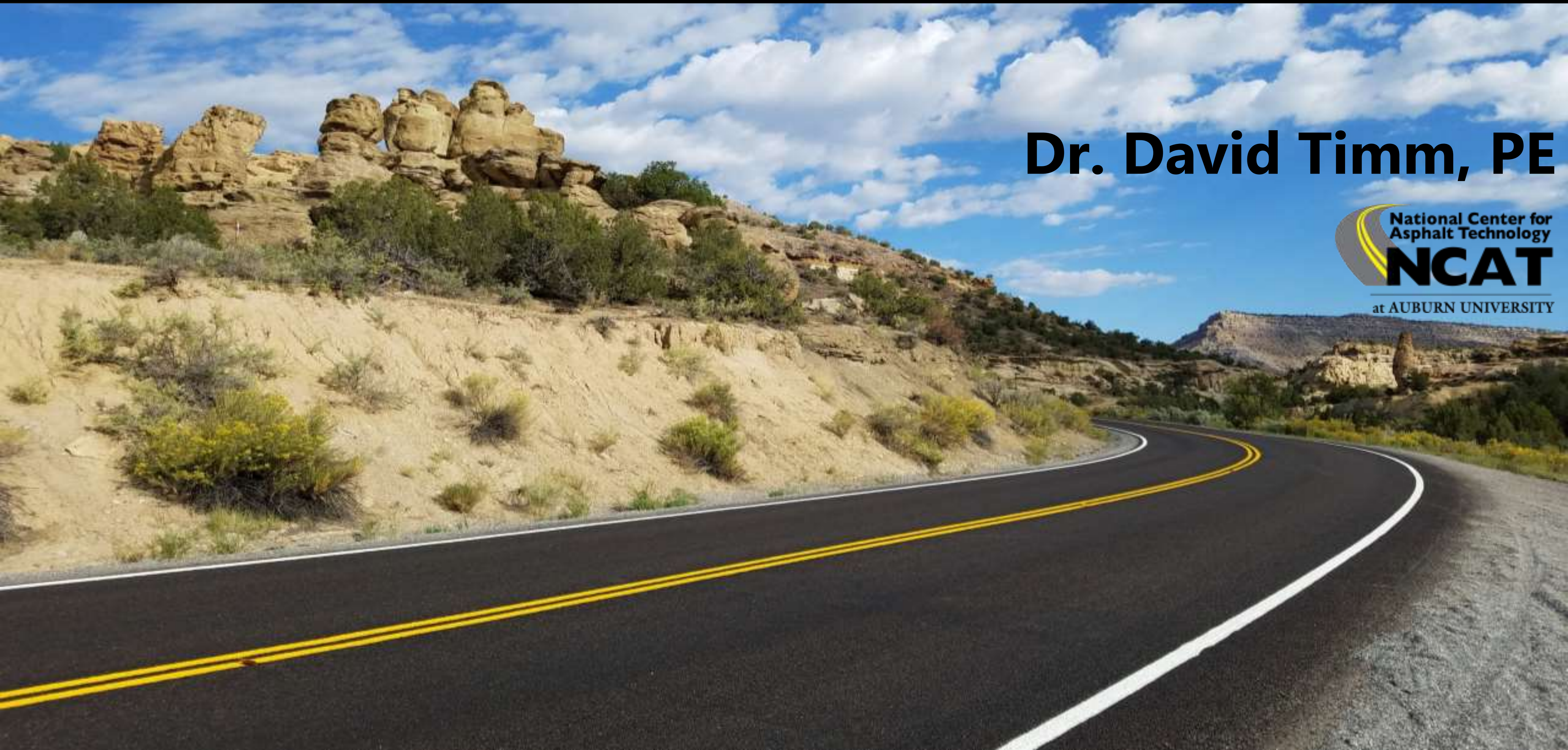
Perpetual Pavements



Dr. David Timm, PE

National Center for Asphalt Technology
NCAT
at AUBURN UNIVERSITY

What is a Perpetual Pavement?

- 35+ Years of Service
- Minimal structural improvements
- No deep structural distresses
  - Only surface remedies needed

Perpetual Pavements in the U.S.

http://www.asphaltmagazine.com/dotAsset/4af55c62-42dd-4bbe-a6cc-8f647455eb22.jpg

Goal of Perpetual Pavement Design

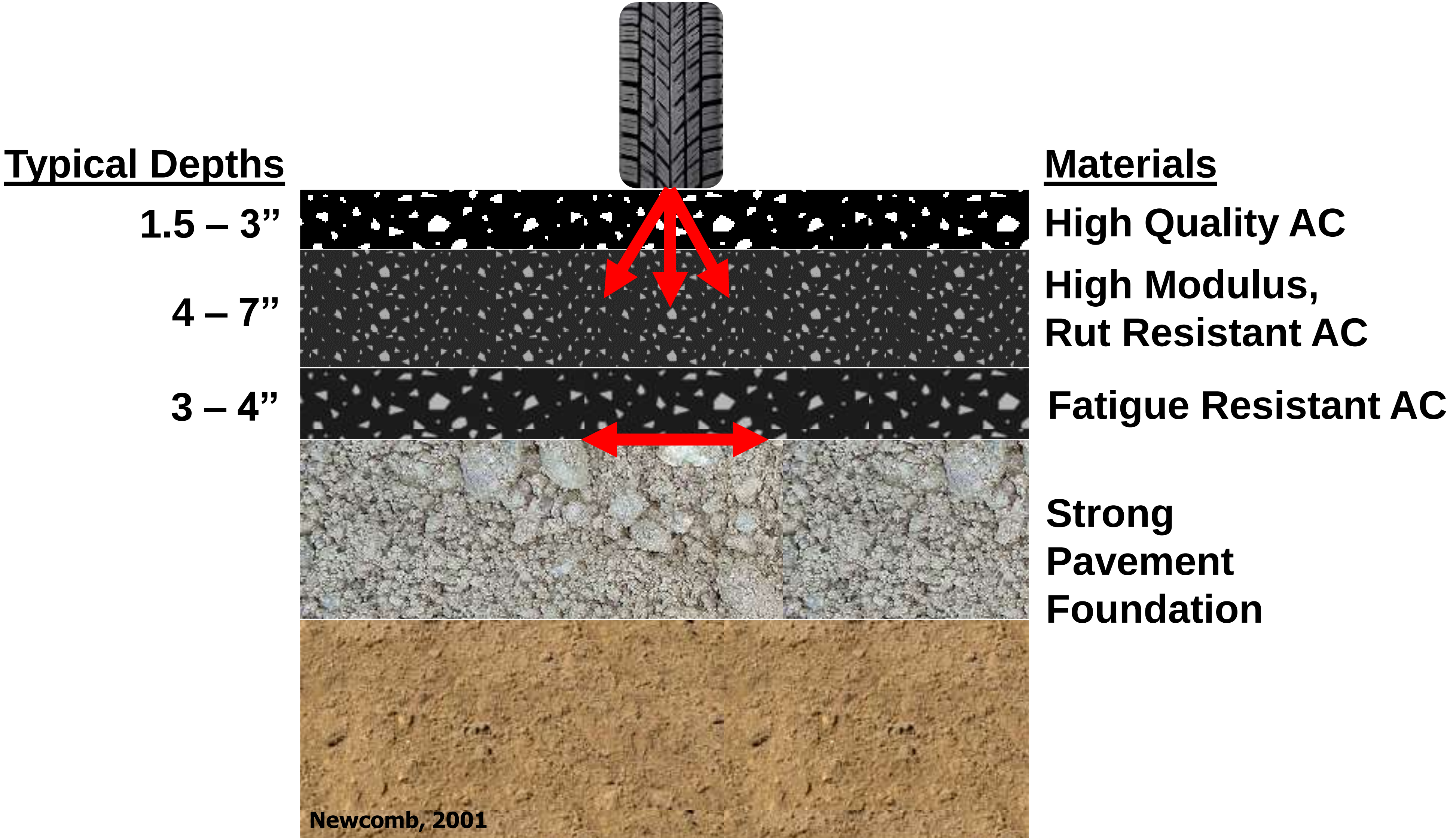
- Design against deep structural distresses

