Marvin Traylor

PERPETUAL PAVEMENT

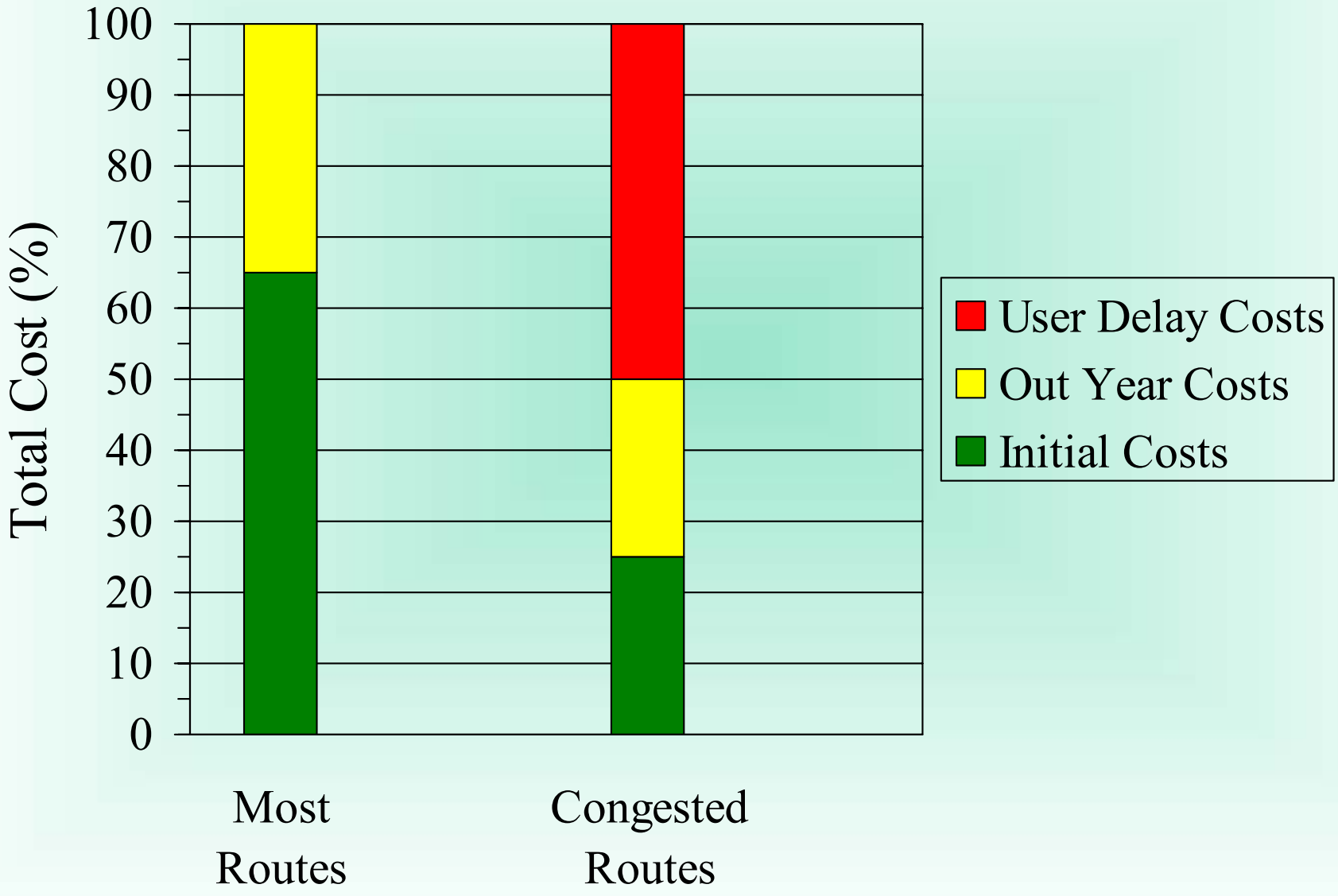
And Selected Short Subjects

A Modern Life Cycle Cost Analysis

- Initial Costs
- Out Year Costs
- User Delay Costs

Score Card

	PCC	HMA
Initial Costs		
Out Year Costs		
User Delay Costs		


Total Cost (%)
100
90
80
70
60
50
40
30
20
10
0
Most Routes
Congested Routes
User Delay Costs
Out Year Costs
Initial Costs

State	% of Pavements Constructed with Asphalt	State	% of Pavements Constructed with Asphalt
1. Alaska	100%	26. Tennessee	72%
2. Vermont	99%	27. Texas	67%
3. Maine	98%	28. Arkansas	64%
4. Montana	95%	29. South Carolina	63%
5. New Hampshire	94%	30. California	59%
6. New Mexico	93%	31. Oklahoma	55%
7. Arizona	93%	32. Kentucky	52%
8. Florida	92%	33. West Virginia	52%
9. Hawaii	92%	34. Mississippi	50%
10. Idaho	92%	35. South Dakota	49%
11. Nevada	91%	36. Nebraska	42%
12. Utah	91%	37. New Jersey	40%
13. Maryland	91%	38. Minnesota	37%
14. Alabama	90%	39. Connecticut	31%
15. Oregon	90%	40. Ohio	29%
16. Wyoming	89%	41. Wisconsin	28%
17. Massachusetts	88%	42. Louisiana	25%
18. Rhode Island	85%	43. New York	24%
19. Washington	85%	44. Pennsylvania	18%
20. Georgia	84%	45. Michigan	18%
21. Colorado	84%	46. Indiana	17%
22. North Carolina	81%	47. Missouri	12%
23. Kansas	79%	48. Iowa	9%
24. Virginia	78%	*49. Illinois* ****	*3%*
25. North Dakota	74%	50. Delaware	1%

Source: The Federal Highway Administration; Highway Statistics 1997; Table HM-31; Page V-18

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7. Arizona	93%	32. Kentucky	52%
8. Florida	92%	33. West Virginia	52%
9. Hawaii	92%	34. Mississippi	50%
10. Idaho	92%	35. South Dakota	49%
11. Nevada	91%	36. Nebraska	42%
12. Utah	91%	37. New Jersey	40%
13. Maryland	91%	38. Minnesota	37%
14. Alabama	90%	39. Connecticut	31%
15. Oregon	90%	40. Ohio	29%
16. Wyoming	89%	41. Wisconsin	28%
17. Massachusetts	88%	42. Louisiana	25%
18. Rhode Island	85%	43. New York	24%
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9. Hawaii	92%	34. Mississippi	50%
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11. Nevada	91%	36. Nebraska	42%
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13. Maryland	91%	38. Minnesota	37%
14. Alabama	90%	39. Connecticut	31%
15. Oregon	90%	40. Ohio	29%
16. Wyoming	89%	41. Wisconsin	28%
17. Massachusetts	88%	42. Louisiana	25%
18. Rhode Island	85%	43. New York	24%
19. Washington	85%	44. Pennsylvania	18%
20. Georgia	84%	45. Michigan	18%
21. Colorado	84%	46. Indiana	17%
22. North Carolina	81%	47. Missouri	12%
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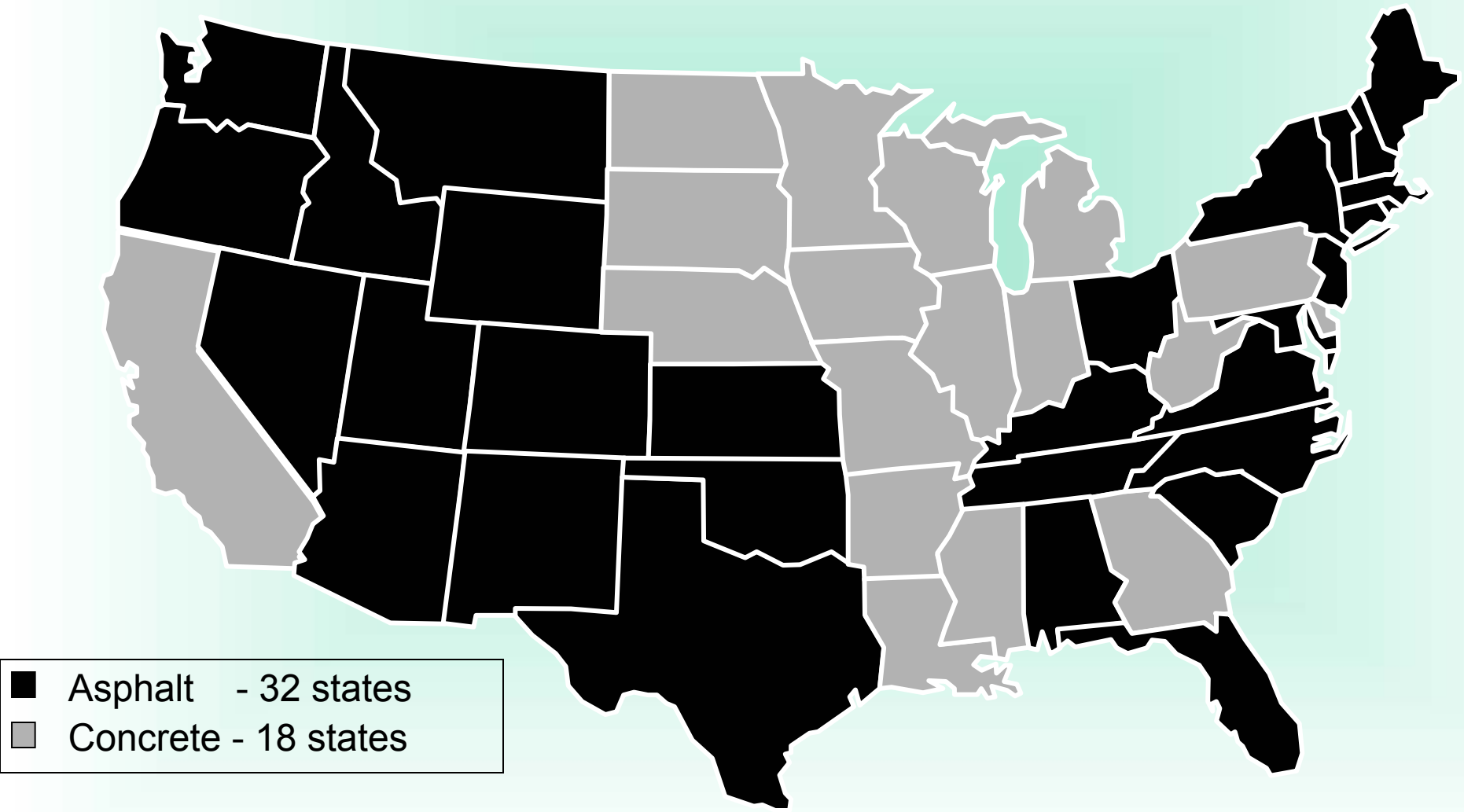
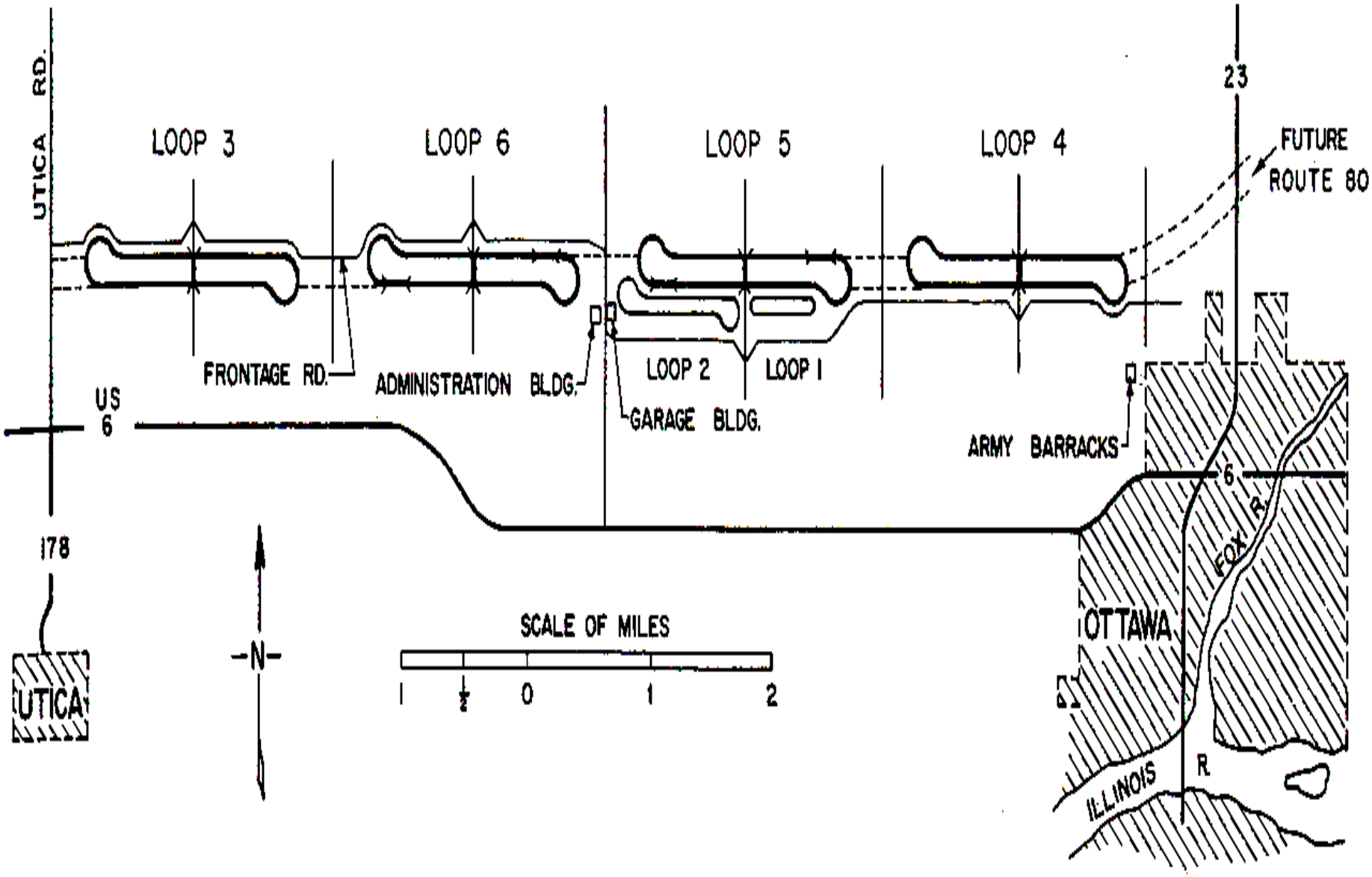
Source: The Federal Highway Administration; Highway Statistics 1997; Table HM-31; Page V-18

