RUSS COLLEGE of Engineering and Technology

Perpetual Pavement for Local Roads

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The Perpetual Pavement Concept

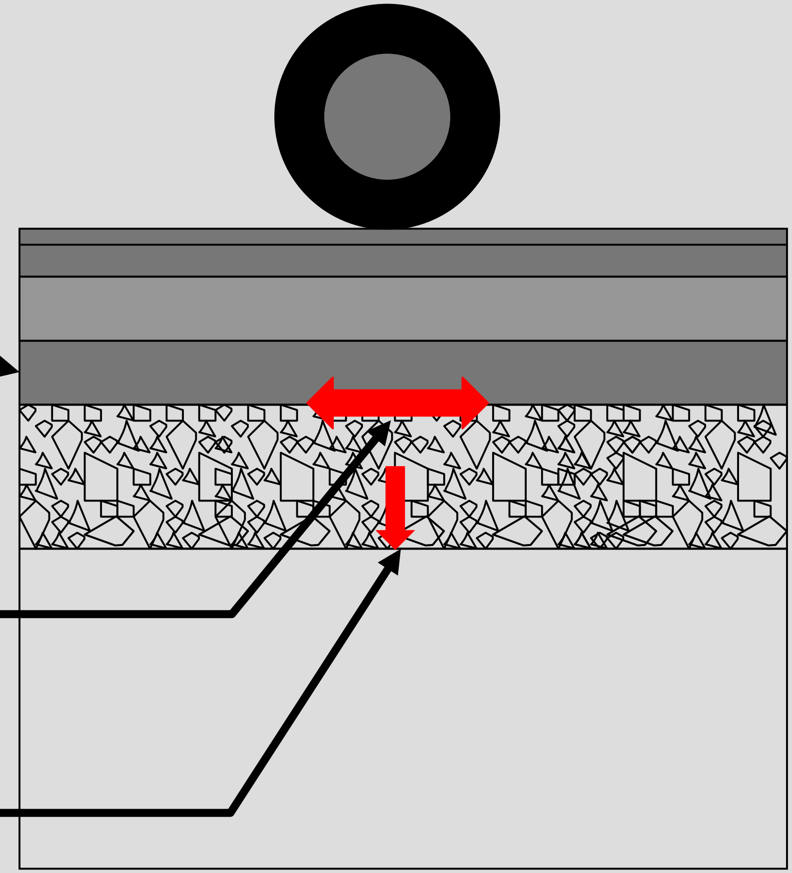
"an asphalt pavement designed and built to last longer than 50 years without requiring major structural rehabilitation or reconstruction, and needing only periodic surface renewal in response to distresses confined to the top of the pavement" (APA, 2002)

Goal of Perpetual Pavement

- Design so there are NO deep structural distresses
  - No bottom-up fatigue cracking
  - No structural rutting
- Distresses limited to those that can be remedied from the surface

