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Asphalt Pavements: Perpetual to Porous

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Sr. Regional Engineer

Asphalt Institute

Topics

- Perpetual (long-life) asphalt pavements:
  - Background, observations, design requirements
- Porous asphalt pavements
  - Design requirements, limitations

ASPHALT INSTITUTE

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- International association of petroleum asphalt producers, manufacturers, and affiliated businesses, established in 1919
- Promotes the use, benefits and quality performance of petroleum asphalt through engineering, research and educational activities.
- HQ office-Lexington, KY, local office-San Antonio area
- www.asphaltinstitute.org

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- All States Asphalt, Inc.
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- Asphalt Materials, Inc.
- Asphalt Processors Inc.
- Asphalt Refining & Technology Company, LLC
- Associated Asphalt, Inc.
- Blacklidge Emulsions, Inc.
- Bitumar, Inc.
- BP Bitumen
- Calumet Specialty Products, L.P.
- Canadian Asphalt Industries Inc.
- Chevron Asia Pacific-Africa & Pakistan Region
- China Offshore Oil & Gas Development & Utilization Company
- Citgo Asphalt Refining Co.
- Colas, S.A.
- ConocoPhillips
- Ergon Asphalt & Emulsions, Inc.
- ExxonMobil
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- Flint Hills Resources, LP
- GAF-Elk Corporation
- Gary-Williams Energy Corporation
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- Henry G. Meigs, LLC
- Holly Asphalt Company
- The Hudson Companies
- Hunt Refining Company
- Husky Oil Marketing Company
- Idaho Asphalt Supply, Inc.
- IKO
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- Interstate Asphalt Corporation
- Isfalt A.S.
- Jebro Inc.
- Koch Materials, Inc.
- Lafarge Asphalt Engineering
- Lundy Texas Refining
- Marathon Petroleum Company, LLC
- Mathy Construction Co.
- McAsphalt Industries Ltd.
- McCall Oil & Chemical Company
- Moose Jaw Refinery
- Murphy Oil USA, Inc.
- Nynäs Bitumen
- Oldcastle Materials Group
- Paramount Petroleum Corp.
- Pelican Refining Company, LLC
- Petro Canada
- Petroleo Brasileiro S.A.-Petrobras
- Repsol YPF
- San Joaquin Refining Co., Inc.
- Sargeant Marine, Inc.
- SemMaterials, L.P.
- SemMaterials Mexico
- Seneca Petroleum Co., Inc.
- Shell Canada Product
- Shell International Petroleum Co., Ltd.
- Shell Oil Products US
- Shelly and Sands, Inc.
- SK energy co., ltd.
- Suit-Kote Corporation
- Suncor Energy (U.S.A.) Inc.
- The SWT Group
- Total Petrochemicals USA, Inc.
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- Ultrapave

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Background

- Many "long life" asphalt pavements have been observed in the U.S. and elsewhere
  - Pavements lasting much longer/receiving much more traffic than they were designed for
  - Led to forensic studies and analyses to find out why these pavements performed so well
- With increases in truck traffic, it is necessary to identify efficient, long-term asphalt pavement strategies for "heavy-duty" applications
  - Empirical design procedures consistently overdesign asphalt pavements for high truck traffic volumes

1993 AASHTO Guide

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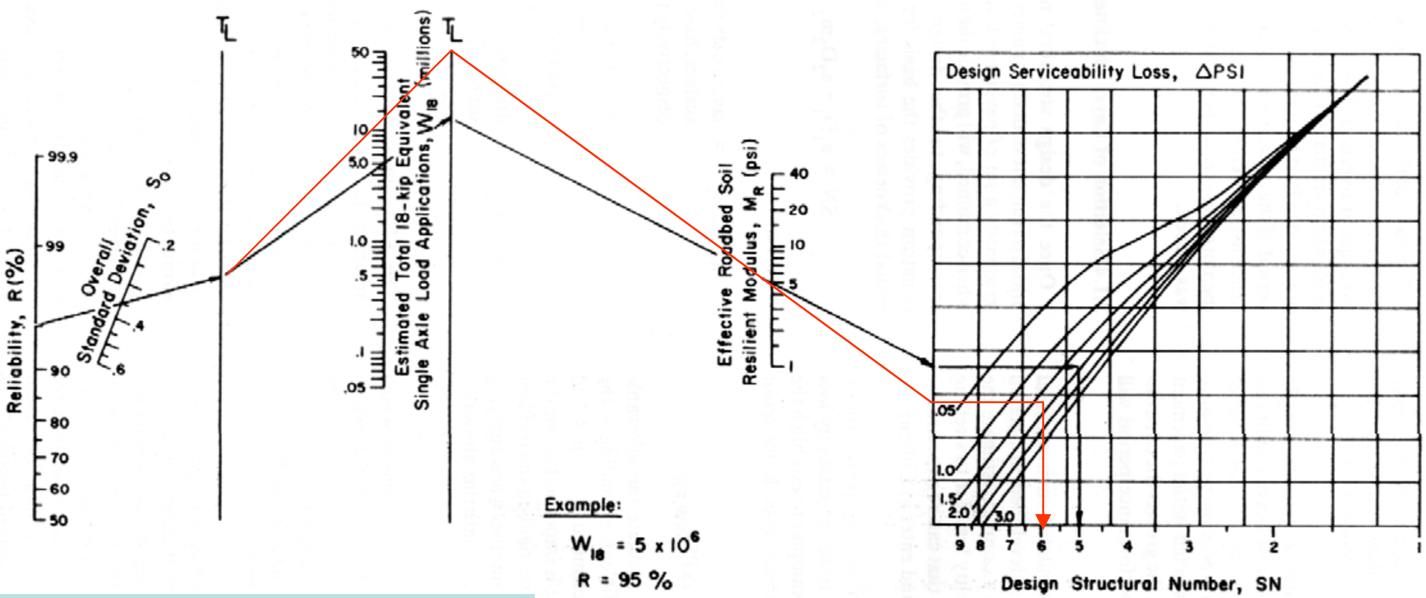
NOMOGRAPH SOLVES:

$$\log_{10}W_{18} = Z_R*S_o + 9.36*\log_{10}(SN+1) - 0.20 + \frac{\log_{10}\left[\frac{\Delta PSI}{4.2-1.5}\right]}{0.40+\frac{1094}{(SN+1)^{5.19}}} + 2.32*\log_{10}M_R - 8.07$$



Example:

$W_{18} = 5 \times 10^6$

R = 95 %

$S_o = 0.35$

M_R = 5000 psi

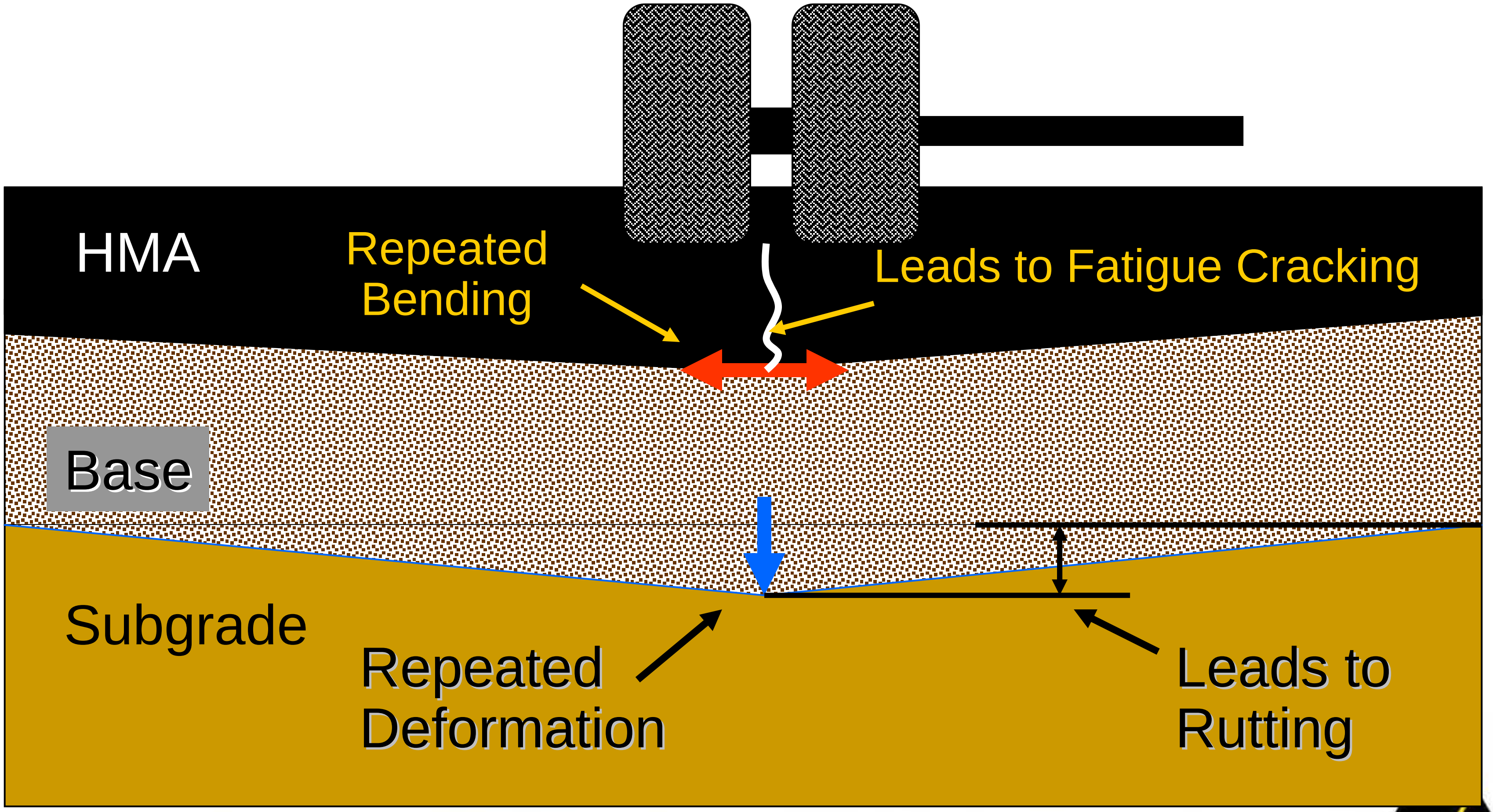
ΔPSI = 1.9

Solution: SN = 5.0

Increasing ESAL results in increased SN, i.e., thicker pavement

Pavement Response to Load

Mechanistic-based methods allow consideration of anticipated axle loads.



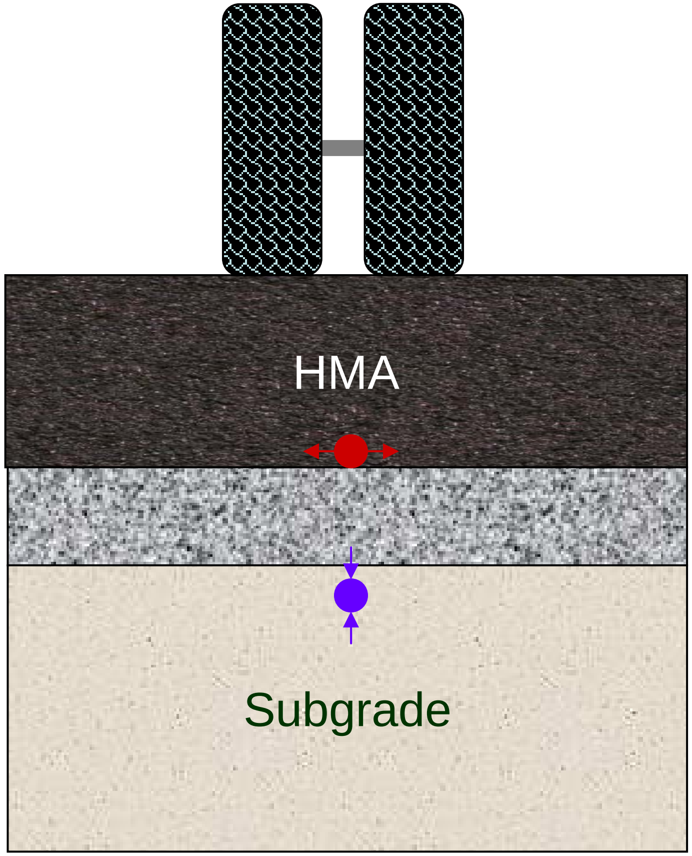
Concept of a Perpetual, or Long Life Asphalt Pavement

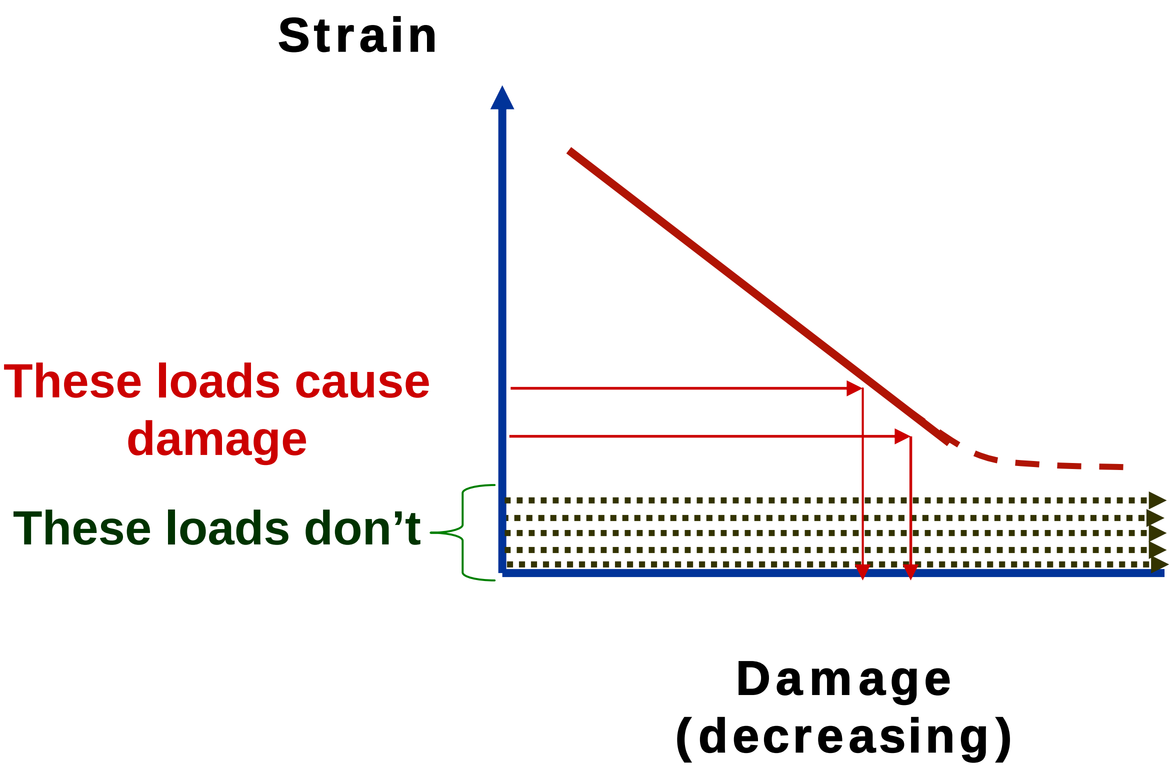
- Reduce load-induced strain under traffic loads to levels that do not damage the foundation or the structural asphalt layers
- Select HMA materials and mixture qualities that resist:
  - Shear deformation (rutting within the asphalt layer)
  - Moisture damage
  - Low temperature/thermal cracking
- Provide the highest level of functional performance available to highway users
  - Smooth, safe and quiet

Perpetual Pavements

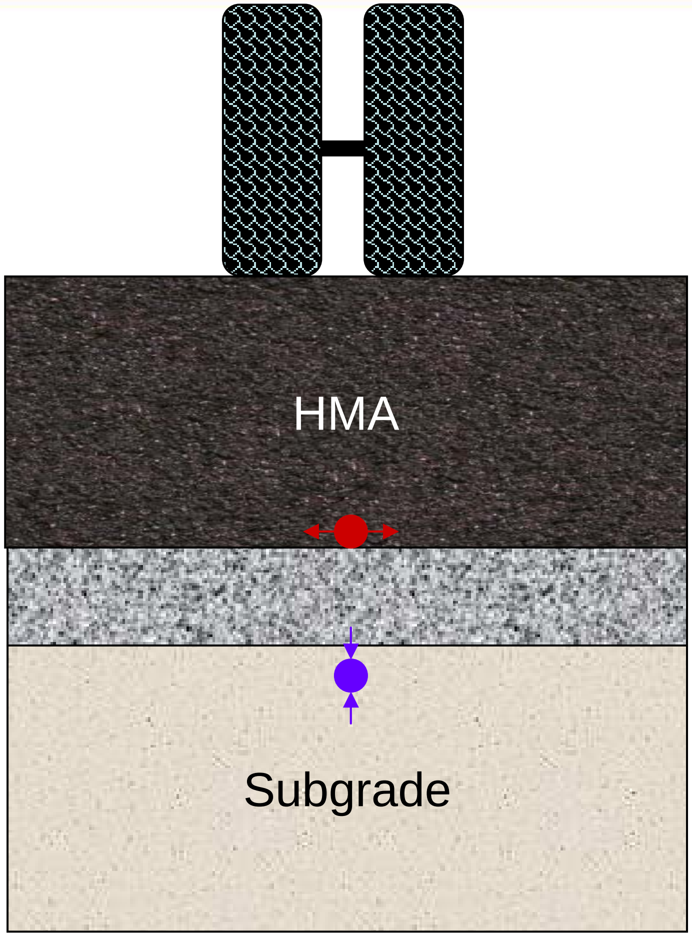
- Designed so the pavement structural layers perform without significant damage
  - For light-duty pavements, “limited” damage per loaded axle application
  - For heavy-duty pavements, minimal damage per loaded axle
- Surface/wearing course replaced periodically
  - Replacement interval depends on mixture/materials type, traffic conditions, etc

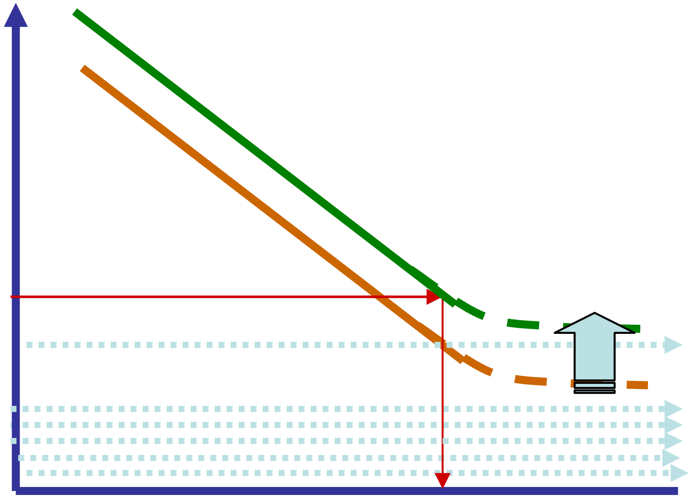
Damage Accumulation-Fatigue





Thicker, Stiffer pavement

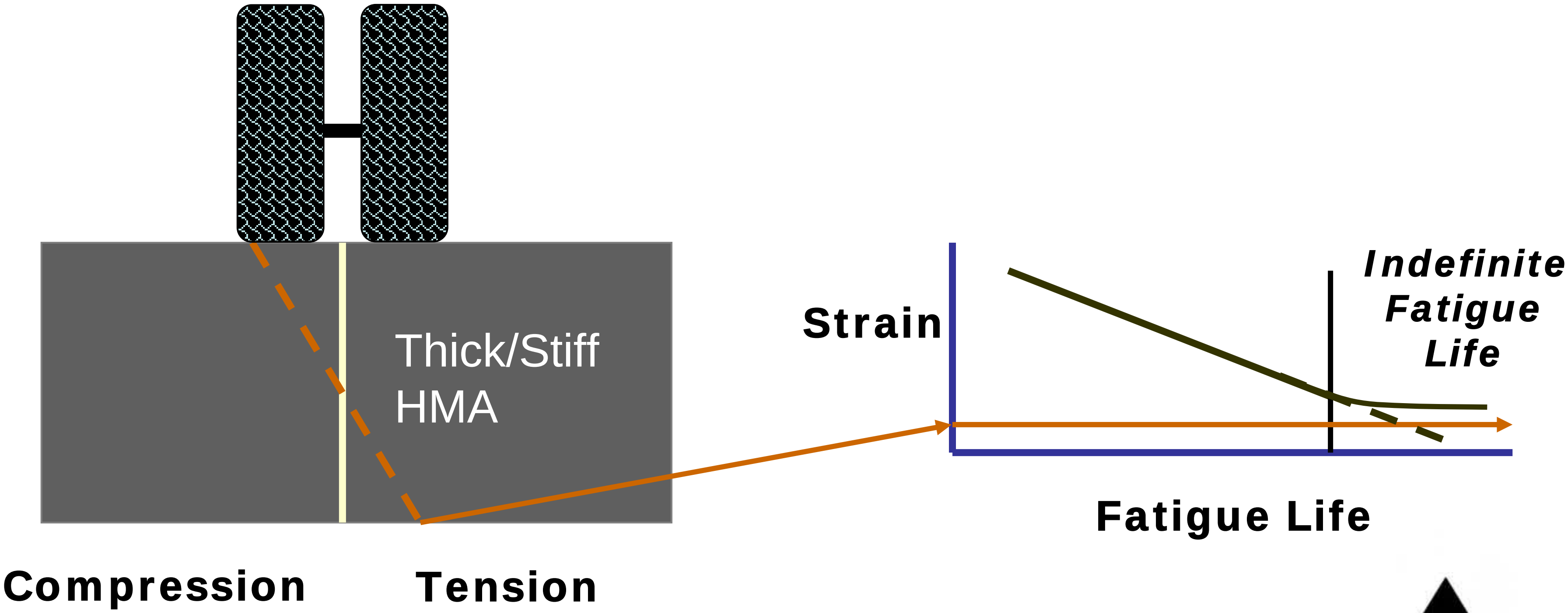




Minimal damage, extended pavement life

Design Strategy-Fatigue

- Strain below fatigue limit = Indefinite Fatigue Life
- Reduce tensile strain by increasing pavement thickness and/or increasing stiffness