Breakout by Majority Pavement Type – Interstate System

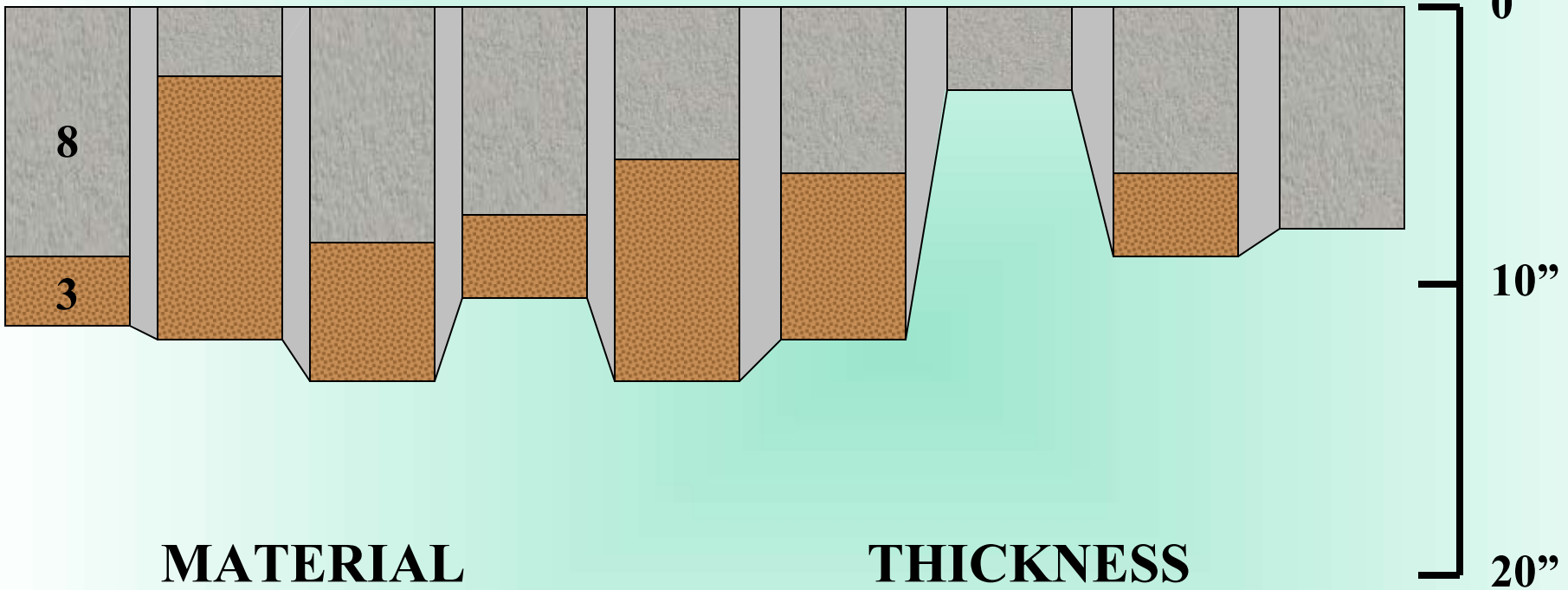


Data source: US DOT, FHWA, Highway Statistics, Section V, Type of Surface, Interstate – Rural and Urban

"AASHO Road Test"