Bottom up fatigue cracking

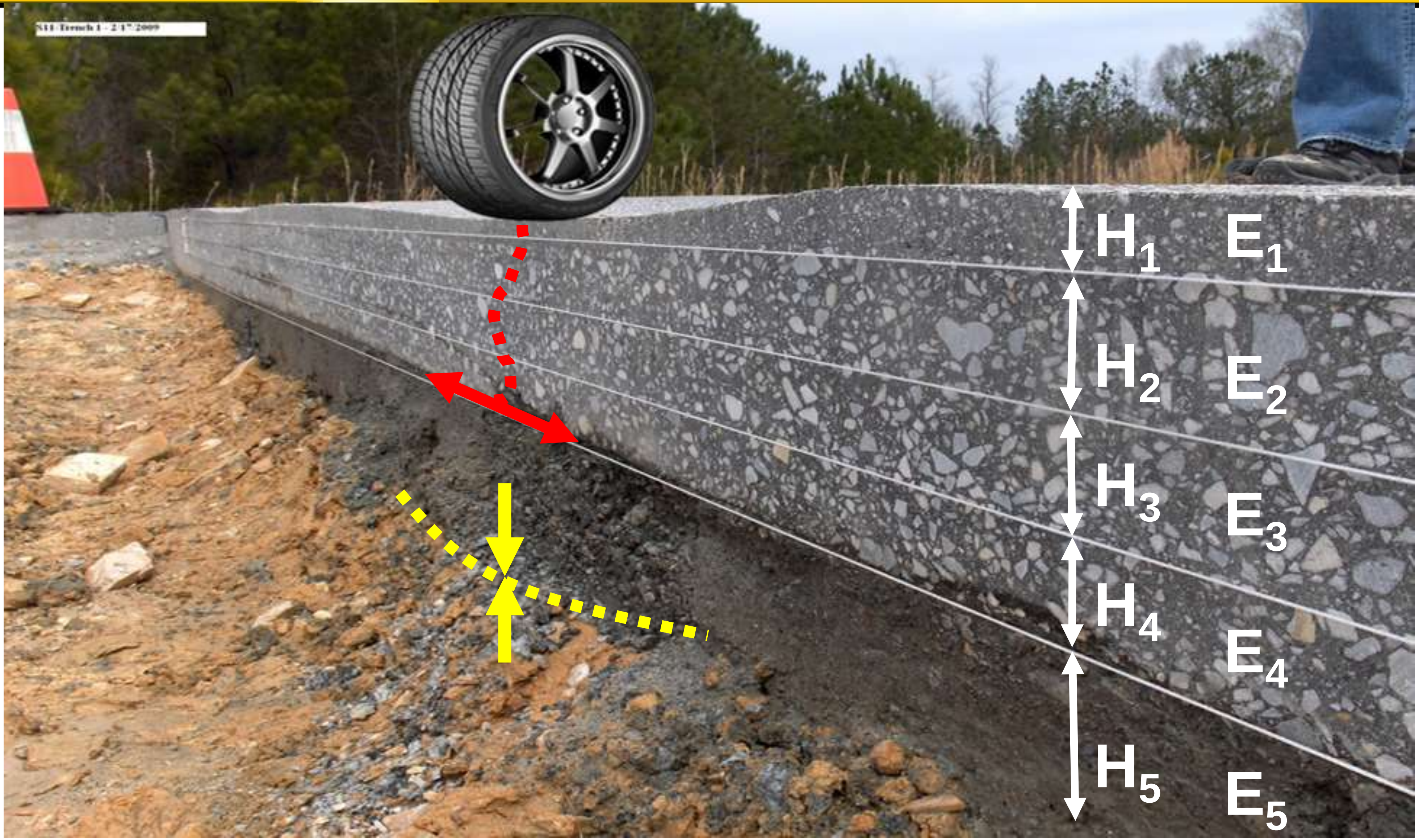
Structural Rutting

Results in a structure with Perpetual or Long-Life

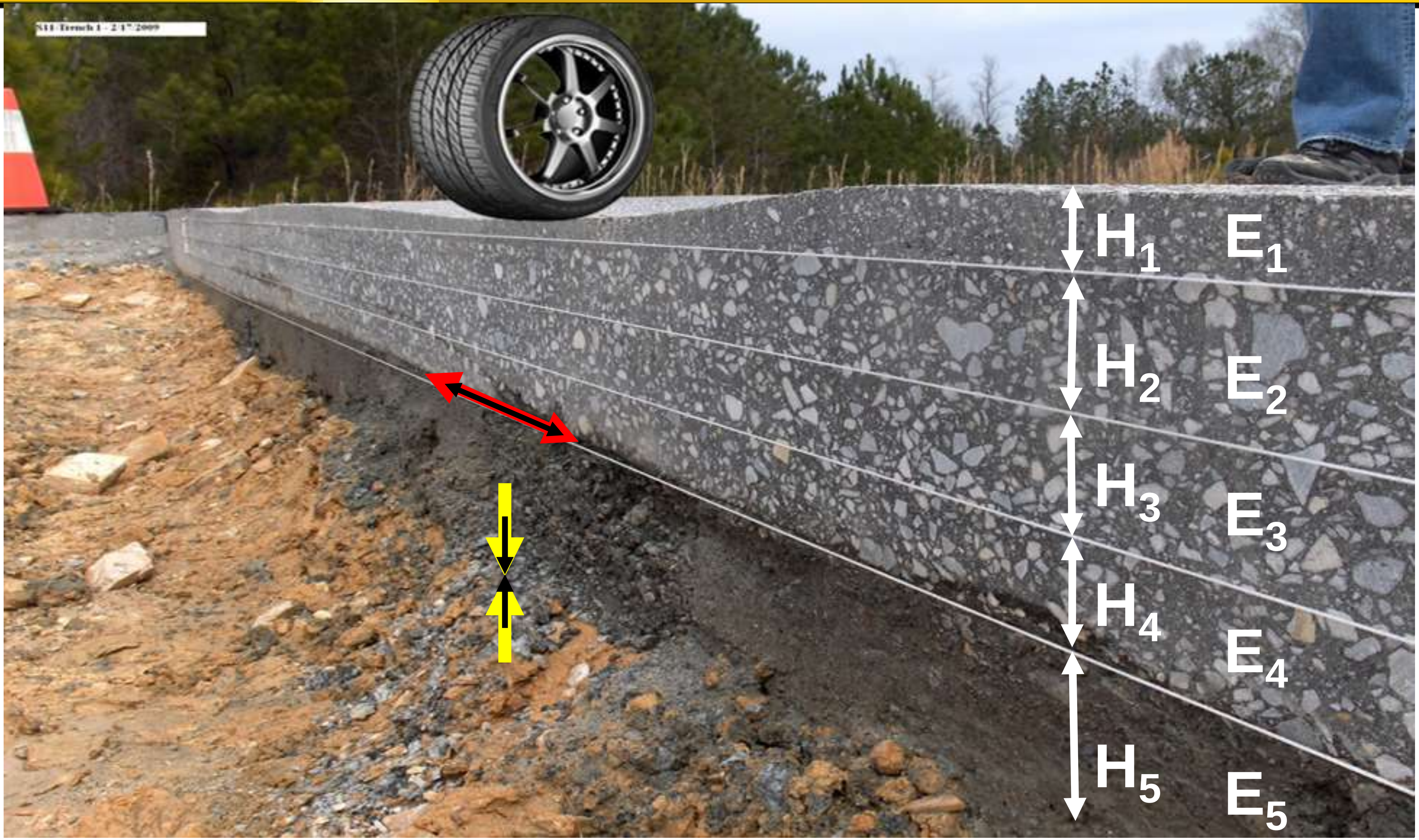
Perpetual Pavement Cross-Section



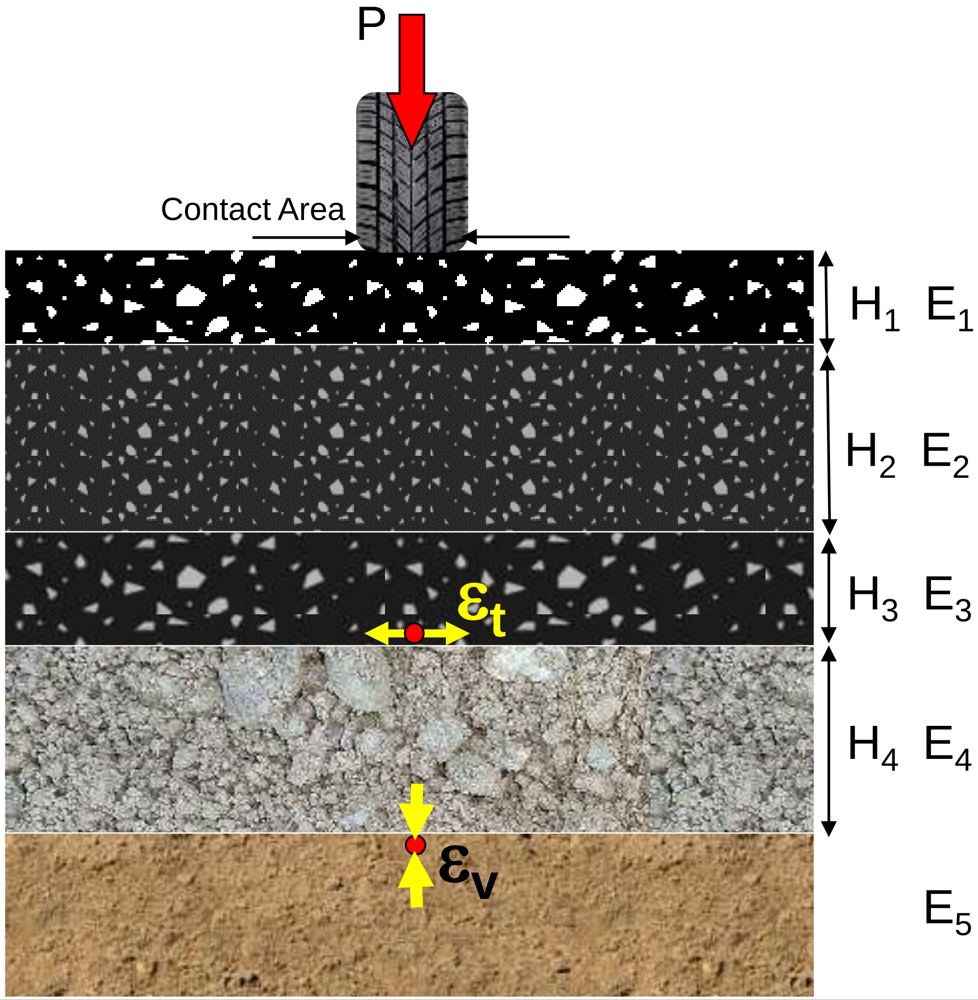
Mechanistic-Empirical Pavement Design

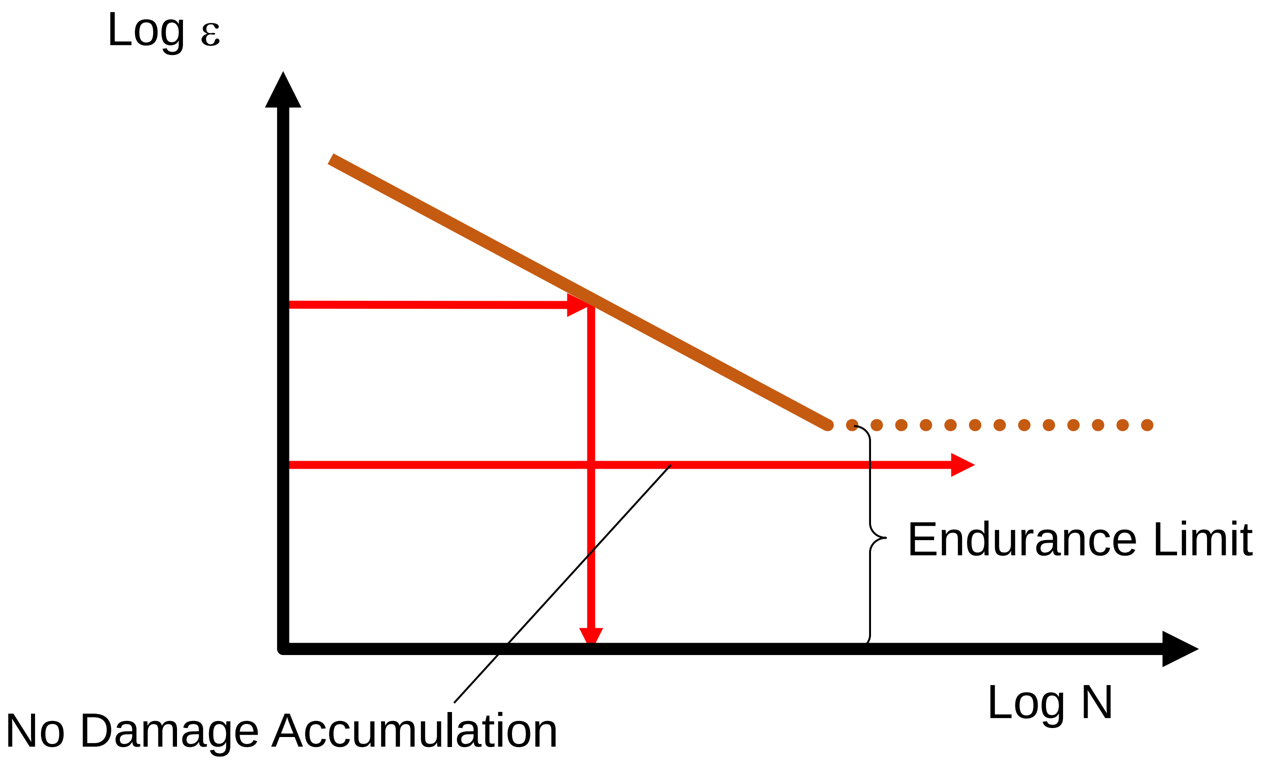


Mechanistic-Empirical **Perpetual** Pavement Design

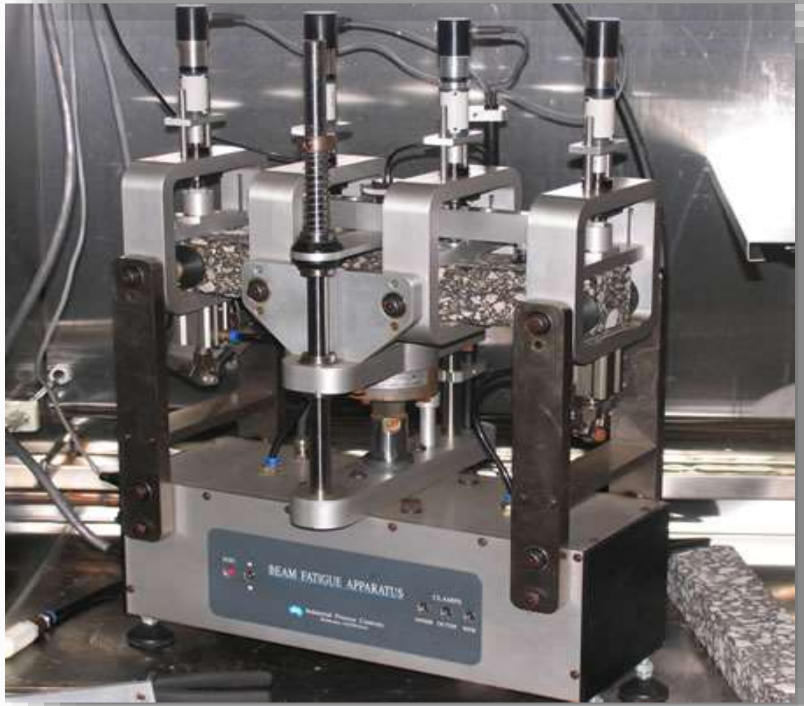


Mechanistic-Empirical **Perpetual** Pavement Design

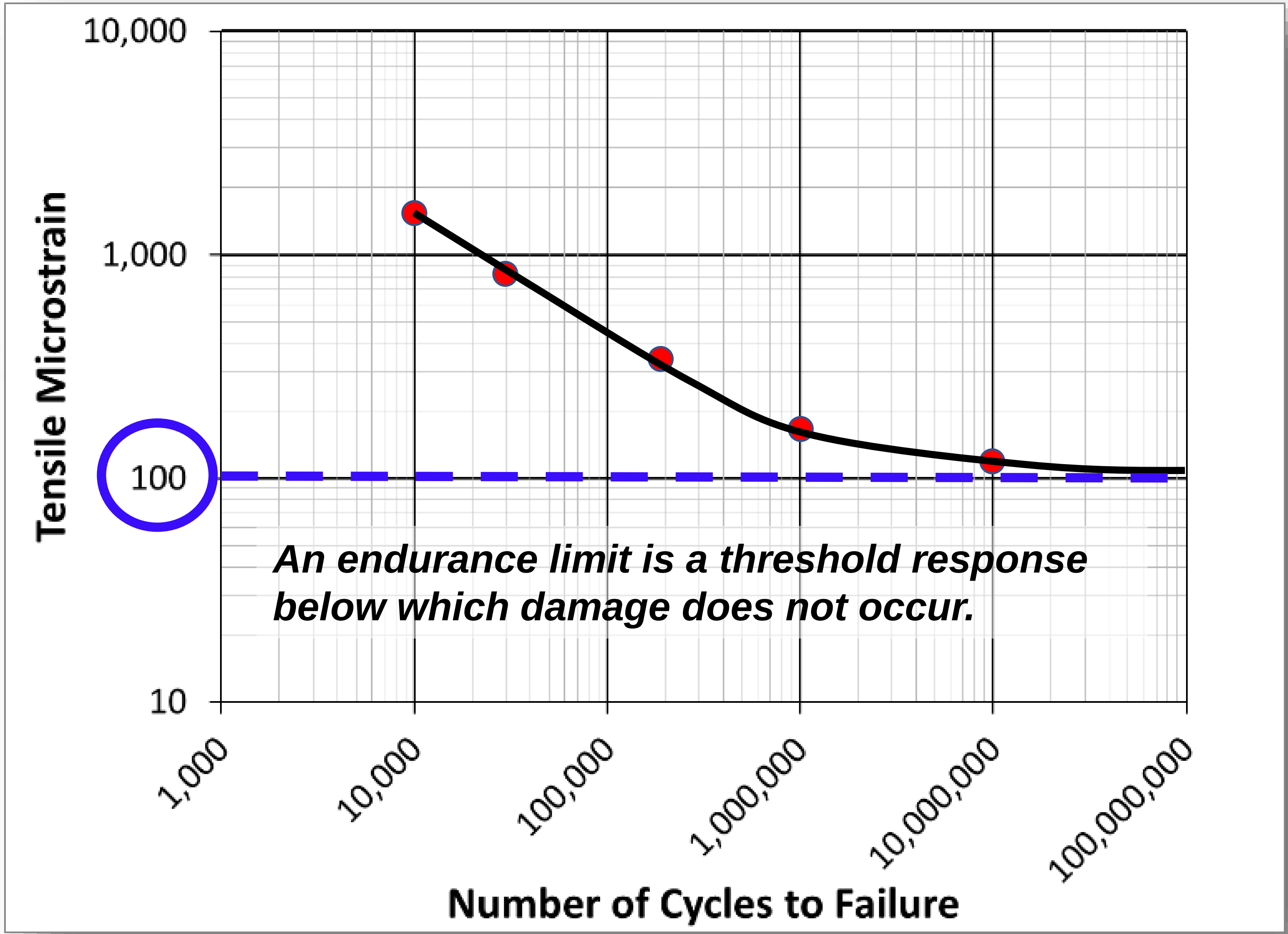




What is the **Endurance Limit** for AC?



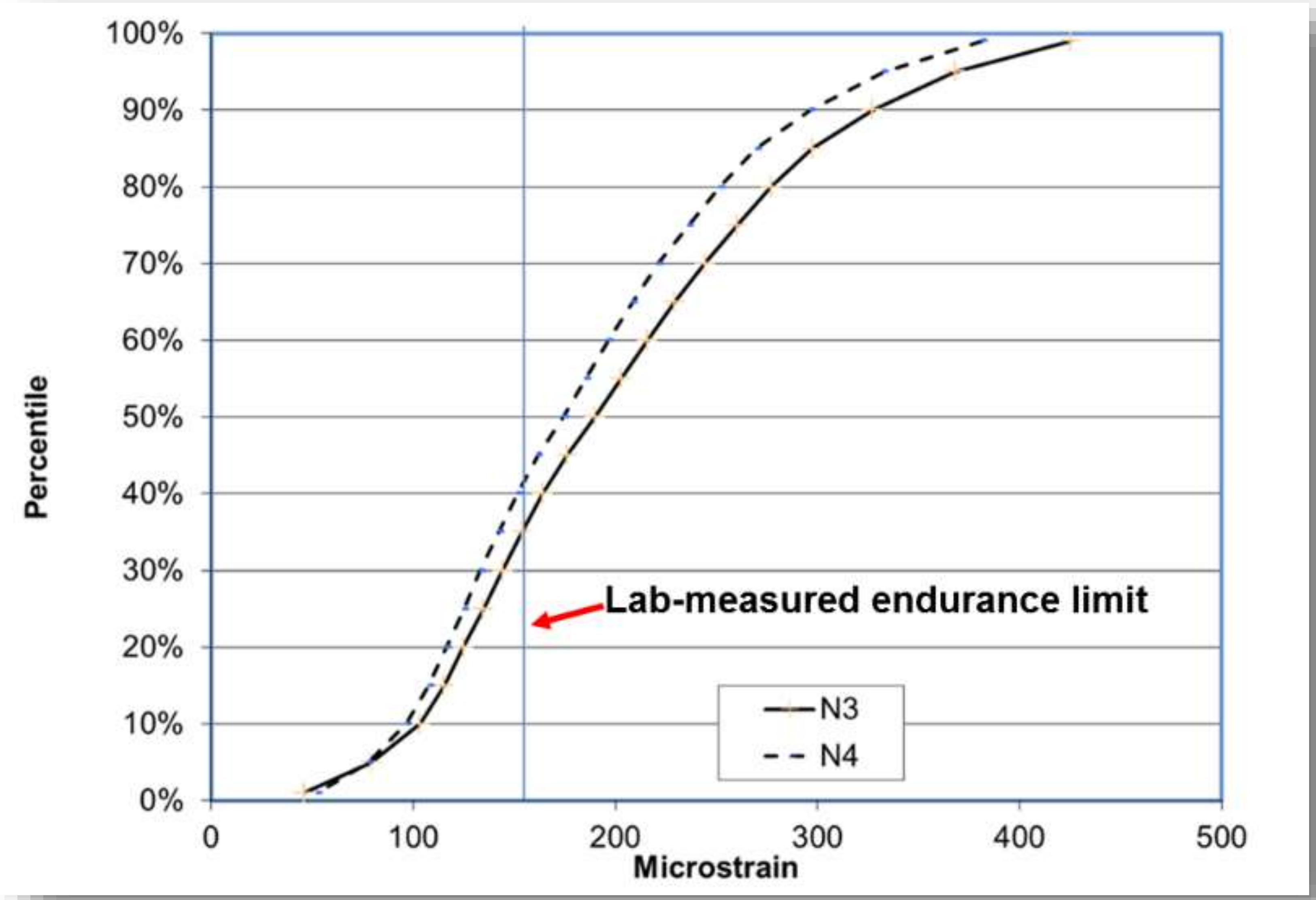
http://www.pavementinteractive.org/wp-content/uploads/2011/07/Device1.jpg



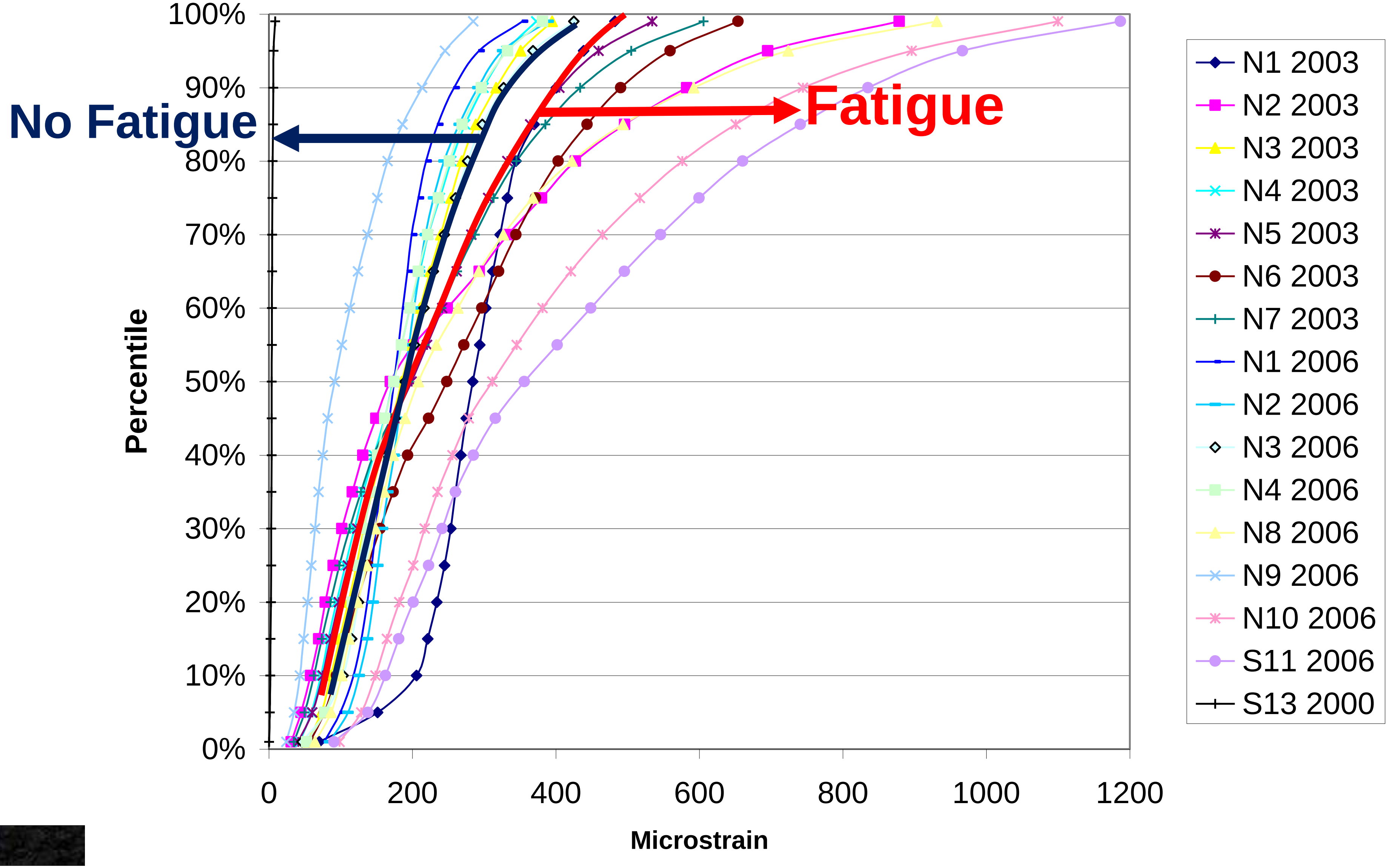
History of Endurance Limits

- 1972 – Monismith estimates about 70 $\mu\varepsilon$
- 2001 – I-710 designed at 70 $\mu\varepsilon$
- 2002 – 70 $\mu\varepsilon$ used by APA
- 2007 – NCHRP 9-38 Lab Study
  - 100 $\mu\varepsilon$ for unmodified binders
  - 250 $\mu\varepsilon$ for modified binders
  - Lab conditions more severe than field
- 2007 – MEPDG uses 100 to 250 $\mu\varepsilon$
- 2008 – Measurements at NCAT Test Track show strains in perpetual pavements well exceeding laboratory values