Mechanistic Criteria

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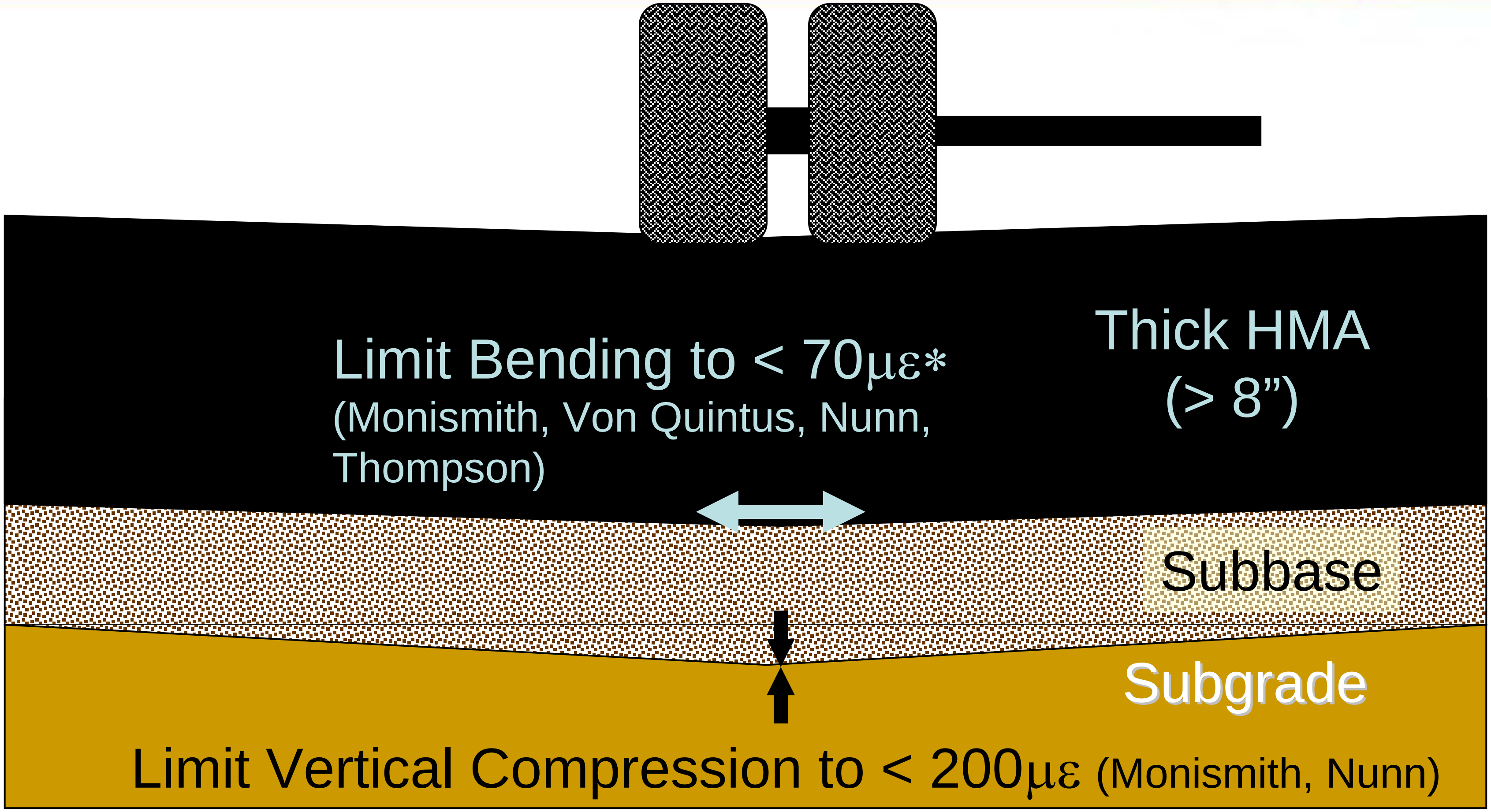

* New research suggests a fatigue higher endurance limit

Can we prove the hypothesis?

Observations:

- Performance of thick HMA pavements in the developed world
  - US Interstate Highways, UK Motorways
- Forensic evaluations suggested no structural damage

Laboratory verification:

- Endurance limit concept well-recognized
- Does it apply to HMA?

United Kingdom

- Changed design period from 20 to 40 years in the 1990's
- TRL investigated the performance of existing heavily trafficked motorways
  - "…failed to detect evidence of deterioration in the main structural layers of the thicker, more heavily trafficked pavements"

U.K. M25 London Orbital Motorway

Courtesy EAPA

Rate of Rutting vs. Total Asphalt Thickness

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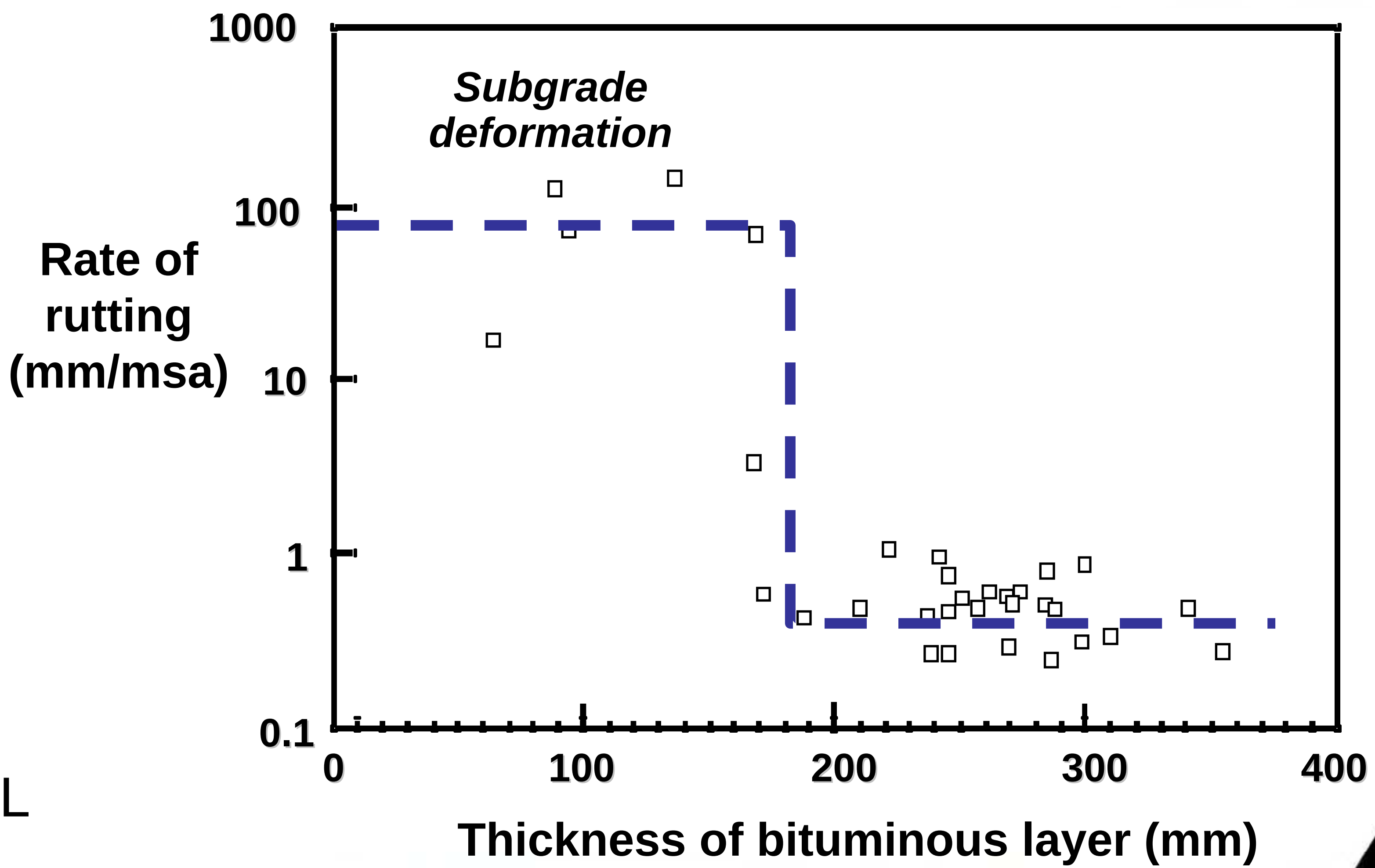

TRL

France & Germany

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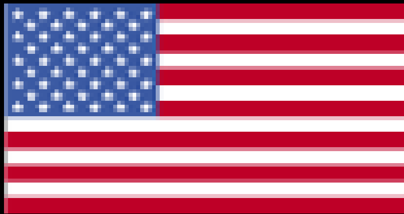
- 40 year design period, strong emphasis on pavement foundation
- French example:
  - Constructed in 1993
  - 40 mm porous surface over 220 mm “high modulus” HMA
- German example:
  - Constructed in 1977
  - *Gußasphalt* surface, over 200 mm HMA over stabilized subbase

Boulevard Periphérique, Paris

A5 Frankfurter Kreuz Interchange

European Observations

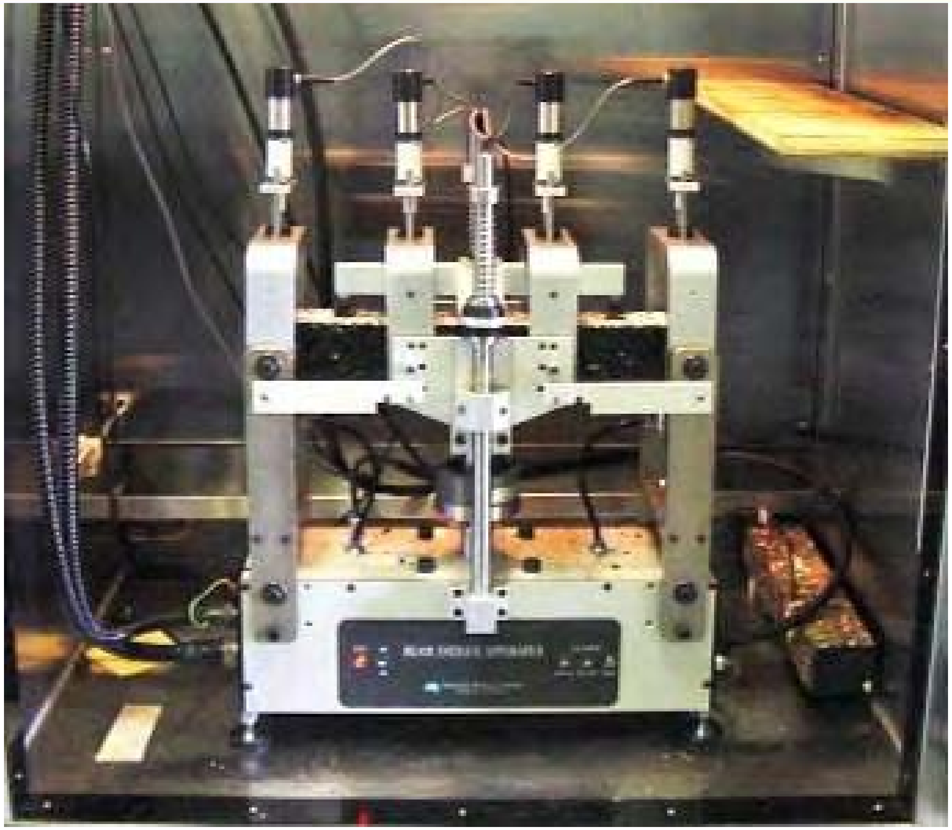
- Ways to realize "long life" bituminous pavements:
  - Increase the stiffness of the HMA layers
    - 2X increase in stiffness increases projected life 2-5X
  - Increasing the thickness of the HMA base layer
    - 10% increase doubles the projected life



USA

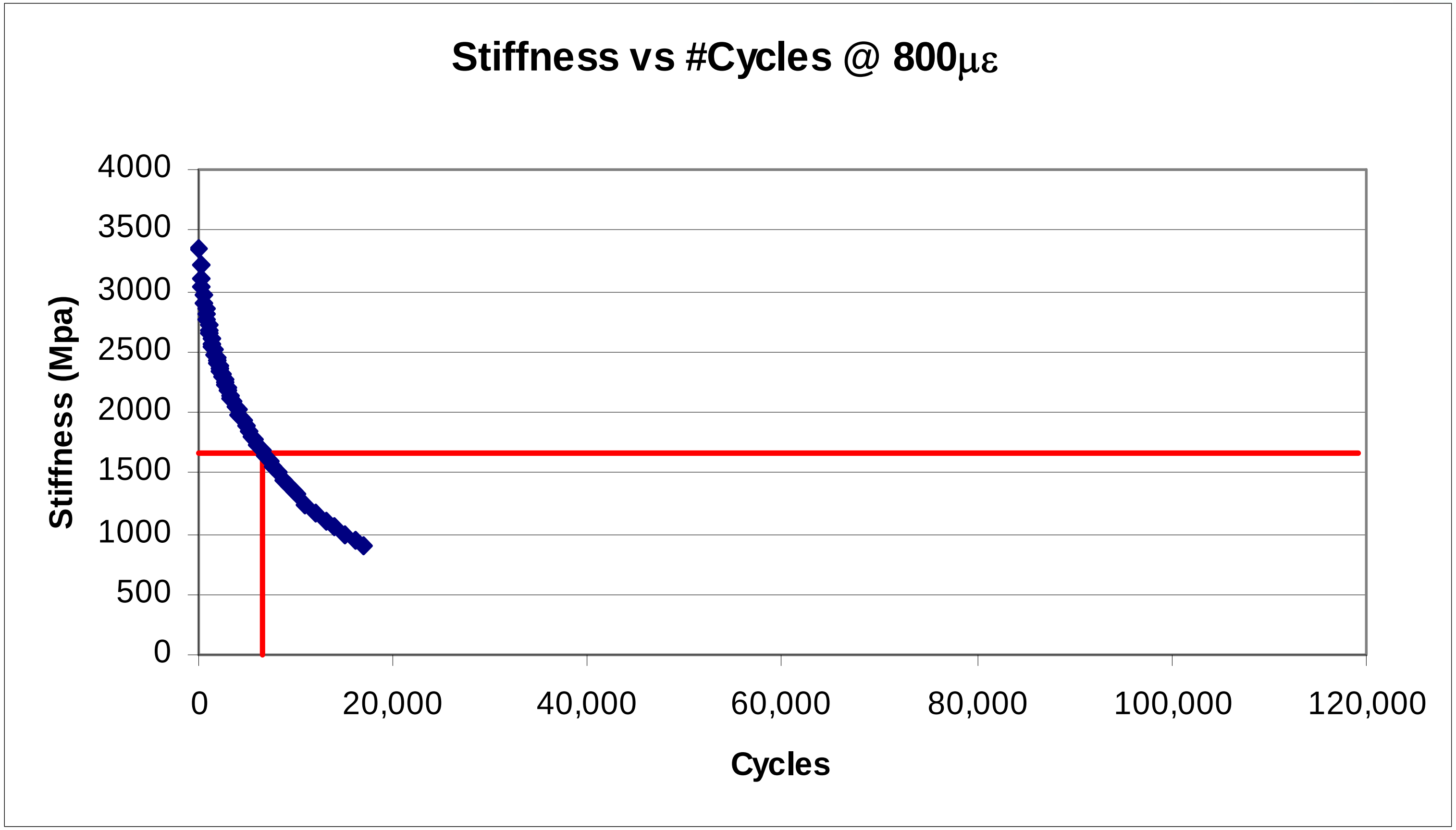
- Observed excellent performance of thick asphalt pavements built on the Interstate system and other major routes
- Interest resulted in TRB Circular No. 503, “Perpetual Bituminous Pavements,” published in 2001
- “Perpetual Pavement” awards highlighted the performance of some of these pavements around the country
  - 39 projects awarded since 2002

Beam Fatigue Testing of HMA



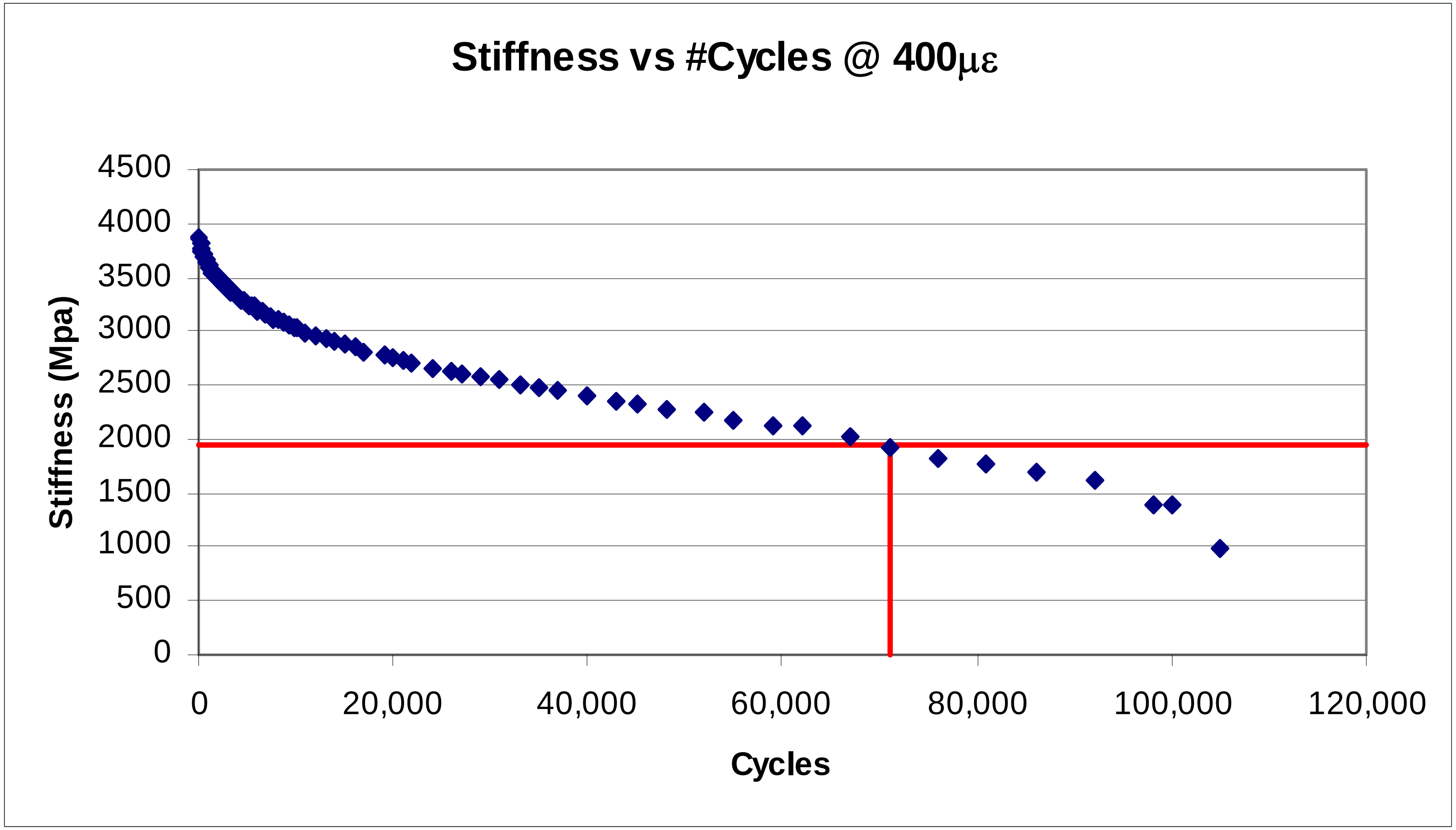
- AASHTO T-321
- Temperature: 20C
- Controlled strain
  - Test @ various levels
- Constantly monitor load (force)
- Failure defined as ½ $S_{initial}$