Perpetual Design Criteria

- No Fatigue Cracking or Subgrade Rutting → **Structural Design**



Perpetual Pavement

- No (Fatigue) Cracking or Subgrade Rutting → **Structural Design**

- No Surface Rutting
- No Thermal Cracking
- No Stripping

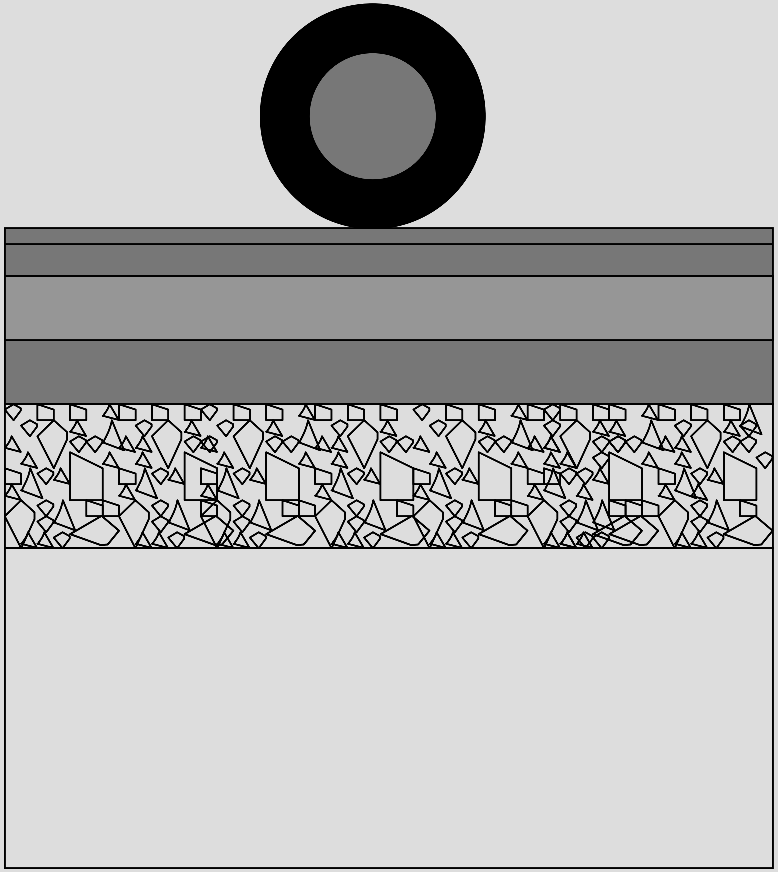
} → **Mix Design**

Perpetual Design Criteria

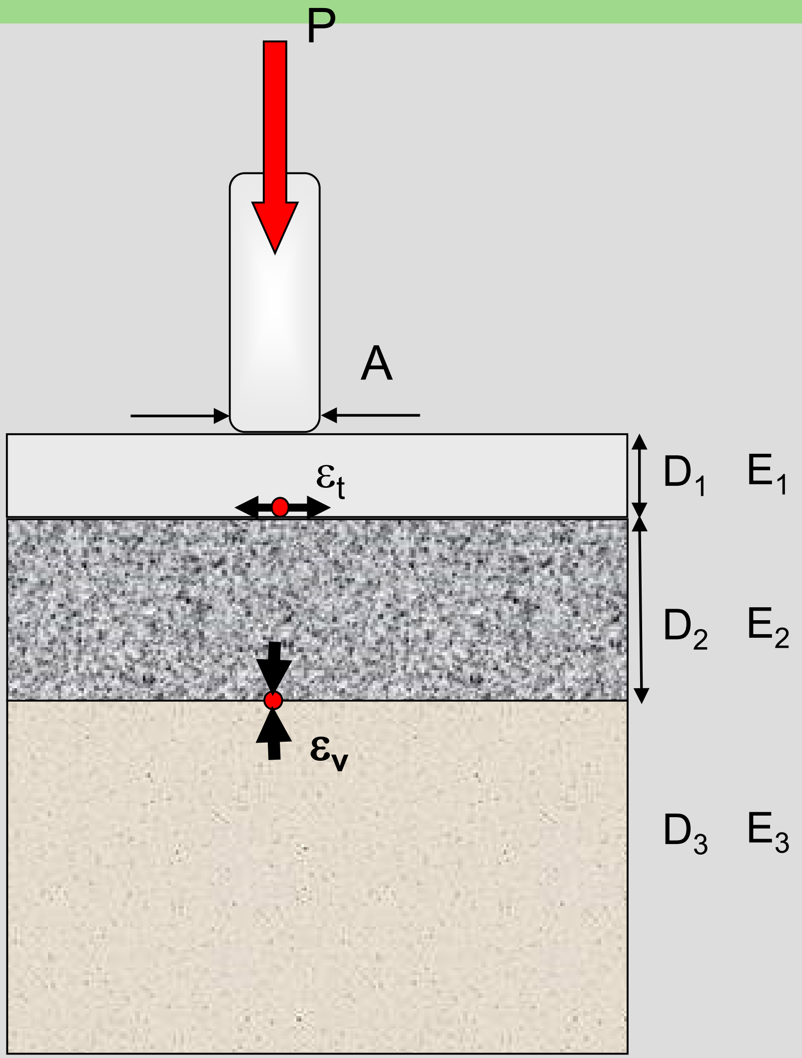
<u>Surface</u>: High Performance