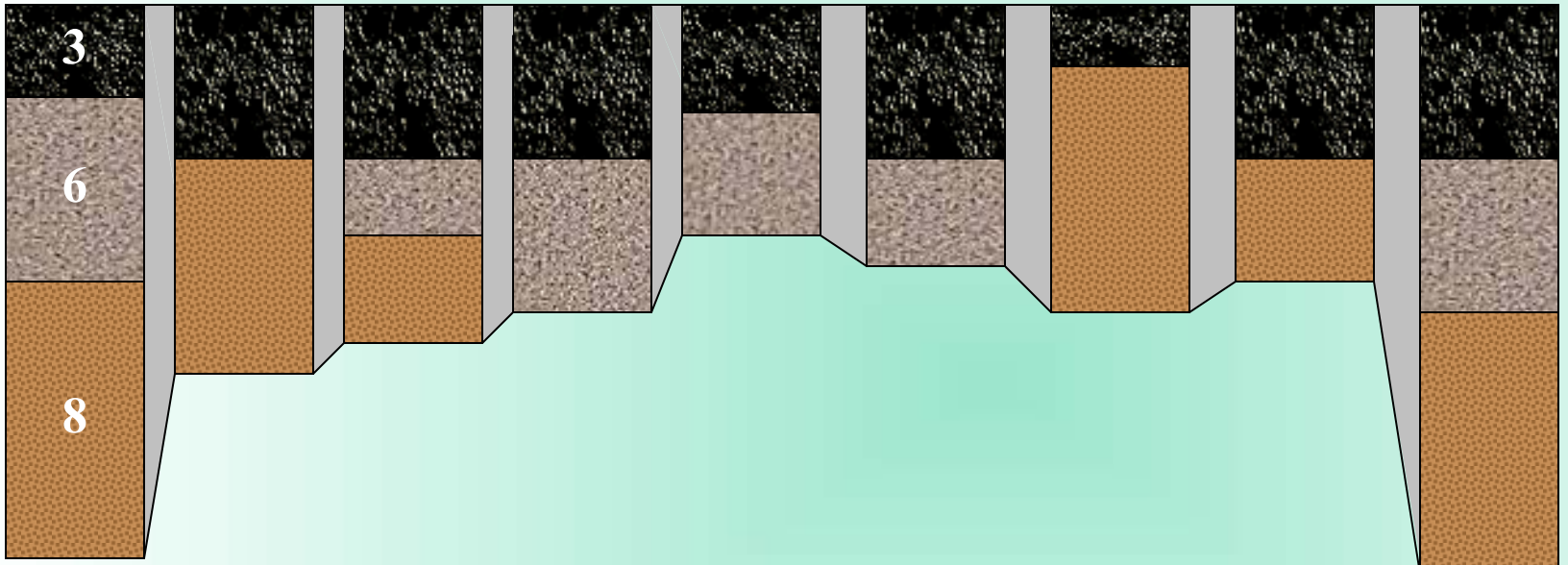


Rigid Profile



MATERIAL	THICKNESS
PCC	3½ 5 6½ 8 9½ 11 12½
SANDY GRAVEL subbase	0 3 6 9

Flexible Profile



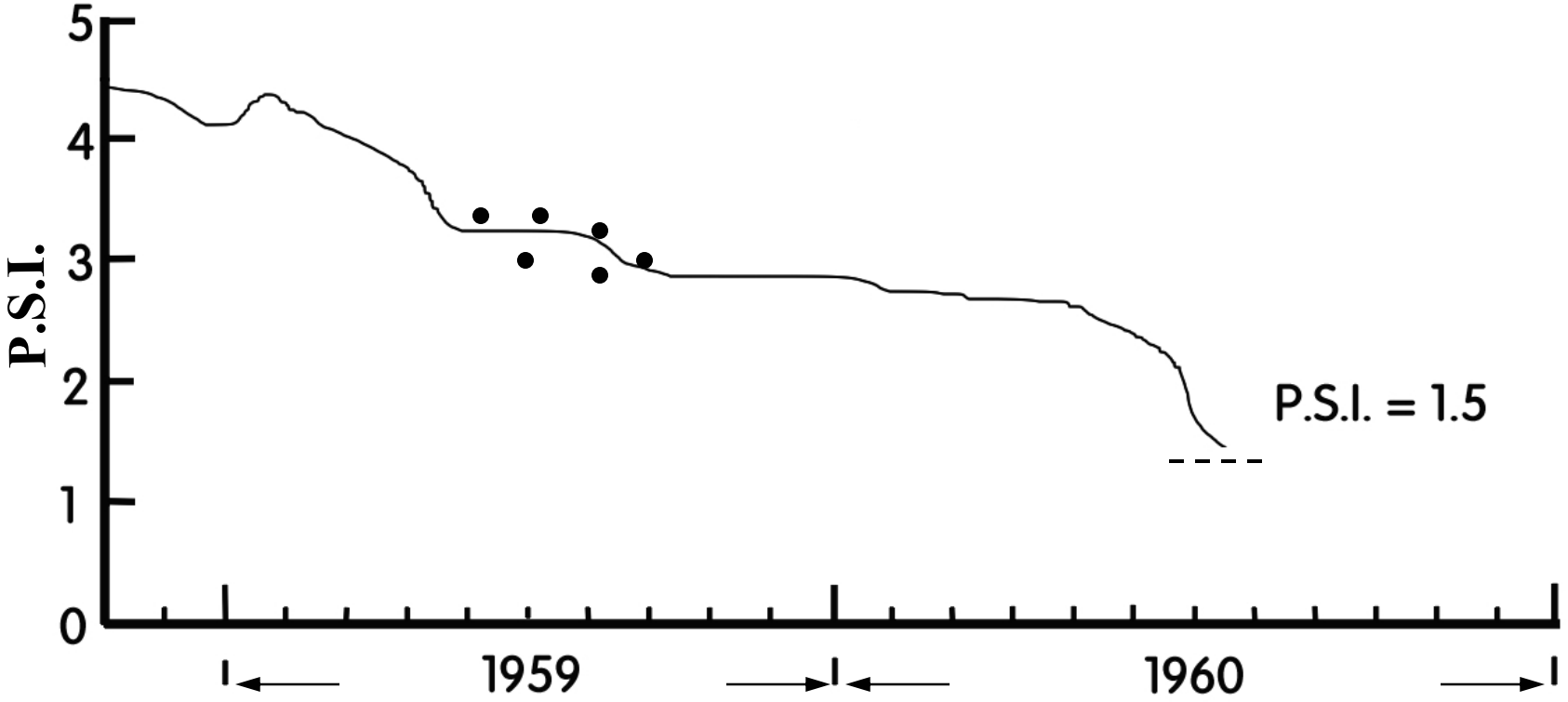
MATERIAL	THICKNESS				
ASPHALT surface	2	3	4	5	6
CRUSHED STONE base	0	3	6	9	
SANDY GRAVEL subbase	0	4	8	12	16

Loading

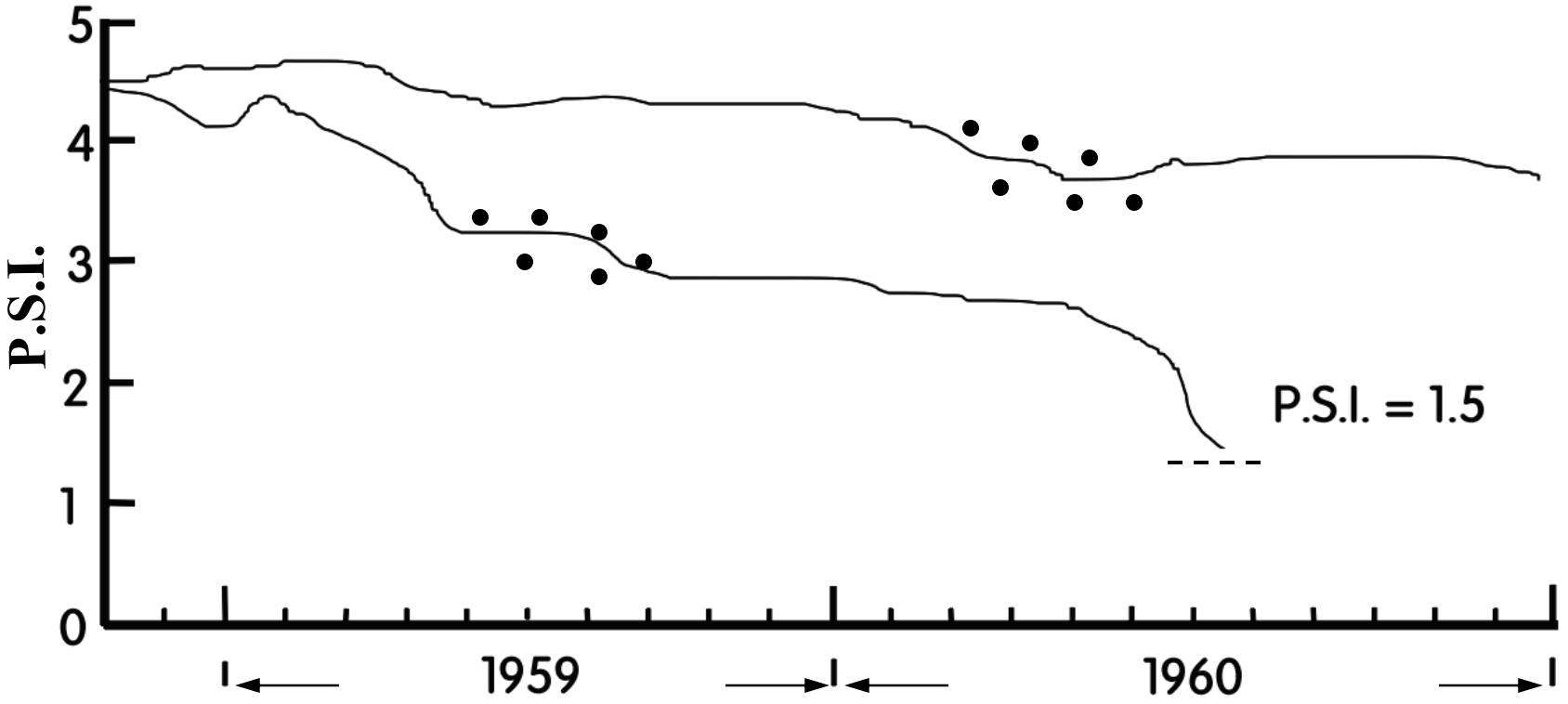
LOOP						
3	4	12	12	6	24	24
4	6	18	18	9	32	32
5	6	22	22	9	40	40
6	9	30	30	12	48	48