Repeated Loading @ 800με

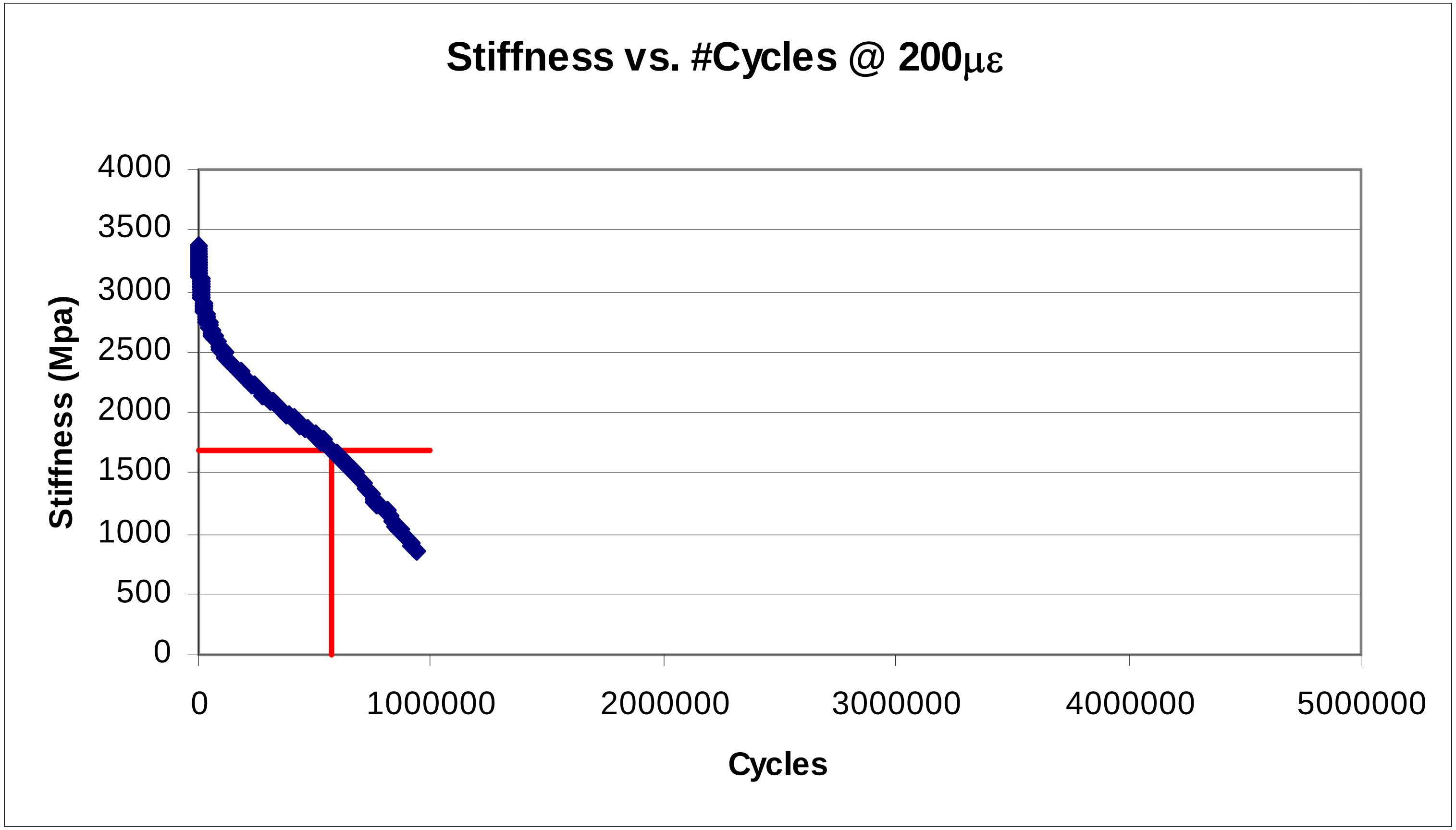


~6500 cycles

Repeated Loading @ 400με



Repeated Loading @ 200με



Note: Reducing strain by half extends fatigue life ~8-10X

Repeated Loading @ 100με

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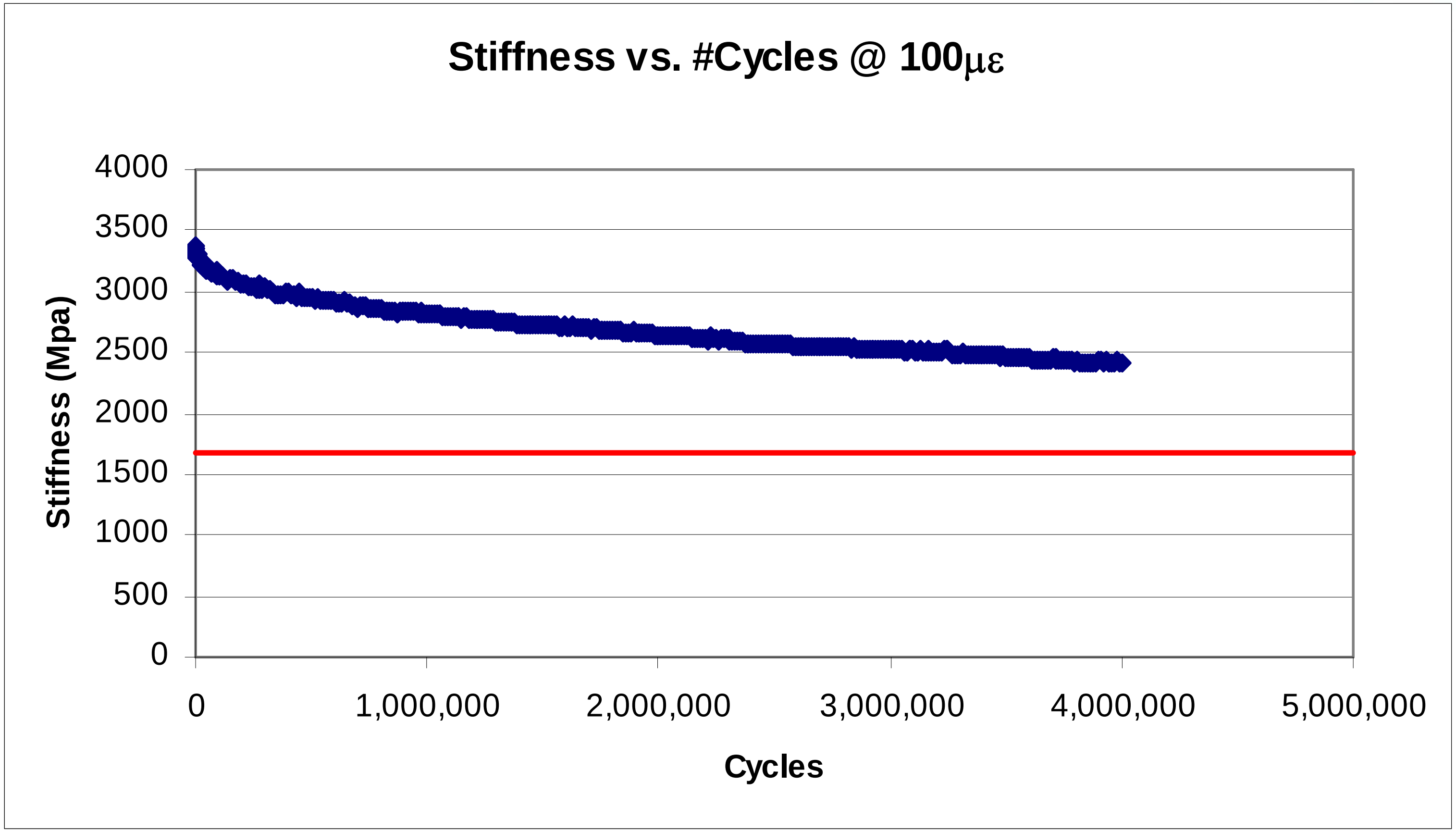

Thompson & Carpenter

Int'l Symposium on Long Lasting Asphalt Pavements, Auburn, AL

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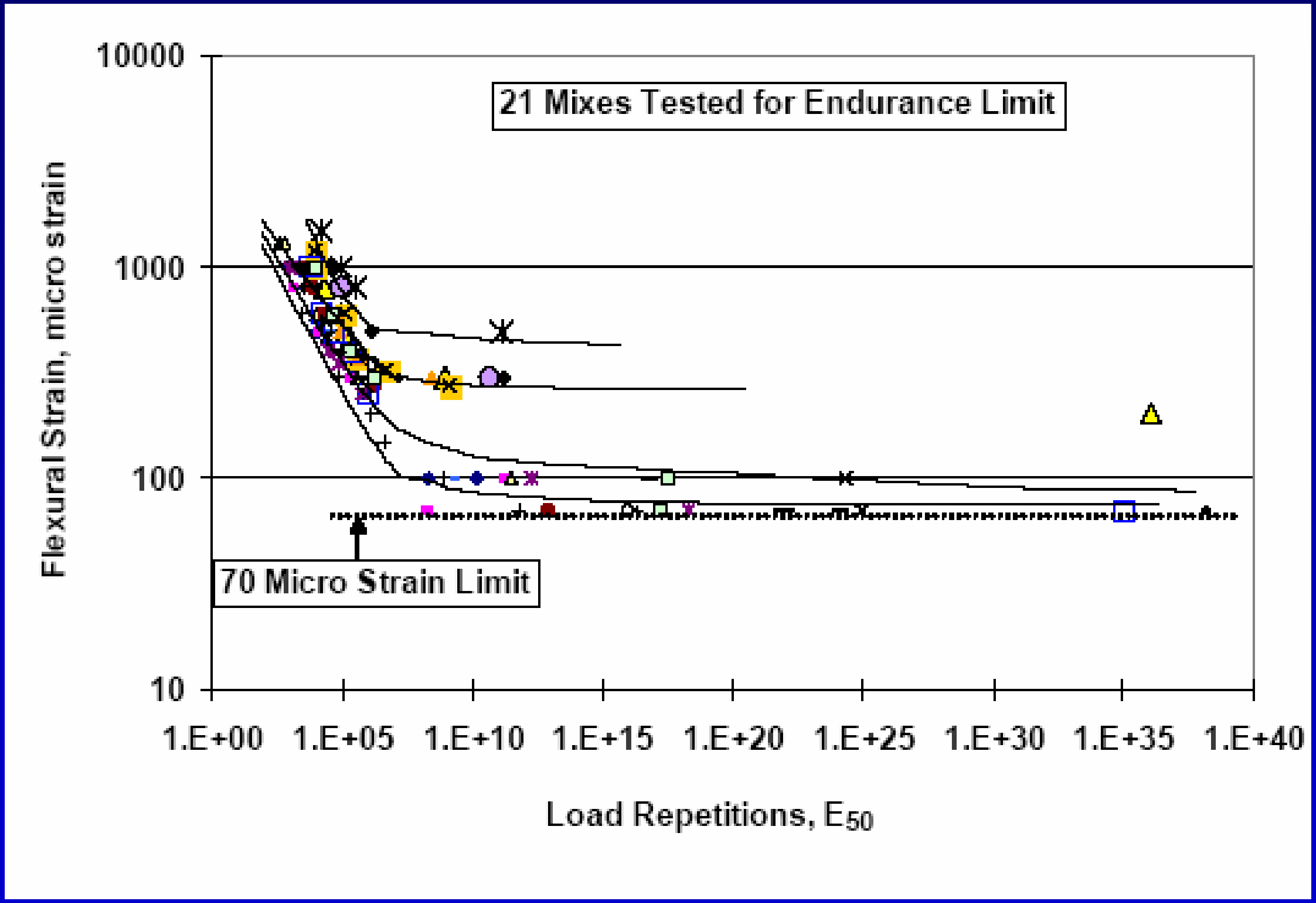

A strain limit was observed for all mixtures, but the limit differed between mixes. All exceeded 70με.

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"Endurance Limit" Research

- NCHRP 9-38, "Endurance Limit of HMA to Prevent Fatigue Cracking in Flexible Pavements"
  - Awarded to NCAT
    - Dr. E. Ray Brown, Principal Investigator
  - Final report currently (2/08) being prepared
- NCHRP 9-44, "Developing a Plan for Validating an Endurance Limit for HMA Pavements"
  - Project not yet awarded

NCHRP 9-38

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- Test the hypothesis that an endurance limit exists for fatigue behavior in HMA and measure its value for a representative range of HMA mixtures
- Suggest how to incorporate an endurance limit into mechanistic pavement design methods

★ Version 1.0 of MEPDG allows for including a fatigue endurance limit as an input for asphalt mixtures

Rutting/Permanent Deformation

- “Structural” rutting is accumulated subgrade permanent deformation
  - If the subgrade deforms, the pavement above it conforms to the shape of the underlying foundation
  - Related to the vertical compressive strain at the top of the subgrade
- Rutting in the asphalt layer is addressed through mixture/materials selection
  - Particularly for upper 4-6 inches of pavement

Rate of Rutting vs. Total Asphalt Thickness

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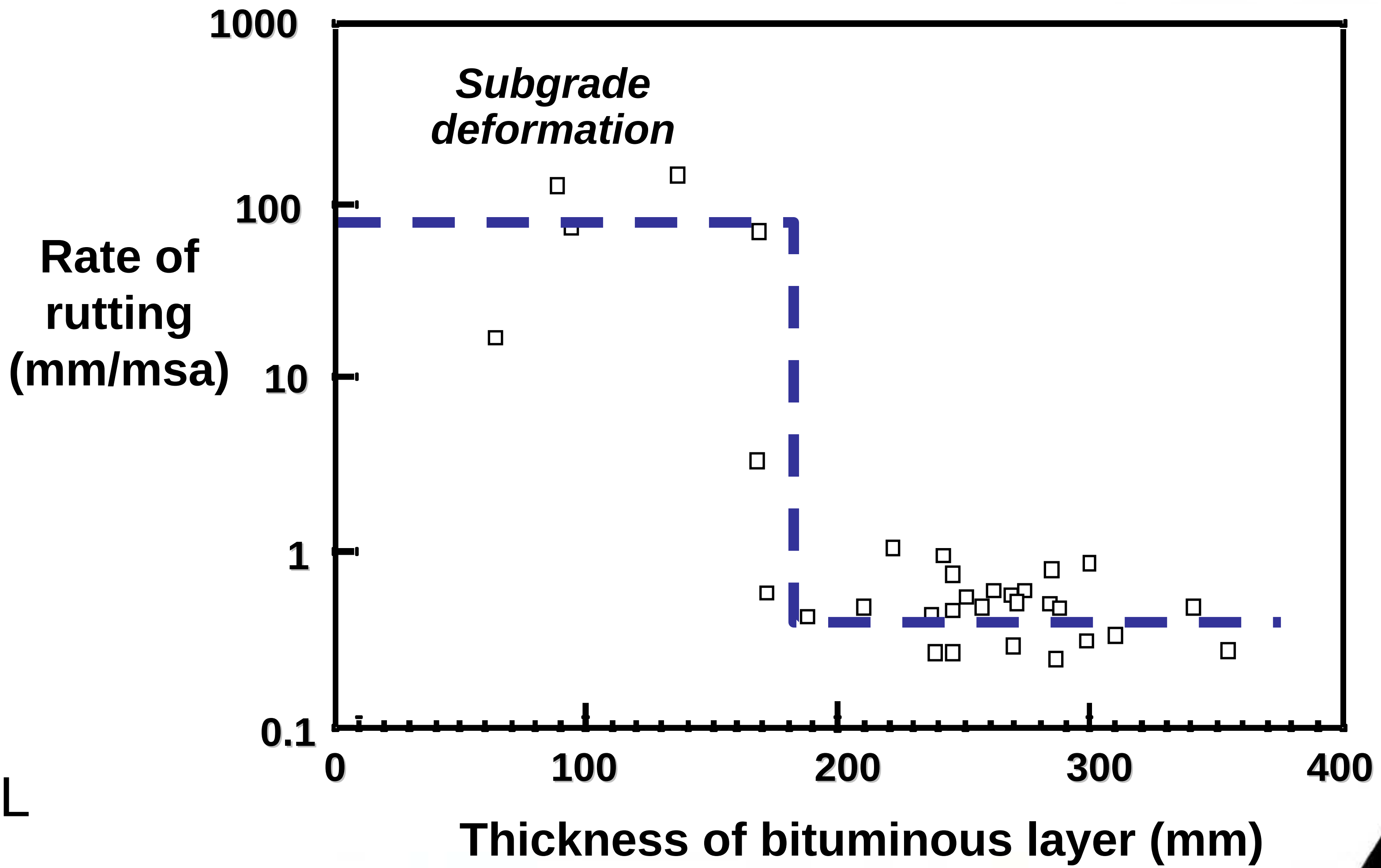
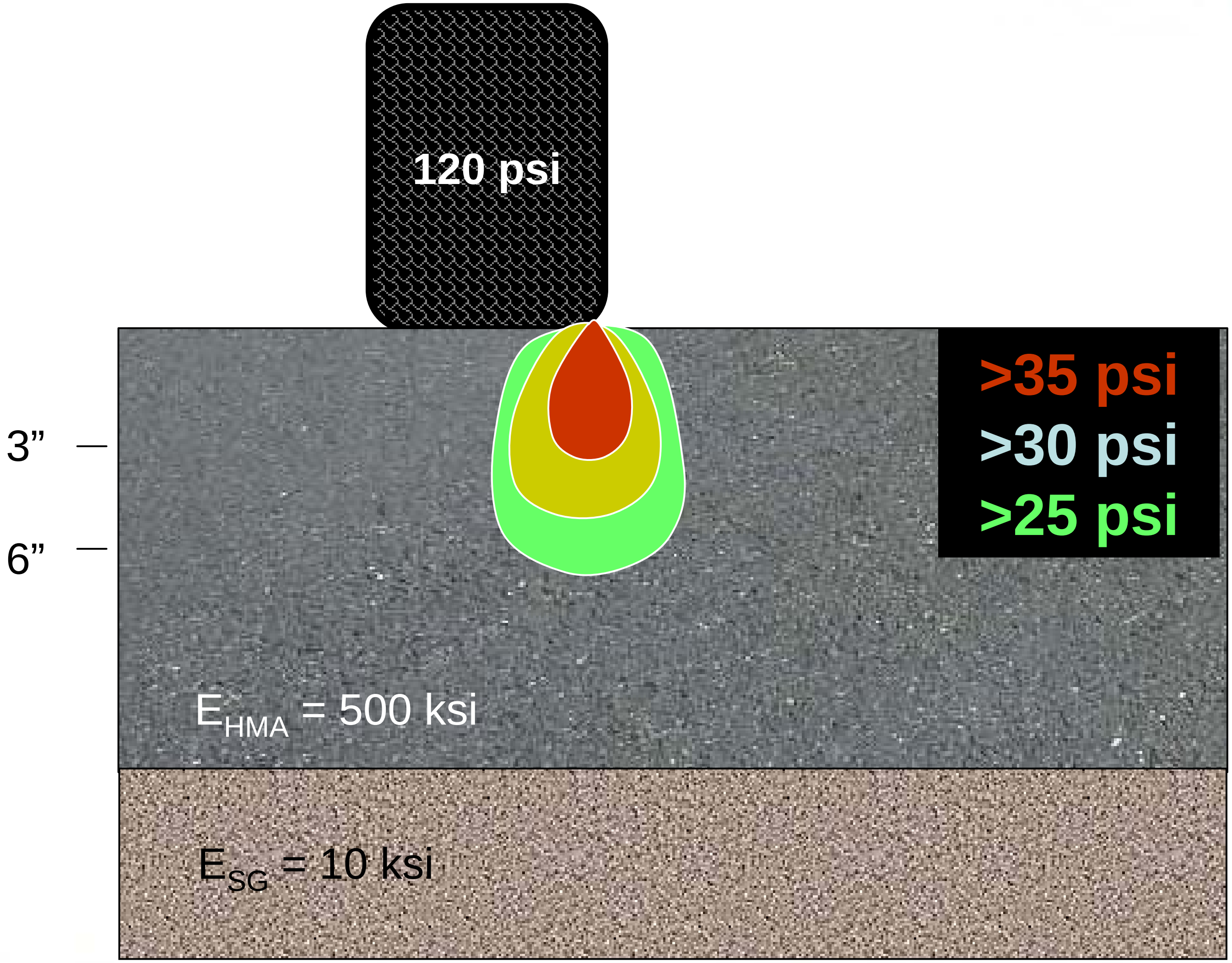


TRL

Shear Stress Within an Asphalt Pavement



Stiff, Rut Resistant Upper Layers

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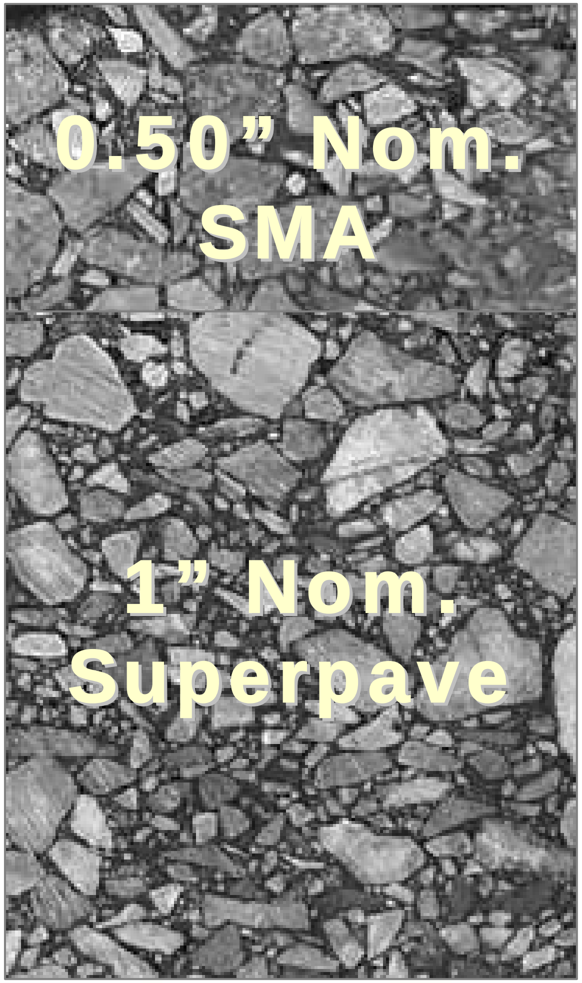

- Particularly important in upper 4-6 inches of pavement
- Use polymer-modified asphalt binders, mixtures that develop aggregate interlock

How do you design a perpetual pavement?

