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Executive Summary Report

Determination of Mechanical Properties of Materials Used in WAY-30 Test Pavements

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Problem

ODOT selected a relocation of US Route 30 near Wooster in Wayne County, the WAY-30 project, as the site for testing long life pavements. The eastbound lanes were constructed with a long-life Portland Cement Concrete (PCC) pavement, and the westbound lanes had an asphalt concrete (AC) perpetual pavement design. The purpose of the study was to evaluate these long life pavement design procedures as alternative pavement design methods. These design methods have been rapidly gaining acceptance in the United States. The perpetual asphalt pavement concept uses mechanistic-empirical design procedure which requires accurate mechanical properties of materials, traffic, and environmental data as input to predict pavement responses and distresses. Using input data and pavement response models, the thickness of each pavement layer is determined to keep certain pavement responses at critical locations within limiting values for perpetual performance. Design of long-lived concrete pavement also requires accurate material properties.

Objectives

- Determine the mechanical properties of the pavement materials used in WAY-30 test pavements during construction and in-service;
- Provide data to calibrate the long life pavement design procedures.

Description

The US Route 30 bypass of Wooster, Ohio, in Wayne County, "WAY-30", was constructed to demonstrate two types of extended service pavements, a long-life Portland cement concrete (PCC) pavement on the eastbound lanes and an asphalt concrete (AC) perpetual pavement on the westbound lanes. Both pavements are designed to provide 50 years or more of service with minimal maintenance (e.g. resurfacing). The PCC pavement structure features a thick and extra-wide slab on an asphalt treated base, while the AC pavement structure features a Superpave surface and a Fatigue Resistant Layer (FRL). Report FHWA/OH-2008/7 [Sargand, Figueroa, and Romanello, 2008] discusses the instrumentation and the response of the pavement under loads.

The AC perpetual pavements on the WAY-30 project were built of the following materials, from top down: 1.5 in (3.8 cm) stone matrix asphalt (SMA) ; 1.75 in (4.45 cm) ODOT Item 442 Superpave, Type A asphalt concrete mix; 9 in (23 cm) ODOT Item 302, asphalt treated base; 4 in (10 cm) Fatigue Resistant Layer (FRL) mix AC (modified Item 302); 6 in (15 cm) dense graded aggregate base (DGAB); and prepared in-situ subgrade soil. Asphalt mix designs and volumetrics are given in Table 1. Superpave binder test results for two binders used in the project are also given in Table 2.

The long-lived Portland cement concrete (PCC) pavements were built as follows: 10 in (25 cm) jointed plain PCC pavement in 15 ft (4.6 m) slabs with 1.5 in (3.8 cm) diameter dowel bars in the joints at a 12 in (30.5 cm) spacing; 3 in (7.5 cm) asphalt treated base, ODOT Item 301, 4 in (10 cm) DGAB subbase; and prepared in-situ subgrade soil. The PCC came in two mixes: Mix A featured 4.9% SSD Ground Granular Blast Furnace Slag (GGBFS) and was used in Test Sections 876-877; and Mix B featured 3.3% SSD fly ash and was used in Test Section 664. PCC mix designs mix properties are presented in Table 3.

For this study, samples of all pavement materials, including soils, granular subbase material, PCC mixes, and AC mixes were tested in the laboratory to determine material parameters. The AC materials included mixes used in different layers of the perpetual pavement structure, while two mixes of the PCC were used in different sections of the road.

The subgrade material was subjected to grain size, Atterberg limit, Standard Proctor, maximum dry density, and resilient modulus measurements. The subgrade was ODOT type A-4a (AASHTO A-4). The granular subbase material was subjected to a sieve analysis and a resilient modulus test. It was type A-1a.

PCC tests included: unit weight, modulus of rupture, static modulus of elasticity, Poisson's ratio, splitting tensile strength, compressive strength, maturity, and thermal coefficient of linear expansion. AC tests included: bulk specific gravity, maximum specific gravity, air void content, resilient modulus, rutting evaluation using an asphalt pavement analyzer, moisture susceptibility, creep, fatigue, and thermal stress restrained specimen test.