<u>Base</u>: Economical & Durable

<u>Fatigue Resistant Layer</u>



Vertical Strain Limit

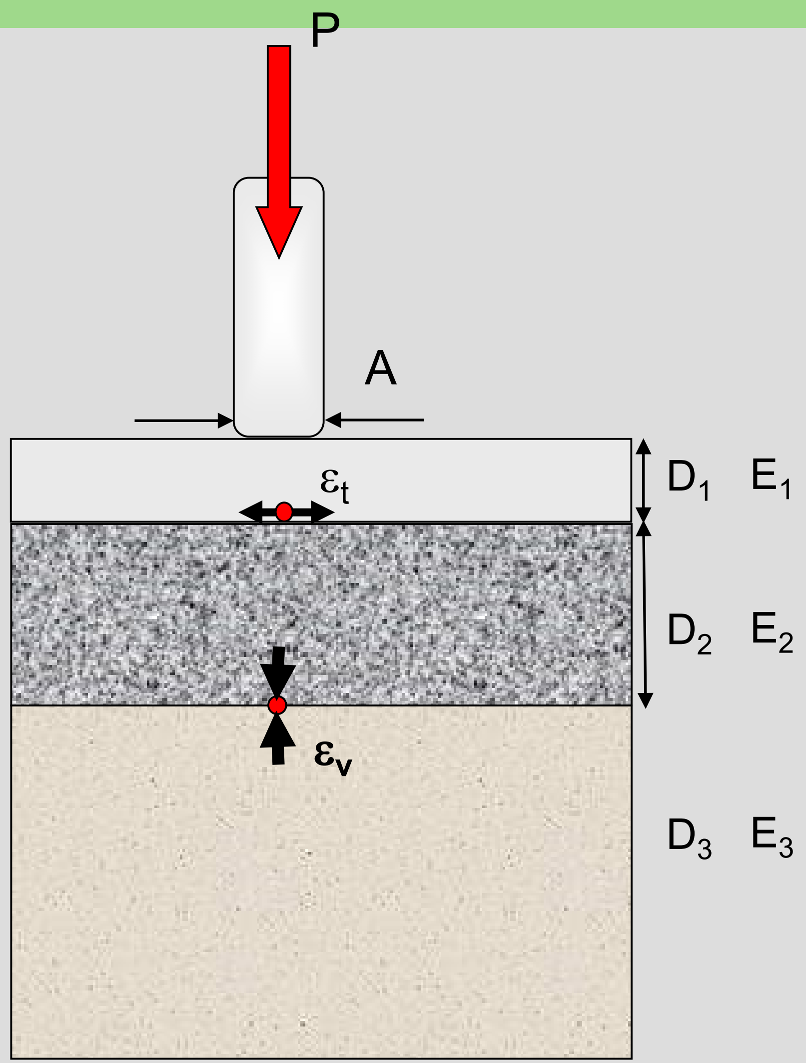


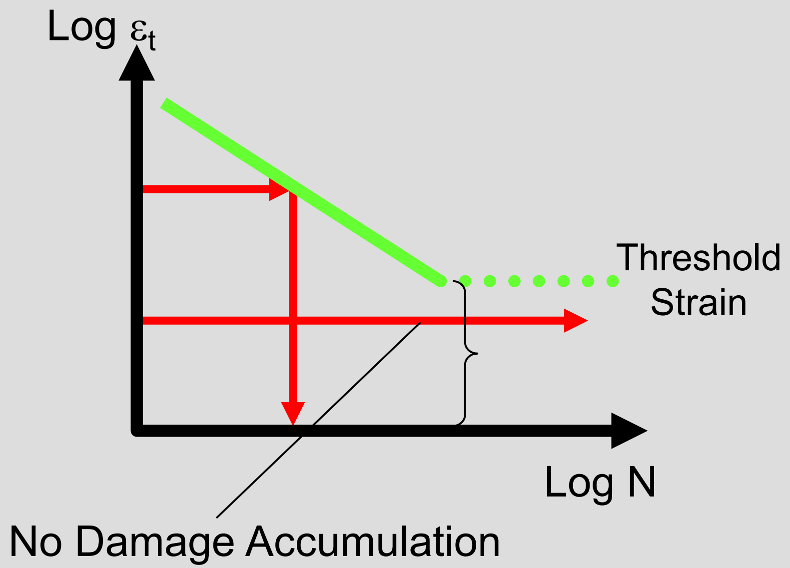
To control structural rutting:

- $\varepsilon_v < 200\ \mu\varepsilon$ to prevent structural rutting is commonly used
  - Tran et al. (2015) used compressive vertical strain at 50th Percentile < 200 $\mu\varepsilon$

Source: (Robbins and Timm, 2015: TRB Webinar)