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- Develop a trial pavement design
  - Using AASHTO, AI, or other pavement design procedure
  - Download PerRoad software (www.asphaltalliance.com)
- Identify key inputs for elastic layer theory/PerRoad
  - Modulus, Poisson's ratio for each pavement layer and subgrade, thickness for each pavement layer
    - Layer stiffness values may vary according to season
  - Damage function constants (k-values) for HMA, subgrade
  - Traffic load spectra

TRL Design Chart

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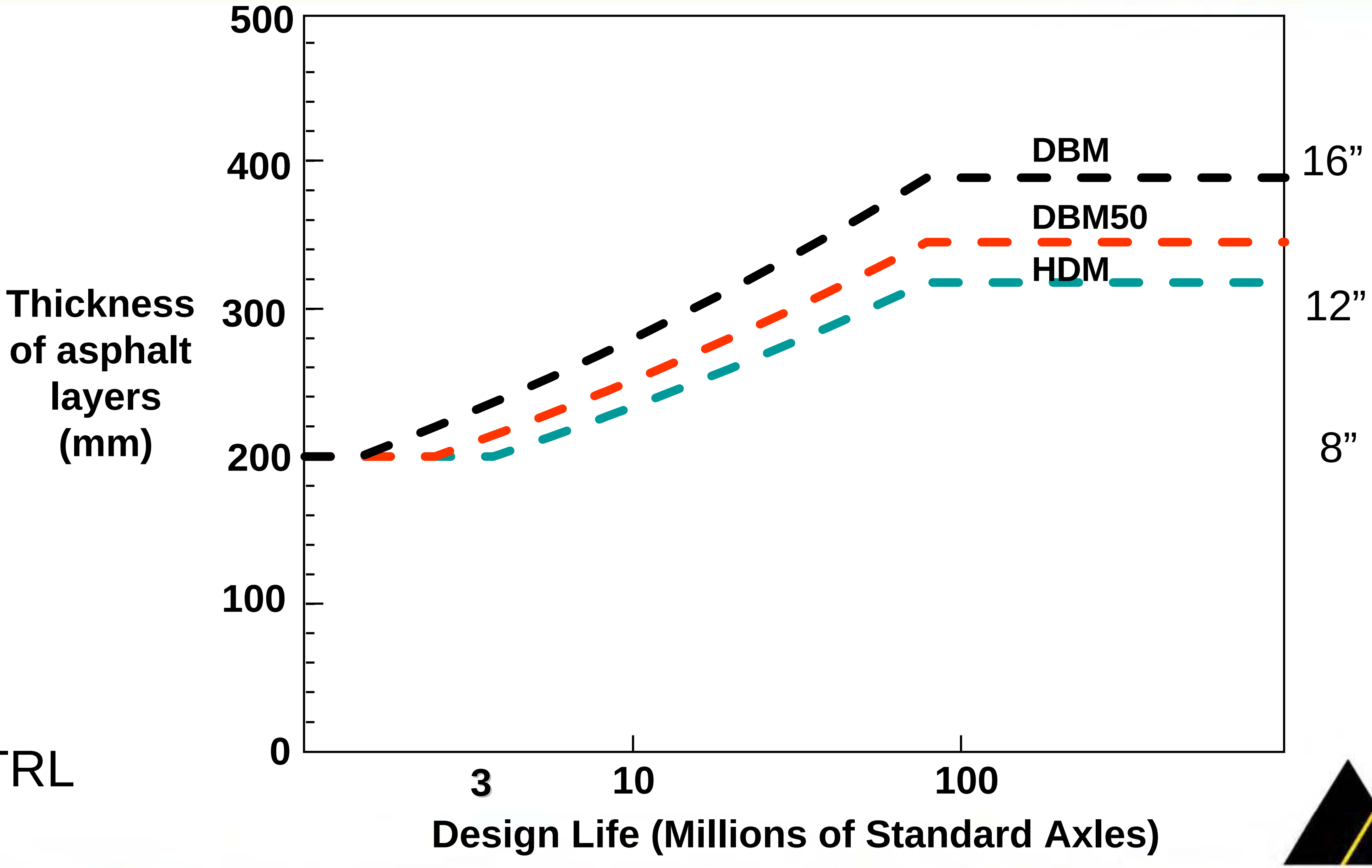
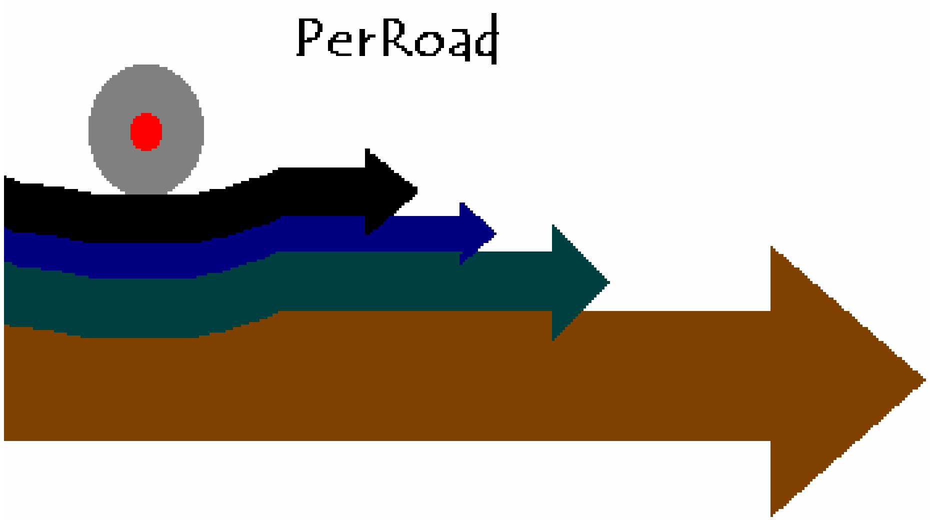


TRL

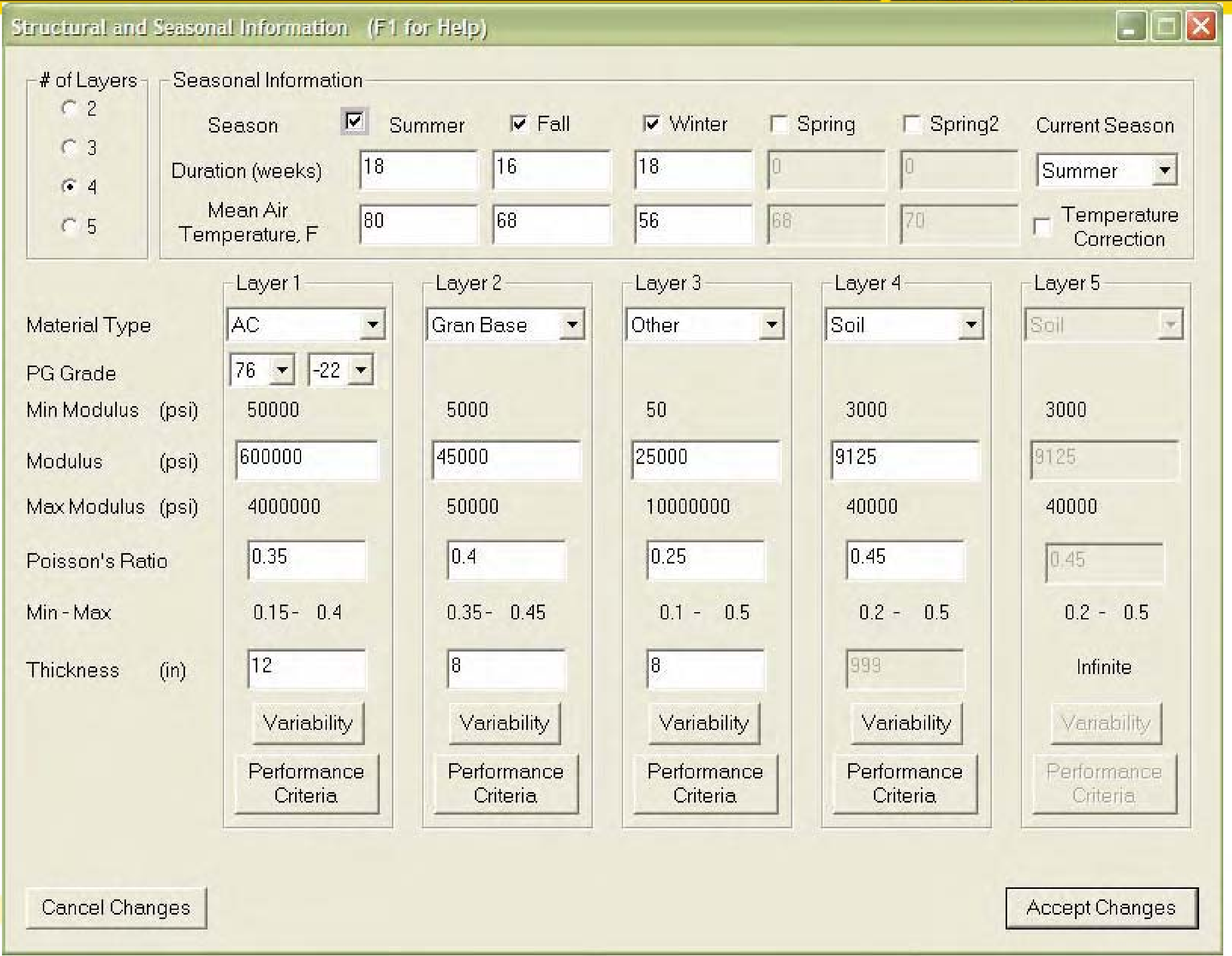
PerRoad 3.2

- Sponsored by APA
- Developed at Auburn University / NCAT
- M-E Pavement Analysis Tool



Software is available
www.asphaltalliance.com

PerRoad Input-Structure & Materials



PerRoad Input-Traffic Load Spectra

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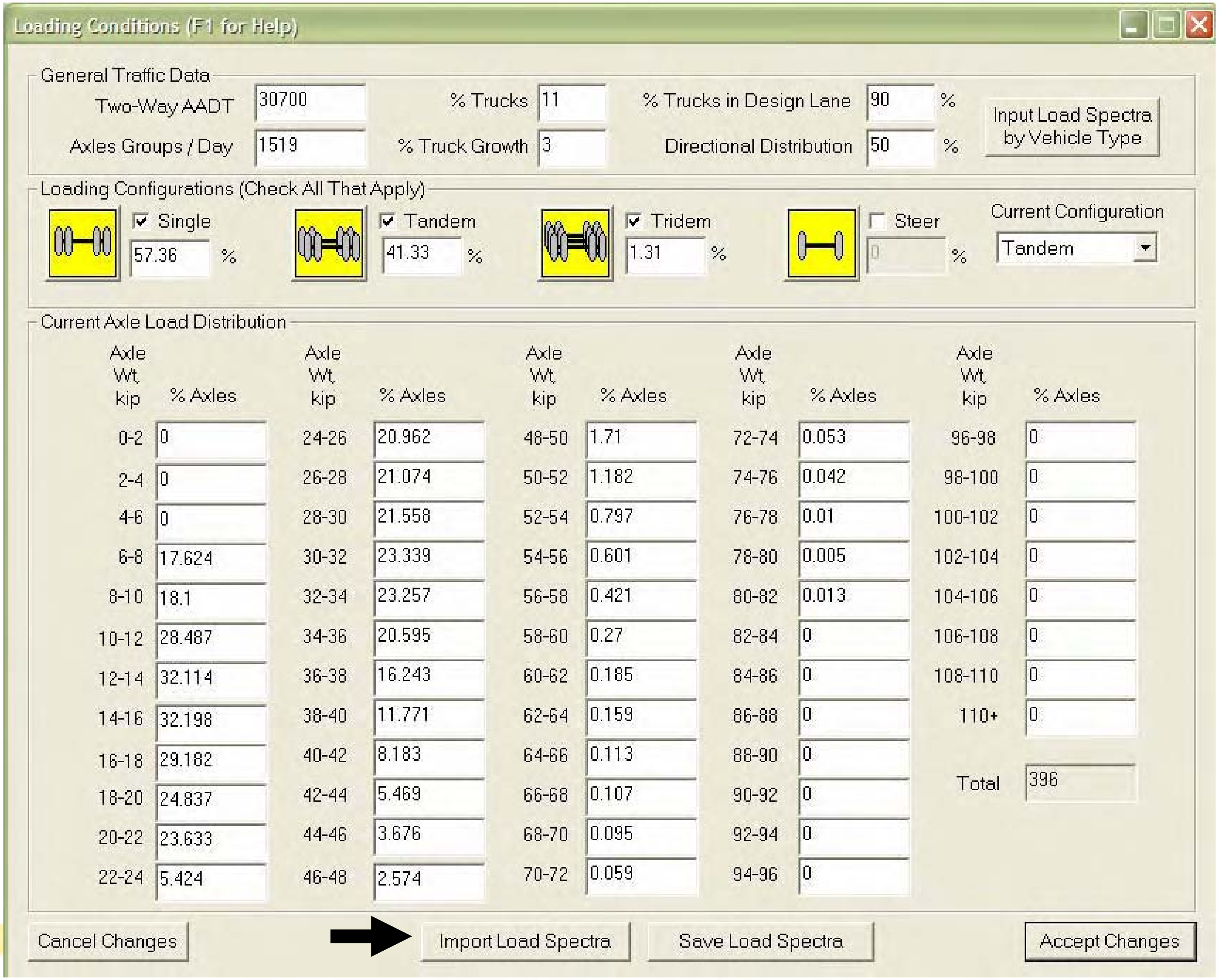


Loading Conditions (F1 for Help)

General Traffic Data

Two-Way AADT: 30700
Axles Groups / Day: 1519
% Trucks: 11
% Truck Growth: 3
% Trucks in Design Lane: 90 %
Directional Distribution: 50 %

Input Load Spectra by Vehicle Type

Loading Configurations (Check All That Apply)

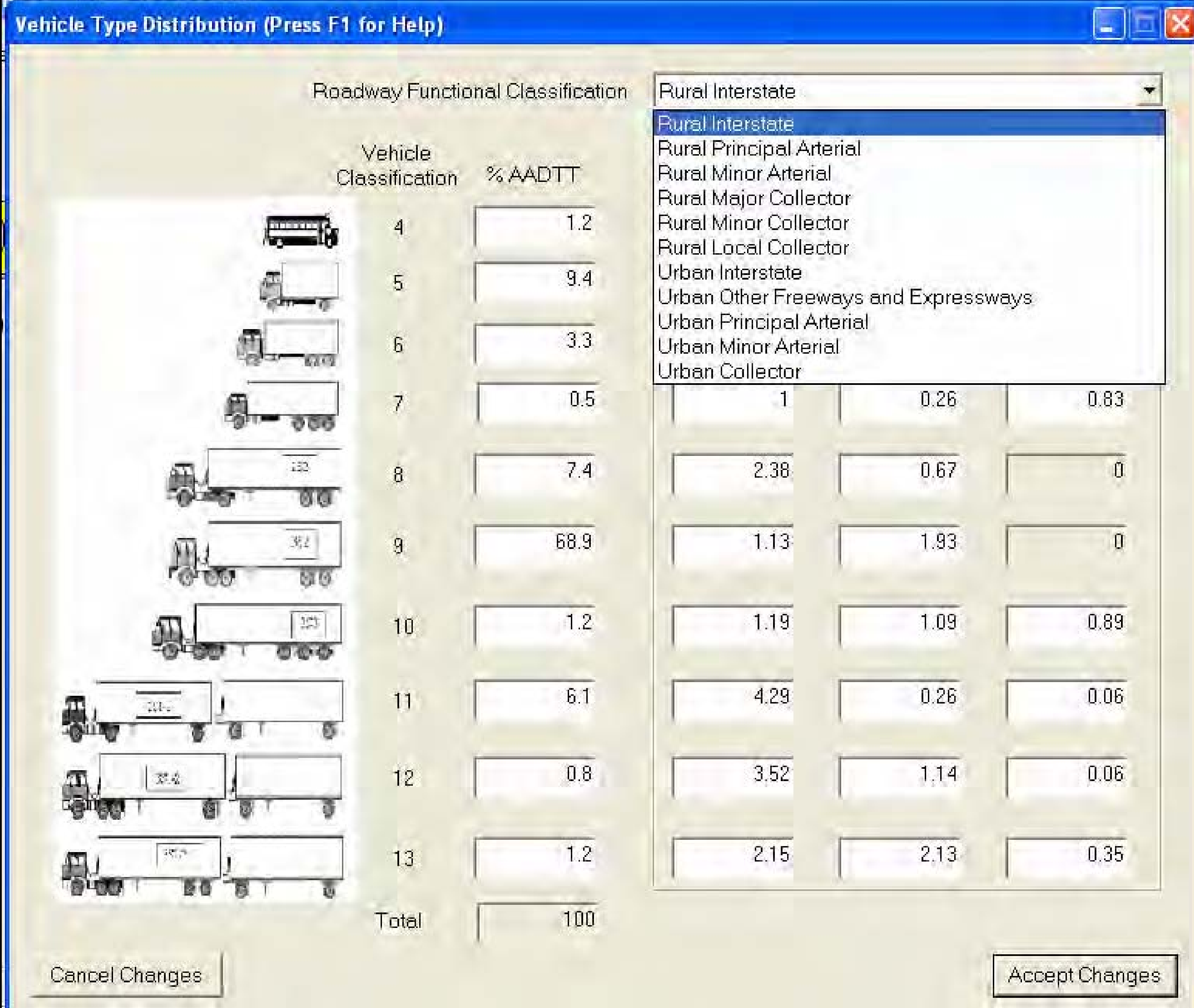
☑ Single 57.36 %
☑ Tandem 41.33 %
☑ Tridem 1.31 %
☐ Steer 0 %

Current Configuration: Tandem

Current Axle Load Distribution

Axle Wt. kip	% Axles	Axle Wt. kip	% Axles	Axle Wt. kip	% Axles	Axle Wt. kip	% Axles	Axle Wt. kip	% Axles
0-2	0	24-26	20.962	48-50	1.71	72-74	0.053	96-98	0
2-4	0	26-28	21.074	50-52	1.182	74-76	0.042	98-100	0
4-6	0	28-30	21.558	52-54	0.797	76-78	0.01	100-102	0
6-8	17.624	30-32	23.339	54-56	0.601	78-80	0.005	102-104	0
8-10	18.1	32-34	23.257	56-58	0.421	80-82	0.013	104-106	0
10-12	28.487	34-36	20.595	58-60	0.27	82-84	0	106-108	0
12-14	32.114	36-38	16.243	60-62	0.185	84-86	0	108-110	0
14-16	32.198	38-40	11.771	62-64	0.159	86-88	0	110+	0
16-18	29.182	40-42	8.183	64-66	0.113	88-90	0		
18-20	24.837	42-44	5.469	66-68	0.107	90-92	0	Total	396
20-22	23.633	44-46	3.676	68-70	0.095	92-94	0		
22-24	5.424	46-48	2.574	70-72	0.059	94-96	0		

Cancel Changes | Import Load Spectra | Save Load Spectra | Accept Changes



Vehicle Type Distribution (Press F1 for Help)
Roadway Functional Classification
Rural Interstate
Rural Interstate
Rural Principal Arterial
Rural Minor Arterial
Rural Major Collector
Rural Minor Collector
Rural Local Collector
Urban Interstate
Urban Other Freeways and Expressways
Urban Principal Arterial
Urban Minor Arterial
Urban Collector
Vehicle Classification
% AADTT
4 1.2
5 9.4
6 3.3
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