2 Years = 1.1 Million Axle Loads

Pavement Performance



Pavement Performance

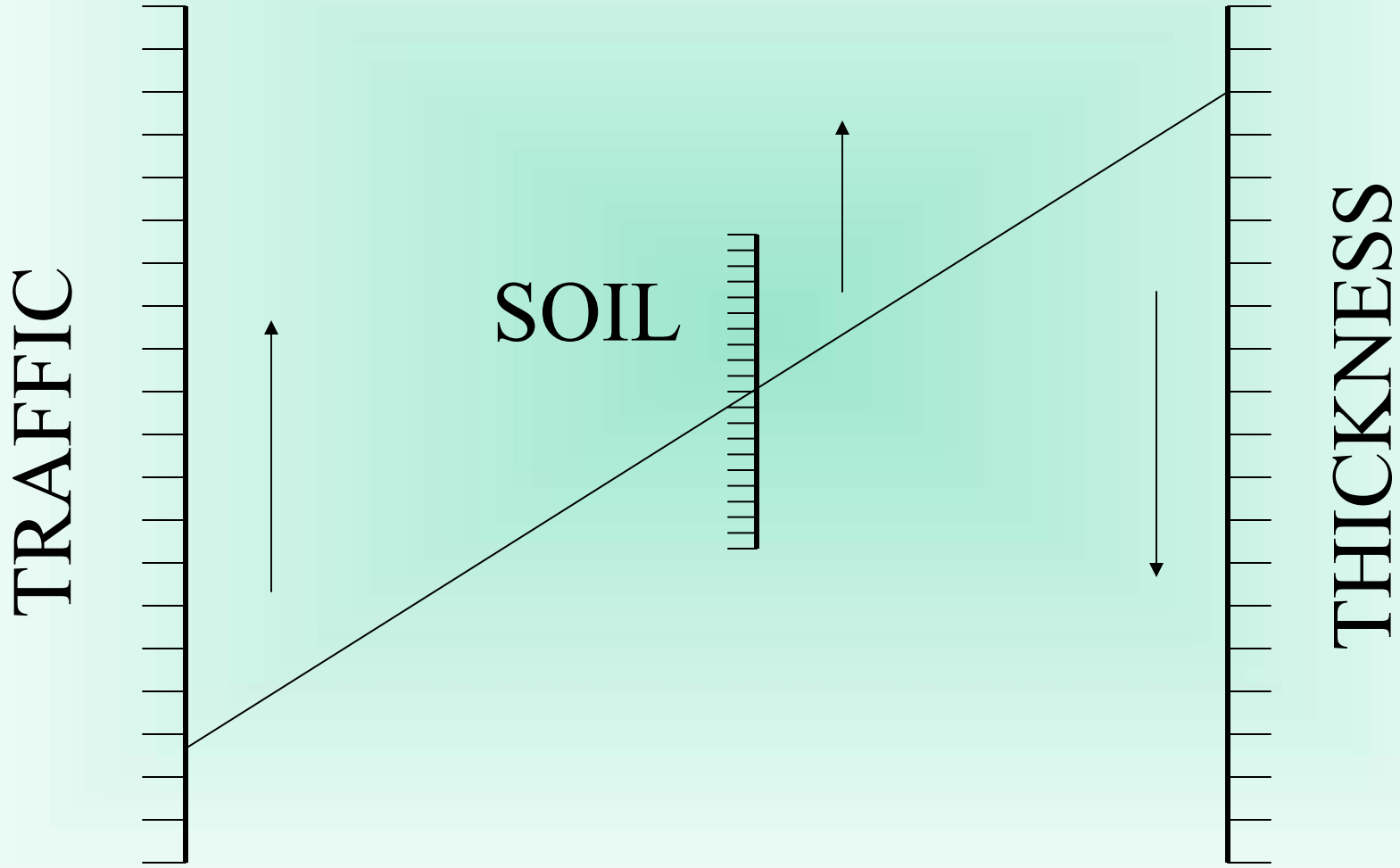


Rigid Findings

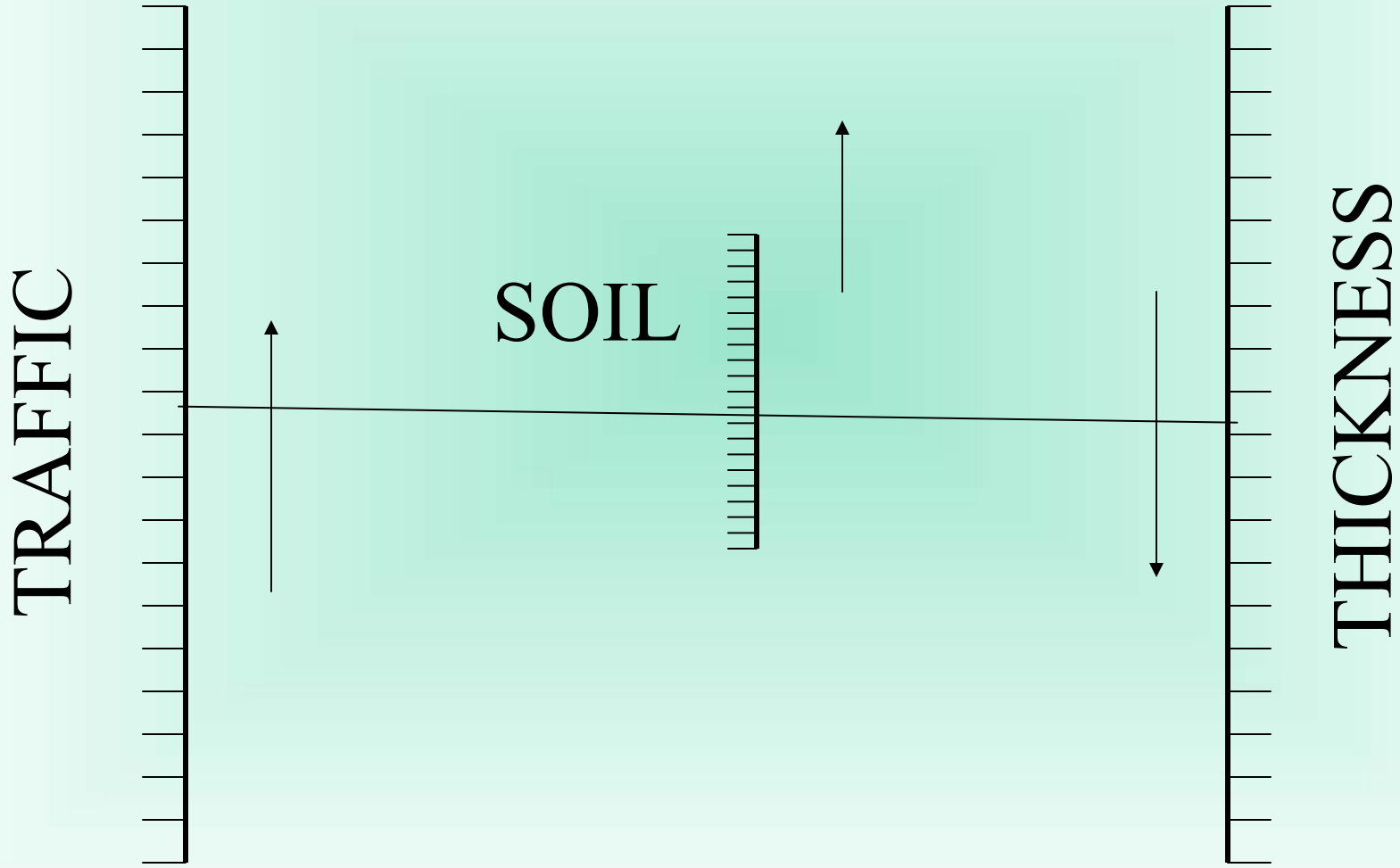
Subbase Necessary to

Prevent Pumping

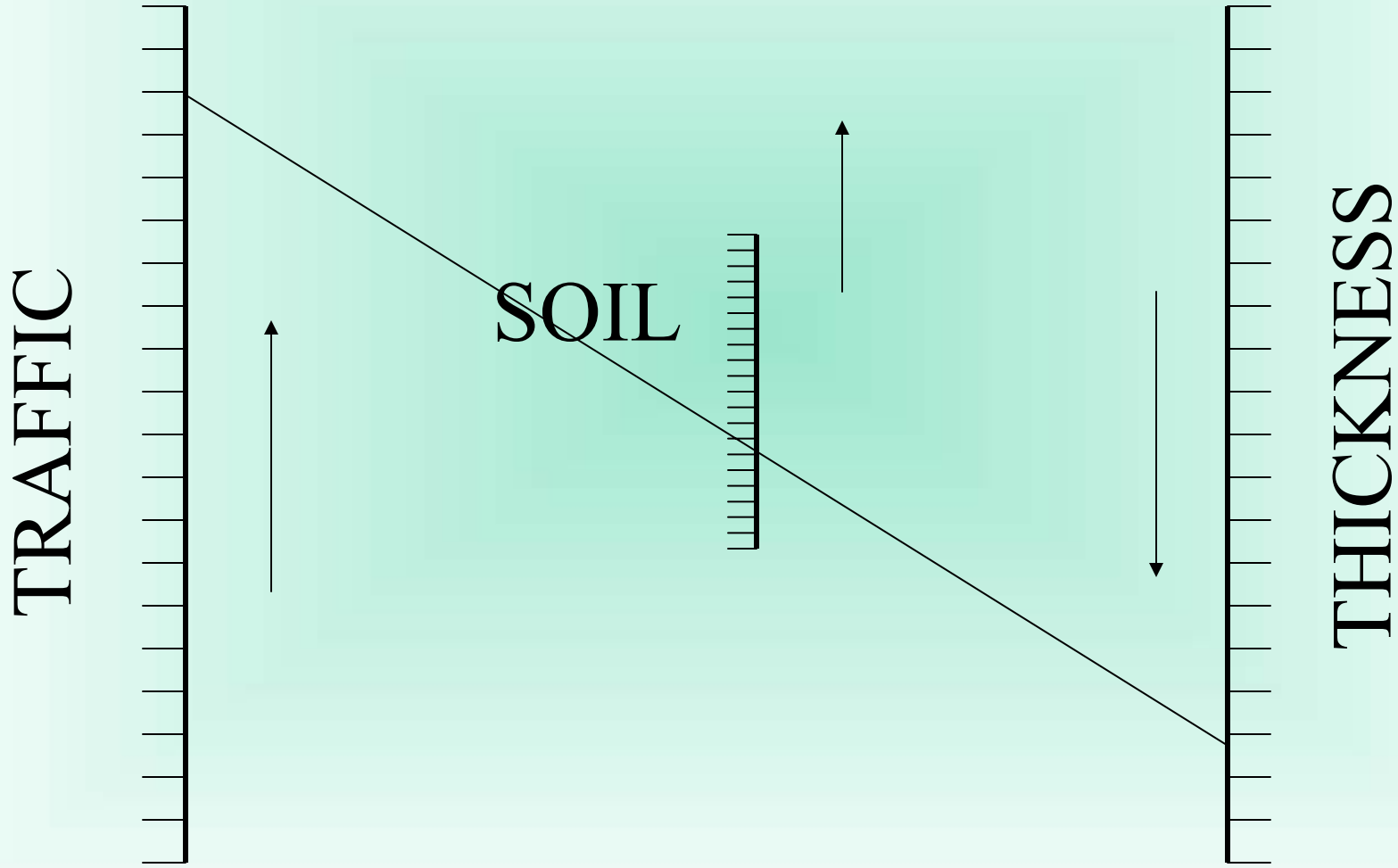
Rigid Nomograph



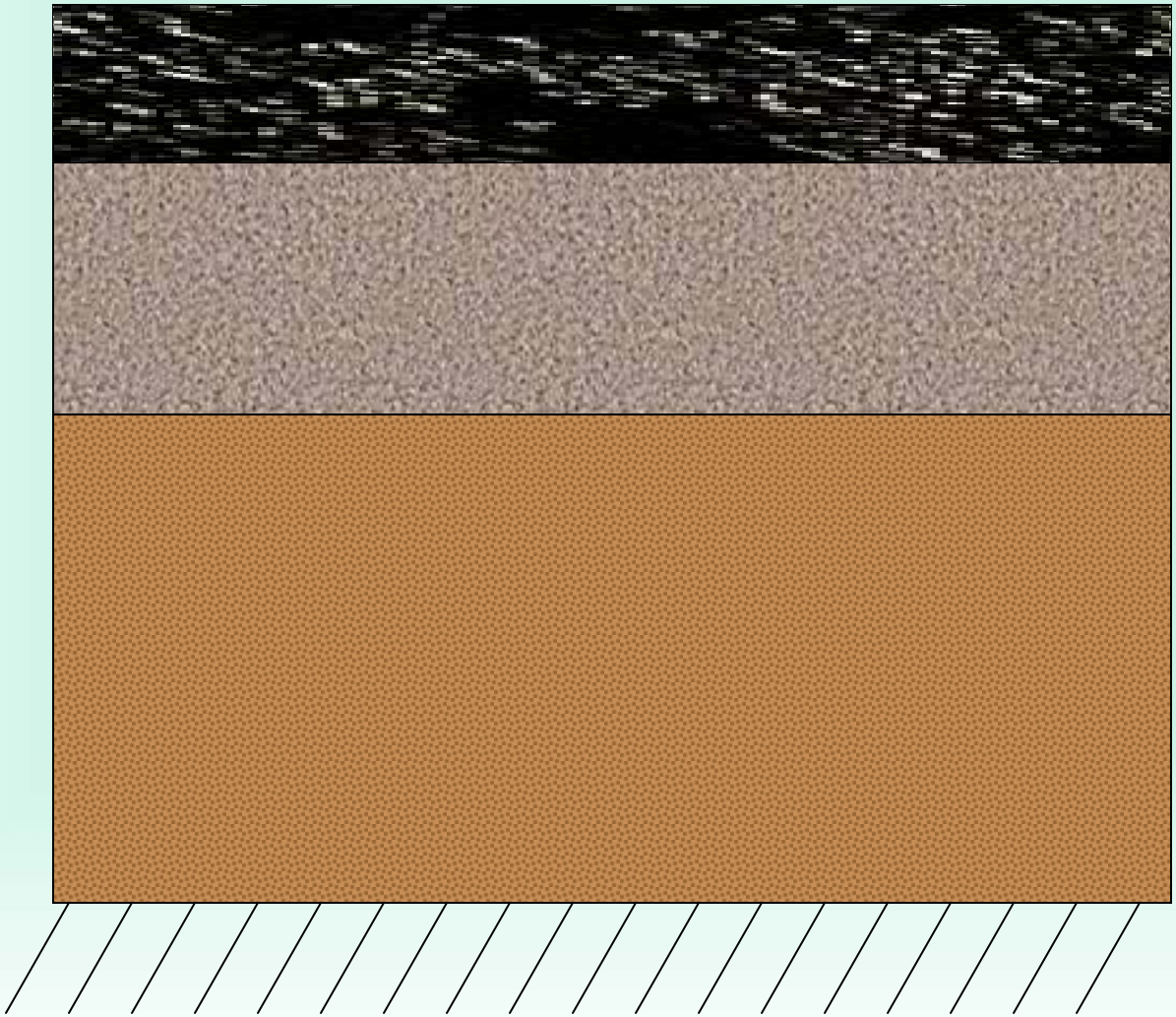
Rigid Nomograph



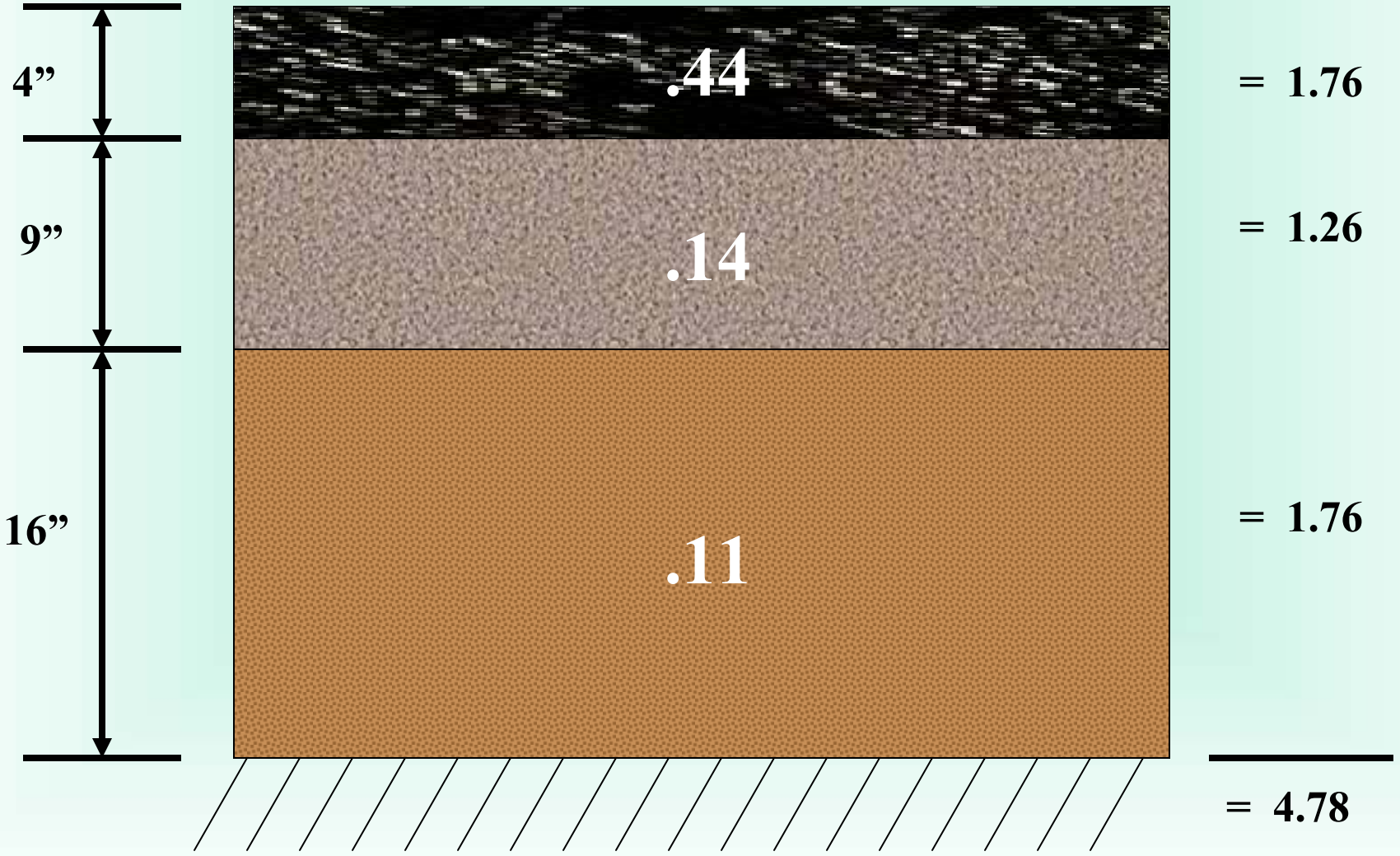
