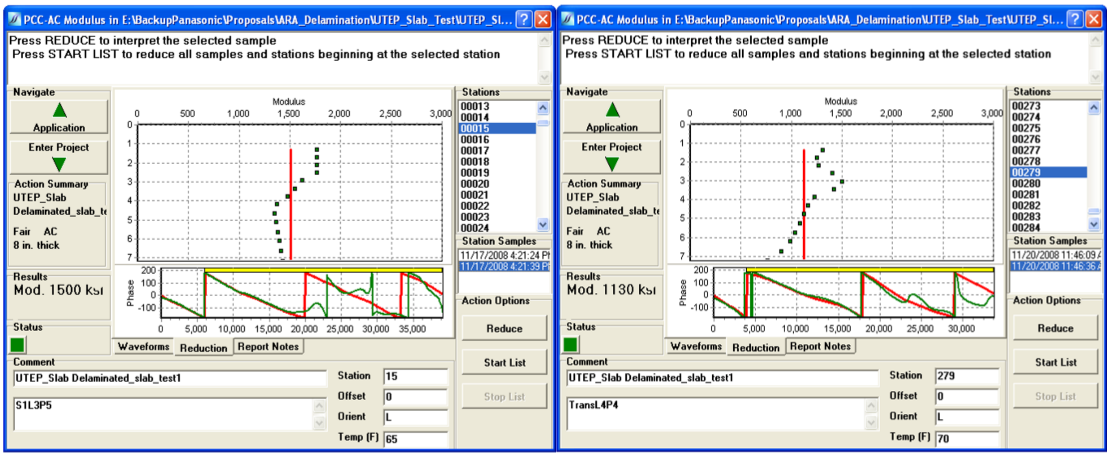
Figure 1. Schematic of section constructed and location of test points.

4 PRESENTATION OF RESULTS

The PSPA USW detailed analysis can be found in Celaya et al. [1]. The variation in the phase velocity with wavelength is called a dispersion curve. For the intact area dispersion curve is fairly uniform, whereas for damaged points, a sharp decrease in modulus below the location of the damage is typically evident as can be seen in Figure 2. In this study, dispersion curves of Line 4 along ten sections are presented in Figure 3 with prepared debonded areas marked when applicable. Average modulus and standard deviation of control sections were used to describe the effectiveness of USW. Debonded areas generally exhibited lower moduli as anticipated. However, some partially debonded sections exhibited normal moduli for both mixes. Also, deep debonding was not as well-defined as for the similar sections with coarse surface HMA.

The temperature adjusted moduli were compared using color-coding in Figure 4. The average modulus ($E_{control}$) and standard deviation ($\sigma_{control}$) of each control section (1 and 6) were used as reference. Modulus above the average minus one standard deviation are colored as green, between average minus one and average minus two standard deviations are highlighted in yellow, and less than average minus two standard deviations are colored as red. In this case most of the fully debonded points along lines 4 and 5 were identified for both mixes. Some partially debonded areas showed indication of marginally less stiff (marked as yellow), but some were found to be intact (green) or substantially less stiff (red). Most of the intact locations (line 1 and sections 1 and 6) were identified as intact. Since HMA modulus is temperature dependent, the values presented were converted to a reference temperature of 77ºF using [10]:

$$Modulus_{77F} = \frac{Modulus_T}{(-0.00307 \ * T + 1.2627)}$$



a) Intact b) Severe Debonding

Figure 2. Dispersion Curve Results with PSPA on Small Scale Study

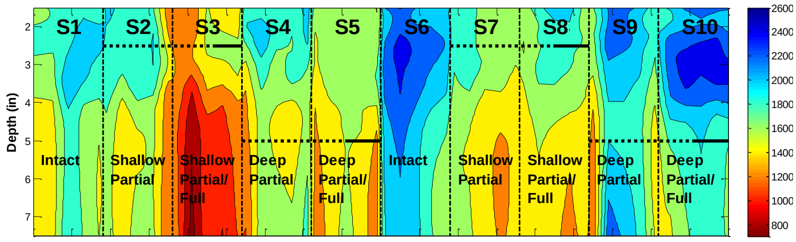


Figure 3. Dispersion curve results for Line 4.

	S1, Intact					S2, Shallow Partial					S3, Shallow Partial/Full					S4, Deep Partial					S5, Deep Partial/Full				
	P1	P2	P3	P4	P5	P1	P2	P3	P4	P5	P1	P2	P3	P4	P5	P1	P2	P3	P4	P5	P1	P2	P3	P4	P5
N/A																									
Line 1	1768	1777	1812	1736	1991	2231	2236	1951	2214	1929	1983	1891	1956	1933	1633	1808	1955	1668	1724	1645	1666	1783	1914	1845	1733
Line 2	1921	1690	1714	1636	1829	1685	1957	1755	1778	1626	1874	1527	1611	1643	1347	1715	1729	1612	1502	1712	1827	1374	1879	1767	1851
Line 3	1674	1835	1854	1589	1825	1977	1807	1899	1974	1563	1908	2325	1617	1714	1747	1666	1815	1676	2025	1984	1651	1614	1684	1914	1652
Line 4	1602	1626	1963	1891	1751	1804	1643	1740	1768	1320	1289	987	1326	1266	1387	1453	1817	1696	1653	1837	1442	1573	1690	1599	1508
Line 5	1745	1699	1683	1876	1922	1902	1667	1626	1774	1146	1048	1151	1313	1054	1091	1044	1548	1726	1511	1437	1527	1284	1481	1421	1627
N/A																									