Tandem Axle Load Spectra

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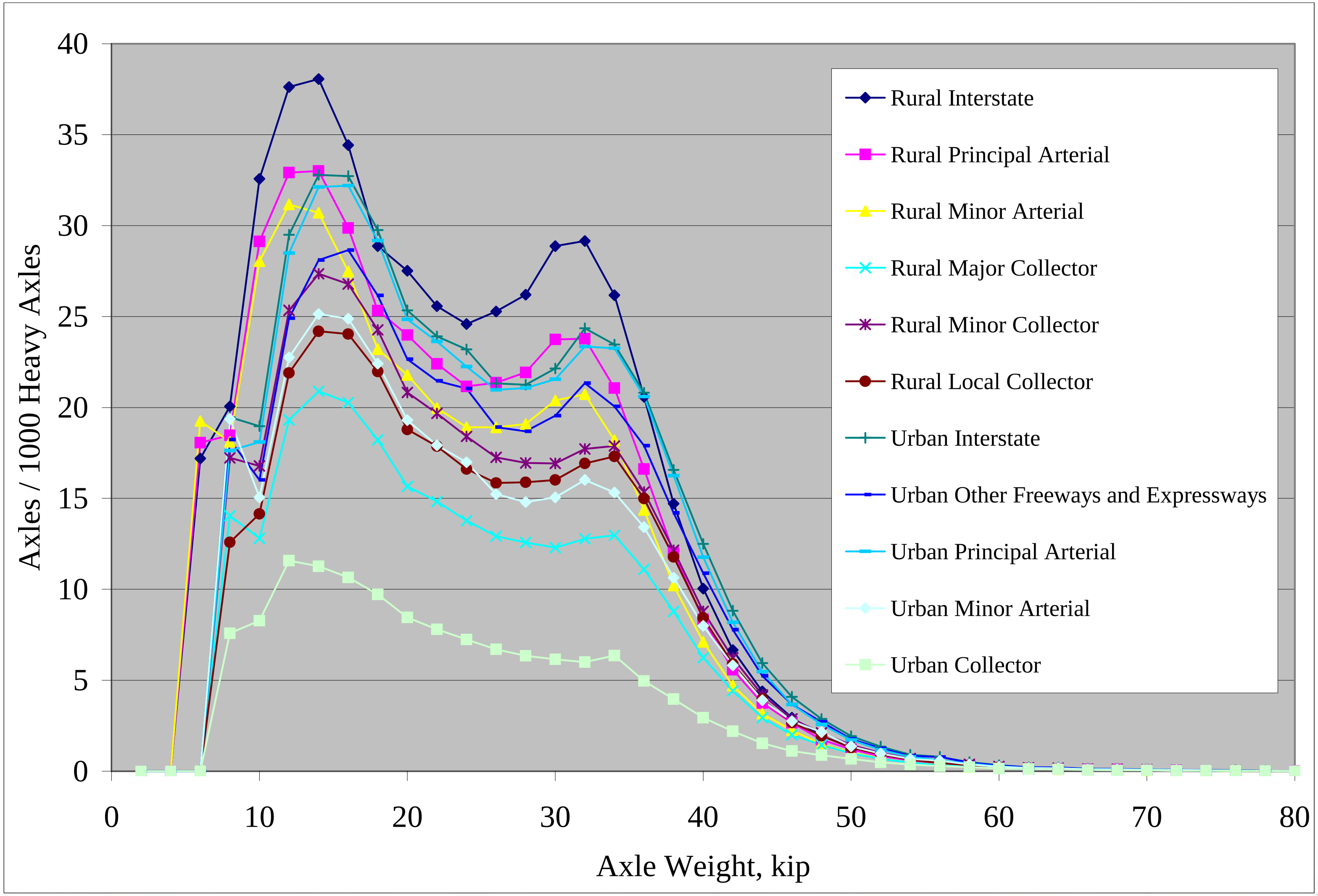
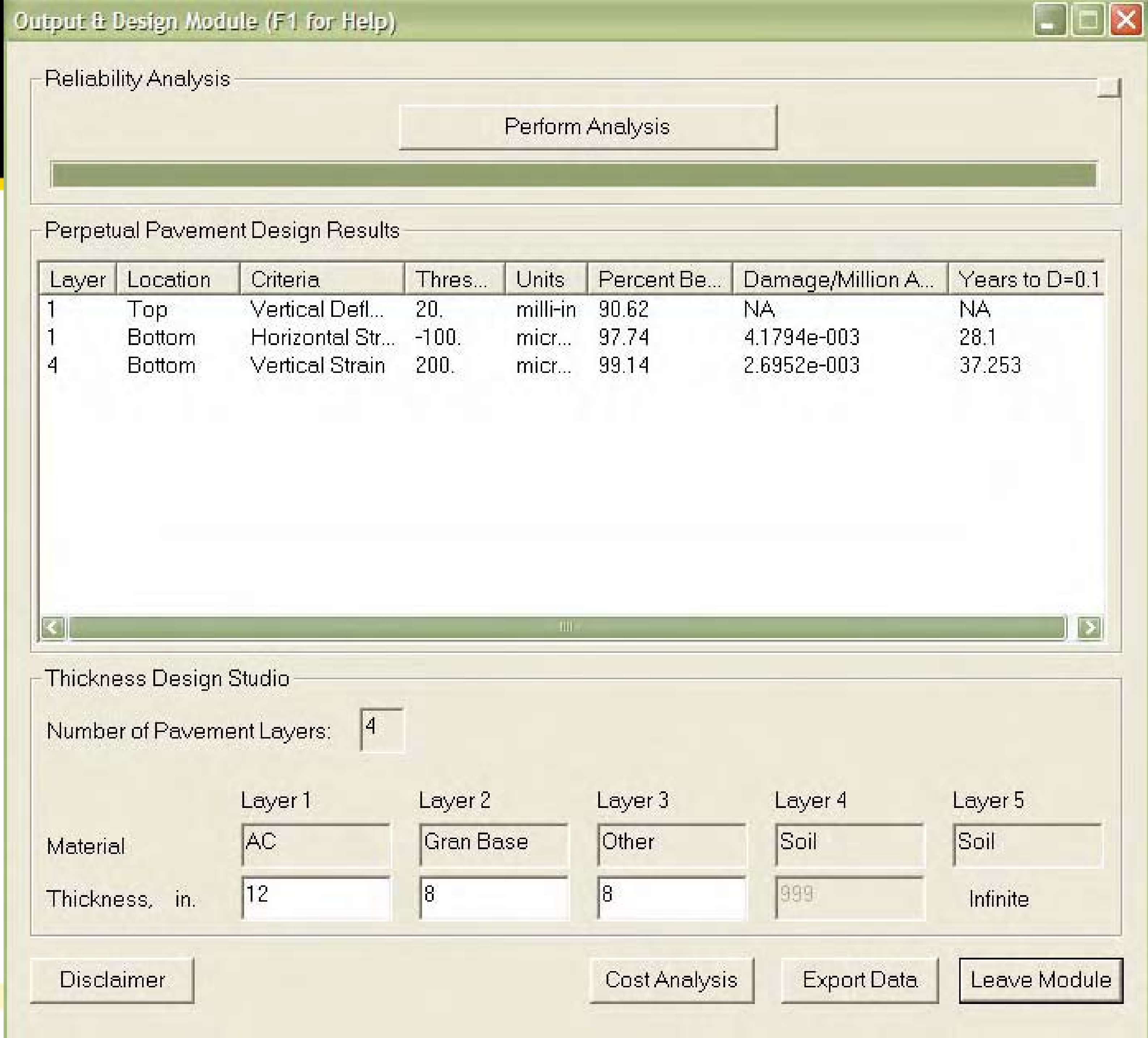


Output


Output & Design Module (F1 for Help)
Reliability Analysis
Perform Analysis
Perpetual Pavement Design Results
Layer | Location | Criteria | Thres... | Units | Percent Be... | Damage/Million A... | Years to D=0.1
1 | Top | Vertical Defl... | 20. | milli-in | 90.62 | NA | NA
1 | Bottom | Horizontal Str... | -100. | micr... | 97.74 | 4.1794e-003 | 28.1
4 | Bottom | Vertical Strain | 200. | micr... | 99.14 | 2.6952e-003 | 37.253
Thickness Design Studio
Number of Pavement Layers: 4
Layer 1
Layer 2
Layer 3
Layer 4
Layer 5
Material
AC
Gran Base
Other
Soil
Soil
Thickness, in.
12
8
8
999
Infinite
Disclaimer
Cost Analysis
Export Data
Leave Module

I-49 Extension, Caddo Parish, Louisiana

- New Interstate highway construction, Shreveport to Arkansas state line
- Preliminary designs performed for asphalt and concrete pavements

Project Location

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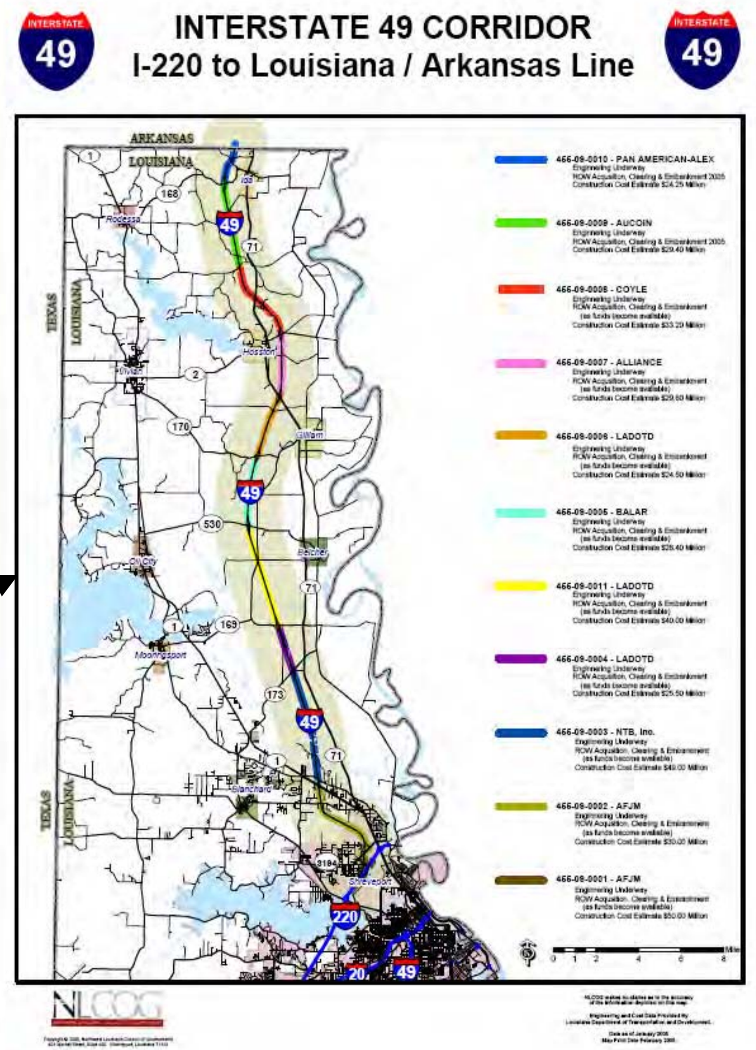

Input data sources

- Obtained inputs used for AASHTO design from LaDOTD pavement design office
- Used FWD data from similar projects to estimate layer stiffnesses to be used as input in the pavement analysis

Traffic data

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- AADT: 10,000
- % trucks: 21.2%
- Growth rate: 2.9%

Loading Conditions (F1 for Help)

General Traffic Data

Two-Way AADT	10000	% Trucks	21	% Trucks in Design Lane	90 %
Axles Groups / Day	2868	% Truck Growth	2.9	Directional Distribution	50 %

Input Load Spectra by Vehicle Type

Loading Configurations (Check All That Apply)

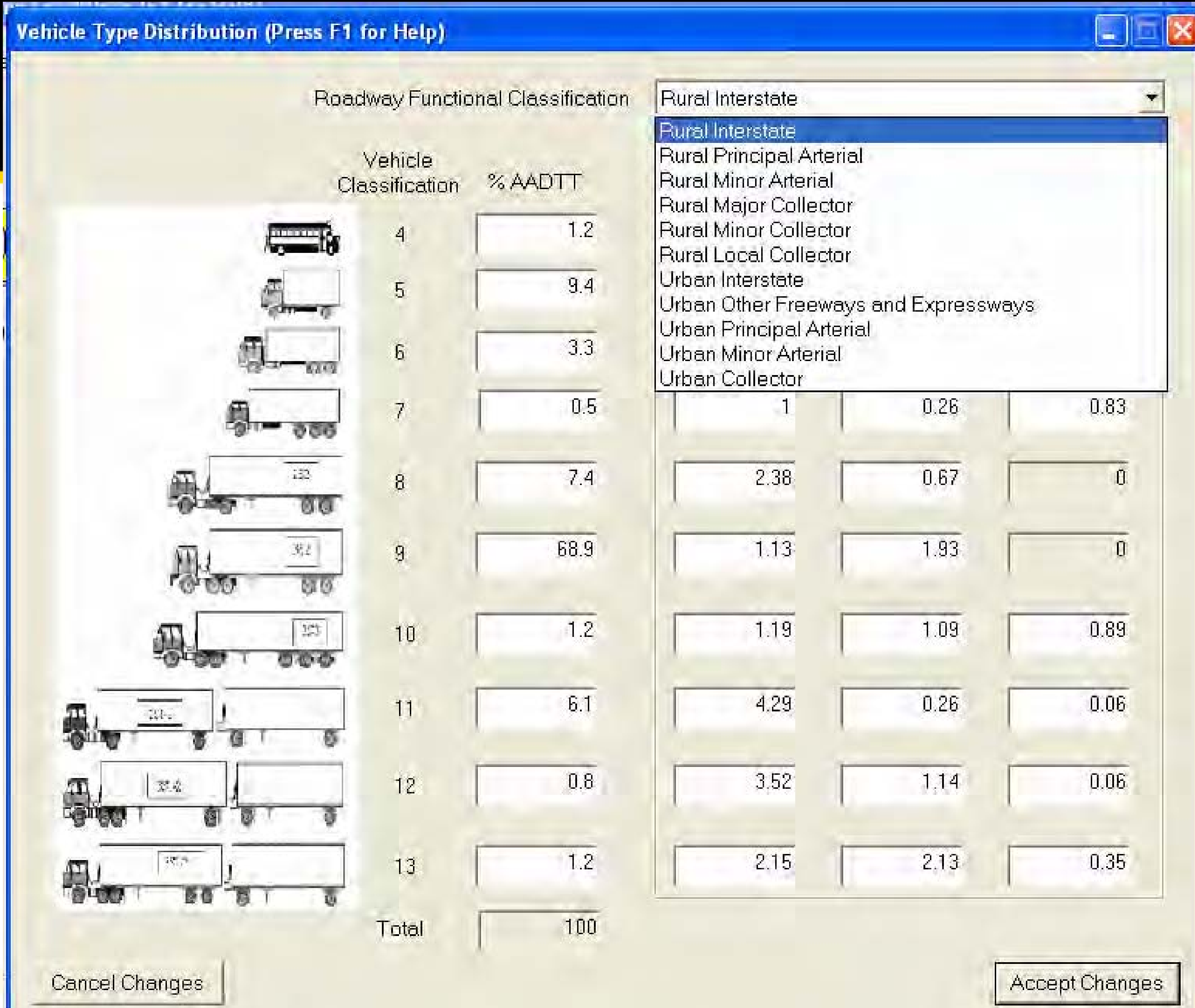
Single	☑	50.43 %
Tandem	☑	48.81 %
Tridem	☑	0.76 %
Steer	☐	0 %

Current Configuration: Tandem

Current Axle Load Distribution

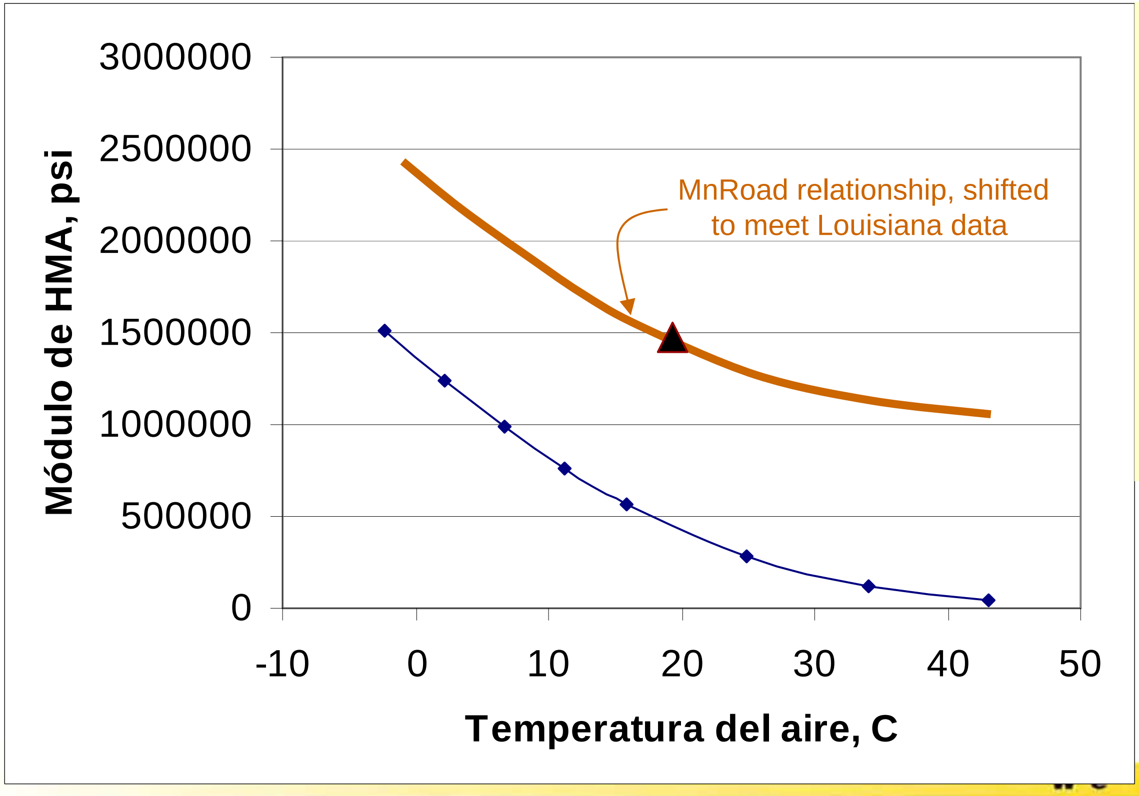
Axle Wt. kip	% Axles	Axle Wt. kip	% Axles	Axle Wt. kip	% Axles	Axle Wt. kip	% Axles	Axle Wt. kip	% Axles
0-2	0	24-26	5.04	48-50	0.4	72-74	0.01	96-98	0
2-4	0	26-28	5.18	50-52	0.27	74-76	0.01	98-100	0
4-6	0	28-30	5.37	52-54	0.18	76-78	0	100-102	0
6-8	3.53	30-32	5.92	54-56	0.13	78-80	0	102-104	0
8-10	4.11	32-34	5.98	56-58	0.09	80-82	0	104-106	0
10-12	6.68	34-36	5.37	58-60	0.06	82-84	0	106-108	0
12-14	7.72	36-38	4.22	60-62	0.04	84-86	0	108-110	0
14-16	7.8	38-40	3.02	62-64	0.03	86-88	0	110+	0
16-18	7.06	40-42	2.06	64-66	0.02	88-90	0		
18-20	5.92	42-44	1.37	66-68	0.02	90-92	0	Total	100
20-22	5.64	44-46	0.9	68-70	0.02	92-94	0		
22-24	5.24	46-48	0.6	70-72	0.01	94-96	0		

Cancel Changes | Import Load Spectra | Save Load Spectra | Accept Changes


Vehicle Type Distribution (Press F1 for Help)
Roadway Functional Classification
Rural Interstate
Rural Interstate
Rural Principal Arterial
Rural Minor Arterial
Rural Major Collector
Rural Minor Collector
Rural Local Collector
Urban Interstate
Urban Other Freeways and Expressways
Urban Principal Arterial
Urban Minor Arterial
Urban Collector
Vehicle Classification
% AADTT
4 1.2
5 9.4
6 3.3
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

Materials data inputs

Season	Avg. air temperature, F	Estimated pavement temperature, F	Duration	E*, ksi
Winter	50	58	17 weeks	1600
Spring/fall	68	76	21 weeks	1250
Summer	82	91	14 weeks	1100



Other layer stiffnesses:

E_{base} = 45,000 psi

$E_{subbase}$ = 25,000 psi

$E_{subgrade}$ = 10,000 psi

Materials data inputs-conservative “design” values

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Season	Avg. air temperature, F	Estimated pavement temperature, F	Duration	E*, ksi
Winter	50	58	17 weeks	800
Spring/fall	68	76	21 weeks	625
Summer	82	91	14 weeks	550

Other layer stiffnesses:

E_{base} = 30,000 psi
$E_{subbase}$ = 15,000 psi
$E_{subgrade}$ = 7,000 psi

Summary of results

T_{HMA}, in	Probabilistic			
	Fatigue		Permanent Deformation	
	% below limit[2]	Estimated life, years	% below limit[3]	Estimated life, years
10	76.1	5.1	85.2	2.1
12	90.2	14.2	92.5	5.7
14	96.8	37.0	97.1	15.7
16	99.0	74.8	98.8	35.8

1. Monte Carlo simulation, 5000 cycles
2. Fatigue Threshold = -70 με
3. Deformation Threshold = 200 με

What if we raised our requirements for subgrade/subbase/base?