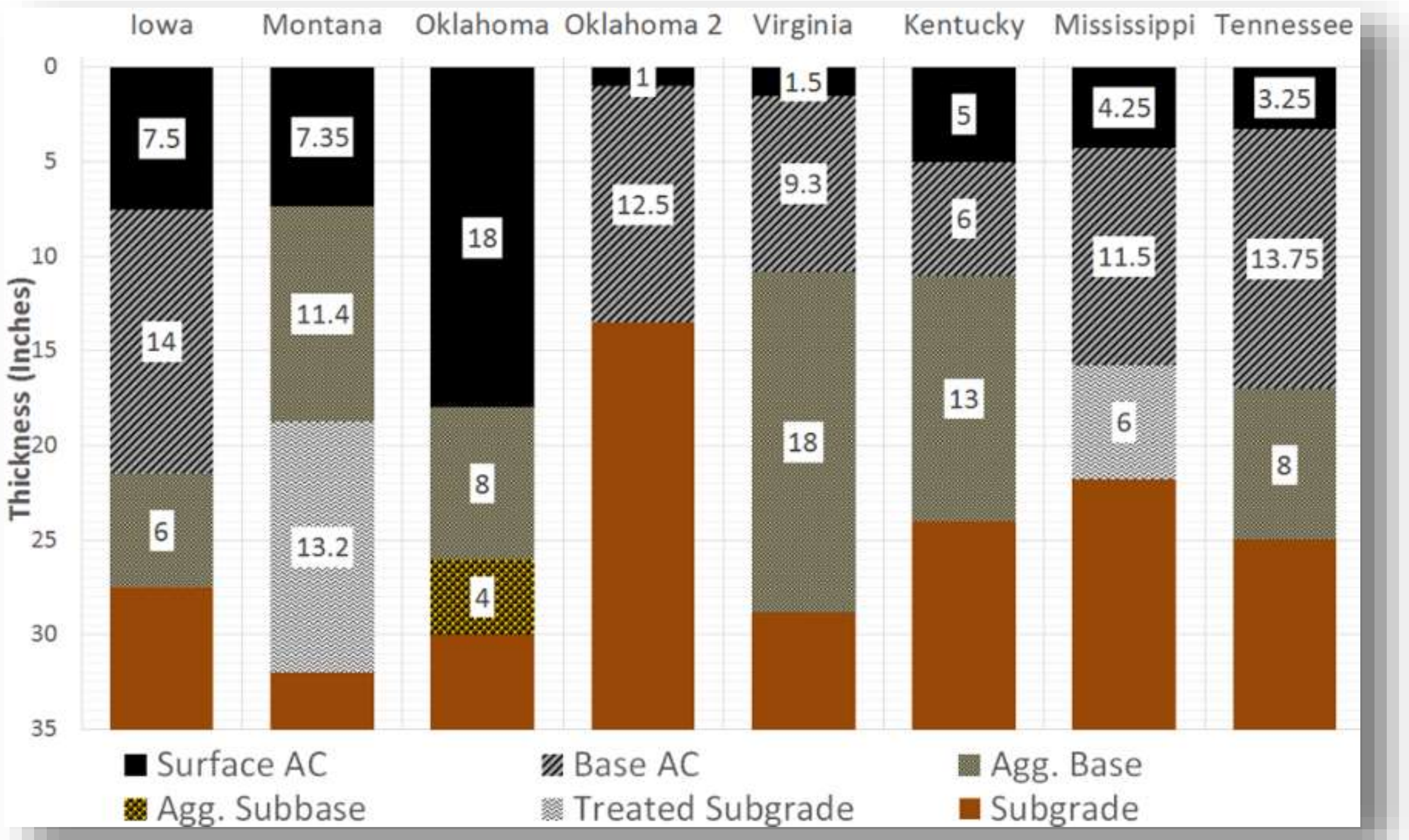
Measured Horizontal Strains and Endurance Limits



Horizontal Strain Distributions at NCAT Test Track



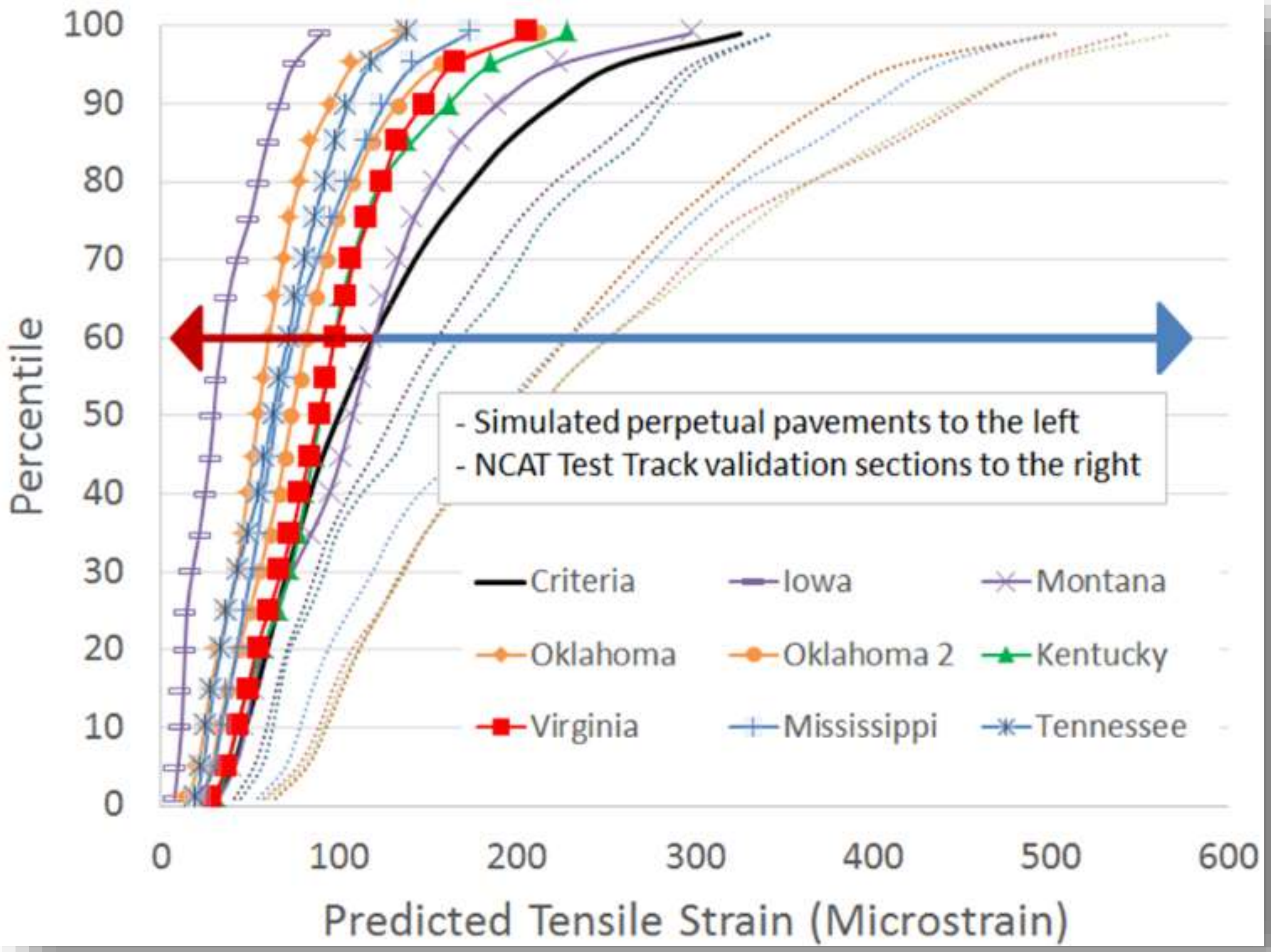
Evaluation of Perpetual Pavement Winners



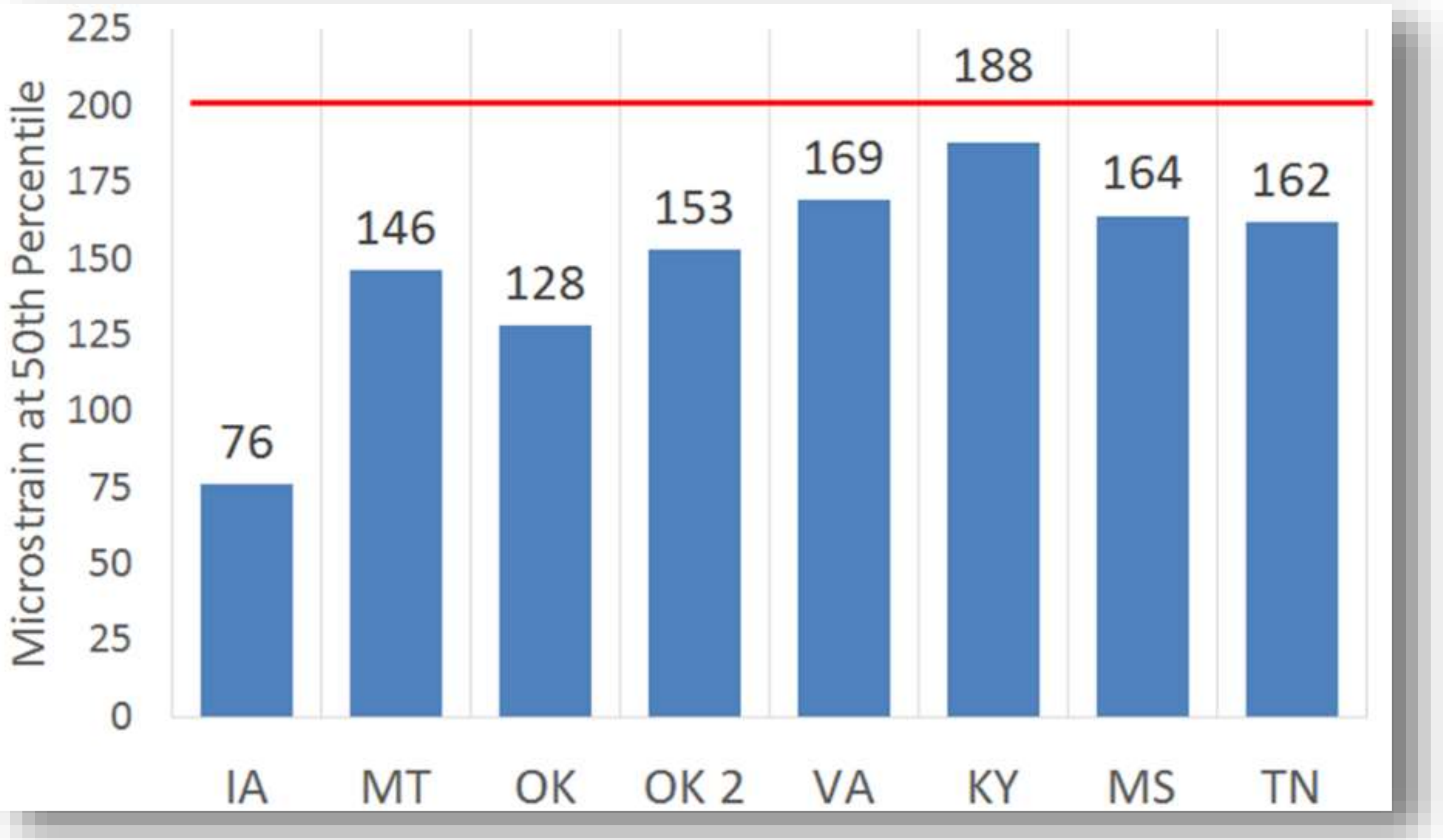
Award Winner Metrics

State	Project	Year Honored	Service Years (Time of award)	Cumulative Traffic (Time of award)
Iowa	I-80, MP 225.9 to 239.9	2002	38	32,000,000 ESAL
Montana	I-90 MP 439.33 to 445.4	2005	44	15,000,000 ESAL
Oklahoma	I-35, MP 185.6 to 192.6	2003	40	61,000,000 ESAL
Oklahoma	I-40, MP 160.2 to 165.5	2002	40	60,000,000 ESAL
Virginia	I-81, MP 318.4 to 324.9	2006	41	29,000,000 ESAL
Kentucky	I-65, Hart County	2009	44	76,000,000 ESAL
Mississippi	I-22, Desoto County	2007	39	60,000,000 ESAL
Tennessee	I-65, MP 22.4 to 32.56	2002	35	25,800,000 ESAL

Horizontal Strain Distribution – Simulation Results



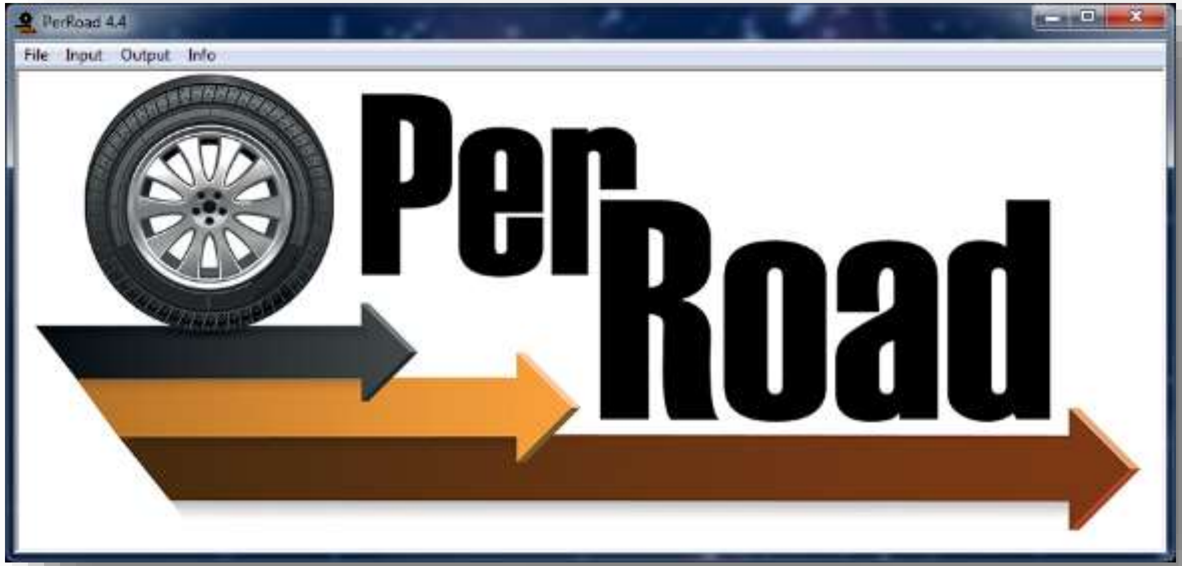
Award Winners – Vertical Strain Rutting Criteria



Need & Justification for Distribution-Based Design

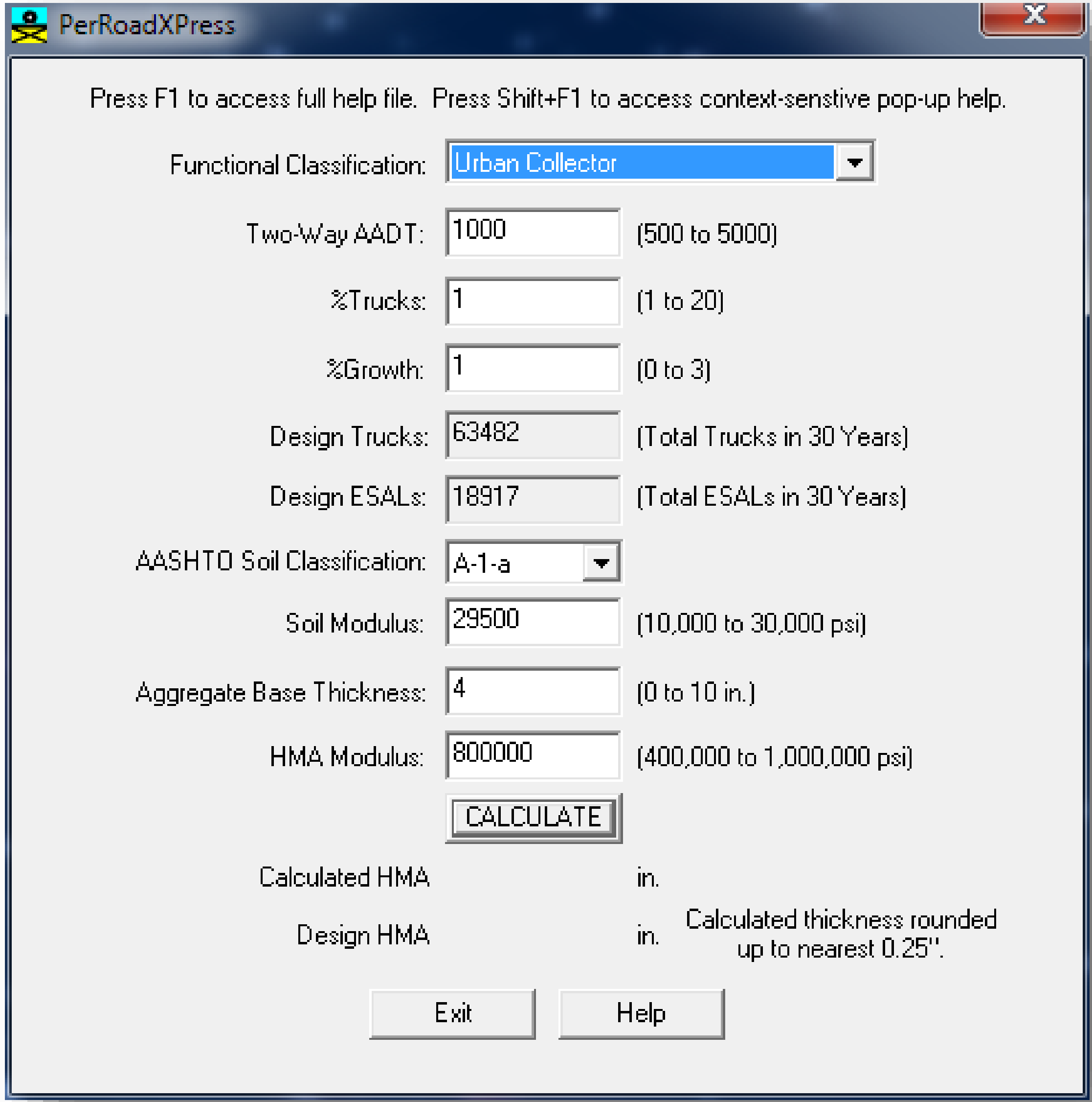
- Pavements experience range of loading and environmental conditions
  - Results in wide range of strain responses
- Traditional M-E design uses transfer functions and sums damage vs. time
  - Fatigue transfer functions difficult to develop and may not be accurate
  - Transfer functions not needed with perpetual pavement design
- Designing with a strain distribution will limit fatigue cracking and avoid transfer functions
  - Also arrive at reasonable perpetual (maximum) pavement thicknesses
- Data from NCAT Test Track and validated with Perpetual Pavement Award Winners supports this approach
  - Horizontal tensile strain distribution for fatigue cracking
  - 200 $\mu\varepsilon$ compressive strain at the 50^{th} percentile for rutting