Rigid Nomograph



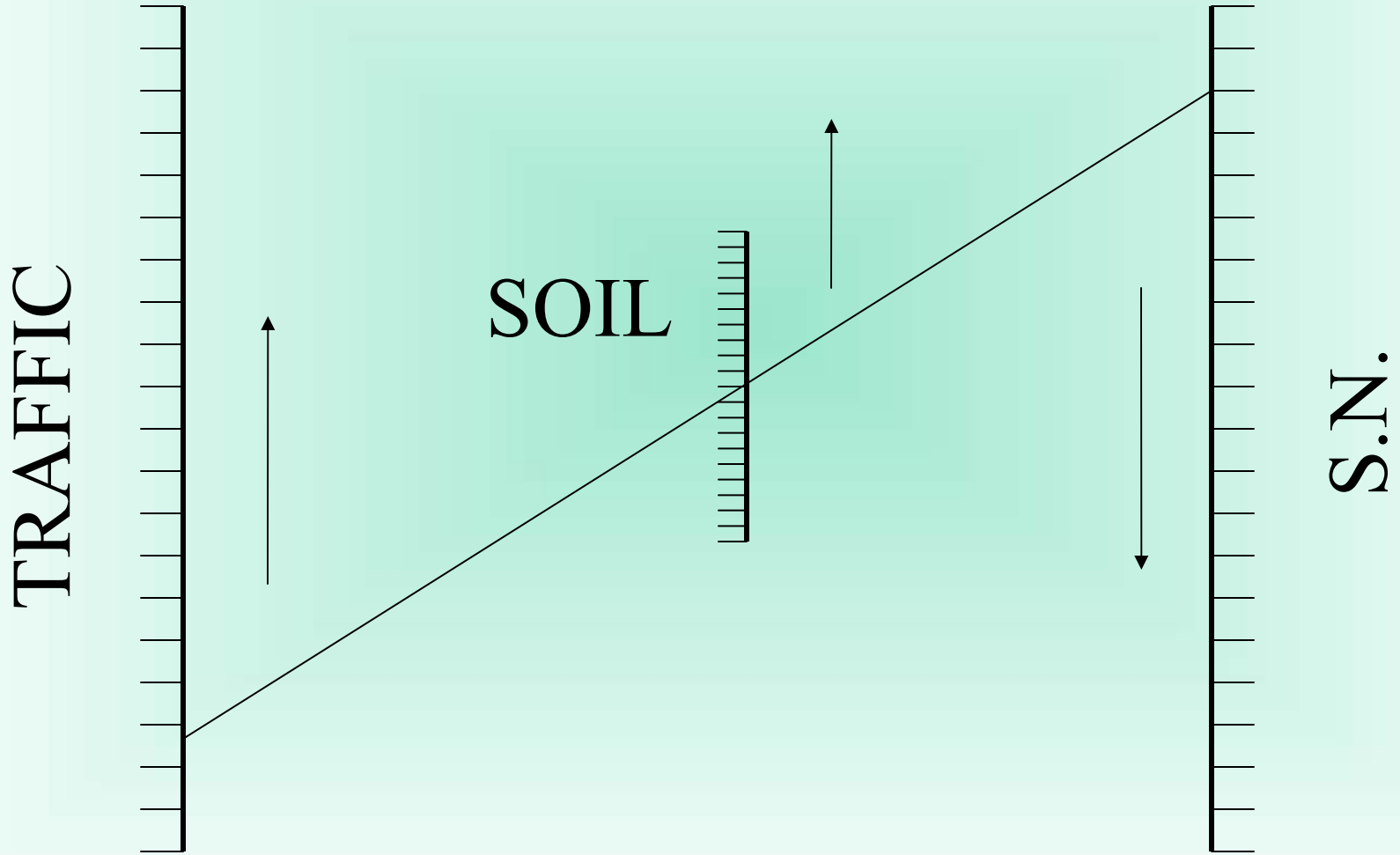
Flexible Findings



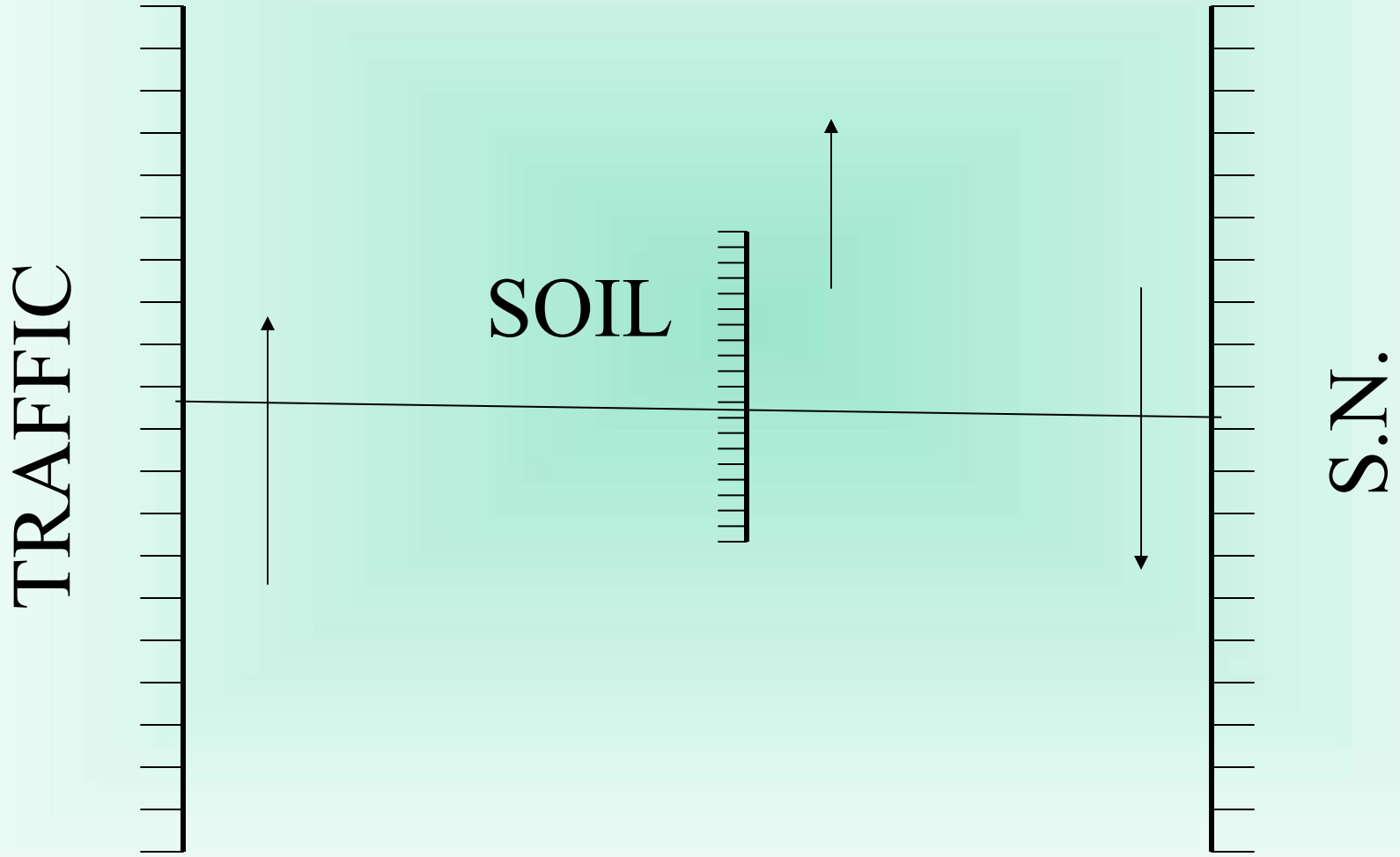
Structural Number Concept



Flexible Nomograph



Flexible Nomograph



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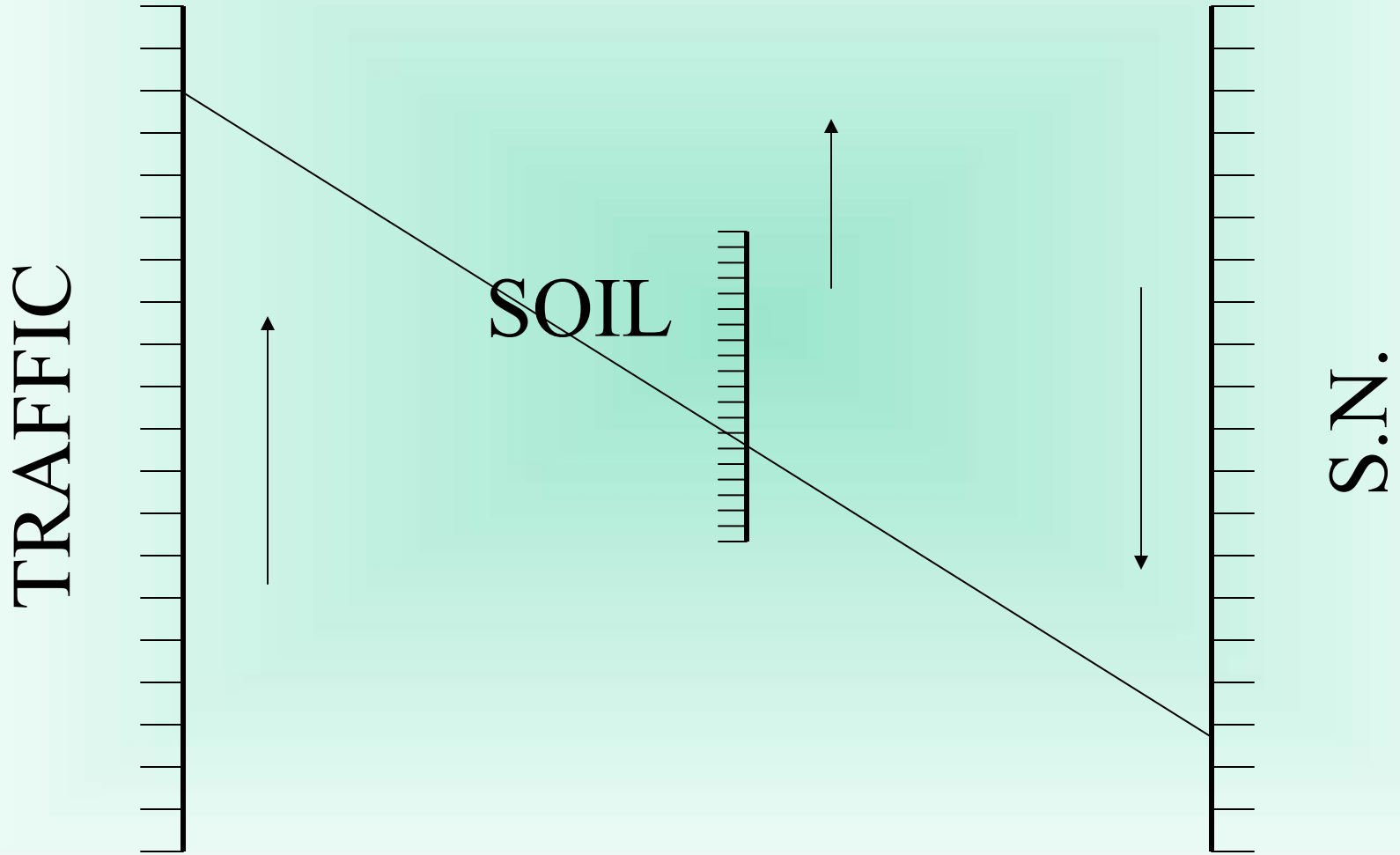


AASHO Advances

- Equivalent 18^{K} Single Axle Loads (ESALs)
- Thickness Designs for both B & W
- "Equivalent" Pavements

AASHO Limitations

- One Set of Materials
- Two Years of Weathering
- 1.1 Million Axles
- No Full Depth
- Totally Empirical

Mechanistic Design

Mechanistic -

> "Concerning the Relationships Between Applied Forces and Material Responses."

Mechanistic Design

Mechanistic -

> "Concerning the Relationships Between Applied Forces and Material Responses."