Conclusions and Recommendations

Subgrade Soil:

- The subgrade soil samples were classified as a moderately plastic silty soil, ODOT classification A-4-a (AASHTO A-4).
- The resilient modulus of the subgrade at 12%-15% water content ranged from about 3 ksi (20 MPa) to 10 ksi (69 MPa).
- The subgrade resilient modulus M_R did not fit well with the MEPDG universal model. A hyperbolic model was used to fit the data

Granular subbase material:

- The granular subbase material was classified as AASHTO type A-1-a, well-graded gravel with sand.
- The resilient modulus of the granular subbase ranged from 8 ksi (55 MPa) to 23 ksi (160 MPa) under deviatoric stresses in the range of 3 psi (21 kPa) to 20 psi (138 kPa). The resilient modulus M_R of the subbase was fitted well with the universal model with model parameters k1 = 0.597608, k2 = 0.458940, and k3 = 0.056241. $r^2 = 0.957$.
- The permeability of the subbase was 1.0013 cm/s (2,838 ft/day), much higher than recommended 0.353 cm/s (1,000 ft/day).

Portland Cement Concrete (PCC):

- The properties of two concrete mixes, as well as the differences between the mixes are given in Table 4. All properties were measured after 90 days of curing. With the exception of modulus of rupture, the various strength parameters for Mix A were greater than those for Mix B.
- The fly ash concrete (Mix B) was cured for 28 days using two different methods, one using a curing compound applied to the top surface and the other involving a water bath. The compressive strength was 14% higher using the curing compound, but that difference declined to 2% at the end of 28 days.
- Strength-maturity relationships were established for both PCC mixes.

Asphalt Concrete (AC):

- AC properties for each mix are given in Table 5
- As expected, the SBS modified mixes (SMA and 442 mixes) showed much higher fatigue resistance than the unmodified mixes.
- The creation of an asphalt-rich bottom by adding additional asphalt binder increased the fatigue resistance by orders of magnitude. At 70 με, the expected fatigue endurance limit and the designed strain level for the structure, regular 302 mix showed 20,000 cycles to failure while asphalt-rich 302 mix (FRL) is estimated to have 20 million cycles to failure.
- Dynamic modulus master curves were fitted well with the Sigmoidal model used in MEPDG.
- For average climatic and traffic conditions (25°C or 77°F; 10 Hz or 0.1 sec loading time), the dynamic moduli and the resilient moduli of asphalt mixes were similar to the values used in the development of the asphalt perpetual pavement structure. For SMA and 442 mixes, the measured moduli were slightly lower than the values used in the design, while for 302 and FRL mixes, the moduli were

significantly higher than the design value. Since the thickness of 302 and FRL layers consists of 80% of the total pavement thickness, the maximum strain at the bottom of FRL would be significantly smaller than the designed 70 με.

- The rutting test results from asphalt pavement analyzer test and flow numbers obtained from the repeated load test indicate that all asphalt mixes are rut-resistant.
- TSRST cracking temperatures of asphalt mixes were lower than the expected pavement temperatures for the project site determined by LTPPBind software, meaning that low temperature thermal cracking is very unlikely to occur.

Implementation Potential

The results and data from this study can be directly implemented by researchers validating or calibrating the long life pavement design procedures. In fact, some of the data have already been used in the ELS analysis in the previous report on WAY-30. [Sargand, Figueroa, and Romanello, 2008] Data obtained from this research project will be used as inputs for the elastic or viscoelastic models used in design of pavements to predict pavement responses. The predicted pavement responses may then be compared with the actual observed pavement response to validate the design. The ultimate result of this process will be revisions in specifications, standard drawings, and the Pavement Design and Rehabilitation Manual to incorporate the new materials and design procedures. There are no immediate impediments to implementation.

Reference

Sargand, Shad, J. Ludwig Figueroa, and Michael Romanello, 2008, *Instrumentation of the WAY-30 Test Pavements*, Federal Highway Administration Report No. FHWA/OH-2008/7, Ohio Research Institute for Transportation and the Environment, Athens, OH, June 2008.