Summary of results, revised

T_{HMA}, in	Probabilistic			
	Fatigue		Permanent Deformation	
	% below limit[2]	Estimated life, years	% below limit[3]	Estimated life, years
10	82.1	7.2	92.2	5.8
12	93.6	21.9	97.4	17.9
14	98.4	54.8	99.1	42.5
16	99.5	93.4	99.6	64.4

<u>Other layer stiffnesses</u>:

E_{base} = 35,000 psi
$E_{subbase}$ = 20,000 psi
$E_{subgrade}$ = 10,000 psi

Fatigue & Deformation

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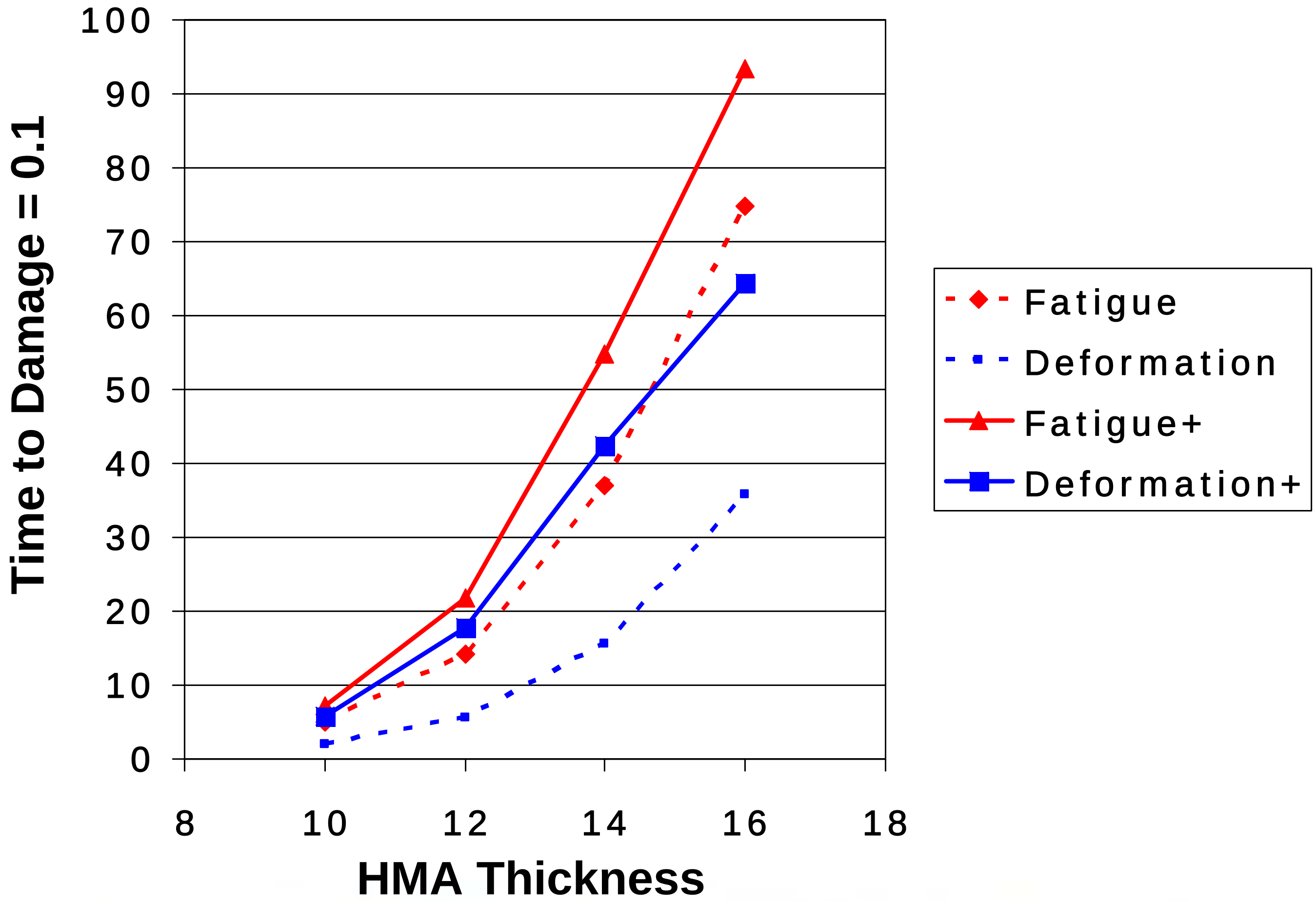

Observations

- Improvement to poor foundation materials can significantly reduce the HMA thickness necessary
  - Proof rolling criterion
  - Consider stiffness/modulus as an acceptance requirement for pavement foundation
    - Intelligent compaction equipment, FWD, LWD, DCP
- Need to collect and analyze FWD data to develop ranges of values to expect seasonally for local climate and materials

Texas Perpetual Pavement Project Locations

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- I-35, Waco District
  - McLennan County
  - Hill County, *under construction*
- I-35, Laredo District
  - LaSalle County, (S. of Cotulla)
  - LaSalle County, NBL (N. of Cotulla)
  - LaSalle County, (S. of first project)
  - Webb County, *under construction*
- I-35, San Antonio District
  - Comal County (New Braunfels)

Considerations for All Layers

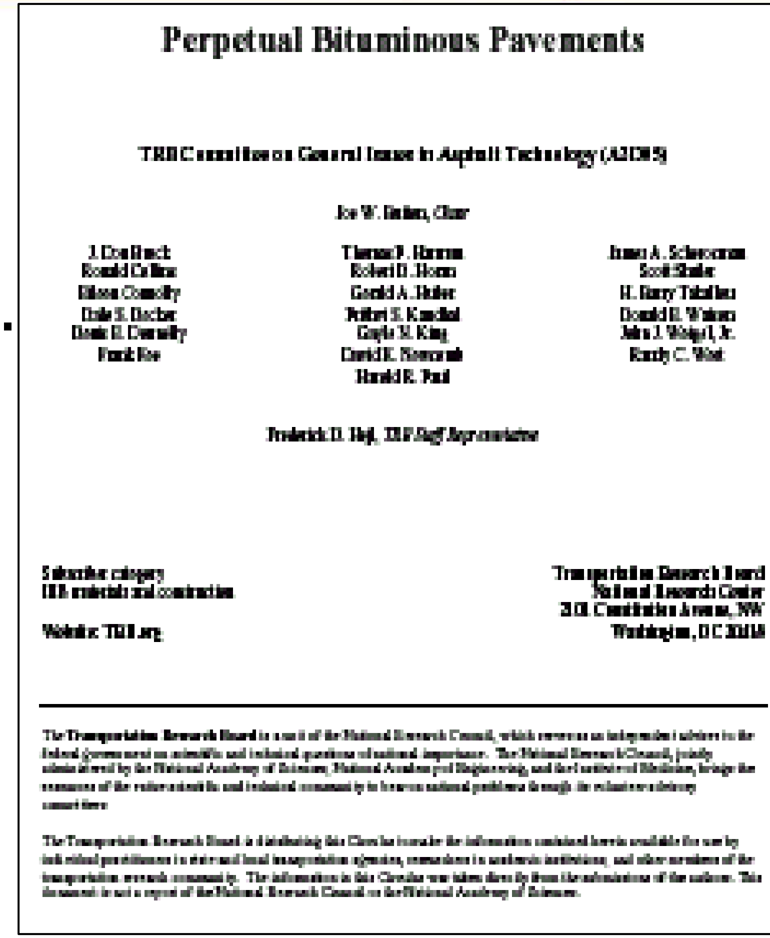
- Initial compaction is critically important
  - HMA must be compacted to a nonporous condition for optimal performance
- Support conditions and lift thicknesses must allow compaction to be achievable
  - Design the pavement foundation!
  - Fine-graded mixtures, ≥ 3X NMS
  - Coarse-graded mixtures, ≥ 4X NMS
  - Consider including loaded wheel test requirements (APA or HWT) for premium mixtures
- Many agencies are reducing N_{des} levels when using asphalt binders that require polymer modification

Summary

- PerRoad is available and easy to use for evaluating pavement designs with respect to mechanistic “perpetual pavement” criteria
- Input data are similar to what are needed when using the “ME Design Guide” developed in NCHRP 1-37A
- www.asphaltalliance.com

Perpetual Pavement Resources

- Check APA website (www.asphaltalliance.com) for references, software, etc.
- Keep alert for articles in trade literature, research reports, etc


Perpetual Bituminous Pavements

Porous Asphalt Pavements

Resources

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- Cahill Associates
  - *Stormwater* magazine article: "Porous Asphalt Pavement with Recharge Beds: 20 Years and Still Working," Michelle C. Adams, Cahill Associates, May/June 2003.
  - http://www.forester.net/sw_0305_porous.html
- Newt Jackson
  - Nichols Consulting Engineers
- Kent Hansen
  - Director of Engineering, National Asphalt Pavement Association
- Environmental Protection Agency (EPA), EPA 832-F-99-023, Storm Water Technology Fact Sheet: Porous Pavement
- University of New Hampshire http://www.unh.edu/erg/cstev/porous_asphalt/porous_asphalt-spec_mar_05.pdf
- Numerous articles available online

What are Porous Pavements?

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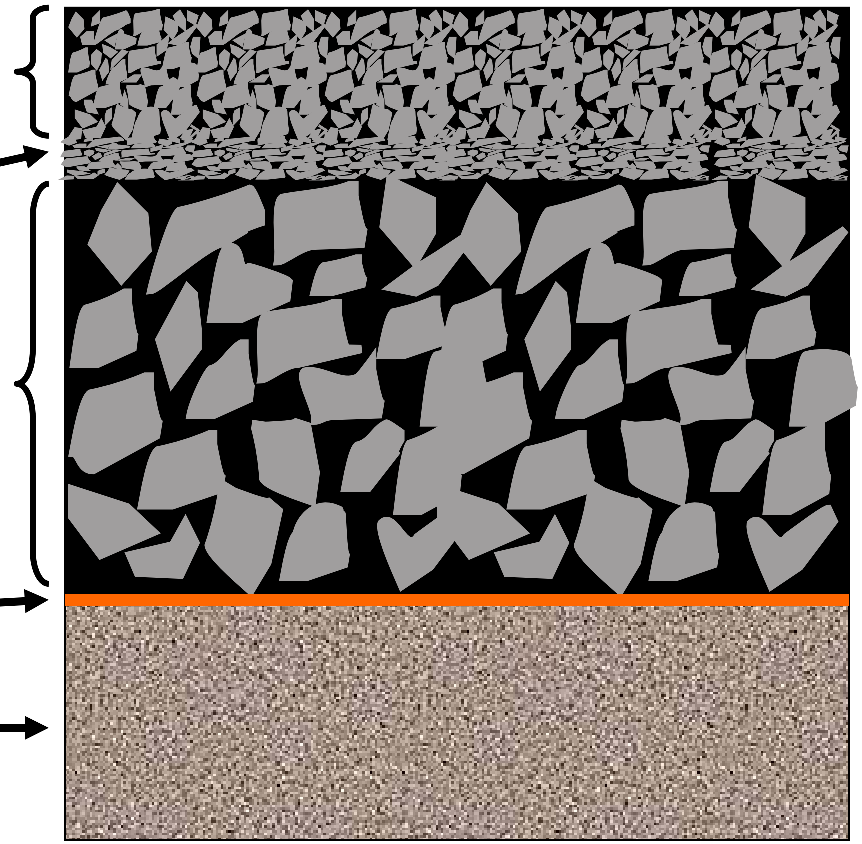
Open-Graded HMA ~ 2 ½”

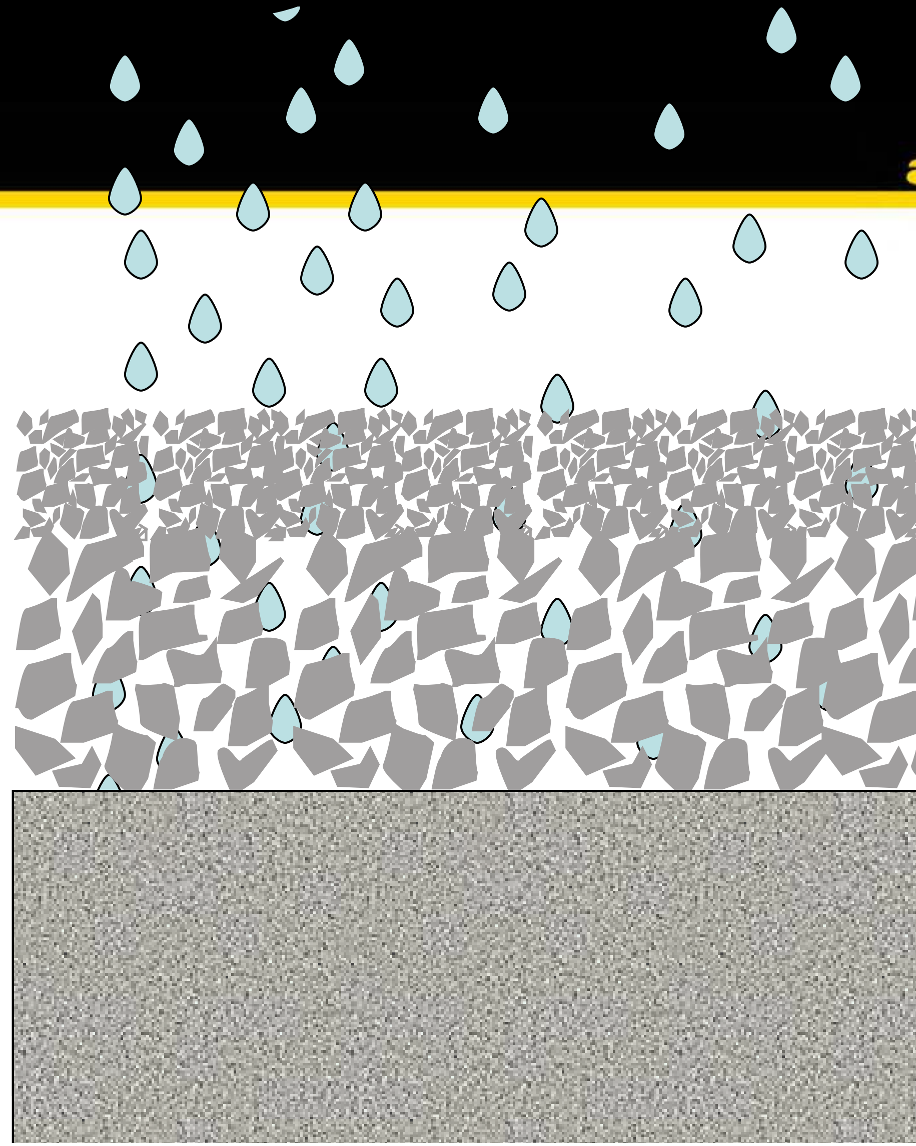
½” Agg. (#7) ~ 1 – 2” Thick

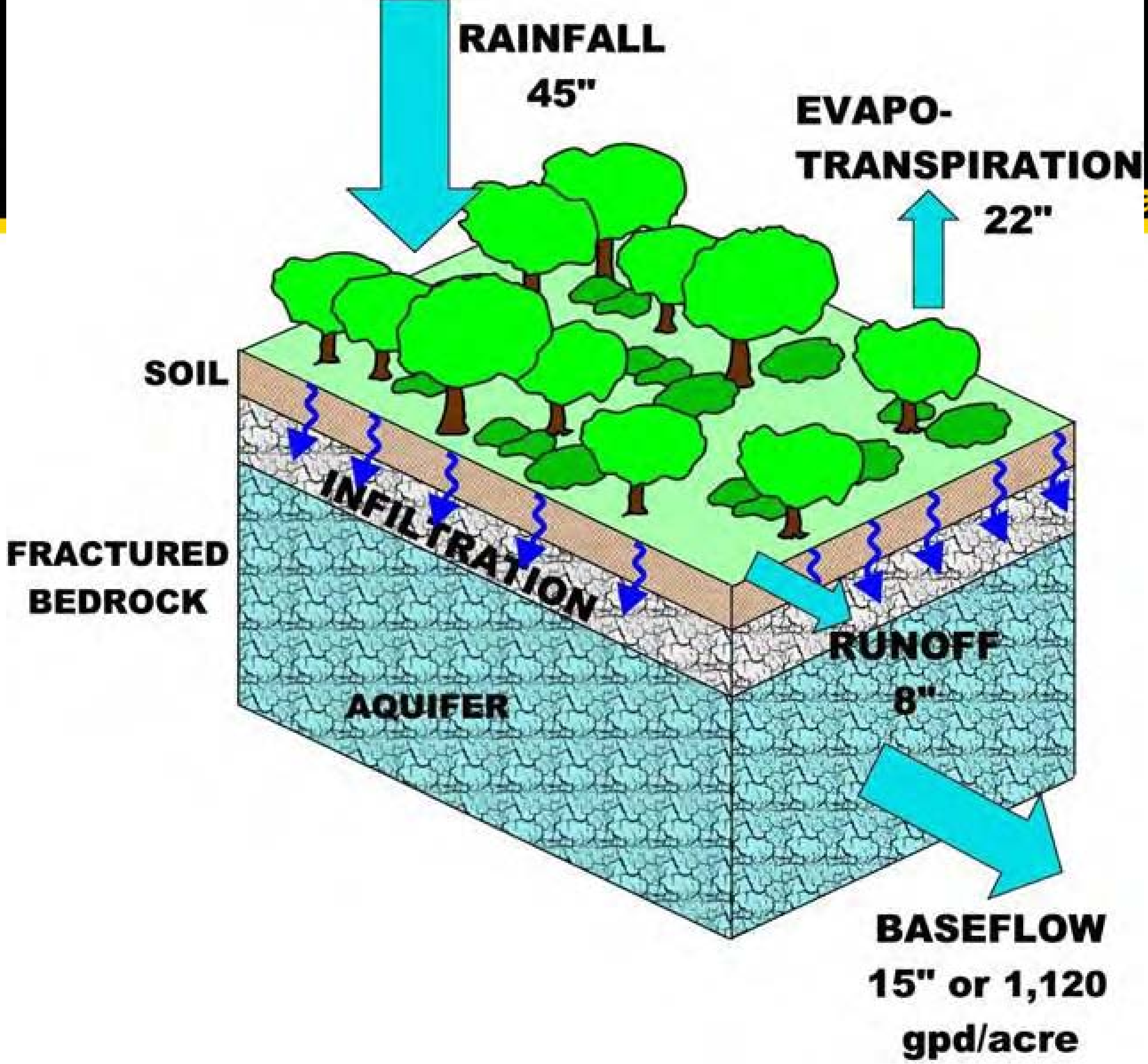
Clean Uniformly Graded 2”-3” Crushed Agg. (#2) – 40% Voids

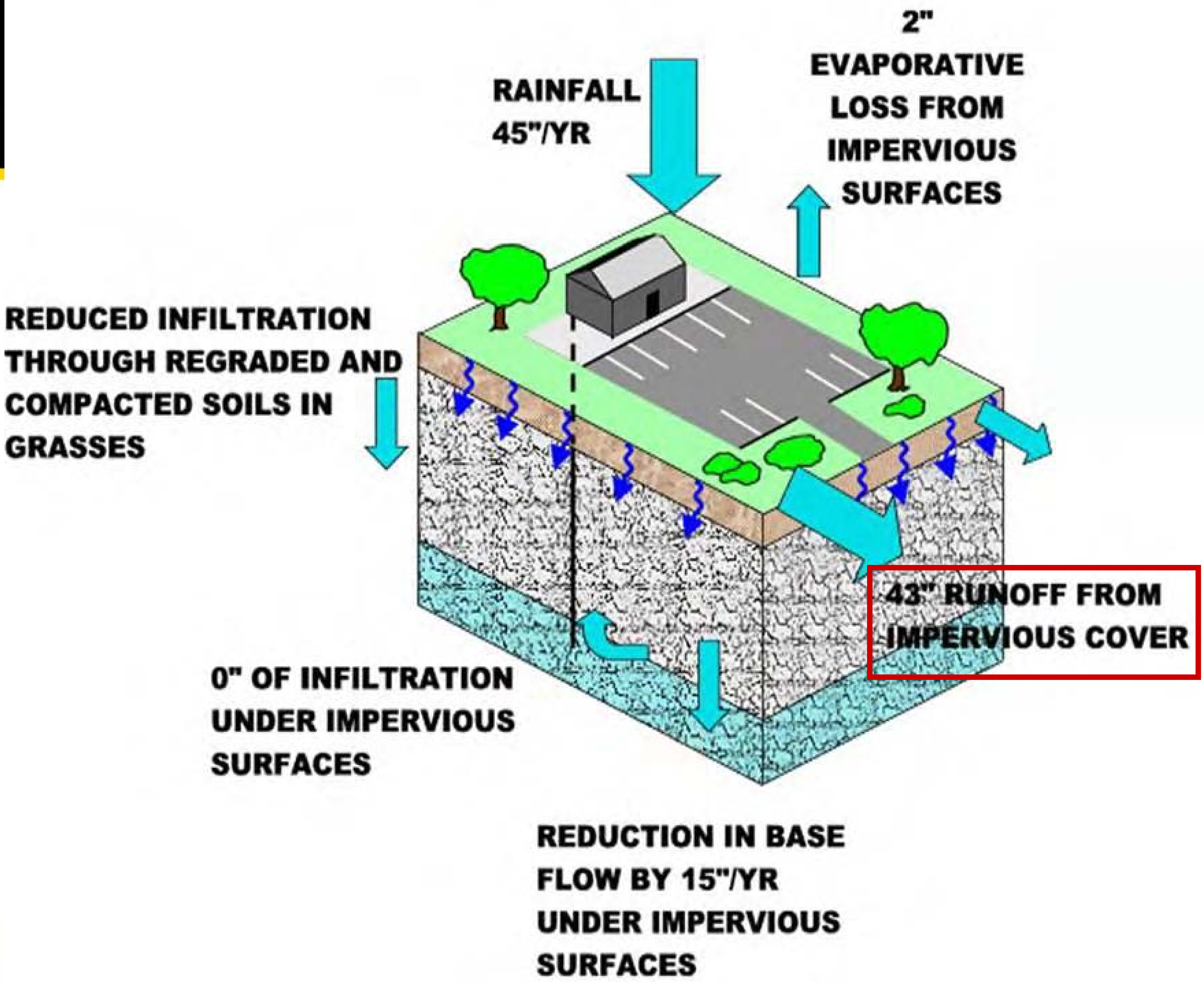
Non-Woven Geotextile

Uncompacted Subgrade






RAINFALL
45"
EVAPO-
TRANSPIRATION
22"
SOIL
FRACTURED
BEDROCK
INFILTRATION
RUNOFF
8"
AQUIFER
BASEFLOW
15" or 1,120
gpd/acre


RAINFALL
45"/YR
2"
EVAPORATIVE
LOSS FROM
IMPERVIOUS
SURFACES
REDUCED INFILTRATION
THROUGH REGRADED AND
COMPACTED SOILS IN
GRASSES
43" RUNOFF FROM
IMPERVIOUS COVER
0" OF INFILTRATION
UNDER IMPERVIOUS
SURFACES
REDUCTION IN BASE
FLOW BY 15"/YR
UNDER IMPERVIOUS
SURFACES