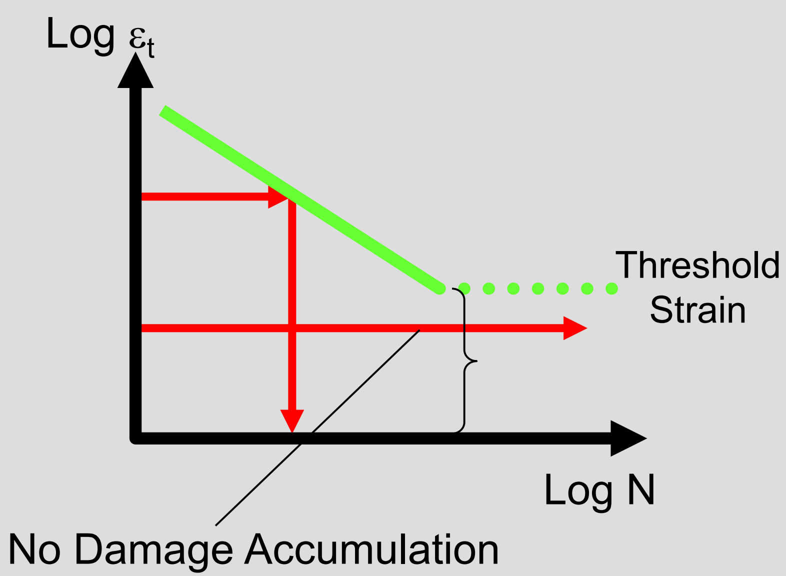
Fatigue Endurance Limit





Source: (Robbins and Timm, 2015: TRB Webinar)

Fatigue Endurance Limit



Damage accumulation, Miner's hypothesis:

$$D = \sum \frac{n_i}{N_i}$$

For conventional pavement design, D ≤ 1.0

<u>For perpetual pavement design, D ≤ 0.1</u>

(for APA definition, years to achieve D ≤ 0.1 should be 50 or more)

Requires transfer function to determine number of loads to failure, N_f, from tensile strain

"*n*" represents actual loads based on traffic estimates

Tensile Strain Threshold

Perpetual Design – Strain Thresholds

Laboratory Fatigue Endurance Limits and Design Thresholds have Varied!

- Monismith and McLean: **70 με**
- Thompson and Carpenter: practical range is **70 to 100 με**
- Prowell et al.: Lab study, **75 to 200 με**
- Carpenter and Shen: Lab study, **90 to 300 με**
- Nishizawa et al.: In-service perpetual pavements in Japan, **200 με**
- Wu et al.: Long life pavements in Kansas, **96 to 158 με**
- Yang et al.: Perpetual pavement design threshold in China, **125 με**
- Von Quintus: LTPP sections with < 2% change of fatigue cracking, **65 με** (95% confidence)
- MEPDG (2007): design threshold, **100 με to 250 με**
- Recent research, laboratory endurance limit a function of
  - Temperature
  - Loading rate
  - Mix composition
  - Aging

Perpetual Pavement – Fatigue Endurance Limit

How does laboratory fatigue endurance limit (FEL) compare with field strain?

Perpetual Pavement – Endurance Limit

- ORITE studies:
  - Objective to demonstrate perpetual pavement design concept and to optimize pavement thickness for perpetual pavement design
    - STA-77, constructed 2003
    - WAY-30, constructed 2005
    - Accelerated Pavement Loading Facility (APLF), Warm Mix Surface (WMA) constructed
    - DEL-23, constructed 2012
    - APLF, Highly Modified Asphalt (HiMA) constructed 2014

Perpetual Pavement – Fatigue Endurance Limit

ORITE Studies

- DEL-23 (2012)

Strains expected < 70 $\mu\varepsilon$ (39D168, 39BS803)

Strains expected > 70 $\mu\varepsilon$ (39BN803)

Layer	Thickness (in.)		
	39D168	39BS803	39BN803
AC Surface	1	1	1
AC Intermediate	2	2	2
AC Base	8	6	4
AC Fatigue Resistant Layer	4	4	4
Total Asphalt Thickness	**15**	**13**	**11**
Aggregate Base	6	6	6
Subgrade:	Unstab.	Chem. Stab.	Chem. Stab.