Perpetual Pavement Design Tools



https://goo.gl/i3FMej

http://www.asphaltroads.org/perpetual-pavement/about-perpetual-pavements/



Key Features of PerRoad 4.4

- Layered elastic analysis
- Up to 5 pavement layers
- User enters design criteria
    - Strain distributions
    - Single strain values and control percentiles
    - Conventional M-E criteria with transfer functions
- Many built-in default parameters
    - Material properties and variability
    - Traffic and load distributions
- Program uses Monte Carlo simulation to simulate uncertainty in design

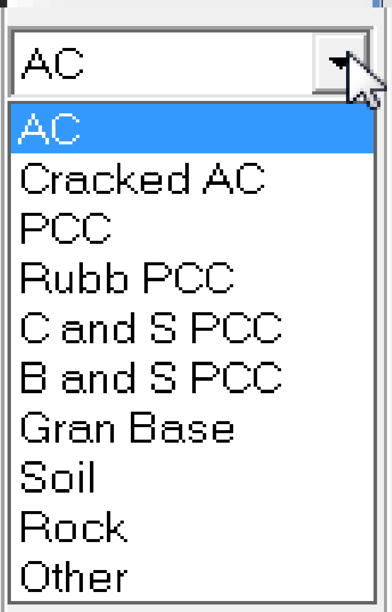
Design Example with PerRoad 4.4

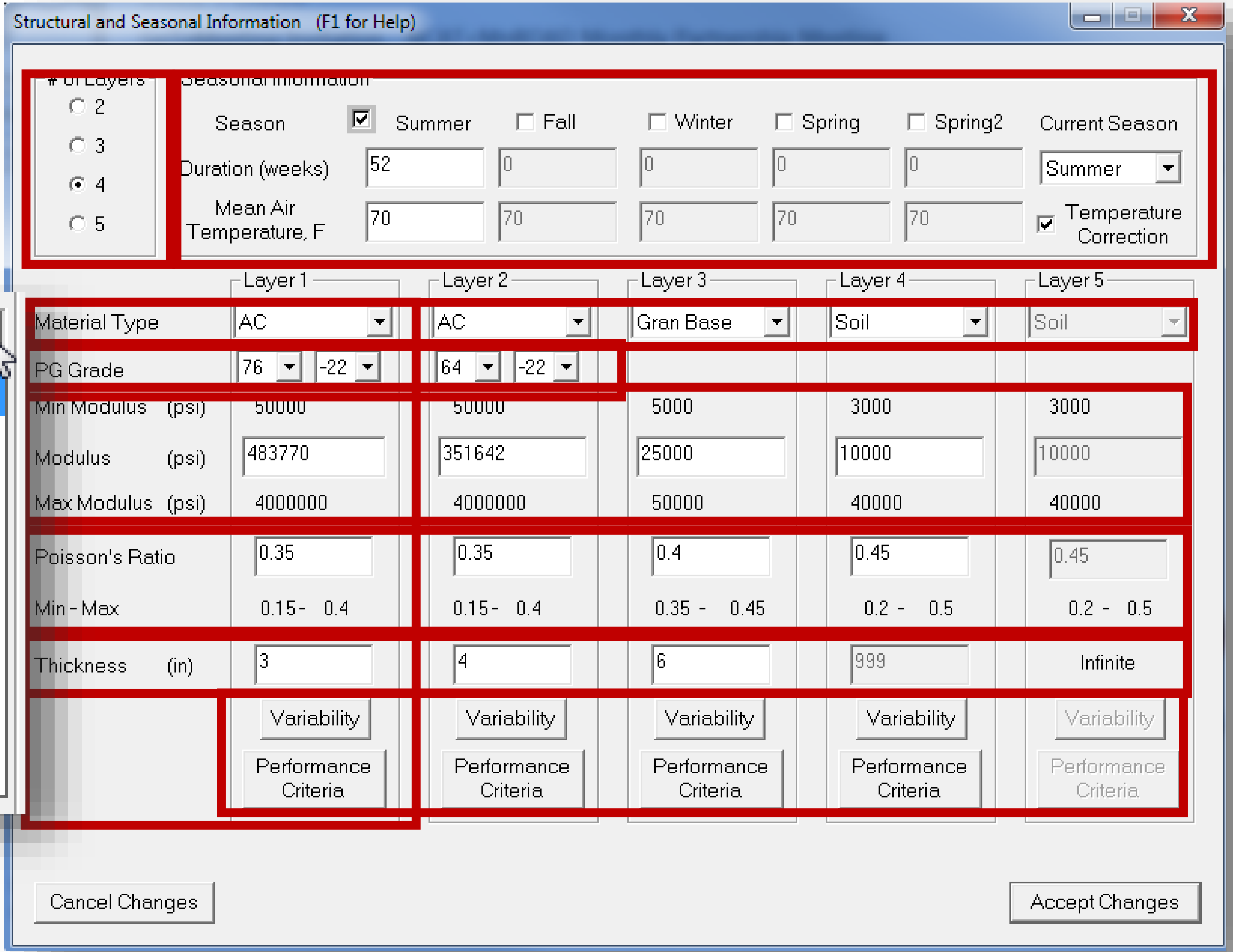
- Interstate pavement
- 4 layer structure
    - 76-22 AC
    - 64-22 AC
    - Granular Base
    - Subgrade Soil
- Moderate Climate

http://www.flexiblepavements.org/sites/www.flexiblepavements.org/files/imagecache/awards_interior/awards/project_16-_interstate_271_kokosing.jpg