Typical Porous Pavement Installation

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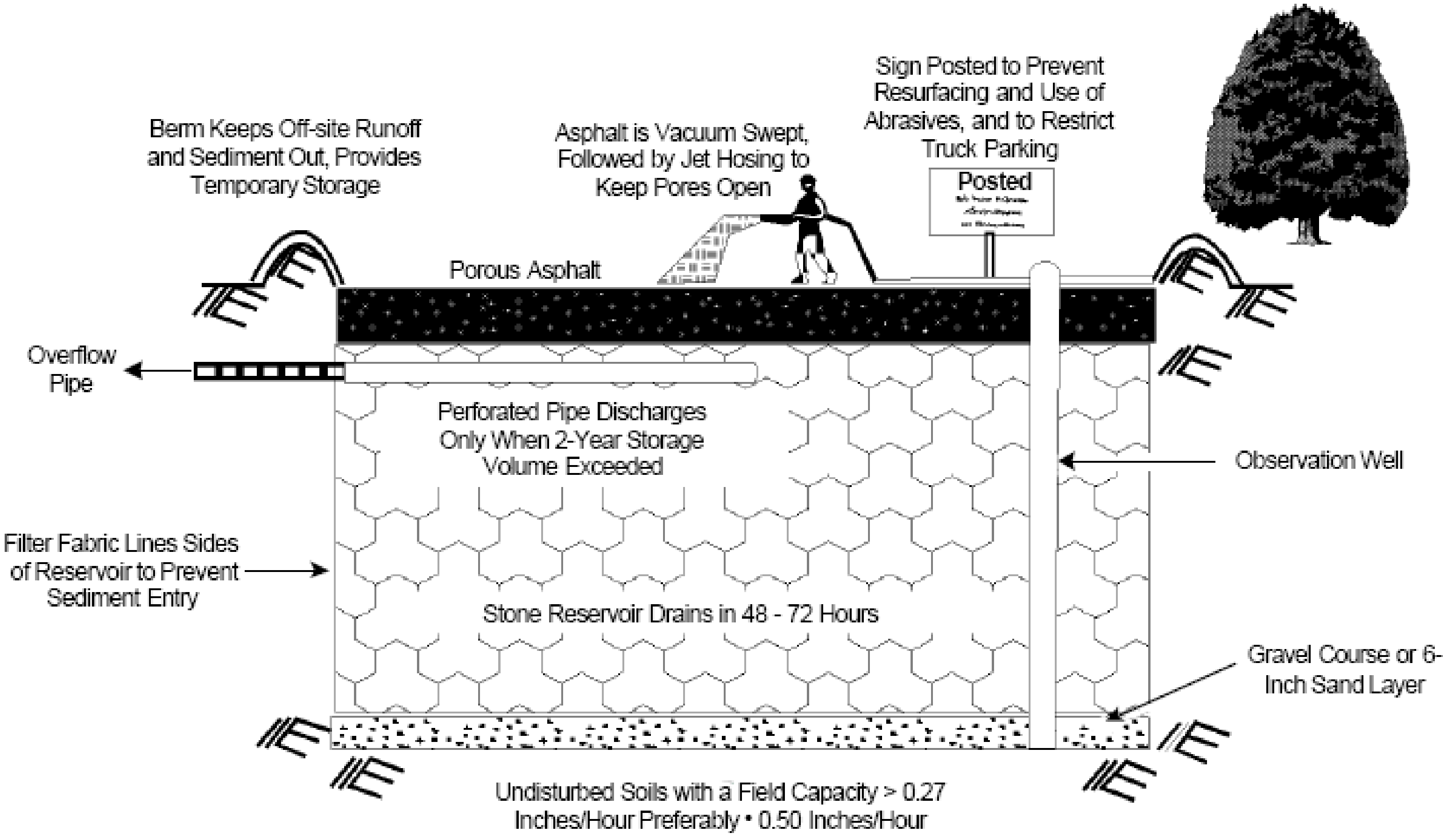

From: *Storm Water Technology Fact Sheet*, USEPA, 09/99

Comparison of Detention vs. Infiltration Design Systems

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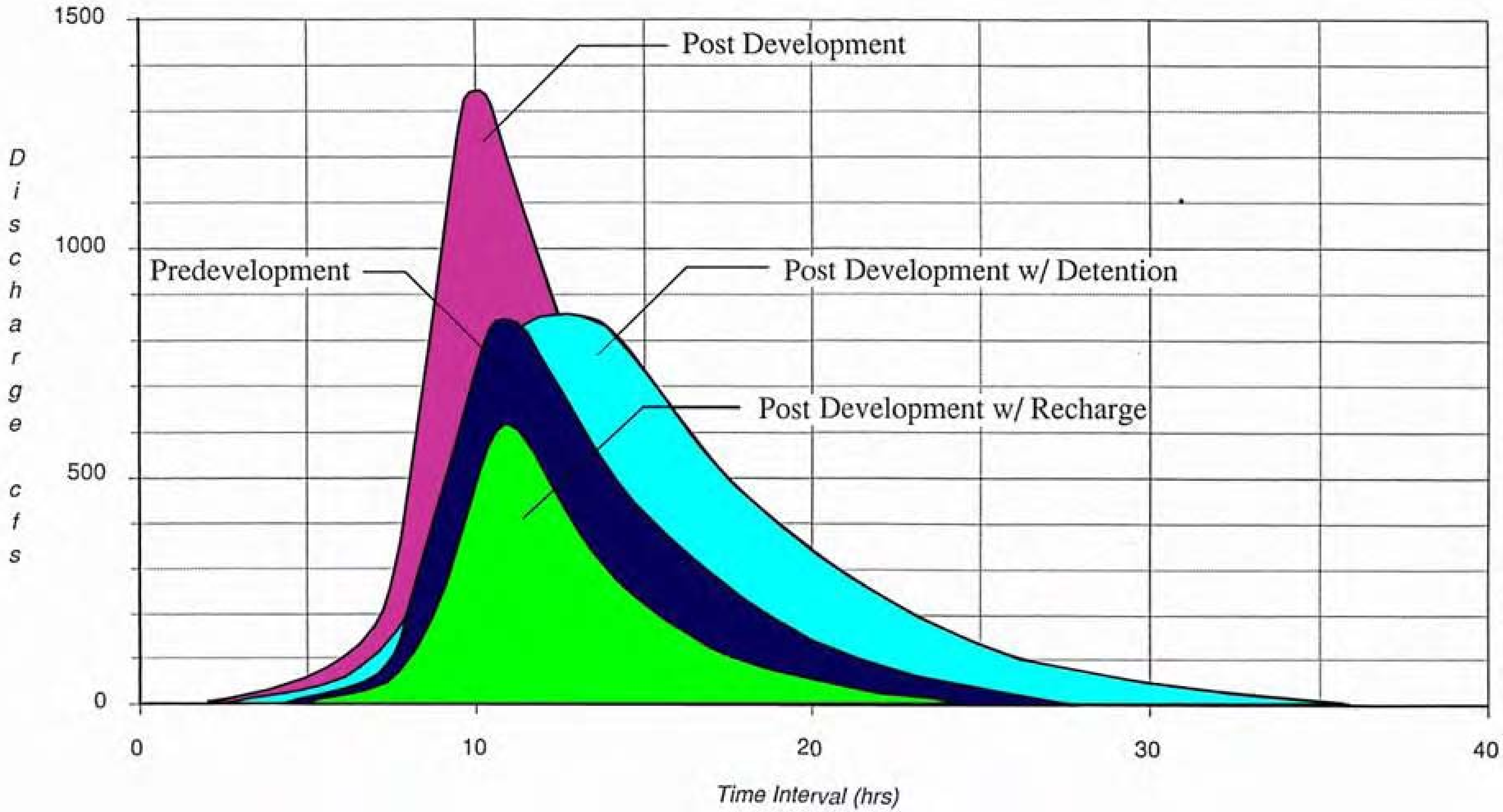
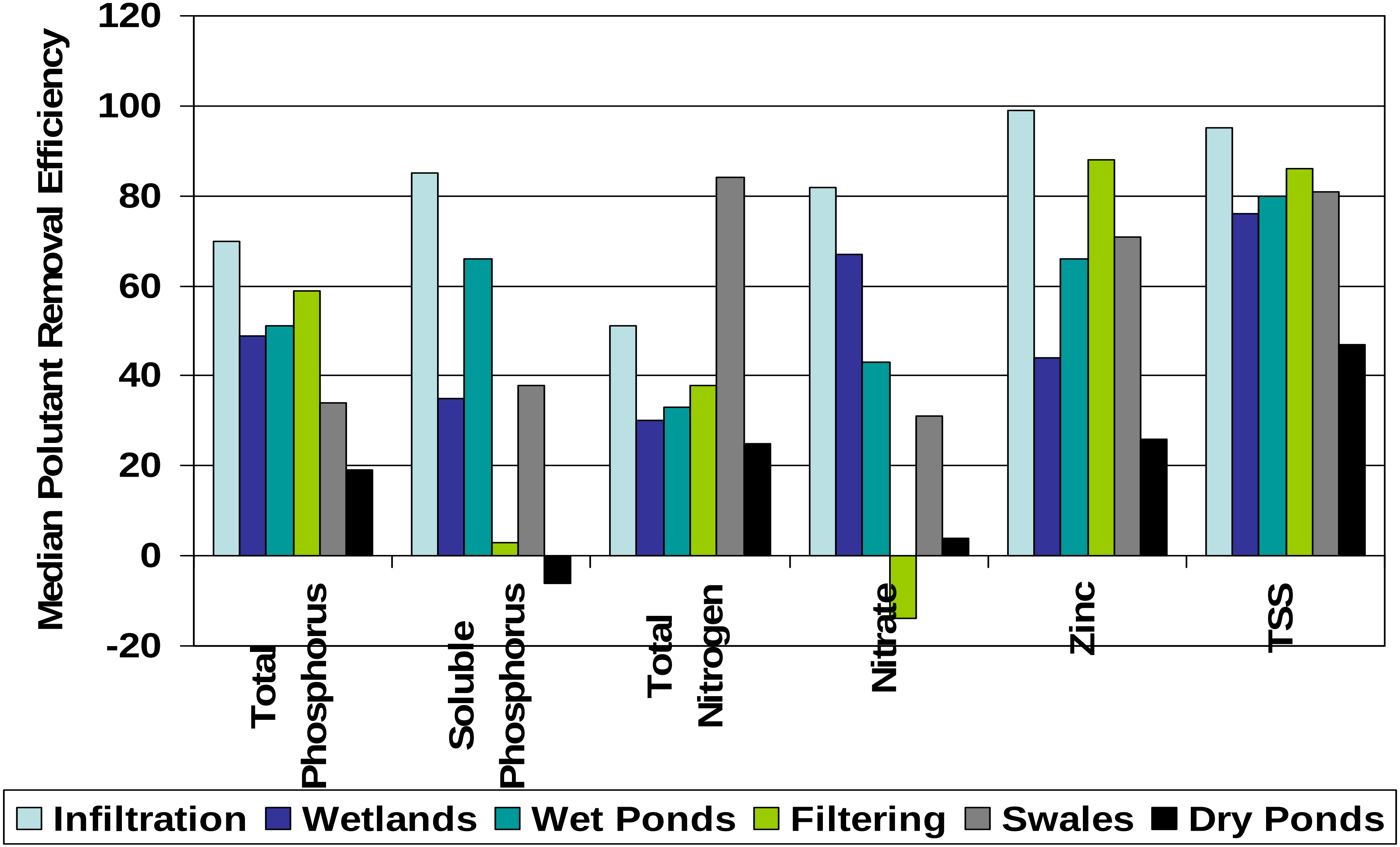


Water Quality



Porous Asphalt Pavements-Background

- Early 1970's
  - USEPA Study, Franklin Institute
  - Pilot projects: Delaware, Pennsylvania, The Woodlands
- Current design approach has been used since 1980
  - Development of geotextiles in 1970's
  - Hundreds of projects built
- Porous surfacing mixtures (PFC, OGFC) have become much more widely used since the early 1990's
  - Modified asphalts, fibers, GTR

Typical Applications

- Lightly vehicle loads
  - Passenger vehicle parking lots
  - Low volume roads (limited truck use)
  - Recreational areas
    - Cartpaths, hike & bike trails
  - Pedestrian walkways
- Roadways?

Roadways

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- Challenges
  - Variable conditions
  - Cuts and fills
  - Slope
  - Soils
  - Designing for heavy vehicles
  - Utilities
- More likely to see the use of porous wearing surfaces or permeable base/subbase instead of porous pavements

Site Conditions

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- Soil permeability/infiltration rate
  - EPA recommends minimum 0.5 in/hr, 3 ft below the bottom of the stone reservoir
    - May consider lower percolation rate (to 0.1 in/hr) depending on site conditions
    - If okay for septic tank dispersion, usually okay for porous pavement
  - Near wetlands, consider using to filter/slow runoff & recharge
- Ideally, 4 ft minimum clearance from the bottom of the system to bedrock or the water table
- Fill – not recommended
- Frost
  - Pavement section should exceed frost depth

Montgomery County, Texas

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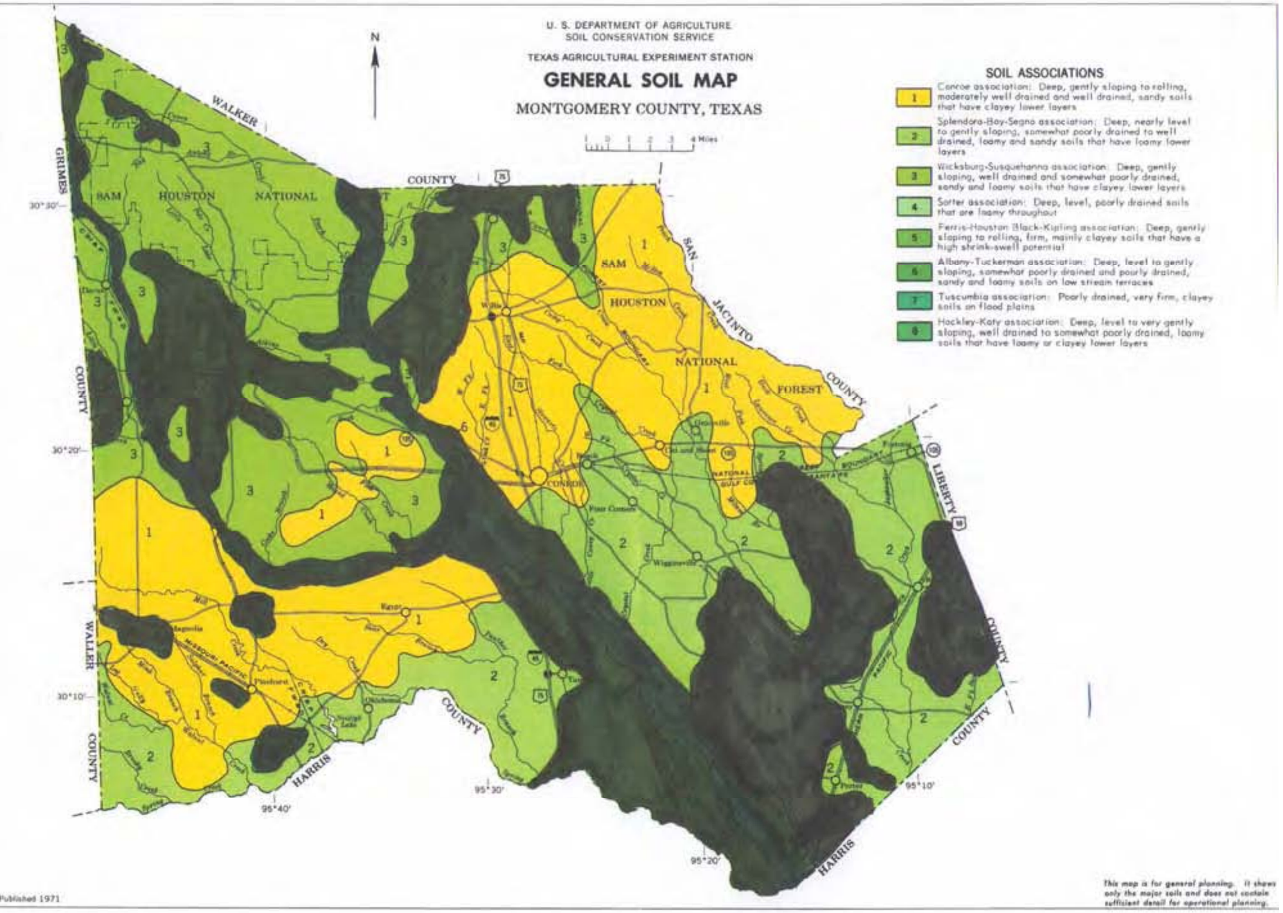

- Black-shaded areas do not appear to be suitable
- ~ 2/3 of soil types appear to be suitable
- Exceptions exist both ways

Oklahoma County, OK
Physical Properties of Soils

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Map symbol and soil name	Depth	Clay	Moist bulk density	Permea-bility (Ksat)	Available water capacity	Linear extensi-bility	Organic matter	Erosion factors Kw	Erosion factors Kf	Erosion factors T	Wind erodi-bility group	Wind erodi-bility index
	In	*Pct*	*g/cc*	*In/hr*	*In/in*	*Pct*	*Pct*					
AhpA:												
Ashport---------------	0-5	27-35	1.30-1.60	0.60-2.00	0.15-0.22	3.0-5.9	1.0-3.0	.32	.32	5	7	38
	5-14	27-35	1.30-1.60	0.60-2.00	0.15-0.22	3.0-5.9	1.0-3.0	.32	.32			
	14-36	18-35	1.40-1.70	0.60-2.00	0.15-0.24	3.0-5.9	0.5-1.0	.37	.37			
	36-96	18-35	1.40-1.70	0.60-2.00	0.15-0.24	3.0-5.9	0.5-1.0	.37	.37			
AmbE:												
Amber-----------------	0-9	10-18	1.30-1.55	0.60-2.00	0.13-0.20	0.0-2.9	0.5-1.0	.37	.37	5	3	86
	9-11	10-18	1.30-1.55	0.60-2.00	0.13-0.20	0.0-2.9	0.5-1.0	.37	.37			
	11-22	10-18	1.30-1.60	0.60-2.00	0.13-0.20	0.0-2.9	0.5-1.0	.37	.37			
	22-38	5-18	1.30-1.60	0.60-2.00	0.13-0.24	0.0-2.9	0.5-1.0	.37	.37			
	38-84	5-35	1.30-1.70	0.00-2.00	0.13-0.22	0.0-2.9	0.0-0.8	.37	.37			
AshA:												
Asher-----------------	0-8	27-40	1.30-1.60	0.06-0.20	0.18-0.22	3.0-5.9	1.0-3.0	.37	.37	5	7	38
	8-14	27-40	1.30-1.60	0.06-0.20	0.18-0.22	3.0-5.9	1.0-3.0	.37	.37			
	14-31	27-40	1.45-1.70	0.06-0.20	0.18-0.22	3.0-5.9	0.5-2.0	.37	.37			
	31-88	8-18	1.40-1.65	0.60-2.00	0.07-0.24	0.0-2.9	0.0-1.0	.37	.37			

Soils Investigation

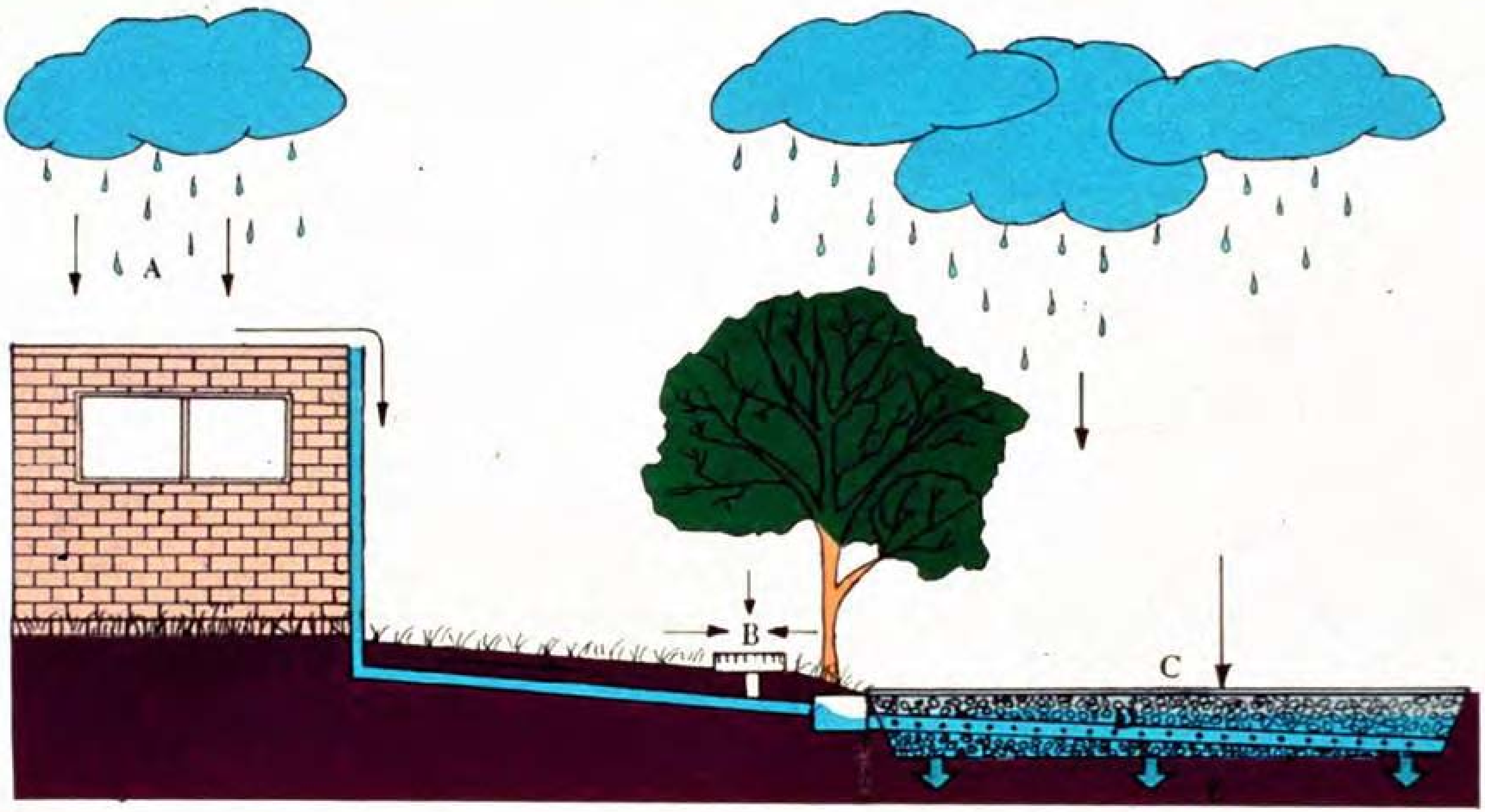
- Excavate 6-8 ft deep test pits/trenches
  - Percolation tests
  - Observe soil horizons
- Drilling
  - Depth to bedrock/claypan
  - Depth to water table