Table 1. ACC mix design and mix volumetrics.

	SMA	**442**	**302**	**FRL**
Mix Design Type	Superpave	Superpave	Marshall	Marshall
Coarse Aggregate	Limestone	Limestone	Limestone	Limestone
Fine Aggregate	Limestone	Limestone / N Sand	N Sand	N Sand
Gradation				
1 1/2" (38 mm)	100	100	100	100
1" (25.4 mm)	100	100	87	87
3/4" (19 mm)	100	99	74	74
1/2" (12.5 mm)	93	88	59	59
3/8" (9.5 mm)	70	81	52	52
#4 (4.75 mm)	23	54	34	34
#8 (2.36 mm)	16	44	26	26
#16 (1.18 mm)	13	29	18	18
#30 (0.600 mm)	11	18	12	12
#50 (0.300 mm)	10	9	6	6
#100 (0.150 mm)	9	5	4	3
#200 (0.075 mm)	8.0	4.0	2.8	2.3
Aggregate Blend G_{sb}	2.574	2.567	2.572	2.572
G_{mm}	2.395	2.458	2.477	2.455
% Binder Content	6.6	4.8	4.0	4.6
% Virgin Binder	6.6	4.0	3.0	3.4
% G_{mm} @ N_{ini} [a]	83.6	88	--	--
% G_{mm} @ N_{des} [a]	96.5	96	--	--
% G_{mm} @ N_{max} [a]	--	97.7	--	--
Asphalt Binder	PG76-22 SBS	PG76-22 SBS	PG 64-22	PG 64-22
Design Air Void, %	3.5	4.0	4.0	3.0
VMA, %	16.1	12.5	11.6	11.8
F/A ratio	1.2	0.9	--	--
50-30 Ratio	-1	-1	--	--
TSR Ratio (%)	85.7	82.5	--	--
Cellulose Fiber	0.30%	--	--	--
CA Angularity (%)	100	100	--	--
FA Angularity (%)	46.5	45.47	--	--
RAP %	0	10	20	20
RAP %AC		6.01	5.20	6.01

Table 2. Properties of PG binders.

Binder Type	PG 76-22 SBS	PG 64-22
Original Binder		
Rotational Rheometer:Viscosity @ 135ºC Max 3 Pa·s (0.3 poise)	1.139 Pa·s (0.1139 poise)	0.431 Pa·s (0.0431 poise)
Dynamic Shear Rheometer:G*/sin δ, Min 1.00 kPa (0.145 psi) @ 10 rad/s	1.45 kPa (0.211 psi) @76ºC (169ºF)	1.38 kPa (0.201 psi) @64ºC (147ºF)
Rolling Thin-Film Residue		
Mass Loss, Maximum 1.00%	0.291%	0.126%
Dynamic Shear Rheometer:G*/sin δ, Min 2.20 kPa (0.319 psi) @ 10rad/s	2.86 kPa (0.414 psi) @76ºC (169ºF)	3.24 kPa (0.471 psi) @64ºC (147ºF)
Pressure-aging Vessel (PAV) Residue		
Dynamic Shear Rheometer:G* sin δ, Max 5000 kPa (726 psi) @ 10rad/s	1198 kPa (173.9 psi) @31ºC (88ºF)	3129 kPa (454.2 psi) @25ºC (77ºF)
Bending Beam Rheometer:Creep Stiffness, S, Max 300 MPa (43.54 ksi) @ 60 sec	102 MPa (14.8 ksi) @-12ºC (10ºF)	209 MPa (30.4 ksi) @-12ºC (10ºF)
Bending Beam Rheometer: m-value, Min 0.300 @ 60 sec	0.346 @-12ºC (10ºF)	0.316 @-12ºC (10ºF)

Table 3. PCC mix designs and mix properties.