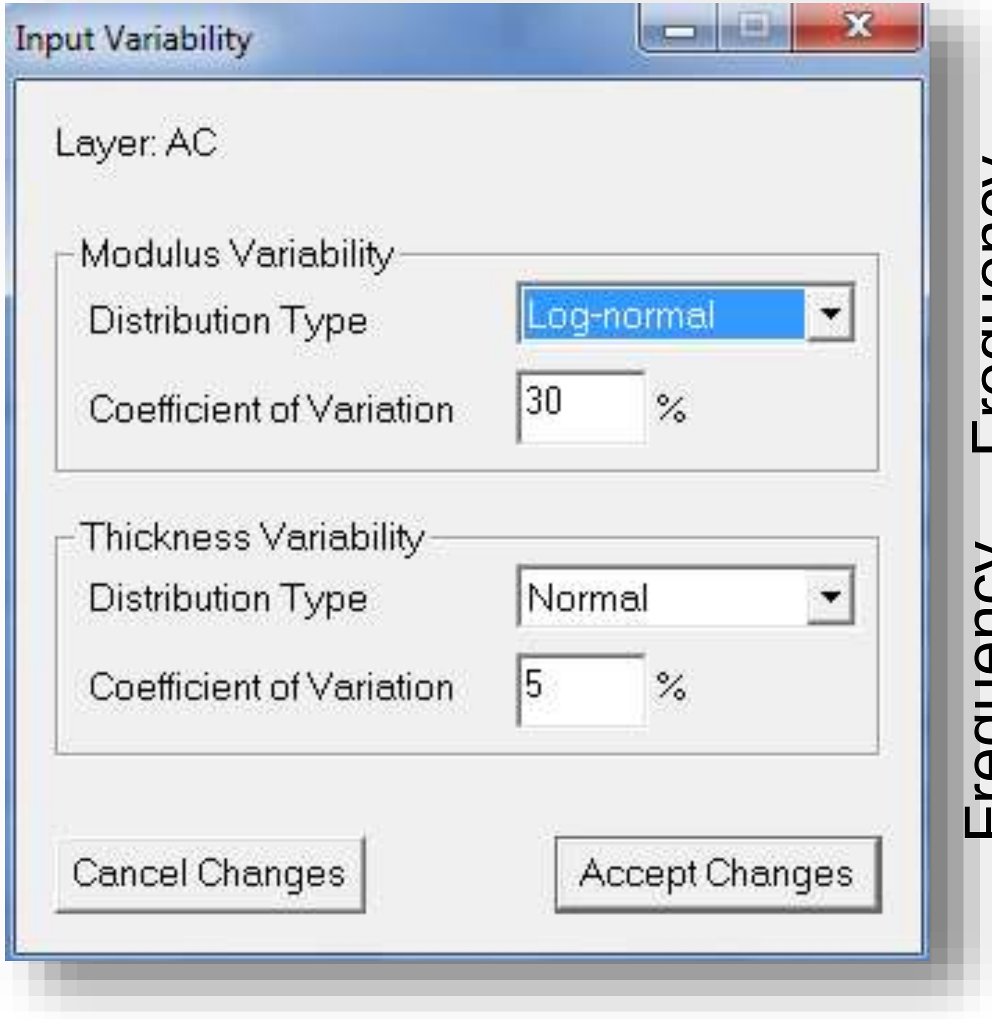
Structural Inputs

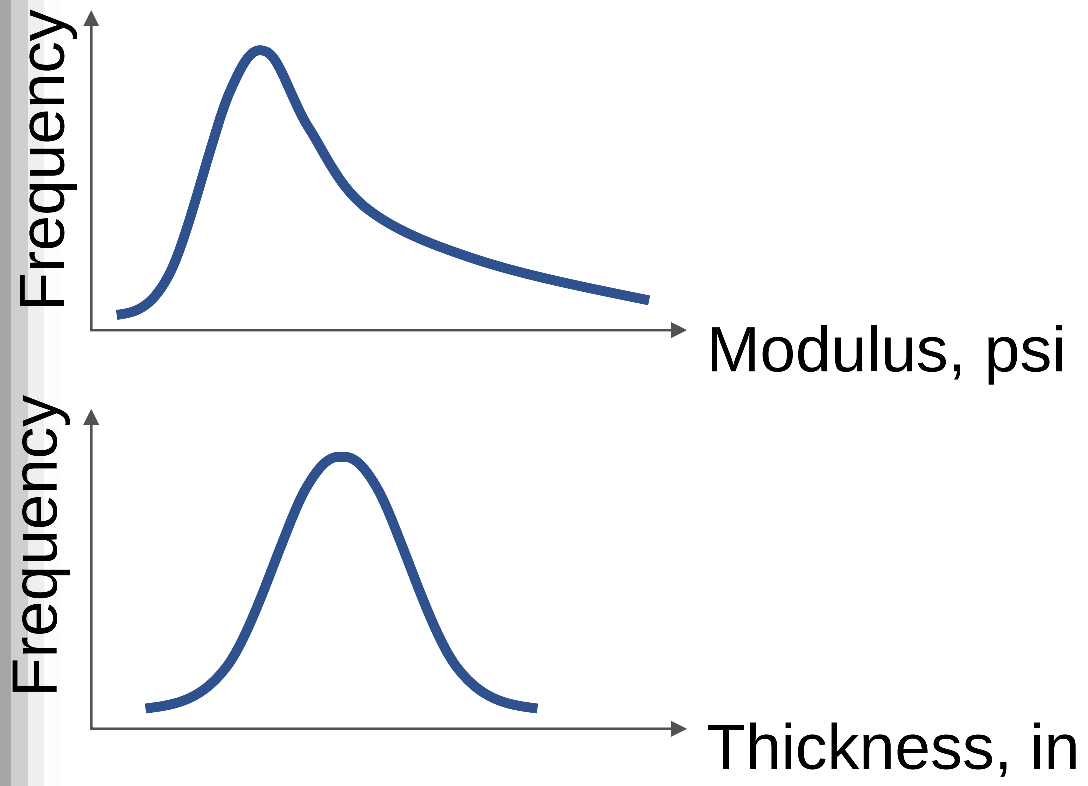
3” 76-22



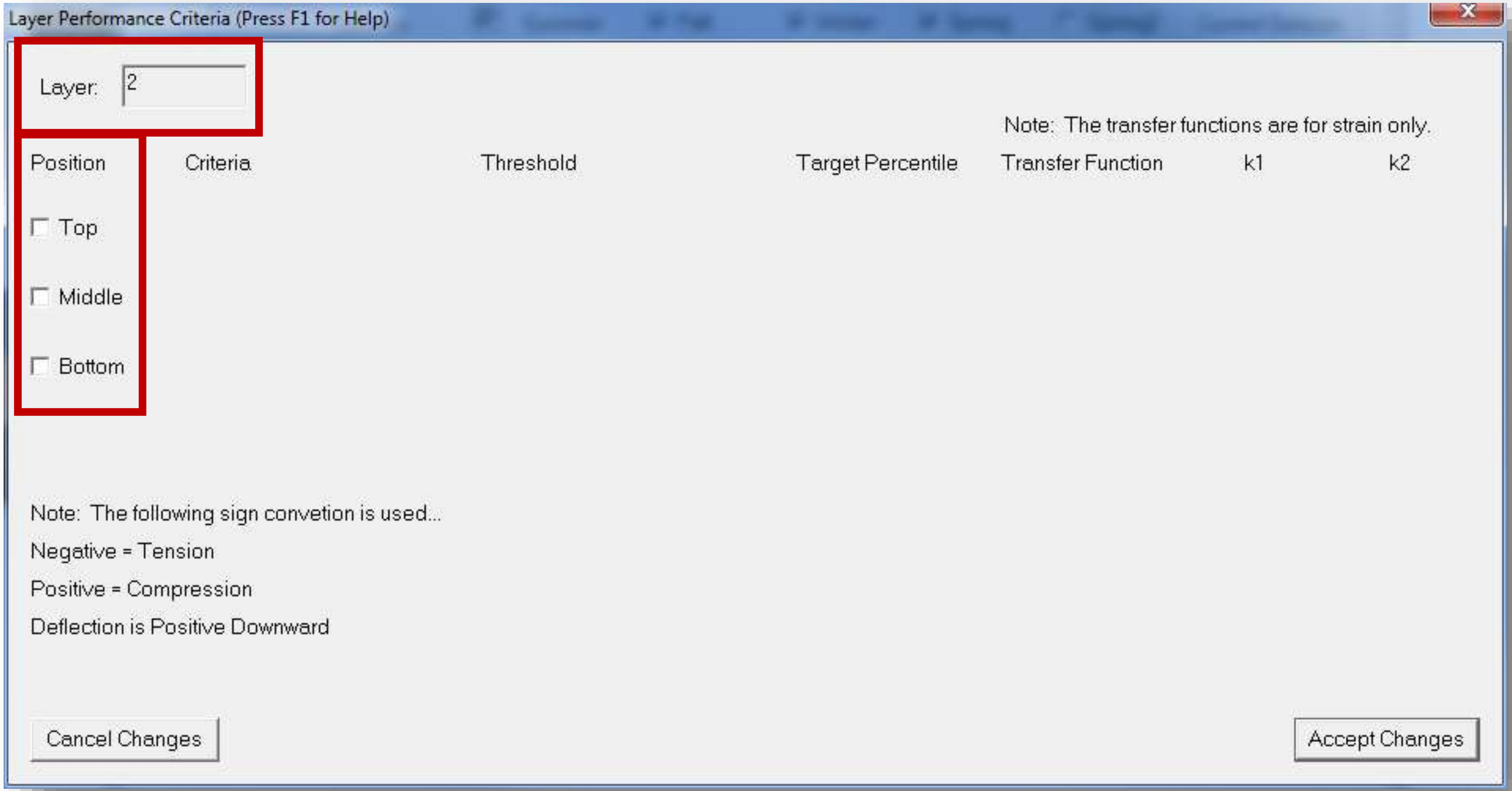


Input Variability

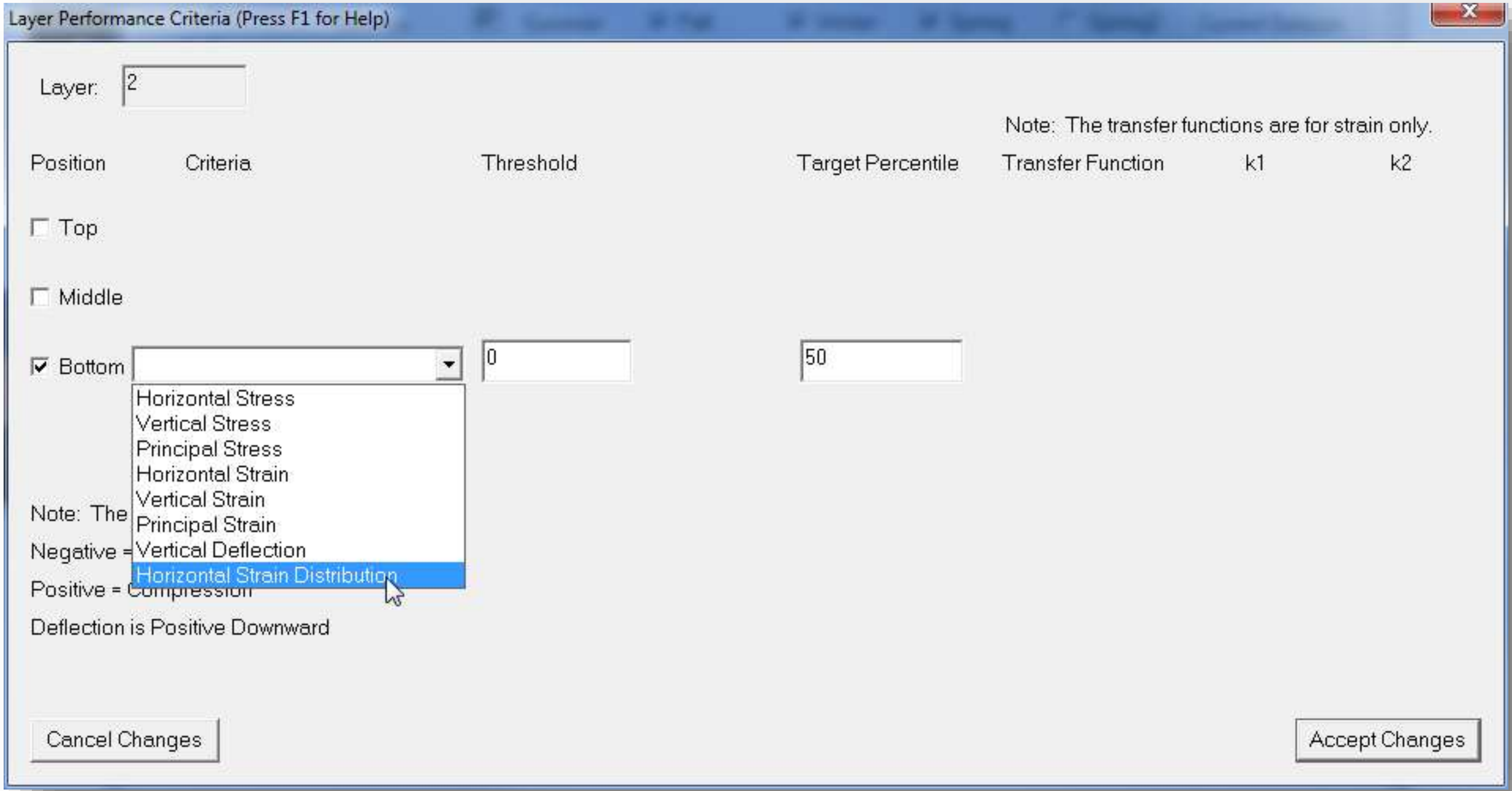




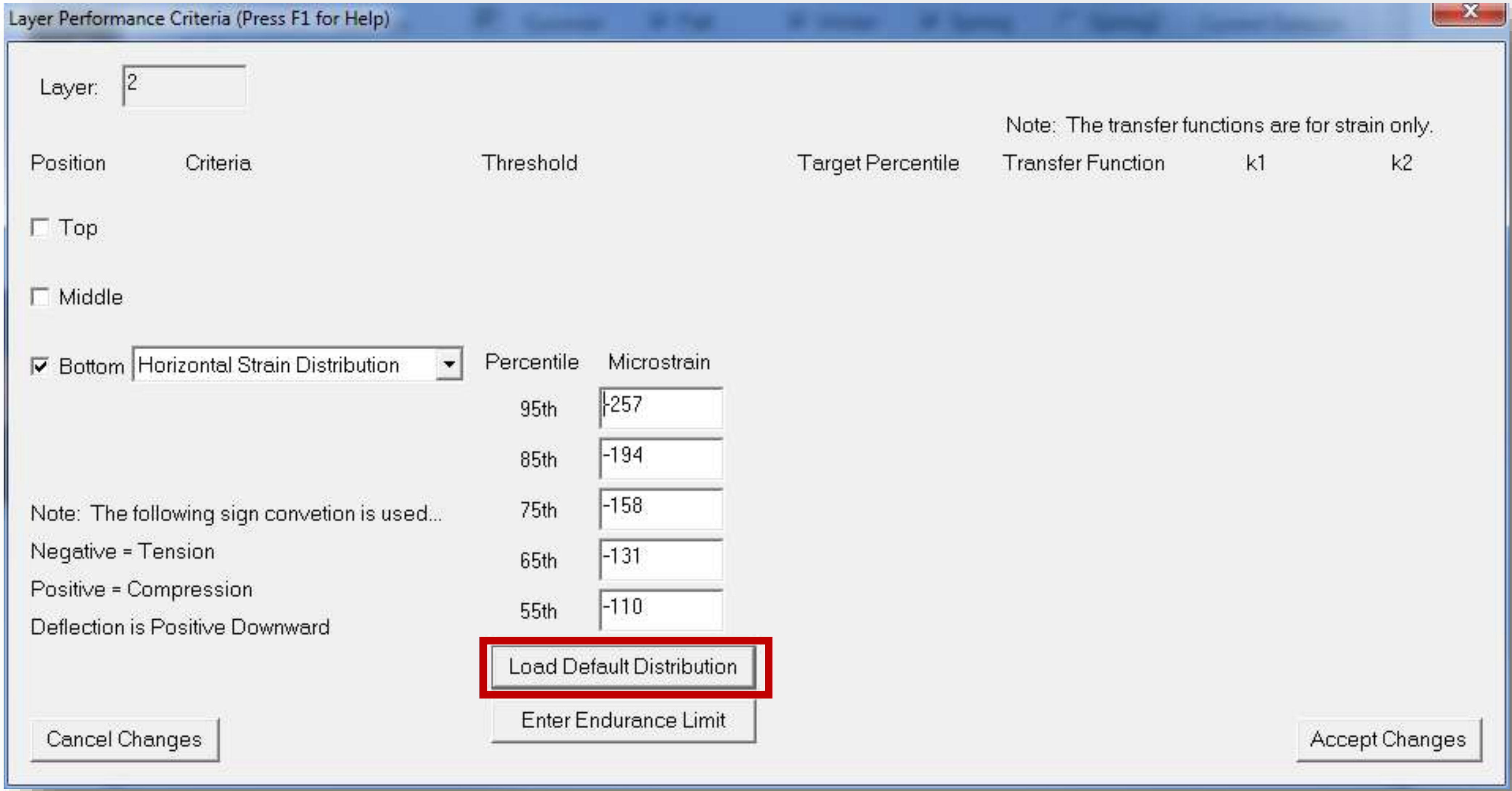
Performance Criteria – Fatigue Cracking



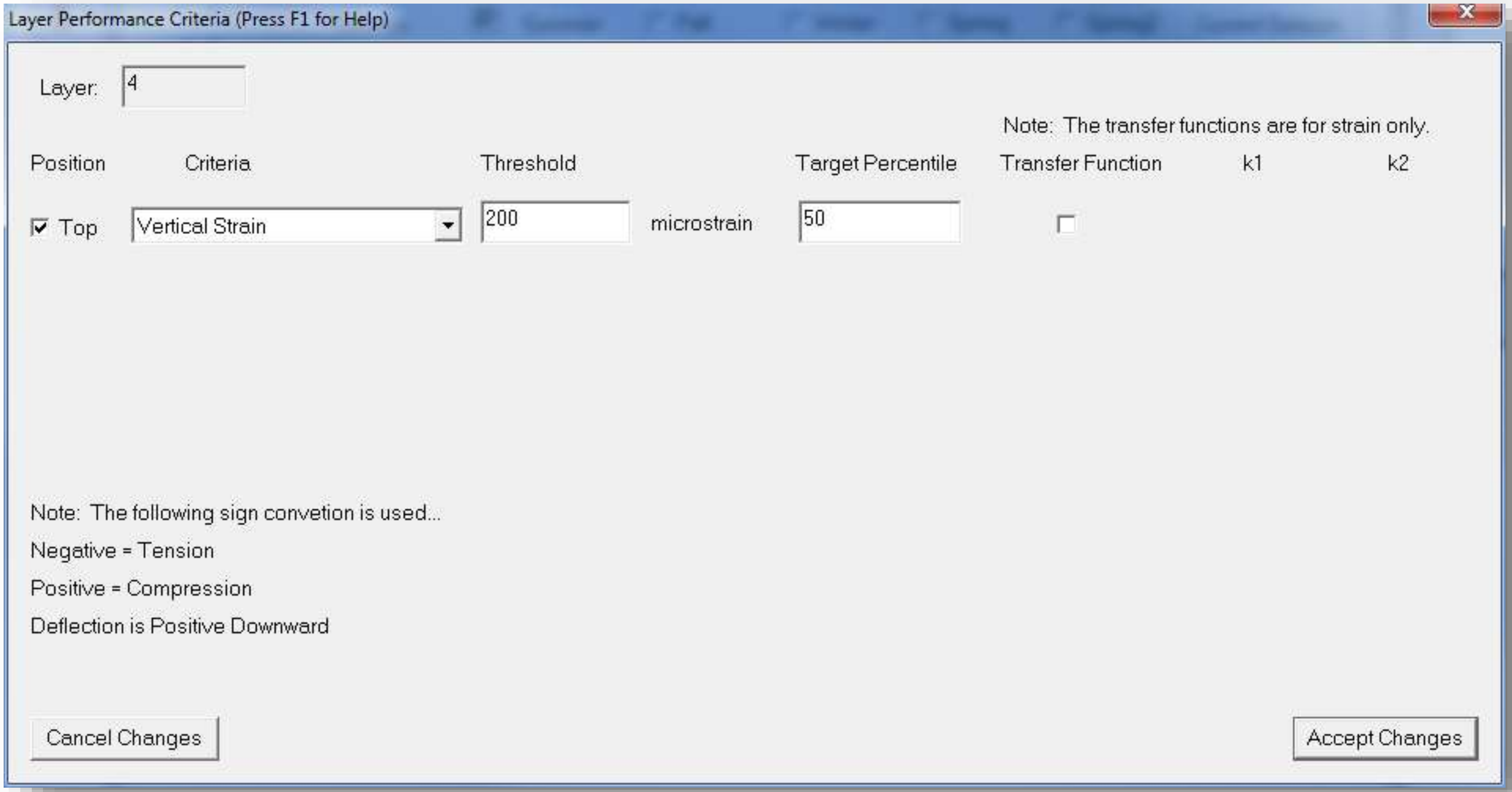
Performance Criteria – Fatigue Cracking



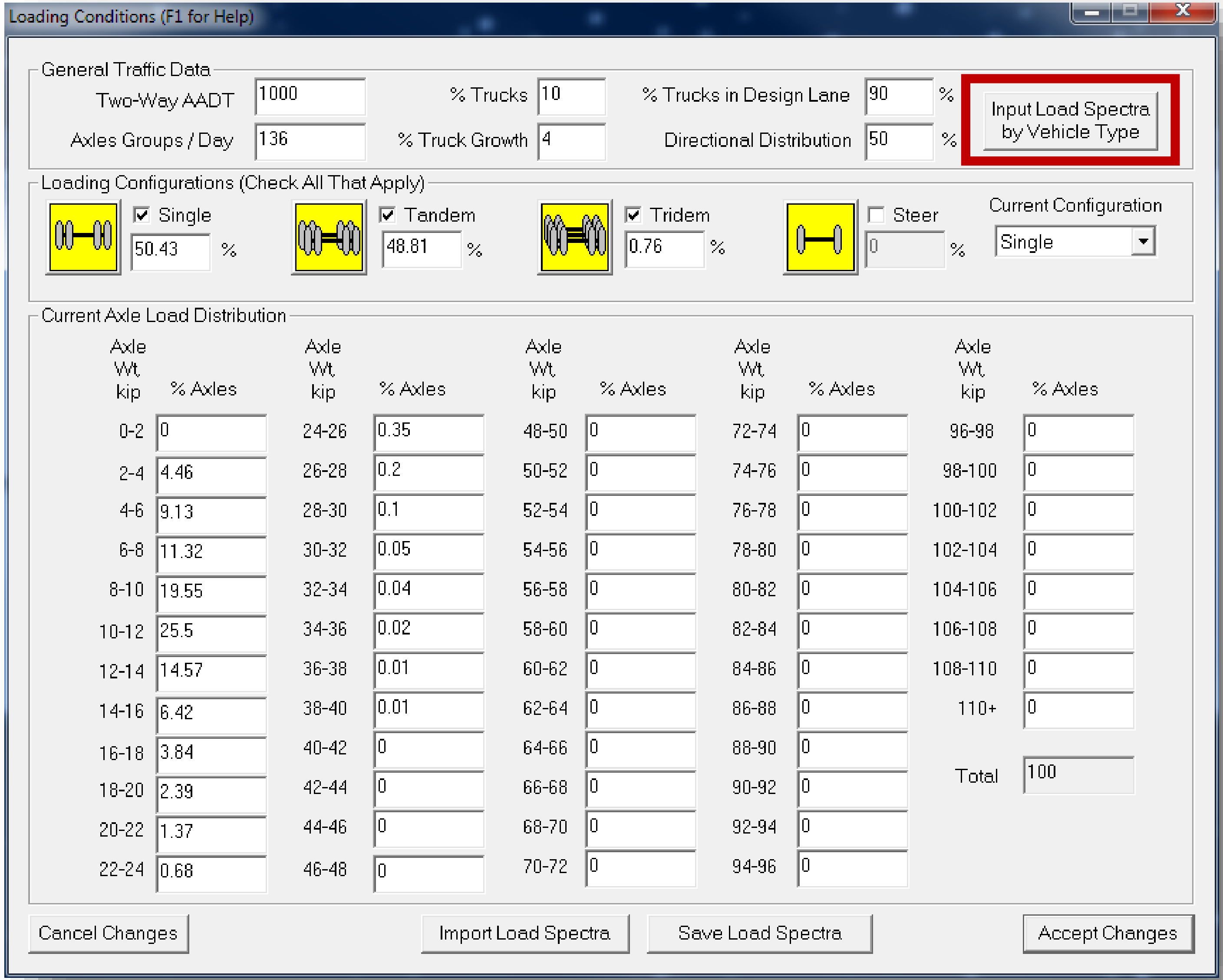
Performance Criteria – Fatigue Cracking



Performance Criteria – Rutting



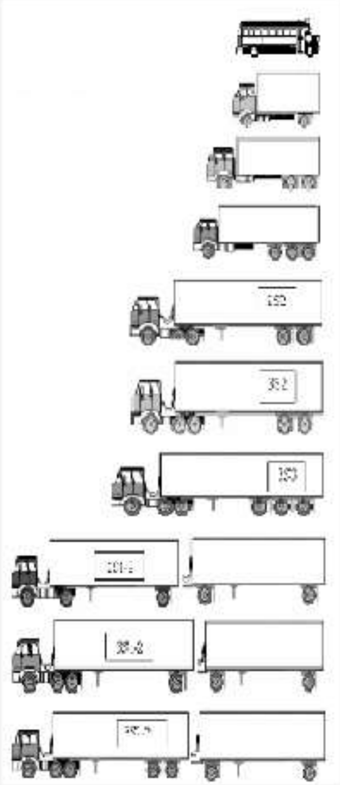
Traffic Inputs



Vehicle Type Distribution

Vehicle Type Distribution (Press F1 for Help)

Roadway Functional Classification: Rural Interstate

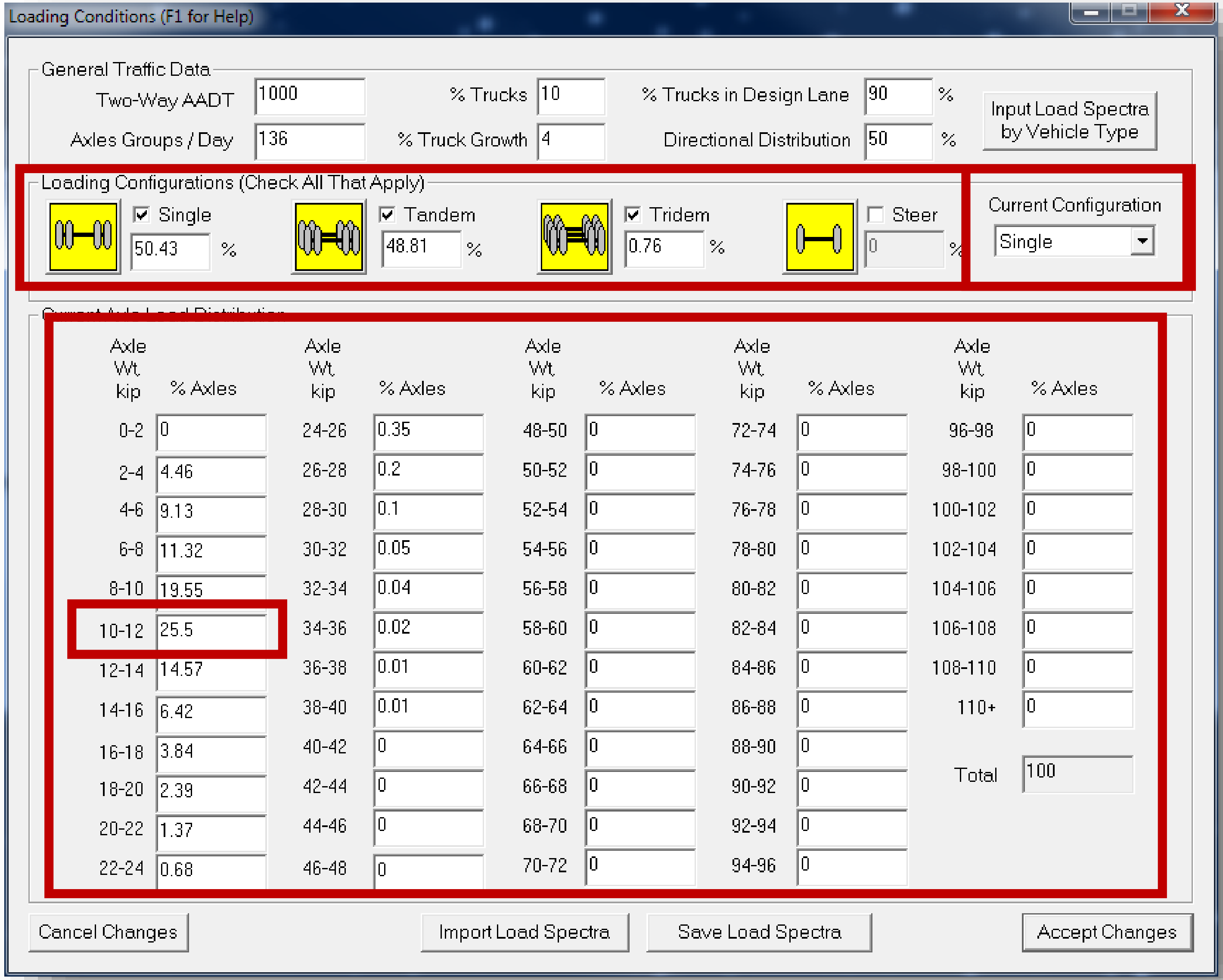


Vehicle Classification	% AADTT	Average Number of Axles Per Vehicle: Single	Tandem	Tridem
4	1.2	1.62	0.39	0
5	9.4	2	0	0
6	3.3	1.02	0.99	0
7	0.5	1	0.26	0.83
8	7.4	2.38	0.67	0
9	68.9	1.13	1.93	0
10	1.2	1.19	1.09	0.89
11	6.1	4.29	0.26	0.06
12	0.8	3.52	1.14	0.06
13	1.2	2.15	2.13	0.35
Total	100			