Design Considerations

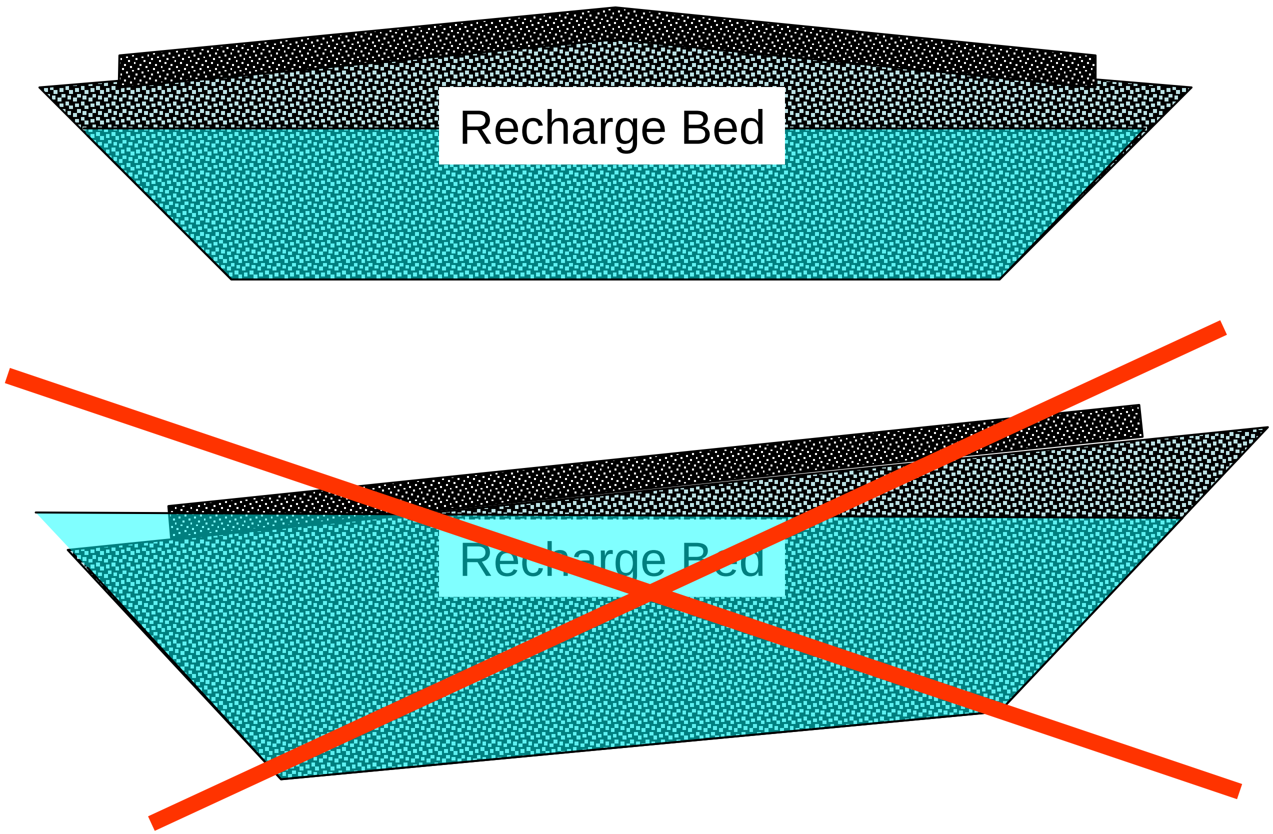
- Slope – as flat as possible
  - Terrace where necessary
  - Use conventional HMA for steep slopes
- Spread infiltration over largest area possible
  - 5:1 ratio: Impervious area: Infiltration area
- Setbacks:
  - Building foundations:
    - 10 ft downgradient
    - 100 ft upgradient
  - Water supply wells: >100 ft

Terraced Parking Lots

Draining Rooftop to Parking Area



Bottom Must Be Flat



Design

- Rainfall
  - Typical design event: 6 month/24 hr storm
    - 1 yr, 24 hr intensity ~ 4 in/hr
  - Conservative design event: 25 year/24 hr storm
    - Intensities range from 1.4 to 15 in./24 hr
    - ~9-10.5 in/24 hr in SE Texas
  - 24 hour drainage time (rec'd by USEPA)
- Meet local & state wastewater mitigation requirements

25-year, 24 hour Rainfall

from National Climatic Data Center

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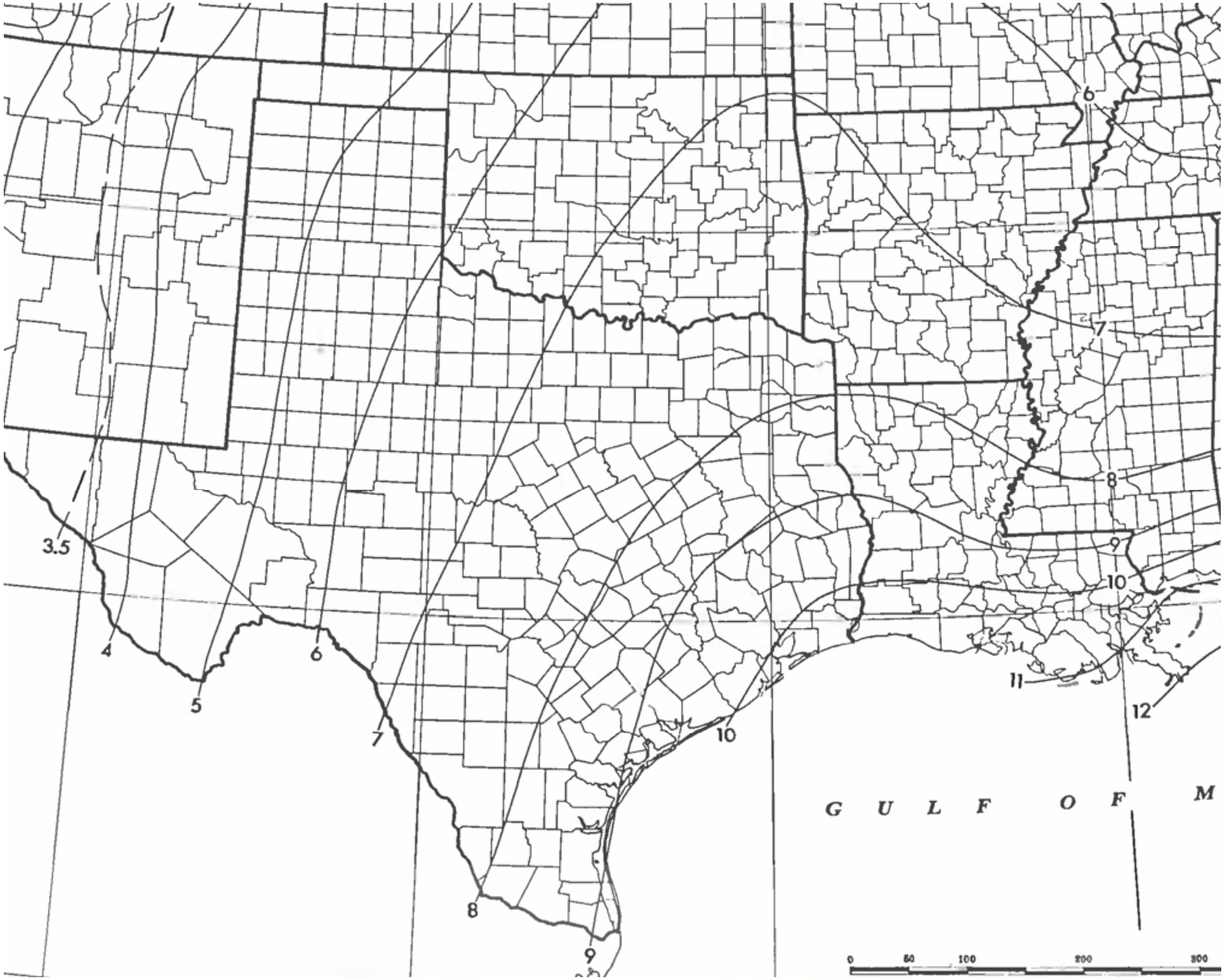


http://lwf.ncdc.noaa.gov/oa/documentlibrary/rainfall.html#atlas14

www.asphaltinstitute.org

Materials Requirements

Reservoir: (unbound crushed stone):

- AASHTO #2 (large aggregate)
- AASHTO #5 (smaller aggregate)
  - TxDOT Item 302, Grades 1 or 2

Choke Stone:

- AASHTO Size 7, 78
- TxDOT Item 302, Grade 4, 4S or 5 (cover stone for chip seal)

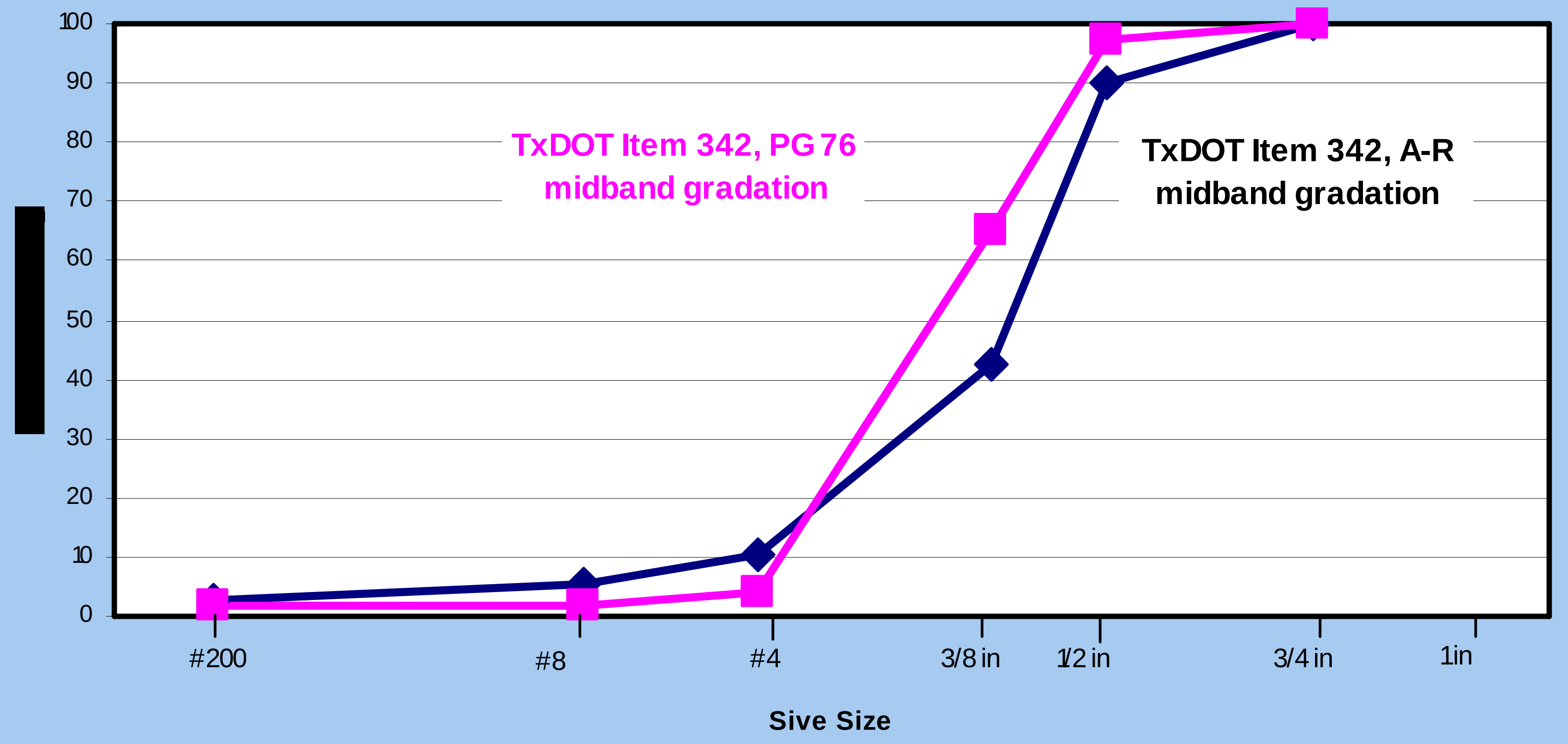
Drainable ATB: (streets, walkways, cartpaths)

- TxDOT Special Specification Item 3077, "Drainable Asphalt Treated Base"

TxDOT Item 342, Permeable Friction Course

- Lab Molded Density: 78.0 - 82.0%
- Binder Content 6.0 - 6.5%
- PG 76-22 + Fibers
  - 5.5 - 7.0% asphalt binder (polymer modified)
  - 0.2 - 0.5% cellulose fibers
  - ≥ 1% hydrated lime
- Asphalt-Rubber
  - 8.0 - 10.0% asphalt-rubber (min. 15% CRM)
  - Fibers, lime not used

Typical Porous HMA Surface Gradations-TxDOT Item 342



Construction Practices

- Build porous pavement last
  - Protect from construction debris
  - Protect from soil laden runoff
- Avoid compacting the subgrade
  - Protect site from heavy equipment
  - When necessary, use tracked or high flotation tires
- Excavate to subgrade
- Place filter fabric
  - Some have placed a sand bedding/leveling course before

Construction Practices

- Place reservoir course 1.5 to 3 in. stone (min. 95% with two fractured faces)
- Place 1-2 in layer of ½ in stone to stabilize the surface of the reservoir course
- Place porous asphalt course (2 to 4 in.) usually rolled with 2-3 passes with 10 ton steel-wheeled roller operated in STATIC mode
  - Consider requiring the use of a tracked paver

Construction Practices

- Restrict traffic for 24 hrs.
  - May not be as important when using modified asphalt binders
- Protect porous pavement from contamination
  - Runoff sediment
  - Construction debris/tracking
  - Keep sediment controls in place until after vegetation is established or areas are well-mulched

Maintenance

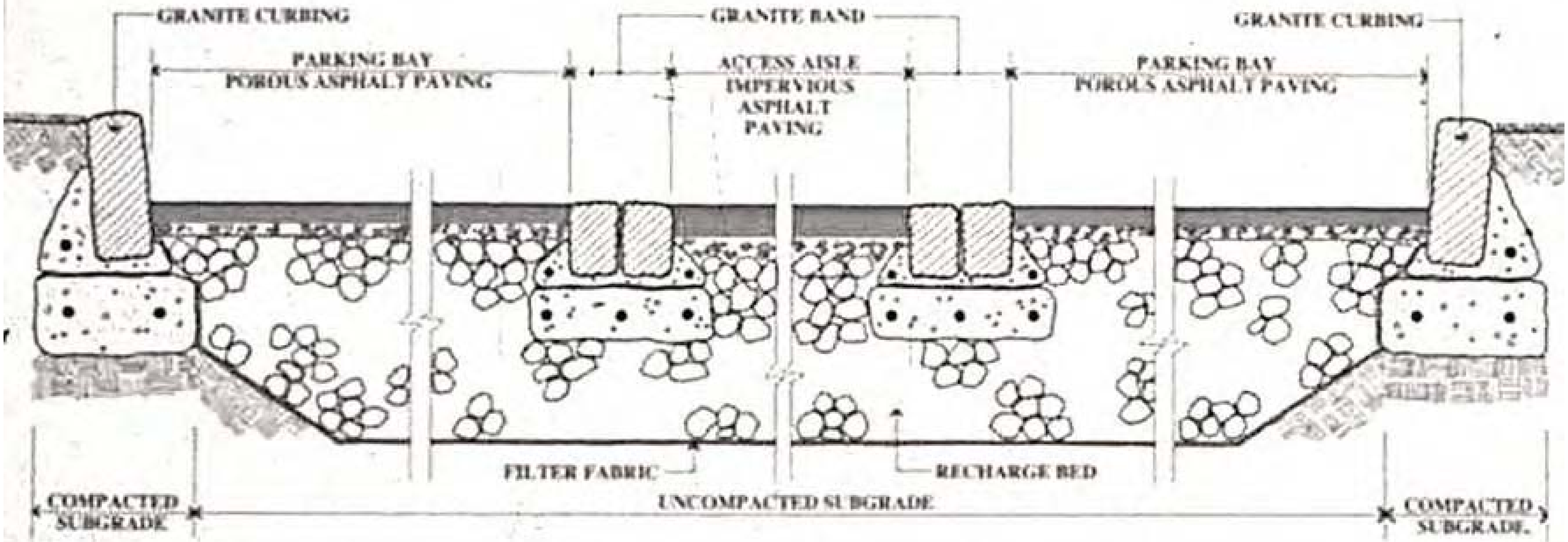
- Sign for maintenance and landscaping personnel
- Do not sand or ash for snow or ice, liquid de-icing compounds may be used
- Inspect annually
- Pavement surface may be periodically flushed or power-washed, or vacuumed
- Damaged pavement (<10% area) can be repaired using conventional HMA

Cost

- Pavement structure is more expensive than a traditional parking lot, BUT
- Increased costs may be offset by reduced drainage costs
  - Initially - reduce or eliminate need for separate detention basin
  - Future – reduce mowing/landscape maintenance costs, no need for pesticide/mosquito control

Morris Arboretum
Philadelphia, PA-1984

Diagram of infiltration bed at Morris Arboretum

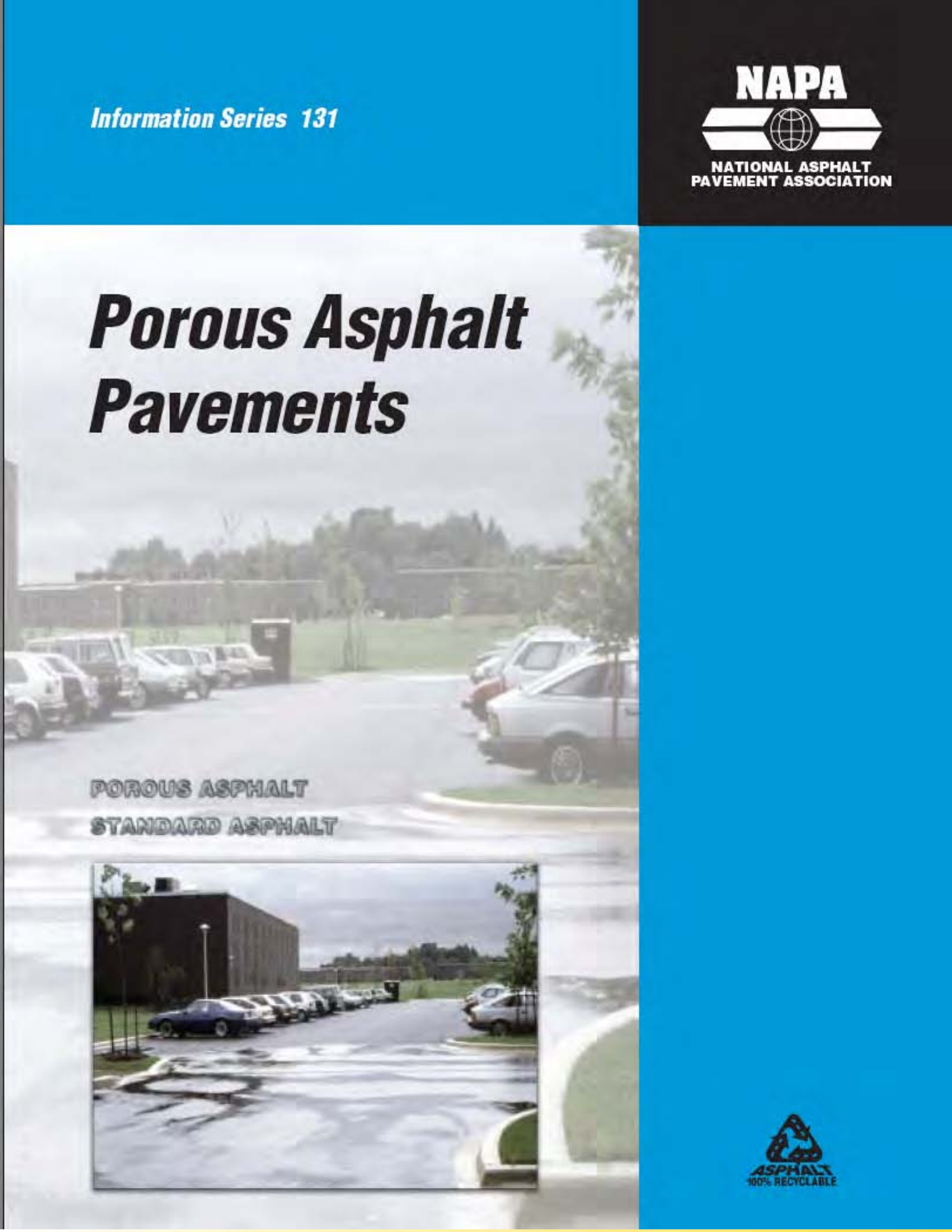


SECTION THROUGH PARKING LOT AND STORMWATER RECHARGE BED

Shared Medical Systems
Malvern, PA-1982

Conclusions

- Porous pavements may offer an alternative to conventional stormwater mitigation
- Site conditions must be right
- Need to protect pavement from contamination during and after construction
- Properly designed and constructed will last more than 20 years



Resources, References

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- NAPA IS-131, *Porous Asphalt Pavements*
- EPA