Perpetual Pavement – Fatigue Endurance Limit

ORITE Studies

- APLF, HiMA (2014)

Layer	Thickness (in.)			
	Lane A (HiMA)	Lane B (HiMA)	Lane C (HiMA)	Lane D (Control)
AC Surface	1.5	1.5	1.5	1.5
AC Intermediate	1.75	1.75	1.75	1.75
AC Base	4.75	5.75	6.75	7.75
AC Fatigue Resistant Layer	0	0	0	0
Total Asphalt Thickness	**8.0**	**9.0**	**10.0**	**11.0**
Aggregate base layer	6	6	6	6
Stabilized subgrade	18	18	18	18

Perpetual Pavement – Fatigue Endurance Limit

ORITE Studies

- Laboratory FEL
  - Based on laboratory-determined material properties, following NCHRP 9-44A (shown below for E_0 = E* and assumed 5 sec. rest period, *f* = 10 Hz, N = 200,000)
  - Dependent on temperature
- DEL-23 (**measured strains < FEL**):
  - Measured strain – single axle, single wide based tire load of 14 kip

Date	Lane	Avg Temp (F)	FEL of FRL (με)	Avg. Peak strain (με)
11/29/2012	39D168	41	85	38
12/18/2012	39BN803	44	86	47
12/19/2012	39BS803	44	86	31
7/1/2013	39D168	84	105	74
7/10/2013	39BN803	90	102	101
7/11/2013	39BS803	81	103	70

Perpetual Pavement – Fatigue Endurance Limit

ORITE Studies

- Laboratory FEL
  - Based on laboratory-determined material properties, following NCHRP 9-44A (shown below for $E_0 = E^*$ and assumed 5 sec. rest period, f = 10 Hz, N = 200,000)
  - Dependent on temperature
- APLF, HiMA (**generally, measured strain < FEL**):
  - Measured strain – tandem axle, dual load of 12 kip

Lane	Mix Type	Avg Temp (F)	FEL of FRL (με)	Avg. Peak strain (με)
A	HiMA Base	70	79	70
		100	97	*106*
B	HiMA Base	70	79	62
		100	97	79
C	HiMA Base	70	79	46
		100	97	61
D	Control Base	70	80	52
		100	99	56

Perpetual Pavement – Fatigue Endurance Limit

- Design strain threshold of 70 $\mu\varepsilon$ has been shown to control fatigue cracking and rutting in Ohio
  - WAY-30: FWD 9 years after construction showed distresses contained to surface only
- HiMA has potential to reduce AC pavement thickness needed to achieve perpetual behavior when used in all AC layers
  - 9 inches of HiMA on 6 inches of DGAB and 18 inches of stabilized subgrade has potential to behave perpetually (i.e. stiffness ratio > 1.0; strains < FEL) based on performance in APLF.
- Two sections on DEL-23 designed to achieve strains < 70 $\mu\varepsilon$, one with stabilized subgrade, one without. Analysis of modulus indicates both may be perpetual
  - Stabilized subgrade enabled reduction of AC pavement thickness of 2 inches.

Perpetual Pavement Design for Local Roads

Perpetual Pavement Design for Local Roads

How does perpetual pavement design for local roads differ from design for Interstates, US and State routes?

Traffic

Budget

Perpetual Pavement Design for Local Roads

- Traffic
  - Truck volumes, truck types, axle weights, etc. differ from interstates and other principal arterials
- Budget
  - It is often assumed cost of perpetual pavement is prohibitive
    - High initial cost
    - Premium mixtures are more costly
    - But….

Perpetual Pavement Design for Local Roads

- Budget
  - But….
    - Perpetual Pavement constructed in Cuyahoga County 2007/2008 (presentation at 2008 OAPC: http://www.flexiblepavements.org/sites/www.flexiblepavements.org/files/events/conferences/driscoll10-28-08Session24pdf.pdf)
      - Initial cost of perpetual pavement only 2% greater than conventional asphalt pavement
      - Included fatigue resistant layer, and polymer modified surface
    - Distresses contained to surface, therefore limited or no major rehabilitation costs (i.e. potential for lower life-cycle costs)

Perpetual Pavement Design for Local Roads

- Findings from ORITE studies:
  - Pavement Layers
    - Laboratory test results of FRL and ODOT Item 302 used on DEL-23 and in APLF, similar enough that FRL could be replaced with asphalt base course
    - Increasing thickness of dense graded aggregate base (DGAB) in APLF sections over thickness used on WAY-30 did not have significant negative impact on measured strain
      - i.e.: an increase in DGAB thickness helped reduce asphalt layer thickness by 2 inches when designing for strain threshold of 70 $\mu\varepsilon$ (Sargand, Figueroa, Edwards and Al-Rawashdeh, 2009)
    - Stabilization of subgrade on DEL-23 had significant impact on reducing strain in FRL
      - AC thickness can be minimized by combining with stabilized subgrade