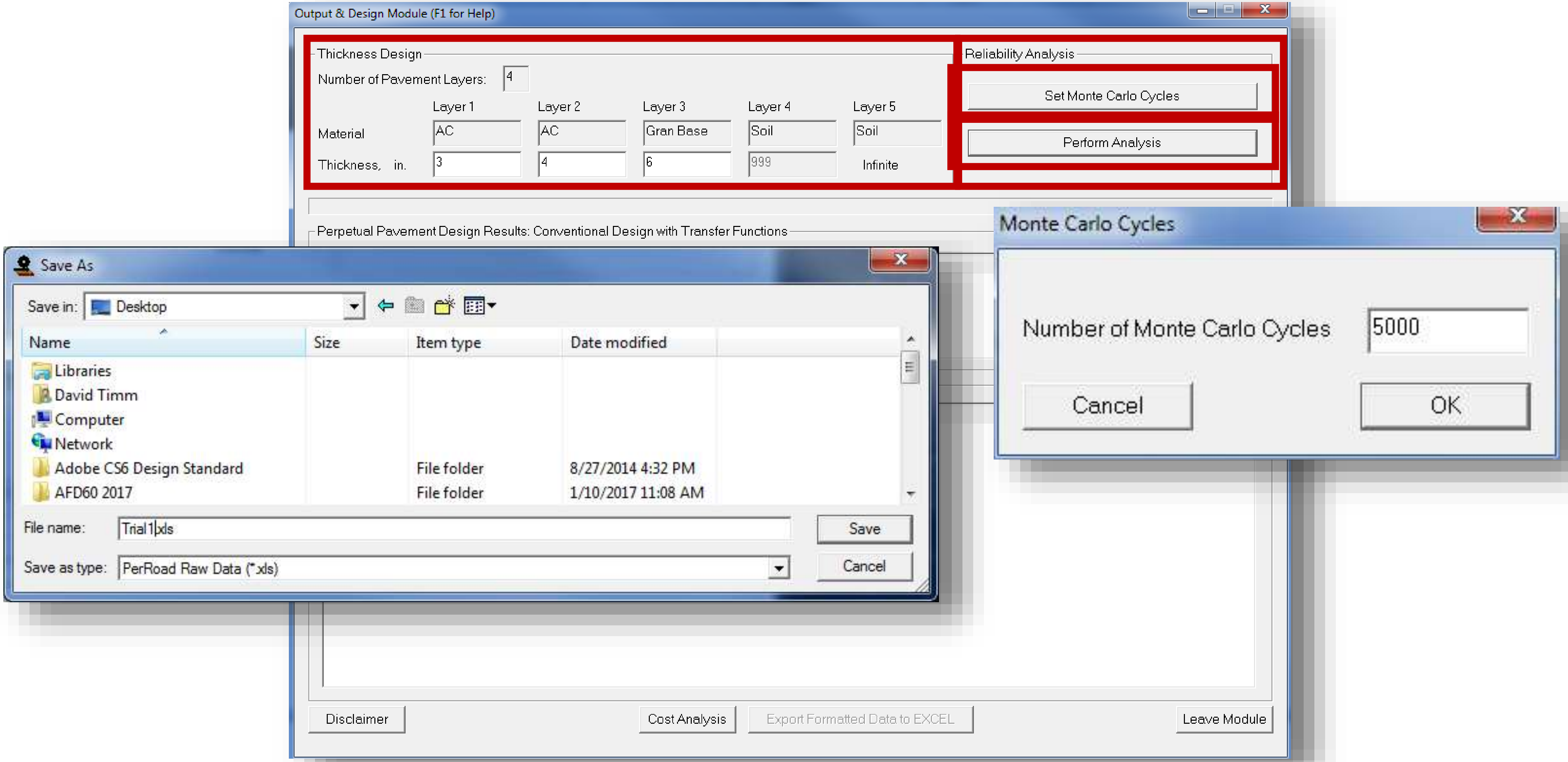
Cancel Changes

Accept Changes

Axle Types & Load Spectra



PerRoad Thickness Design Module



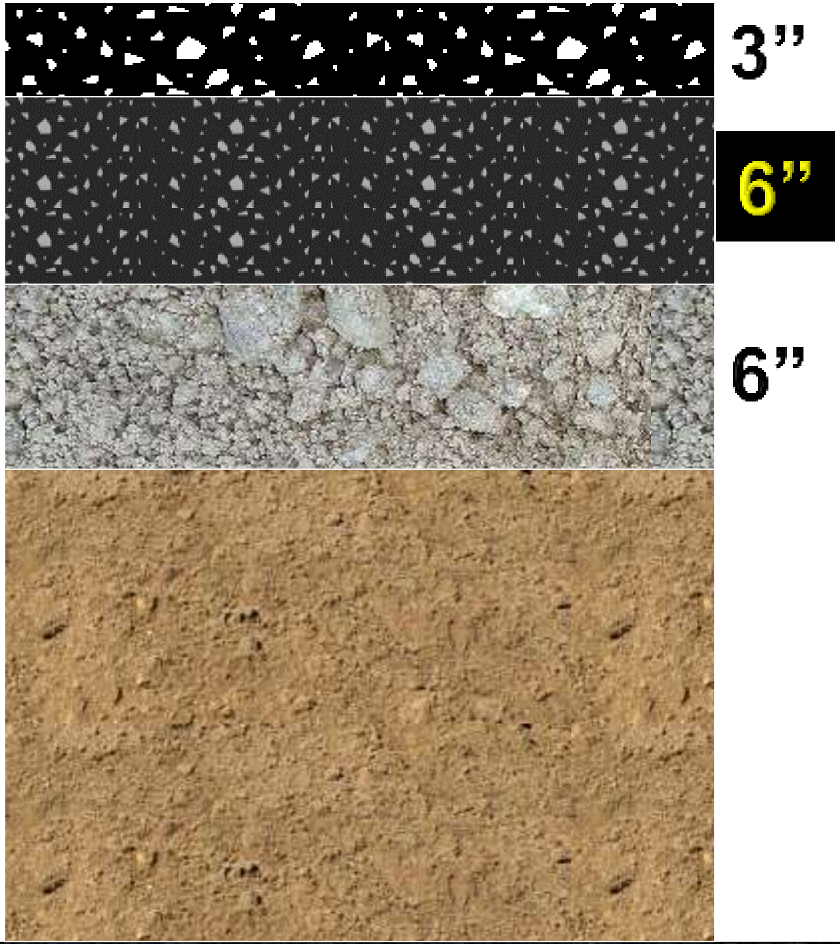
Simulation Results

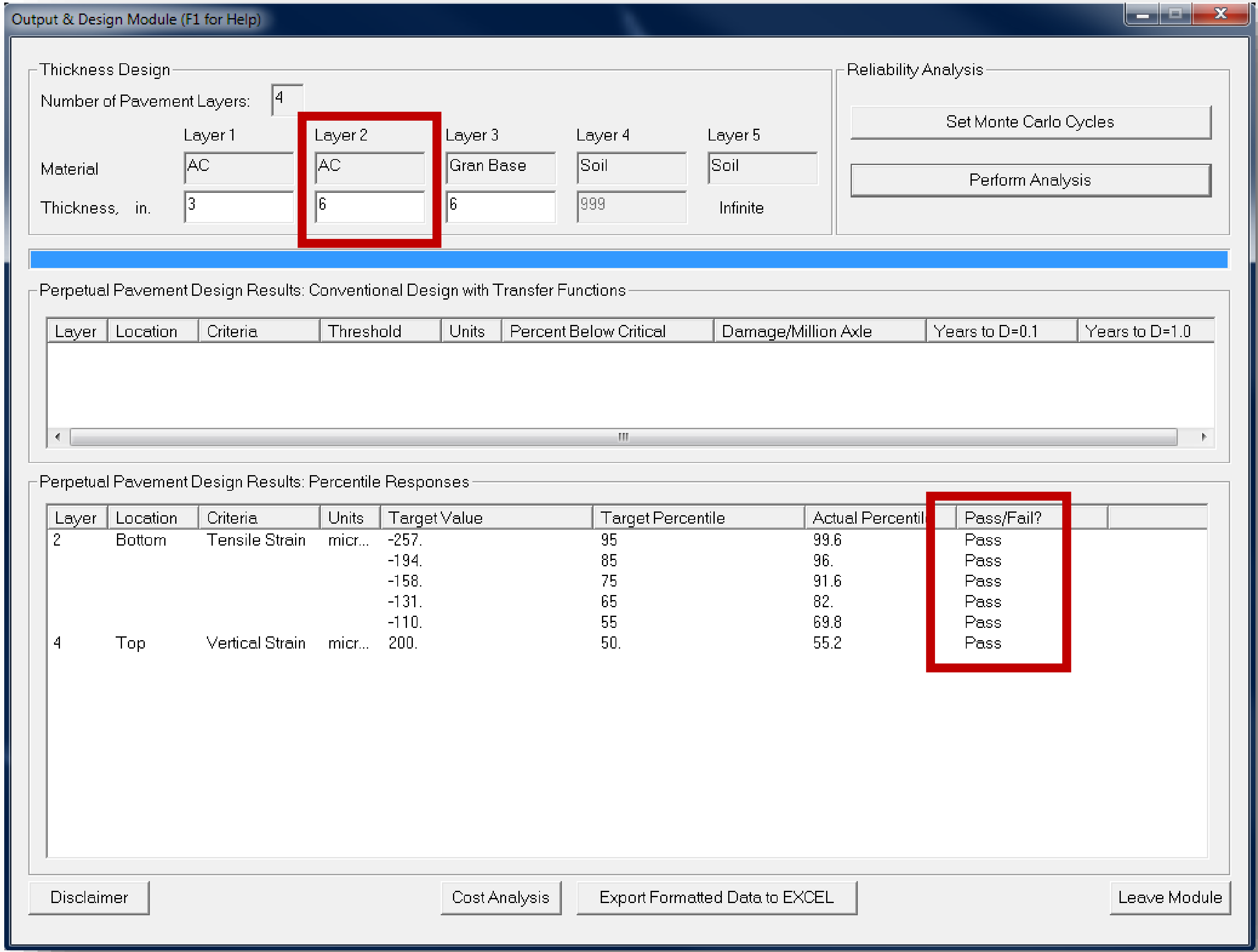
Perpetual Pavement Design Results: Percentile Responses

Layer	Location	Criteria	Units	Target Value	Target Percentile	Actual Percentile	Pass/Fail?
2	Bottom	Tensile Strain	micr...	-257.	95	96.2	Pass
				-194.	85	85.4	Pass
				-158.	75	68.	Fail
				-131.	65	53.4	Fail
				-110.	55	41	Fail
4	Top	Vertical Strain	micr...	200.	50.	31.6	Fail

- Pavement is NOT perpetual
  - Failing in both bottom-up fatigue and rutting
- Change design thicknesses and analyze again

2nd Design Iteration





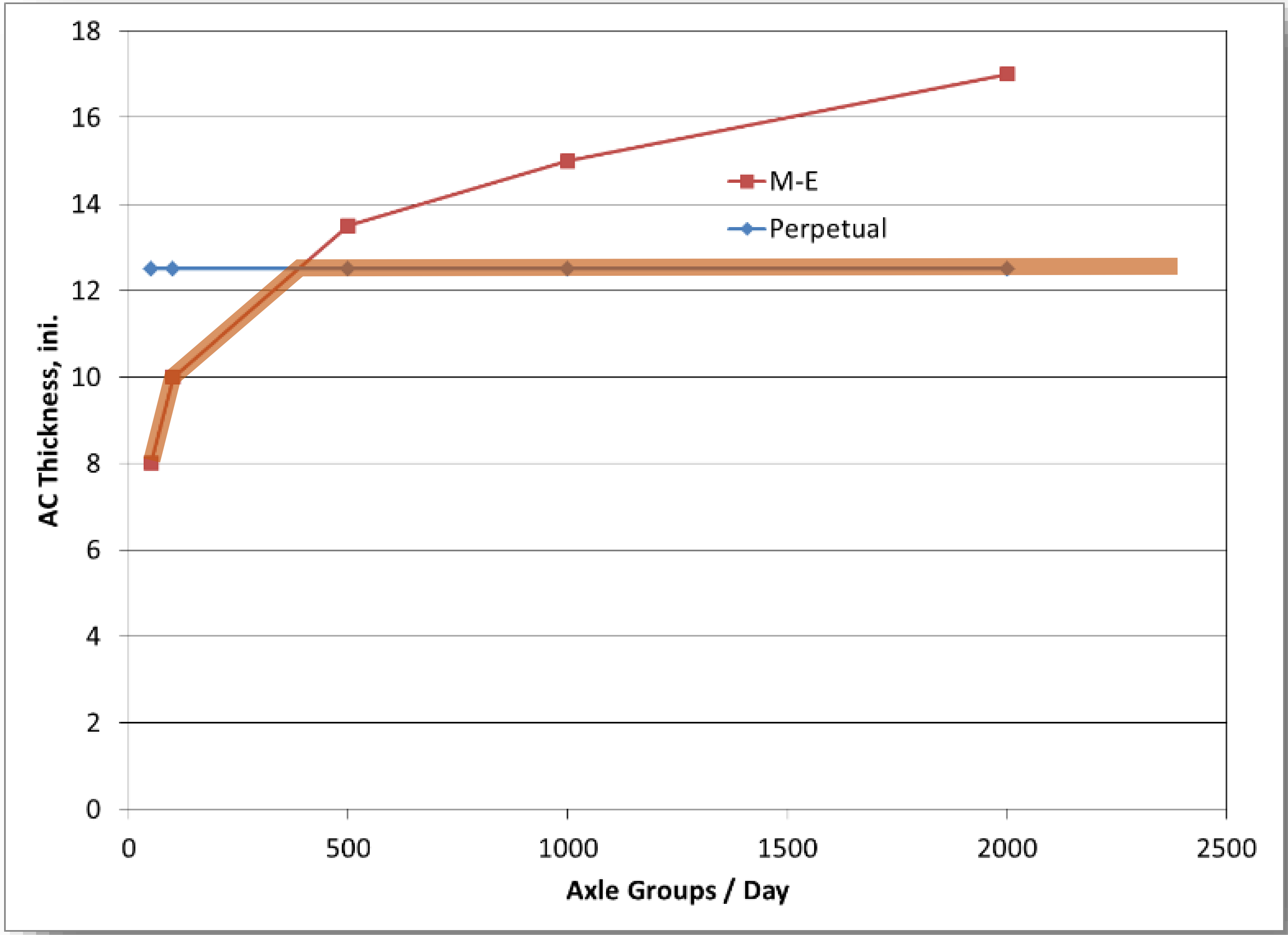
Layer	Location	Criteria	Units	Target Value	Target Percentile	Actual Percentil	Pass/Fail?
2	Bottom	Tensile Strain	micr...	-257.	95	99.6	Pass
				-194.	85	96.	Pass
				-158.	75	91.6	Pass
				-131.	65	82.	Pass
				-110.	55	69.8	Pass
4	Top	Vertical Strain	micr...	200.	50.	55.2	Pass

Additional Design Examples

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
10	30	10.5	14	12	12.2	10.5-14
10	50	10.5	13	12	11.8	10.5-13
10	100	10	12	11	11.0	10-12
20	30	9	12.5	10	10.5	9-12.5
20	50	8.5	12.5	9.5	10.2	8.5-12.5
20	100	8	12	9	9.7	8-12