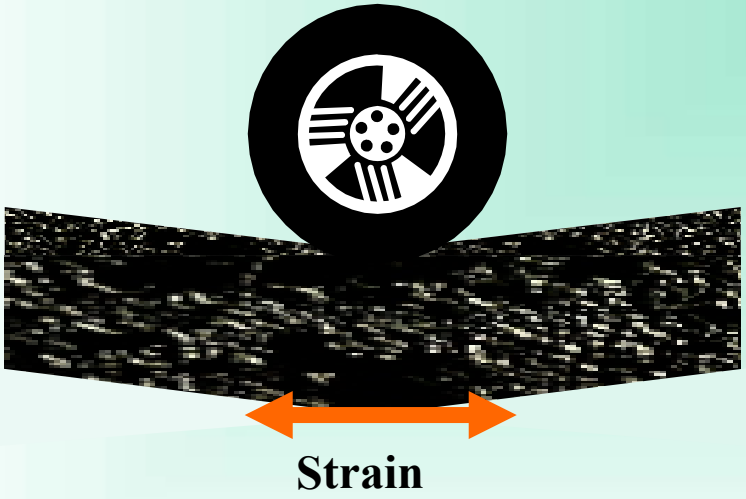
Basic Premise -

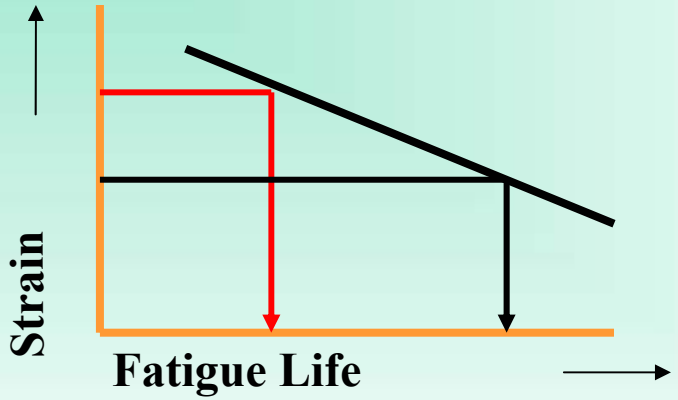
> Low Deflections = Long Life

Fatigue Theory

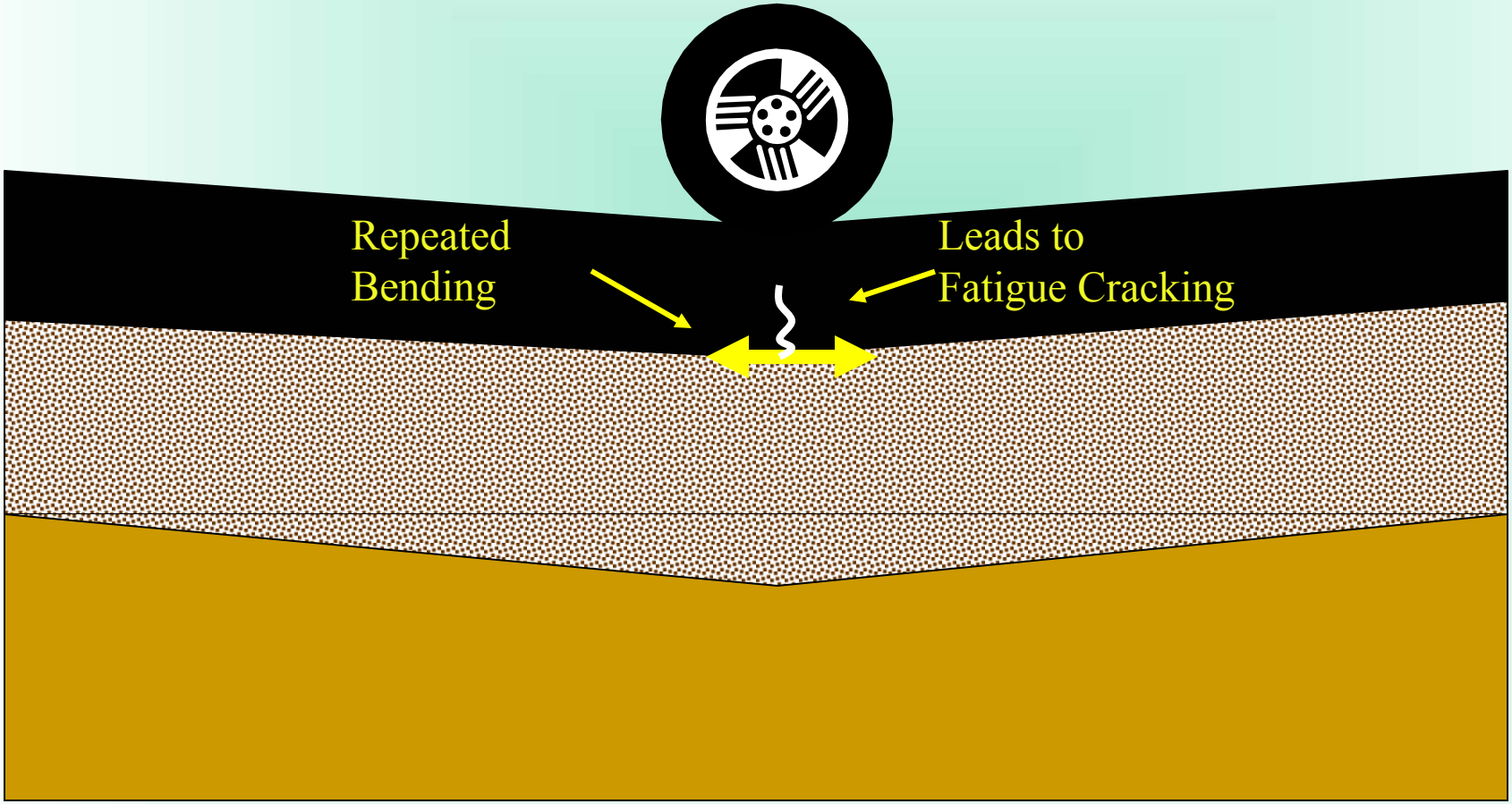
High Strain = Short Life

Low Strain = Long Life

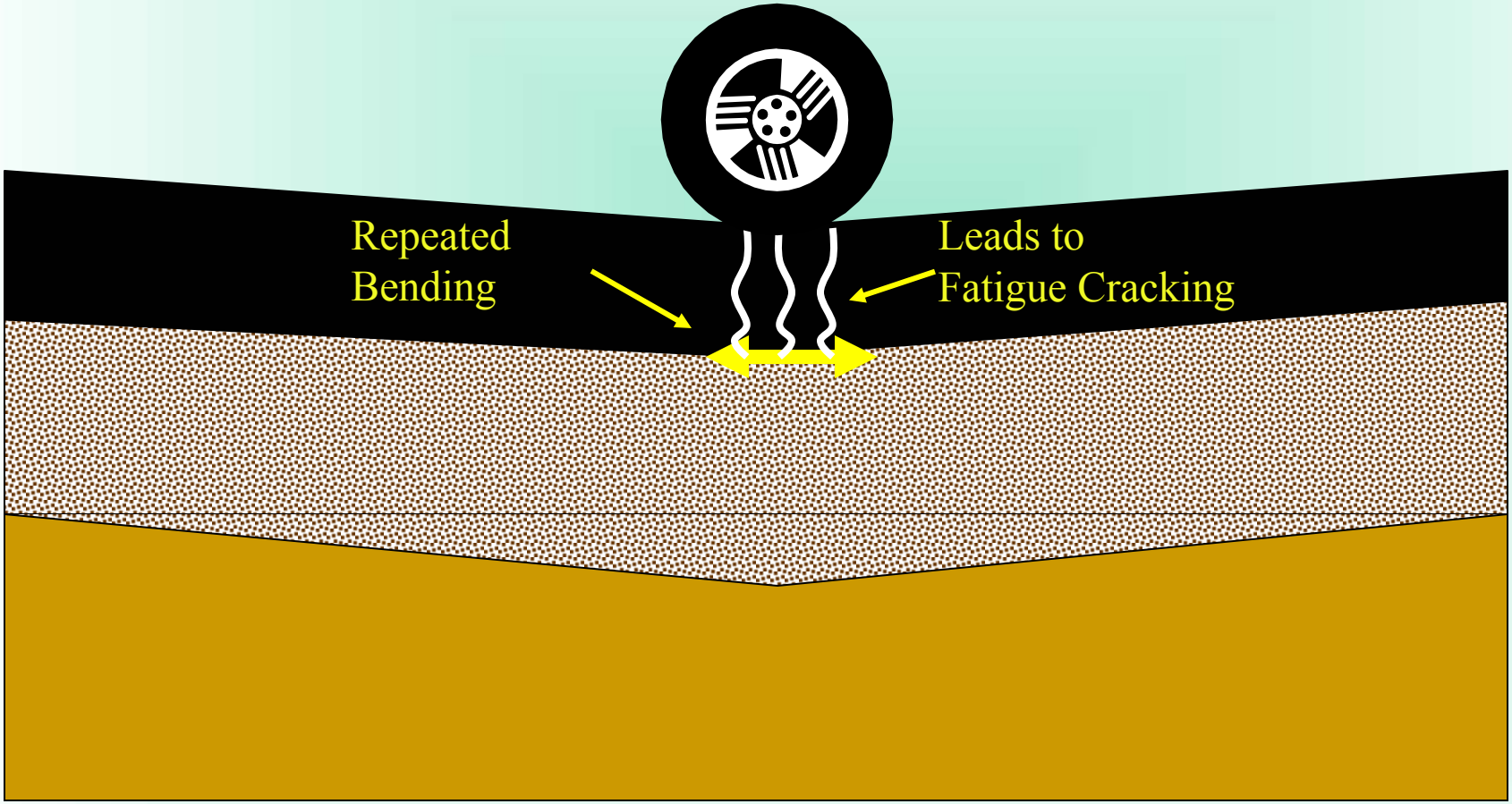


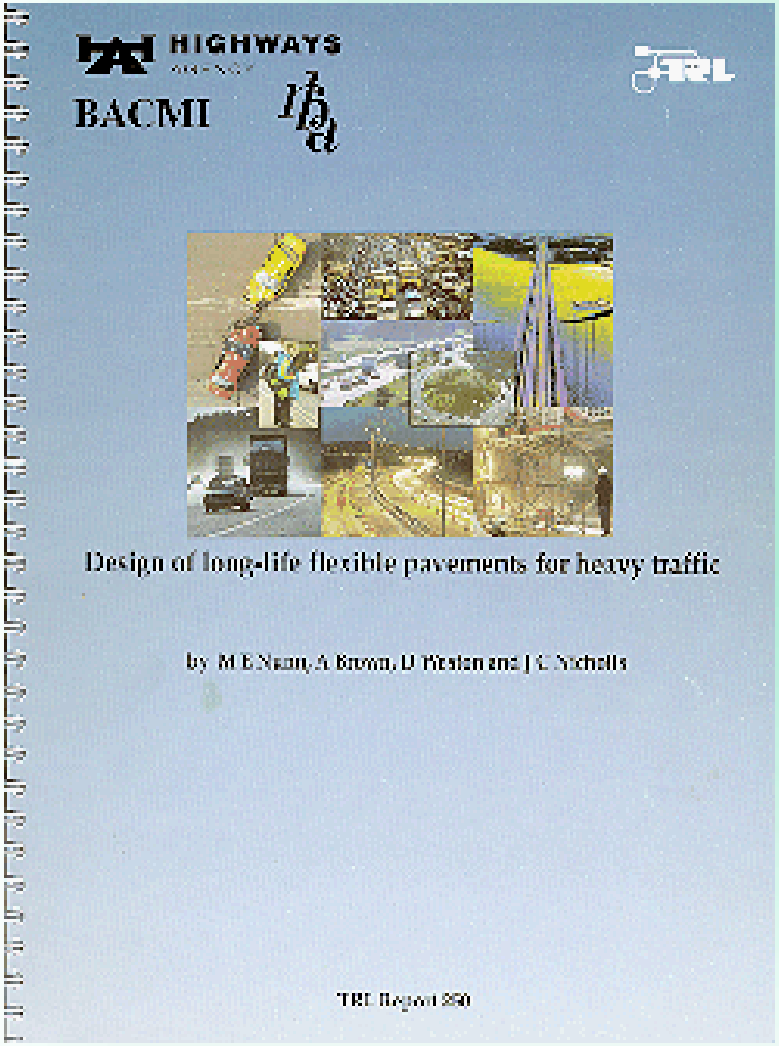


Fatigue Cracking



Fatigue Cracking

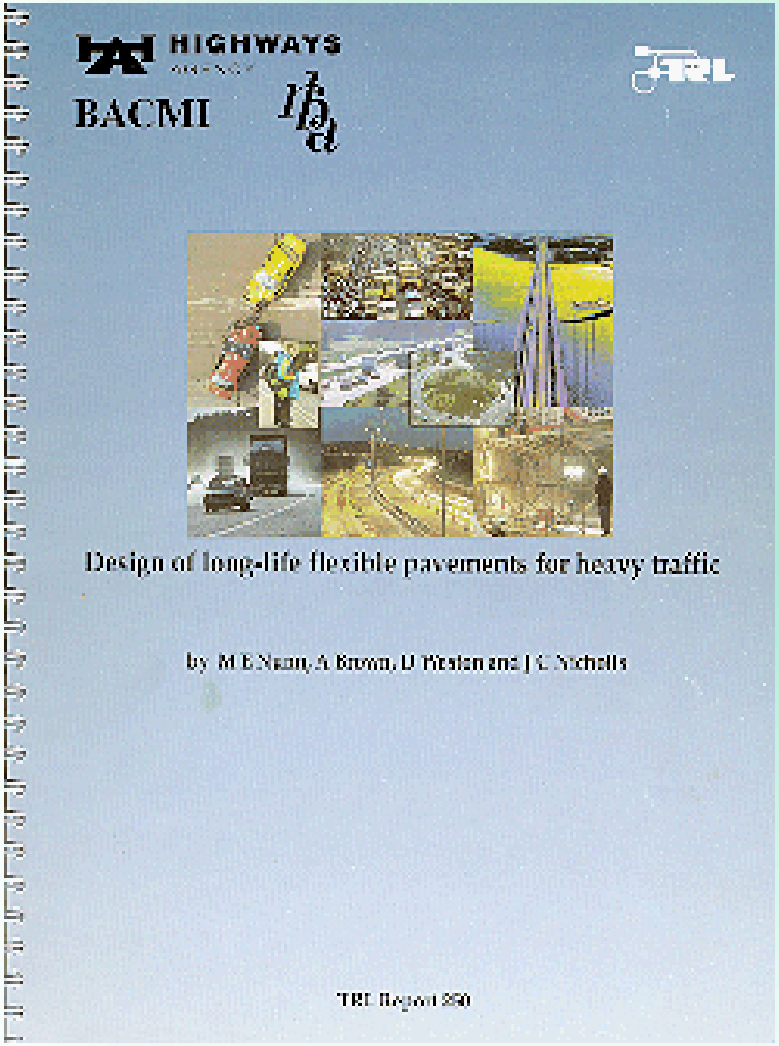




TRL Report 250
Nunn, Brown, Weston
& Nicholls

Design of Long-Life Flexible Pavements for Heavy Traffic

http:\\www.trl.co.uk



"The deterioration of thick, well constructed, fully flexible pavements is not structural, but occurs at the surface as cracking and rutting."

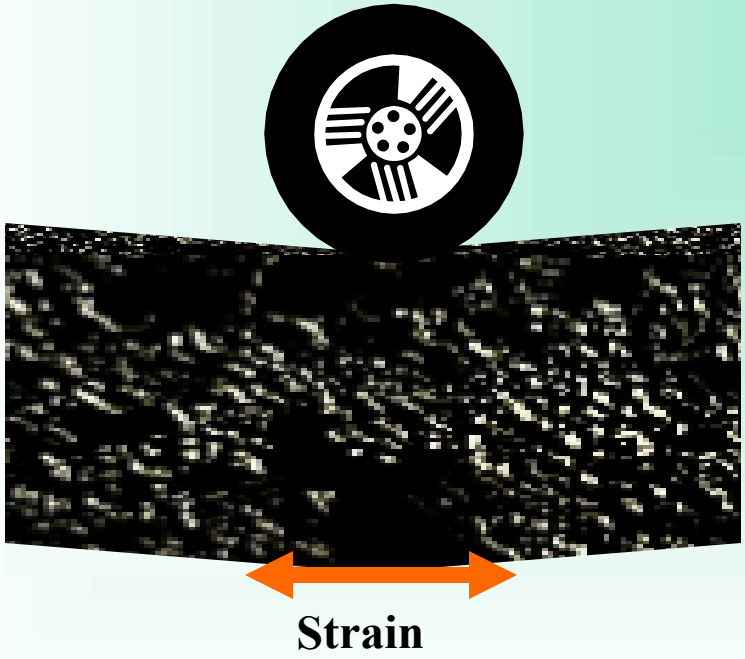
Professor Monismith
University of California, Berkeley
1972 AAPT Proceedings

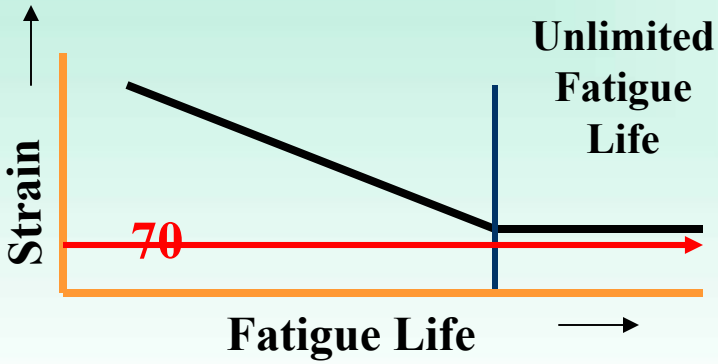
"Moreover, based on recent studies, it was assumed that strains less than 70×10^{-6} would cause no fatigue damage."