	Specific Gravity	Absorption %	GGBFS Mix	Fly Ash Mix
Material Batch Weight SSD, lb/yd^3 of Fresh Concrete (kg/m^3)				
Natural Sand	2.608	1.59	1161 (688.8)	1161 (688.8)
#8 Limestone	2.619	2.29	461 (273.5)	461 (273.5)
#467 Limestone	2.658	1.13	1400 (830.6)	1400 (830.6)
Type I Cement	3.15		415 (246.2)	477 (283.0)
GGBFS	2.72		178 (105.6)	-
Fly Ash (Type F)	2.70		-	119 (70.6)
Water			259 (153.7)	259 (153.7)
Total			3876 (2299.5)	3859 (2289.5)
Admixtures Used, oz/yd^3 (ml/m^3)				
ASTM C 260 AEA			31 (1201)	31 (1201)
ASTM C 494 WRR - Type B,D			11 (426)	11 (426)
Water/CM Ratio			0.44	0.44
Fresh Concrete Properties				
Slump, in. (mm)			1.5 (38)	1.5 (38)
Air Content, %			5.2 – 5.4	5.6 – 6.8
Temperature, °F (ºC)			78-88 (25.6-31.1)	81-86 (27.2-30.0)
Unit Weight, lb/ft^3 (kg/m^3)			143.56 (2300)	142.93 (2289)
Compressive Strength, psi (MPa) 28-day			7880 (54.3)	5290 (36.5)
Specified Design Strength (f'c)			5070 (35.0)	4000 (27.6)
Modulus of Rupture, psi (MPa), 14-day Beam			775 (5.34)	775 (5.34)
Permeability (coulombs)				
28-day			1505	1128
Specified Design Permeability			2000	2000

Table 4. Summary of average WAY-30 concrete material properties at 90 days.

Property	Variable	English unit	Mix A GGBFS	Mix B Fly ash	Δ	Δ/GGBFS
unit weight	γ	pcf	141.9	139.4	-2.5	-1.76%
Modulus of rupture	R	psi	608.7	817.7	209	34.34%
Modulus of elasticity	E	10^3ksi	4.07	3.8	-0.27	-6.63%
Poisson's Ratio	v	-	0.16	0.18	0.02	12.50%
Splitting Tensile Strength	T	psi	622.4	472.3	-150.1	-24.12%
Compressive strength	C	psi	6149	5102	-1047	-17.03%
Coefficient of linear expansion	α	$°F^{-1}$	5.9×10^{-6}	5.8×10^{-6}	0.1×10^{-6}	1.69%
Property	**Variable**	**International unit**	**Mix A GGBFS**	**Mix B Fly ash**	**Δ**	**Δ/GGBFS**
unit weight	γ	kg/m^3	2273	2233	-40	-1.76%
Modulus of rupture	R	kPa	4197	5638	1441	34.33%
Modulus of elasticity	E	GPa	28.1	26.2	-1.9	-6.76%
Poisson's Ratio	v	-	0.16	0.18	0.02	12.50%
Splitting Tensile Strength	T	kPa	4291	3256	-1035	-24.12%
Compressive strength	C	MPa	42.4	35.2	-7.2	-16.98%
Coefficient of linear expansion	α	$C^{\circ-1}$	10.6×10^{-6}	10.4×10^{-6}	0.2×10^{-6}	1.69%

Table 5. Summary of properties measured for WAY-30 AC mixes.