a) Sections 1 to 5

S6, Intact					S7, Shallow Partial					S8, Shallow Partial/Full					S9, Deep Partial					S10, Deep Partial/Full					
P1	P2	P3	P4	P5	P1	P2	P3	P4	P5	P1	P2	P3	P4	P5	P1	P2	P3	P4	P5	P1	P2	P3	P4	P5	
																									N/A
1443	2083	1809	1827	1717	1762	1824	1628	1727	1644	1598	1873	1524	1448	1869	1828	1882	1845	1655	1802	1873	1990	1760	1802	1875	Line 1
1953	2212	2095	2171	1962	1813	1819	1960	2023	1300	1719	1744	1856	1513	1469	1795	1741	1720	1753	1569	1899	1902	2356	1993	1925	Line 2
2134	1967	1828	1968	1569	1961	1750	1880	1854	1649	2051	2048	2335	1919	2141	1836	1825	1922	2050	1646	2117	2058	2234	2213	2340	Line 3
2116	2307	2175	2025	1924	1771	1766	1592	1547	1531	1578	1674	1667	1542	1629	1397	2140	2093	1986	1598	1888	2006	2073	2018	1958	Line 4
1990	2156	2078	2031	2180	1841	1680	1777	1611	1538	1612	1469	1409	1463	1375	1446	2034	1661	1820	1729	1557	1615	1572	1677	1812	Line 5
																									N/A

b) Sections 6 to 10

Figure 4. Statistical Analysis of PSPA Modulus on Small Scale Study

Deflections measured for the seven geophones at an intact and the severely debonded locations are shown in Figure 5. Deflections of Geophones 1 and 2 (labeled as SD1 and SD2) are considerably greater at the severe debonded location. For the other five geophones, differences between intact and deboned deflections are small.

The variation in the deflection along the ten sections is shown in Figure 6 using the criteria used for the PSPA test. The criteria presented in Table 3.2 were used to color code the graph. In this case because higher deflections correspond to less stiff material, standard deviations were added instead of subtracted.

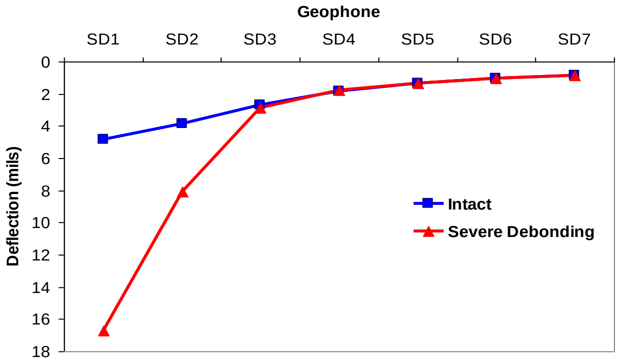
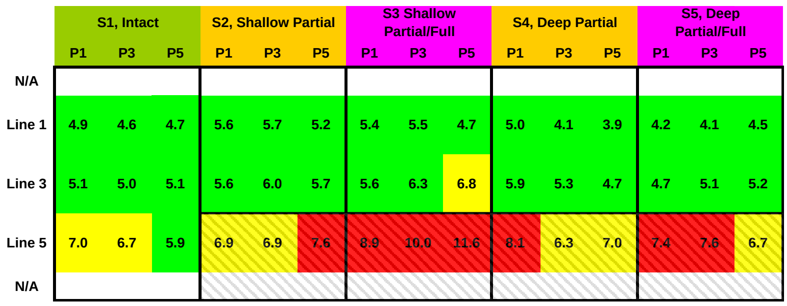
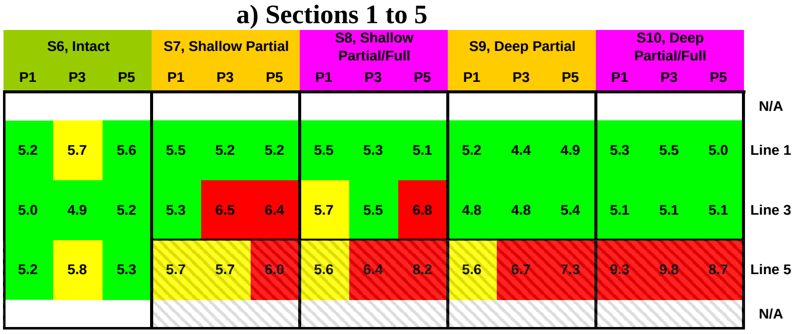


Figure 5. Deflection Examples from FWD on Small Scale Study



a) Sections 1 to 5



b) Sections 6 to 10

Figure 6. Statistical Analysis of FWD Deflection on Small Scale Study

5 CONCLUSIONS

Two NDT methods that have the potential to detect the debonding of the HMA were evaluated on a constructed section with various levels of debonding at different depths and with different asphalt mixes. Based on the outcome of the study, the following conclusions could be drawn (see [1] for details):

- USW, as implemented in the PSPA, could detect 53% of the debonded areas. PSPA could detect the shallow debonding (both partial and full) the best.
- The FWD, could detect about 46% of the debonded areas based on the backcalculation of the modulus of the HMA layer.
- USW results require temperature adjustments for their successful usage.
- Data collection can be carried out in less than 2 minutes with two devices.
- Two devices provide the analysis in real time.
- The FWD analysis is rather straight forward, but an experienced analyst is needed to minimize the uncertainty in the backcalculation.

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