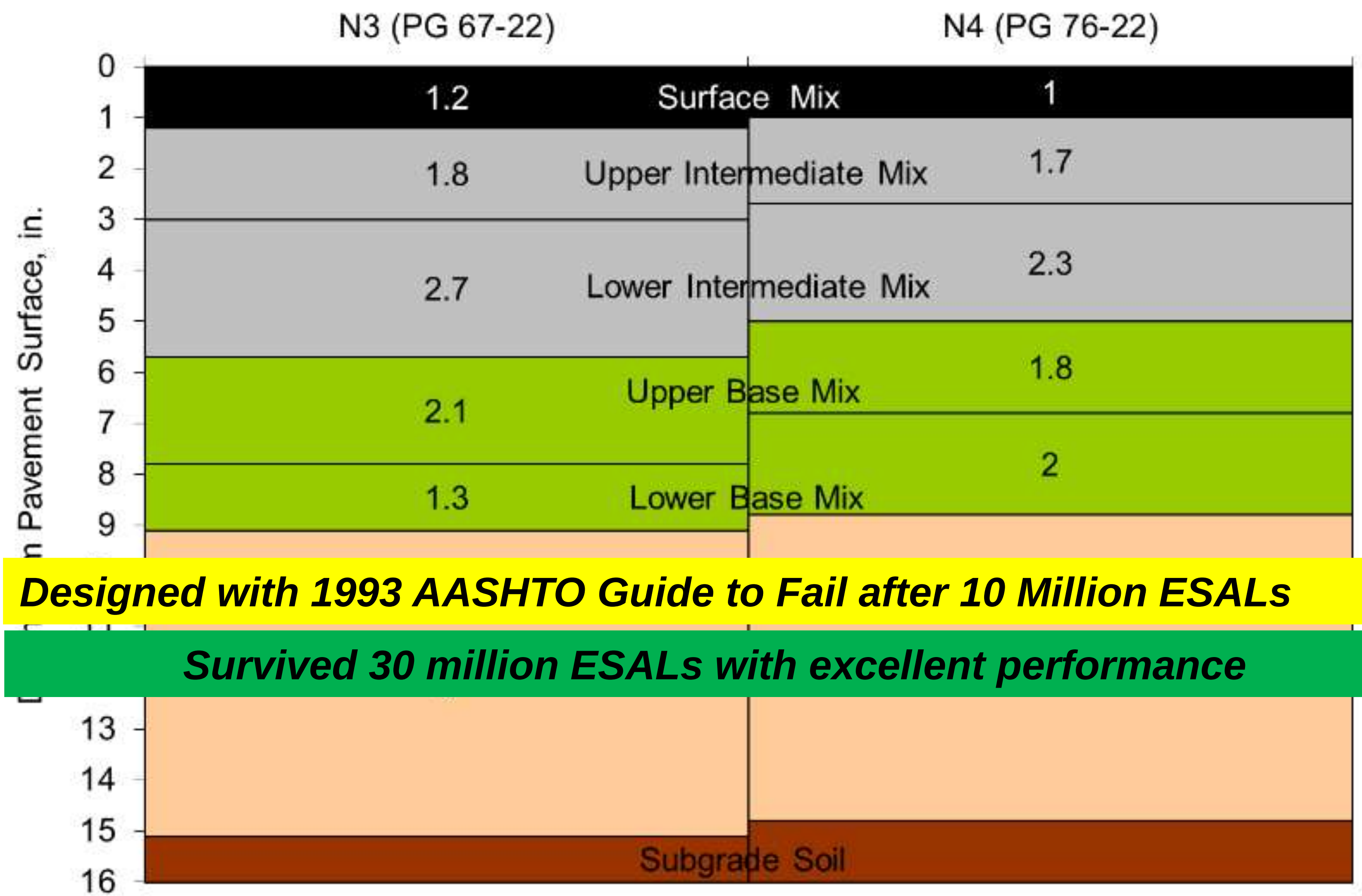
Design Comparison – Perpetual vs M-E

- Minneapolis
- 6" Aggregate Base
  - 30 ksi
- 5 ksi soil
- M-E 35 year analysis



NCAT Test Track – Perpetual Experiments

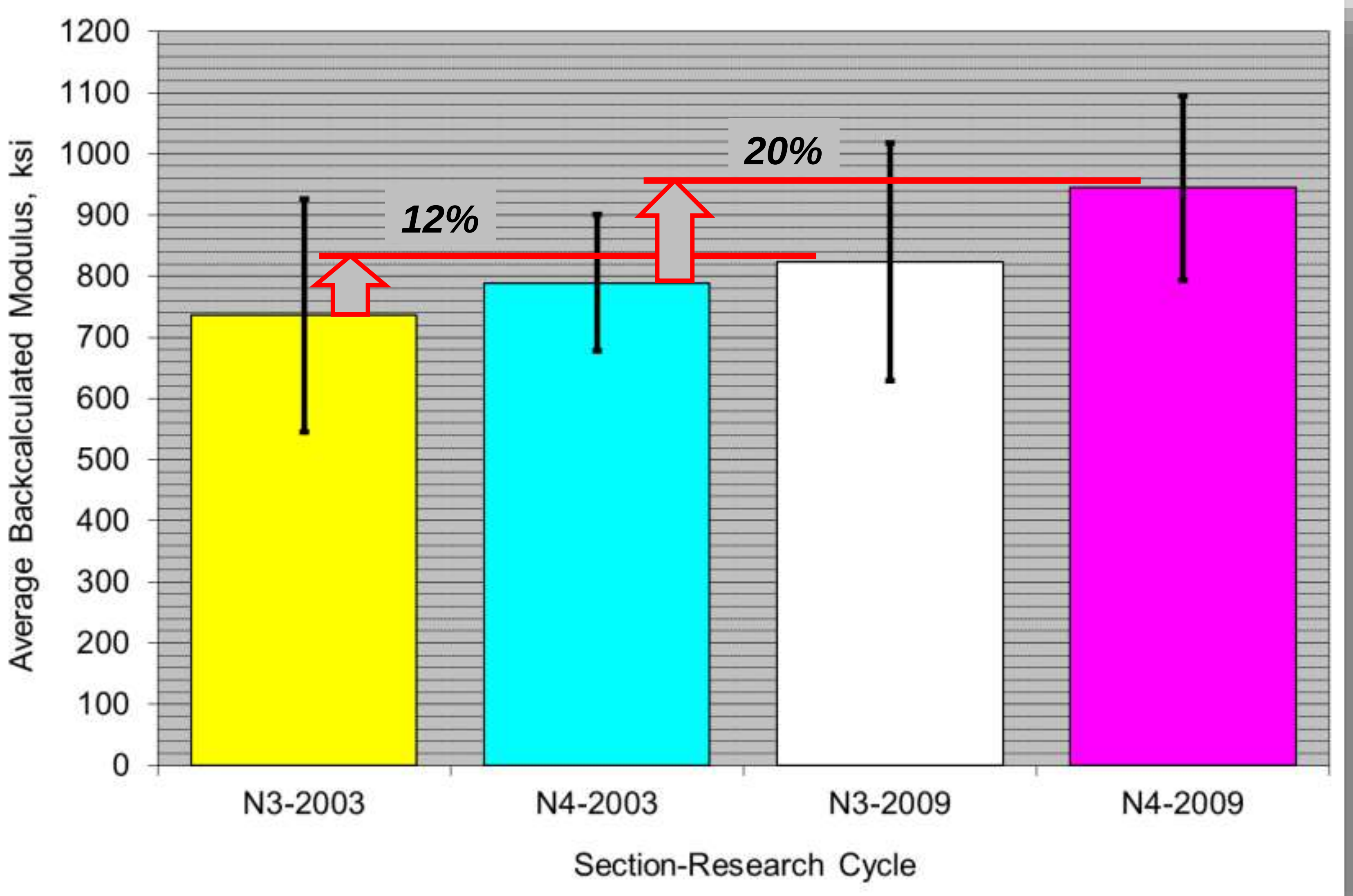
Test Sections – Experiment 1



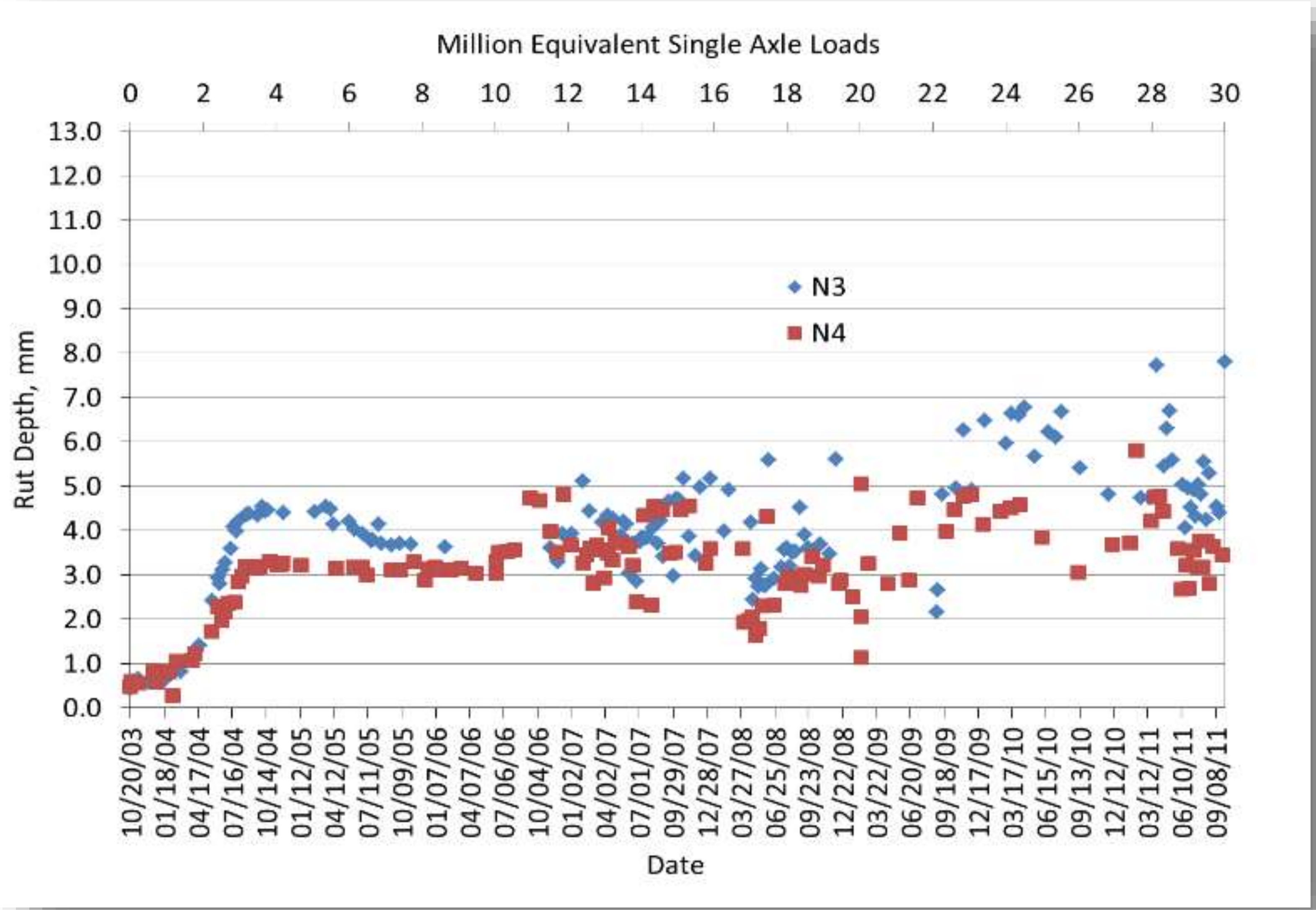
Designed with 1993 AASHTO Guide to Fail after 10 Million ESALs