Property	Variable	English unit	Mix 301	Mix 302	Mix 442	Mix FRL	Mix SMA
Maximum specific gravity	*MSG*	-	2.469	2.497	2.479	2.475	2.469
Instantaneous resilient modulus at 41°F	M_{Ri}	ksi	3700	3805	2985	4390	3320
Total resilient modulus at 41°F	M_{Rt}	ksi	3490	3345	2955	4230	3280
Instantaneous resilient modulus at 77°F	M_{Ri}	ksi	1920	1900	1023	2205	1345
Total resilient modulus at 77°F	M_{Rt}	ksi	1830	1830	967.5	2155	1280
Instantaneous resilient modulus at 104°F	M_{Ri}	ksi	826	753.5	408	944	532
Total resilient modulus at 104°F	M_{Rt}	ksi	720	660.5	349	789.5	485.5
Poisson's ratio (assumed)	ν	-	0.35	0.35	0.35	0.35	0.35
Average rutting after 8000 cycles	-	mil	177	205	146	220	55
Tensile strength ratio	*TSR*	-	0.72	0.68	0.77	0.73	0.80
Tensile strength at -4°F	*T*	psi	903.1	677.7	781.1	831.2	787.9
Tensile strength at 14°F	*T*	psi	892.8	599.8	581.2	745.8	755.1
Tensile strength at 32°F	*T*	psi	783.9	583.2	394.6	802.8	585.9
Cycles to failure at 100 με	N_f	-	-	-	57.6×10^6	22000	2.39×10^9
Cycles to failure at 200 με	N_f	-	-	1500	294000	38000	1.47×10^6
Cycles to failure at 300 με	N_f	-	-	1000	102800	24000	-
Cycles to failure at 400 με	N_f	-	-	295.0	5140.0	650.0	31000.0
TSRST fracture temperature	-	°F	-	-29.6	-18.9	6.68	-37.5
TSRST fracture strength	-	ksi	-	0.072	0.118	0.206	0.067
Dynamic Modulus (Sigmoidal α)			-110.96	-110.96	-110.92	-110.95	-110.96
Dynamic Modulus (Sigmoidal β)			5.32009	5.30814	4.72248	5.41136	4.98943
Dynamic Modulus (Sigmoidal δ)			4.52384	4.53334	4.52665	4.59155	4.51016
Dynamic Modulus (Sigmoidal γ)			0.28965	0.29468	0.2352	0.33314	0.24243
Temperature Shift Function parameters $a(T) = a\,T^2 + b\,T + c$	*a*		-0.001216	-0.00043	-0.00063	-0.00068	-0.00083
	b		0.1987	0.1543	0.146	0.1665	0.1711
	c		-3.623	-3.222	-2.856	-3.164	-3.38
Flow Number at 54.4°C			227	362	240	67	>10000
Absorbed Energy Ratio			-	1.58	1.17	1.44	1.19

Property	Variable	SI unit	Mix 301	Mix 302	Mix 442	Mix FRL	Mix SMA
Maximum specific gravity	*MSG*	-	2.469	2.497	2.479	2.475	2.469
Instantaneous resilient modulus at 5°C	M_{Ri}	GPa	25.51	26.23	20.58	30.27	22.89
Total resilient modulus at 5°C	M_{Rt}	GPa	24.06	23.06	20.37	29.16	22.61
Instantaneous resilient modulus at 25°C	M_{Ri}	GPa	13.24	13.10	7.05	15.20	9.27
Total resilient modulus at 25°C	M_{Rt}	GPa	12.62	12.62	6.67	14.86	8.83
Instantaneous resilient modulus at 40°C	M_{Ri}	GPa	5.70	5.20	2.81	6.51	3.67
Total resilient modulus at 40°C	M_{Rt}	GPa	4.96	4.55	2.41	5.44	3.35
Poisson's ratio (assumed)	ν	-	0.35	0.35	0.35	0.35	0.35
Average rutting after 8000 cycles	-	mm	4.5	5.2	3.7	5.6	1.4
Tensile strength ratio	*TSR*	-	0.72	0.68	0.77	0.73	0.80
Tensile strength at -20°C	*T*	MPa	6227	4673	5385	5731	5432
Tensile strength at -10°C	*T*	MPa	6156	4135	4007	5142	5206
Tensile strength at 0°C	*T*	MPa	5405	4021	2721	5535	4040
Cycles to failure at 100 με	N_f	-	-	-	57.6×10^6	22000	2.39×10^9
Cycles to failure at 200 με	N_f	-	-	1500	294000	38000	1.47×10^6
Cycles to failure at 300 με	N_f	-	-	1000	102800	24000	-
Cycles to failure at 400 με	N_f	-	-	295.0	5140.0	650.0	31000.0
TSRST fracture temperature	-	°C	-	-34.2	-28.3	-14.1	-38.6
TSRST fracture strength	-	MPa	-	0.50	0.81	1.42	0.46