Perpetual Pavement Design for Local Roads

- Findings from ORITE studies:
  - Designing long-life pavements is not limited to new construction
    - Existing pavements can made perpetual
      - Evaluate existing pavement structure with FWD
        - » To determine if feasible and
        - » To design required overlay thickness to achieve predicted strains of 70 $\mu\varepsilon$ or less
- SHRP2 R23: Using Existing Pavement In Place and Achieving Long Life (Newton et al., 2012)
  - Guidance provided on evaluating existing pavements and determining necessary thickness

Perpetual Pavement Design for Local Roads

- Implementing findings from ORITE studies for design of local perpetual pavements:
  - AC pavement thickness needed to achieve perpetual behavior can be reduced by
    - Increasing DGAB thickness
    - Stabilizing subgrade
  - Fatigue resistant layer (FRL) can be replaced with ODOT Item 302 to achieve total AC thickness needed to be perpetual

Perpetual Pavement Design for Local Roads

- Implementing findings from ORITE studies for design of local perpetual pavements:
  - Existing pavements can be made perpetual
    - Cannot have structural distresses
    - FWD analysis needed to determine structural overlay thickness needed to achieve perpetual behavior

Perpetual Pavement Design for Local Roads

- Maximum Thickness Tables developed (Tran et al., 2015: NCAT Report 15-05)
  - Conservative design thicknesses
    - Based on strain distributions and traffic consisting of 100% single axles weighing 20 – 22 kips
    - Available for 3 climates
    - Can be used to check against over design
    - Example, Base = 6 inches:

Subgrade Mr (ksi)	Base Mr (ksi)	Calculated AC Thickness (in.)				Range of Maximum Thicknesses (in.)
		Minneapolis (PG 64-34)	Phoenix (PG 70-22)	Baltimore (PG 64-22)	Average	
5	30	12.5	15.5	14	14.0	**12.5-15.5**
5	50	12	15	14	13.7	**12-15**
5	100	12	14	13.5	13.2	**12-14**
5	250	8.5	12	10	10.2	**8.5-12**
5	500	8	11	9	9.3	**8-11**

Perpetual Pavement Design for Local Roads

- SHRP2 R23: Using Existing Pavement In Place and Achieving Long Life (Newton et al., 2012)
  - Thickness design for renewing existing pavements
    - Based on PerRoad analysis using 100 $\mu\varepsilon$ with transfer functions to achieve $D \leq 0.1$ at 10 and 50 years of service for 5 US locations.
    - To determine AC overlay needed: subtract existing AC thickness (meeting requirements) from thickness in table below (Scoping Methodology, SHRP2 R23, 2014)
    - Example table for overlay where subgrade with M_R = 5,000 psi

HMA Overlay for Subgrade M_R = 5,000 psi.

ESALs (millions)	Existing Pavement or Base Modulus			
	30,000 psi	50,000 psi	75,000 psi	100,000 psi
≤10	10.0	9.0	8.0	6.0
10-25	11.0	10.0	8.5	6.5
25-50	12.0	11.0	9.0	7.0
50-100	13.0	11.5	9.5	7.5
100-200	14.0	12.0	10.0	7.5

Source: Scoping Methodology, SHRP2 R23, 2014

Project reports available on ODOT website

- http://www.dot.state.oh.us/Divisions/TransSysDev/Research/reportsandplans/Pages/PavementReports.aspx
- WAY-30 Perpetual Pavement report titles:
  - *Monitoring and Modeling of Pavement Response and Performance*: State Job No. 134287, Report No. FHWA/OH-2010/3A,
  - *Instrumentation of the WAY-30 Test Pavements*: State Job No. 14815, Report No. FHWA/OH-2008/7
- Variable Depth Perpetual Pavement title – *Performance Assessment of Warm Mix Asphalt (WMA) Pavements*: State Job No. 134312, Report No. FHWA/OH-2009/8
- *Implementation and Thickness Optimization of Perpetual Pavements in Ohio*: State Job No. 465970, Report No. FHWA/OH-2015/17

http://www.ohio.edu/orite/