Survived 30 million ESALs with excellent performance

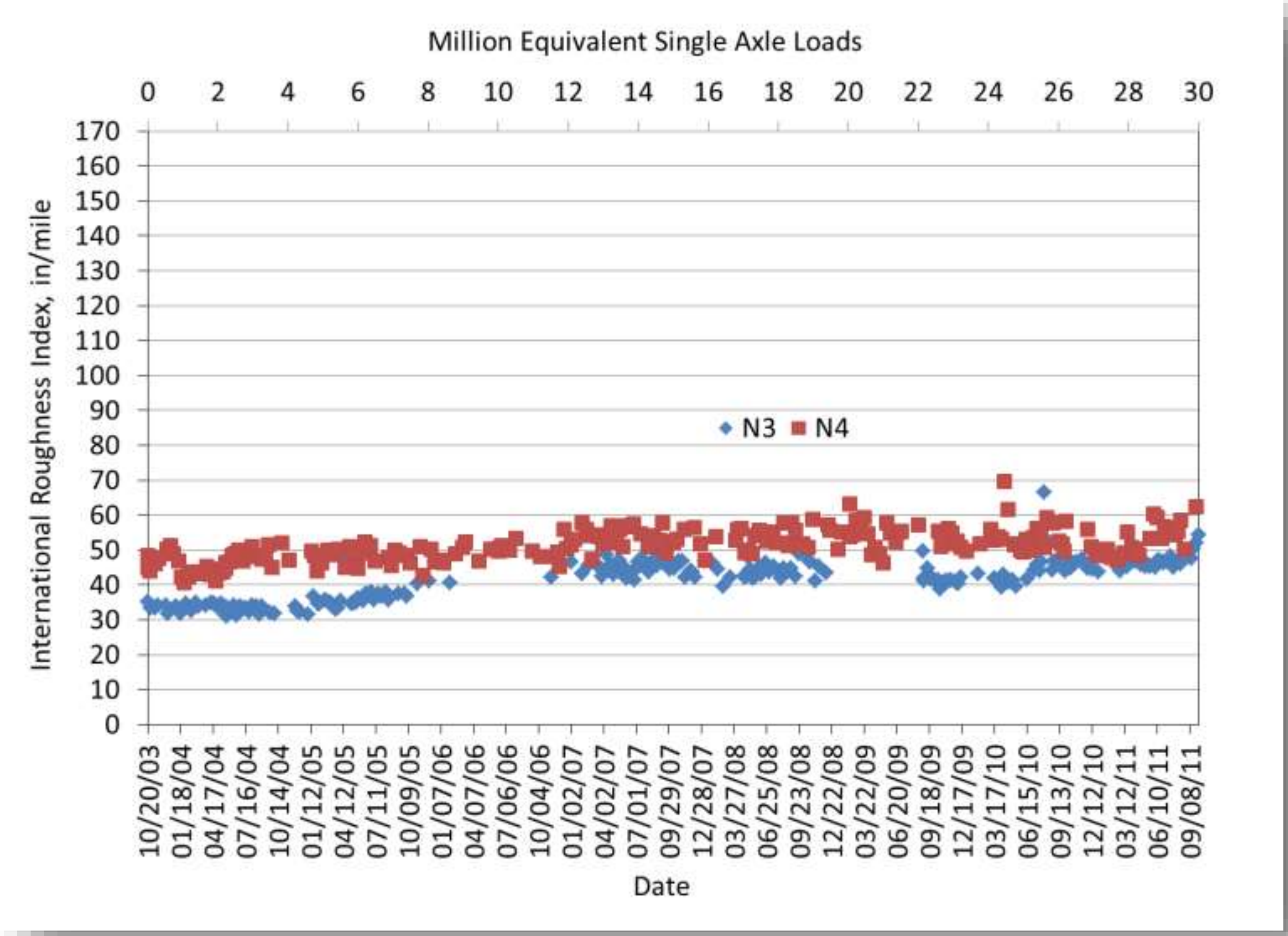
In-Place Modulus vs Time



Rutting Performance



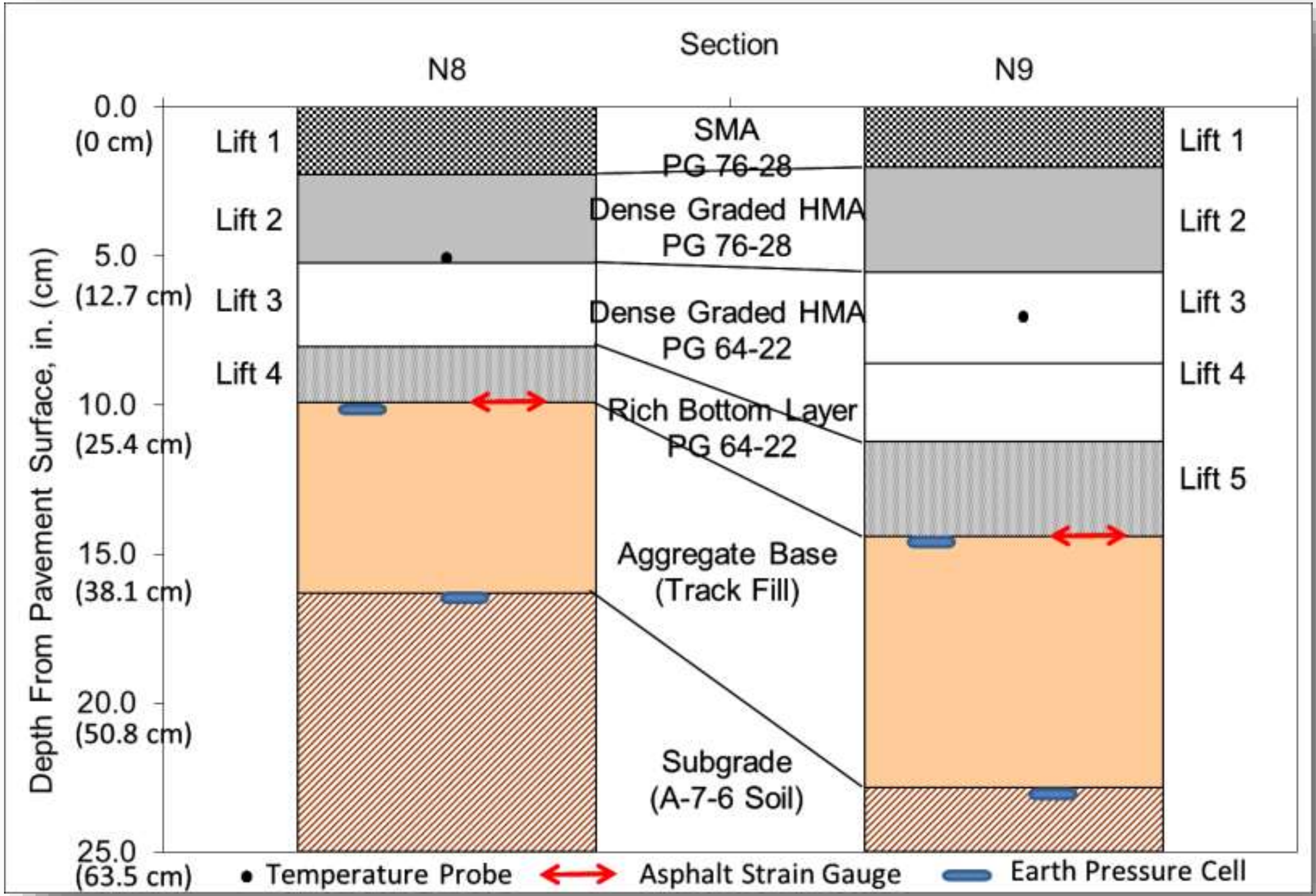
Ride Quality



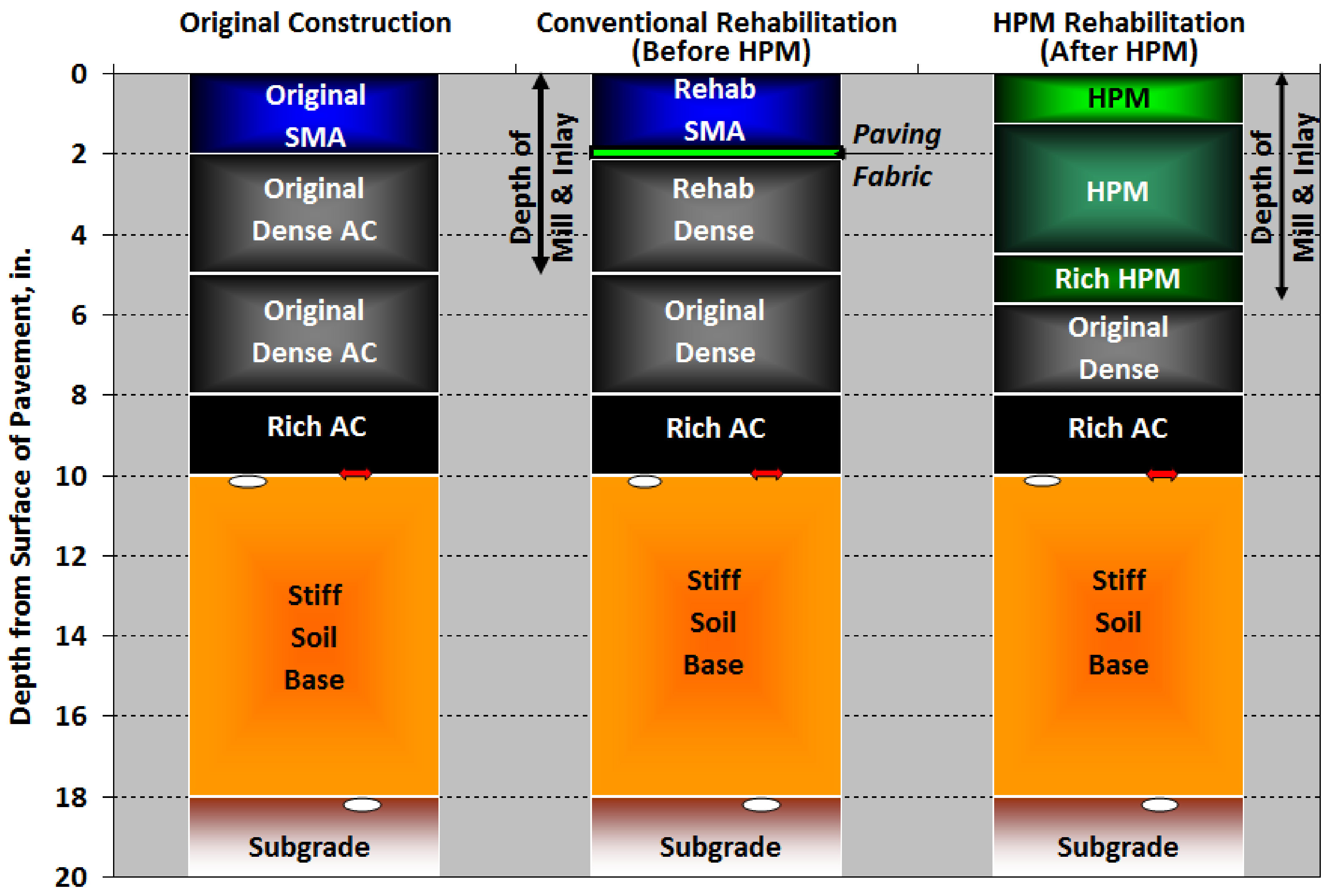
Cracking Performance

Forensic Trenching

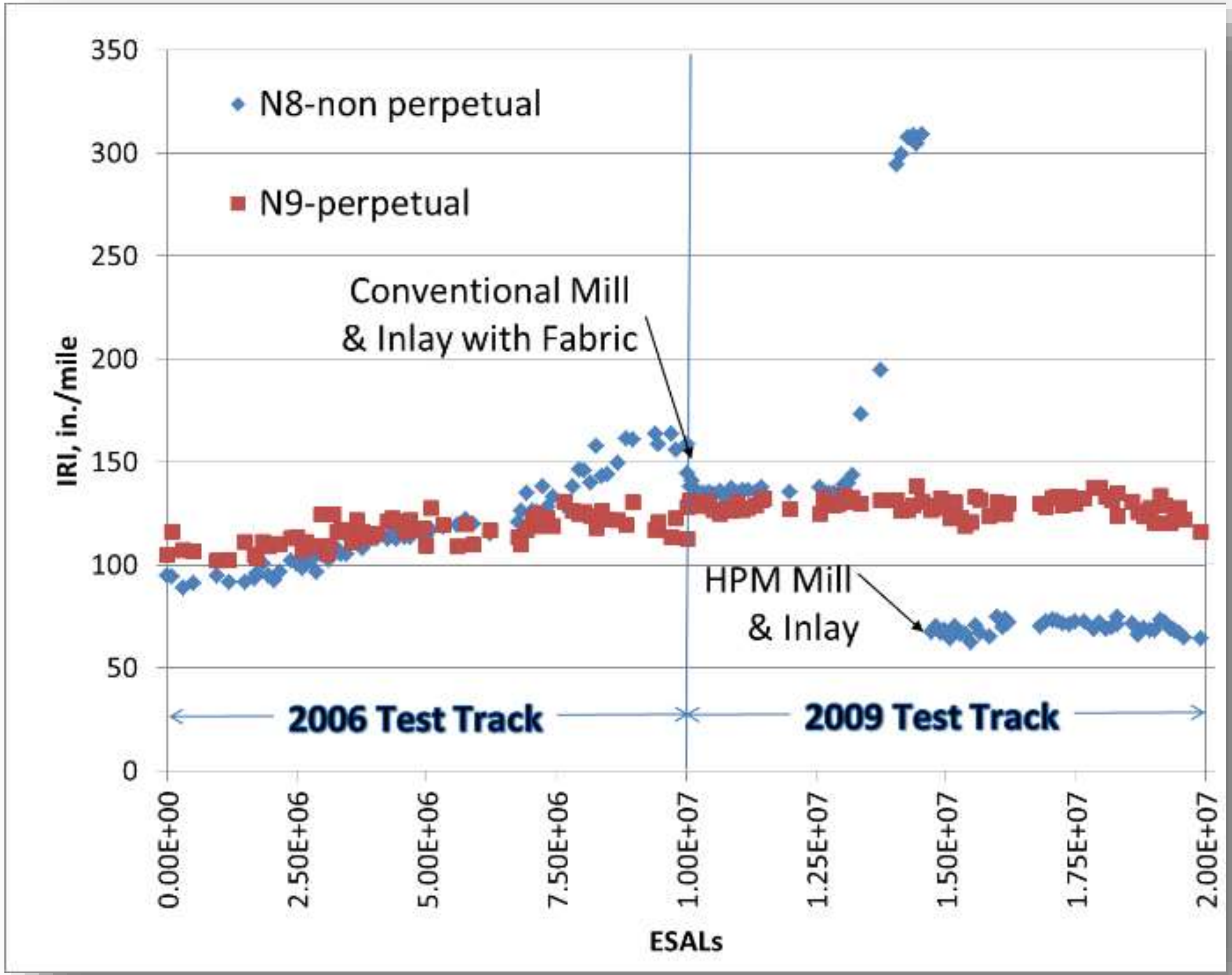
Test Sections – Experiment 2



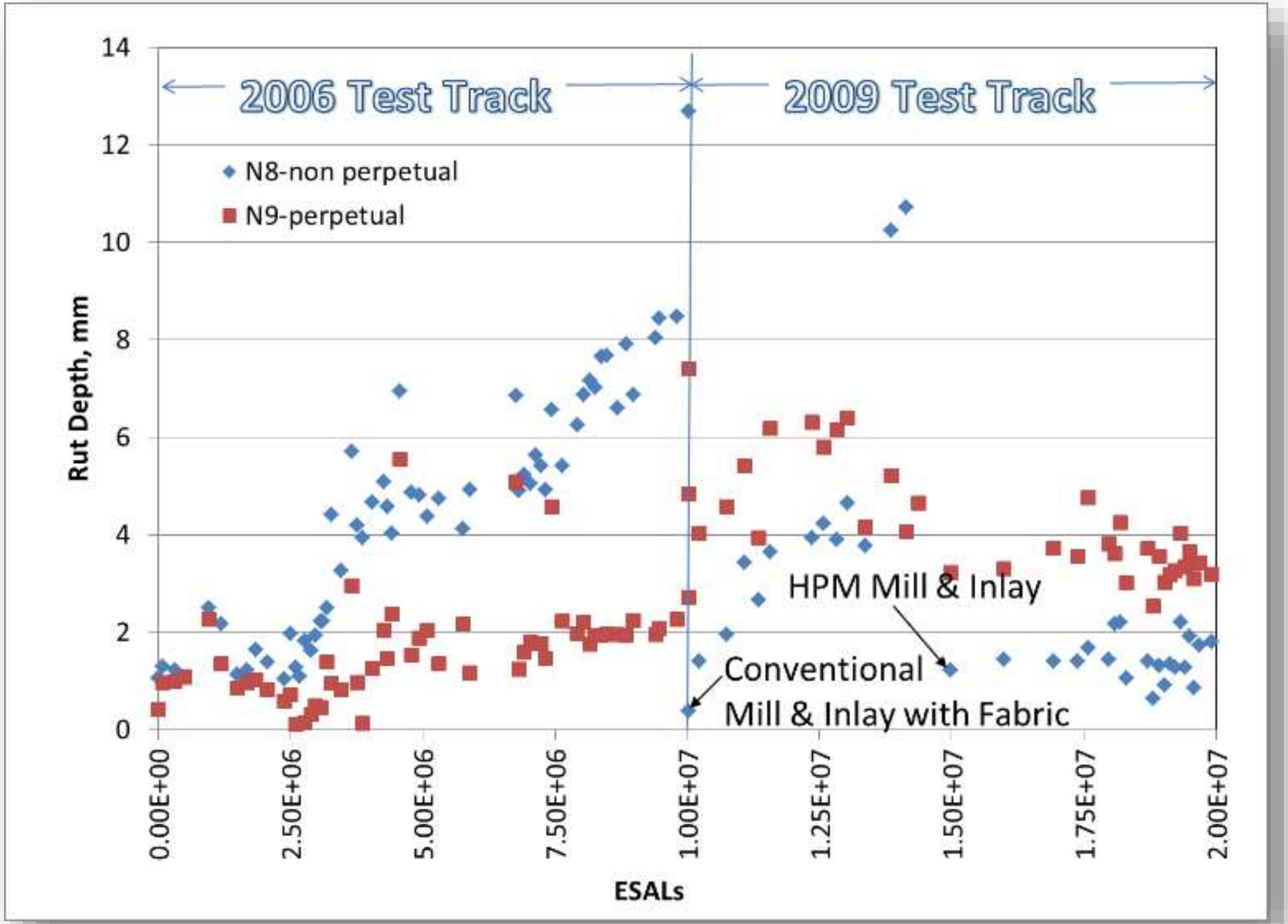
N8 Rehabilitation



Section Performance - IRI

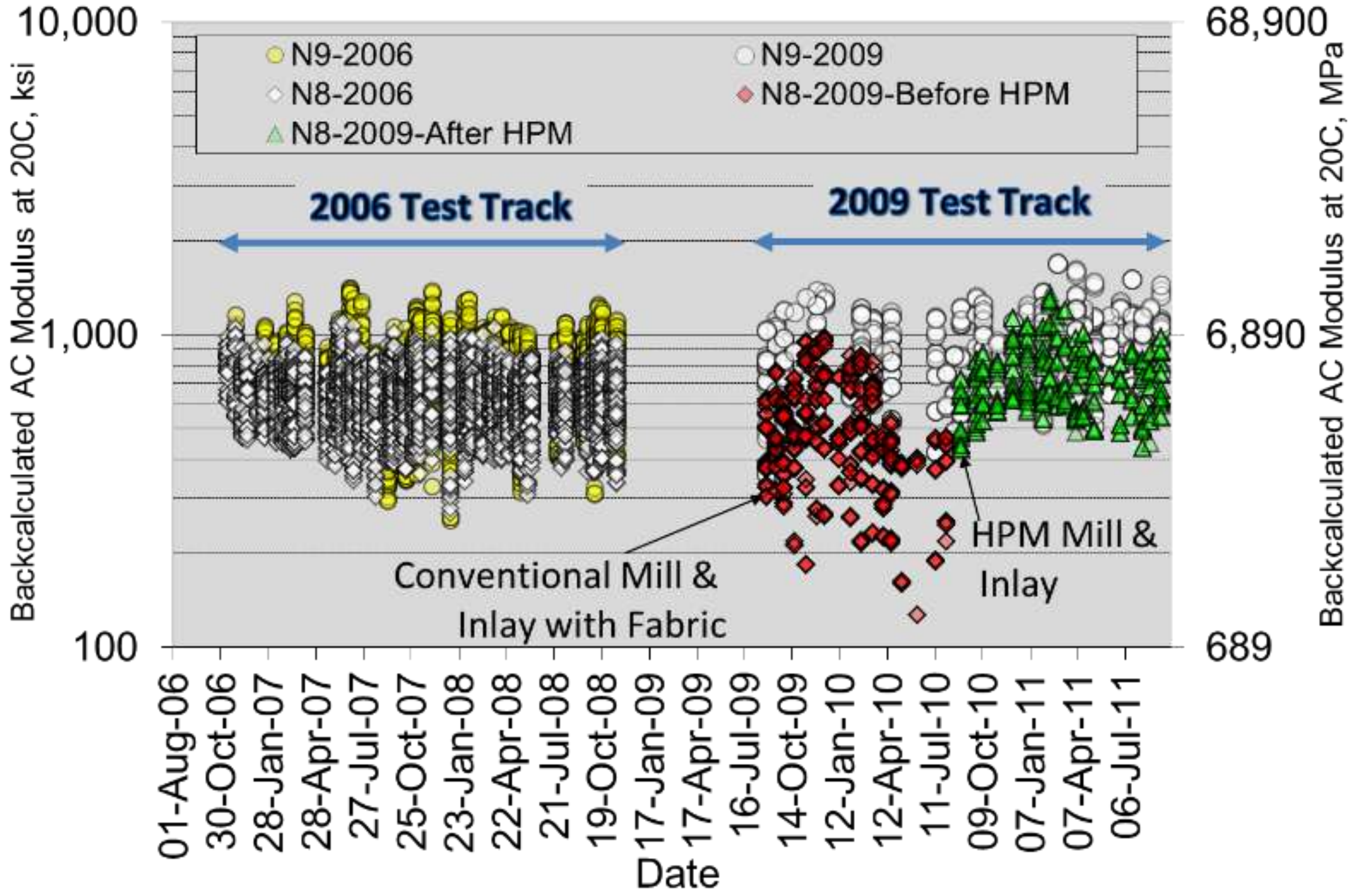


Section Performance - Rutting

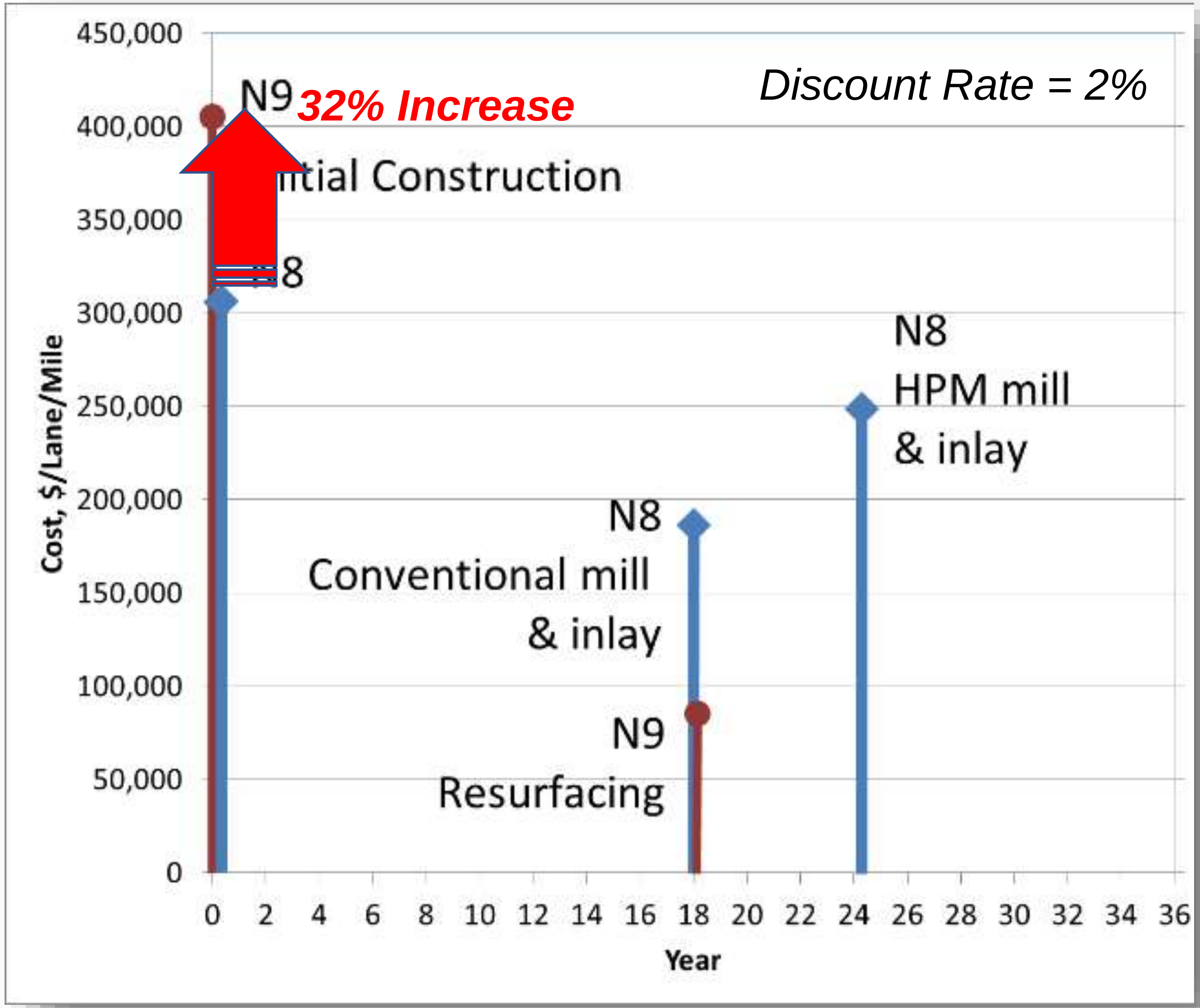


N8 After 1st Rehabilitation @ 3.5 MESAL

AC Modulus vs Date



Life Cycle Cost Analysis – Cash Flow Diagram



Life Cycle Cost Analysis – Net Present Value

Summary & Conclusions

- Perpetual pavements widely recognized across the U.S.
- Perpetual pavements don't have deep structural problems
  - Surface remedies make them an attractive option
- Perpetual pavements can be designed using mechanistic principles
  - Strain distributions developed at NCAT Test Track and validated with award winners
- PerRoad incorporates strain distribution design & Monte Carlo simulation to produce reasonable perpetual pavement cross-sections
  - Can be used to find maximum thicknesses
- Case studies from Test Track highlight key features of perpetual pavement
  - Tend to gain modulus over time
  - Exhibit excellent performance
    - Stable ride quality
    - Minimal rutting
    - No deep structural distresses
  - Cost effective

Thank you!

https://www.wordclouds.com/