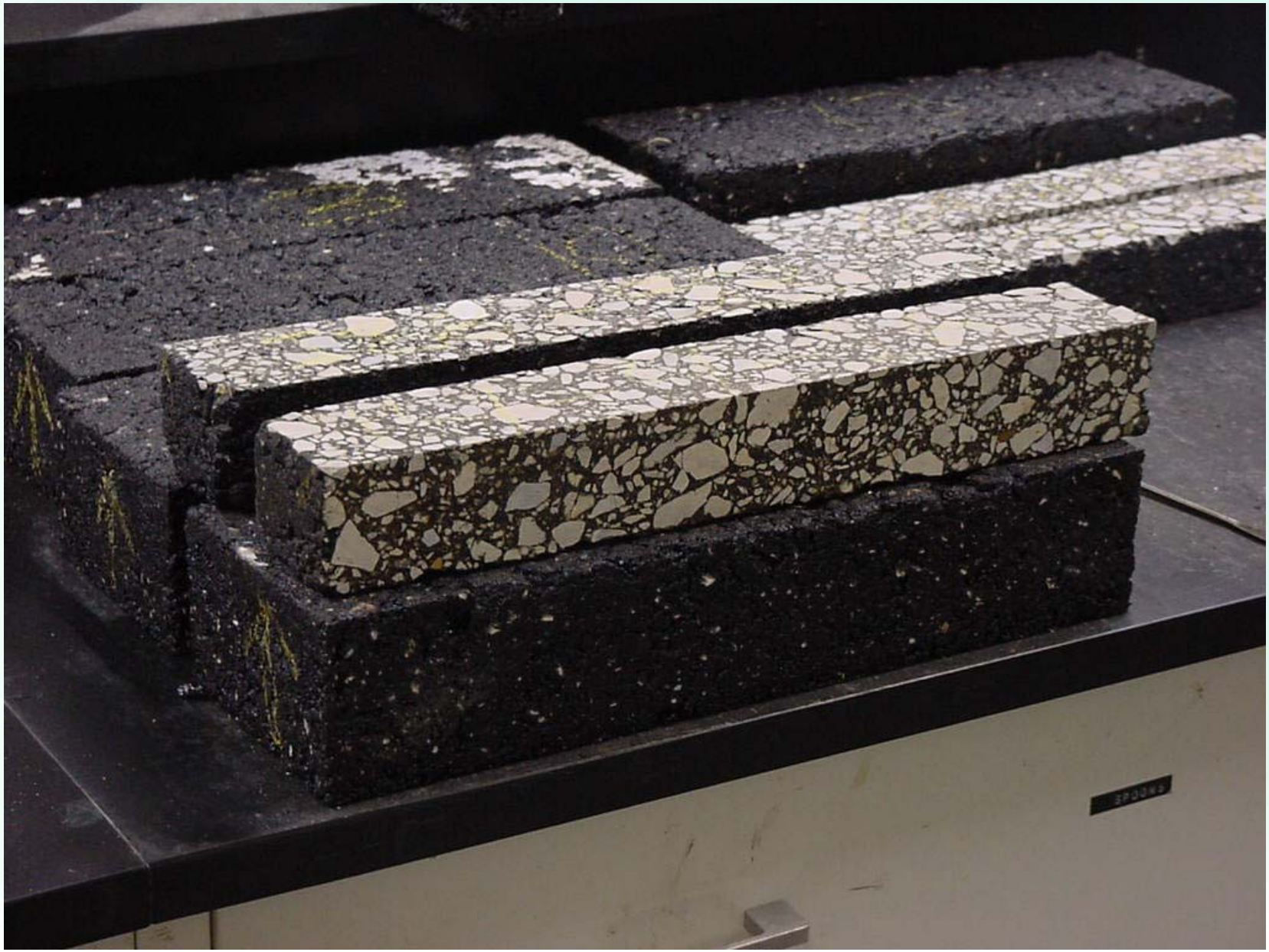
Fatigue Theory for Thick Pavements

High Strain = Short Life

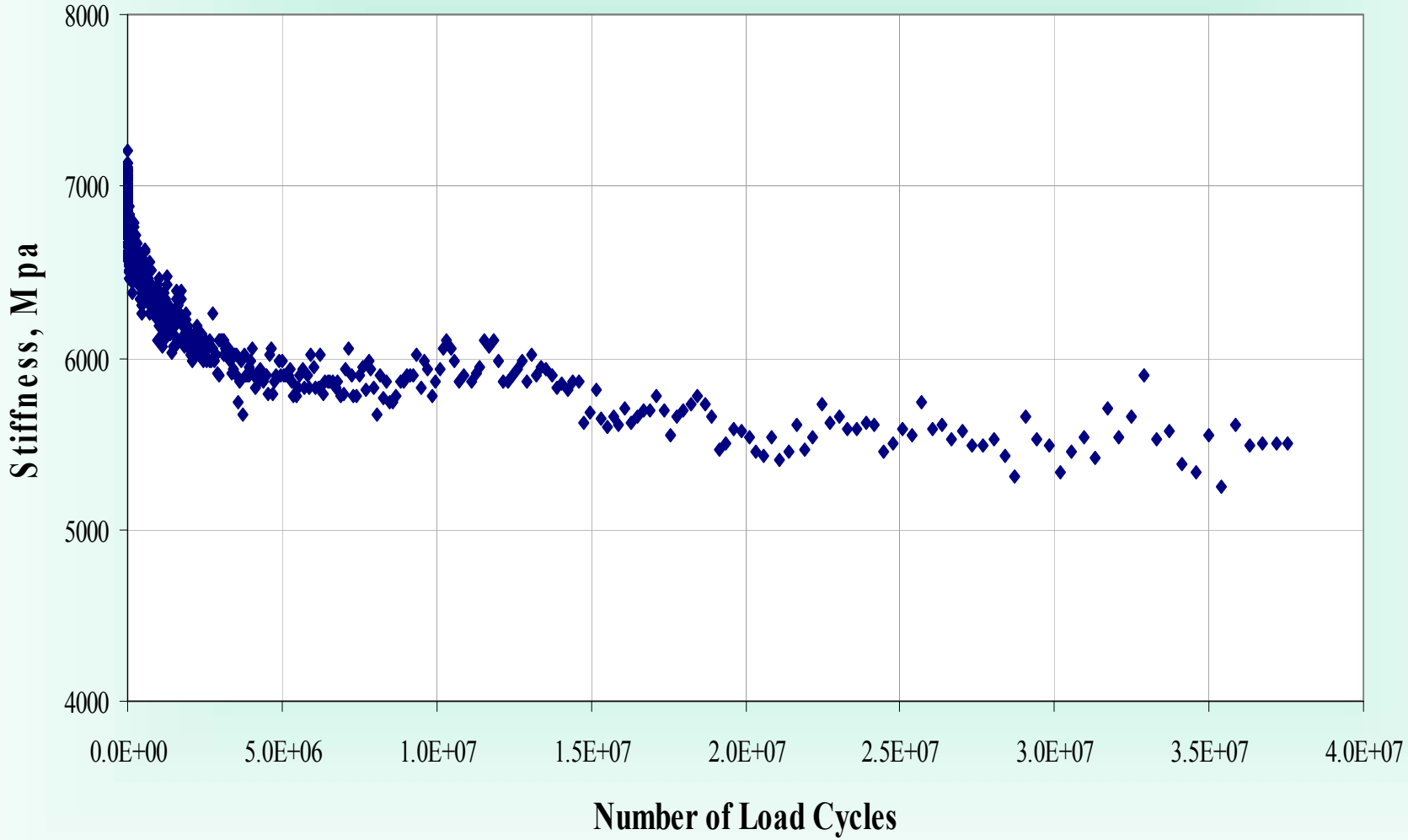
Low Strain = Unlimited Life



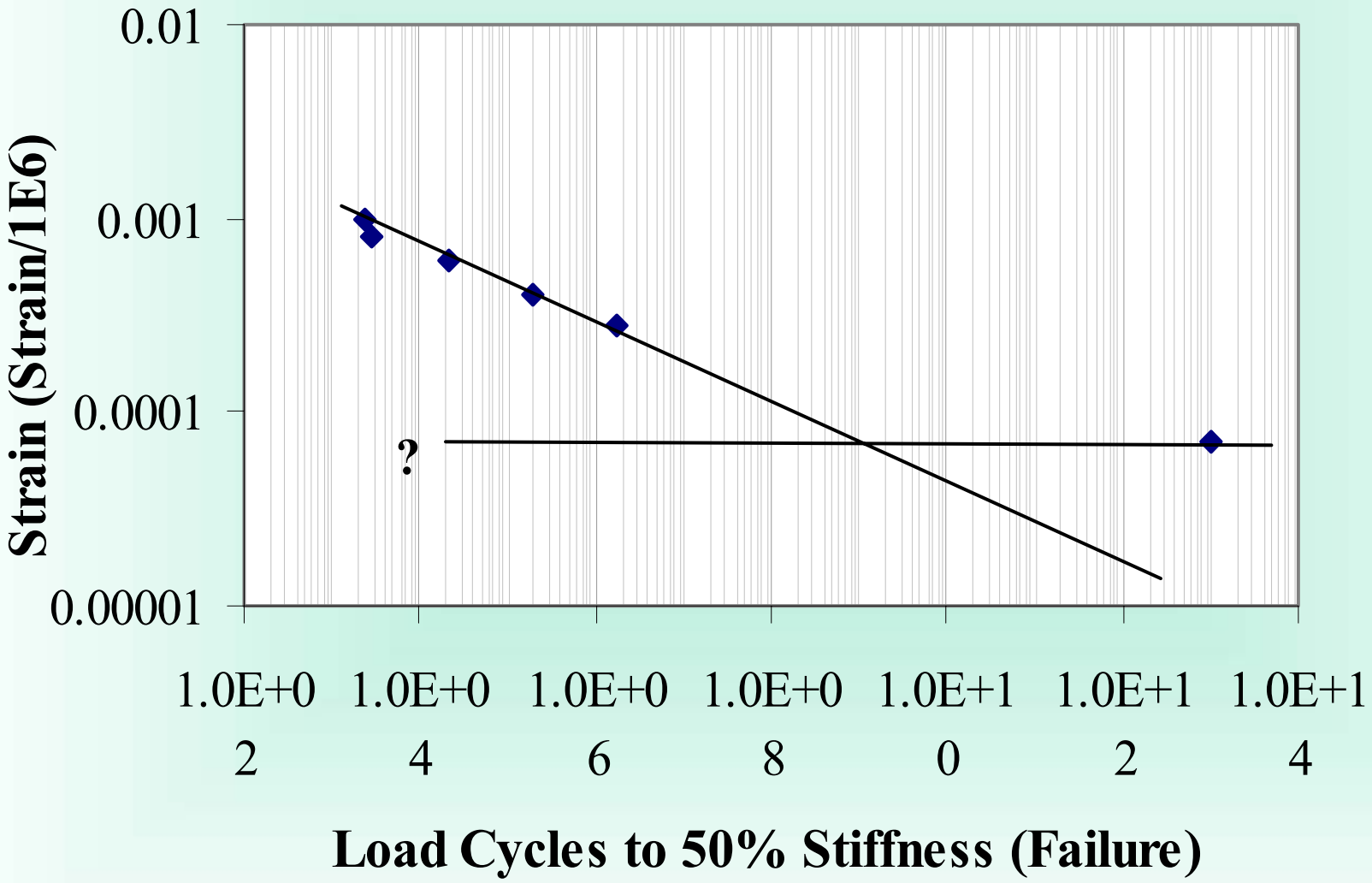




70 Micro Strain Test



Traditional Fatigue Plot



Fatigue-Based Thickness

TF	Microstrain	Thickness
1	100	10.5
2	80	12.5
3	70	13.5
5	60	15.0
10	50	16.5
15	45	18.0
20	40	19.0
30	35	22.0

TF1 = 200 Trucks/Day

Fatigue-Based Thickness

TF	Microstrain	Thickness
1	100	10.5
2	80	12.5
3	70	13.5
5	60	15.0
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20	40	19.0
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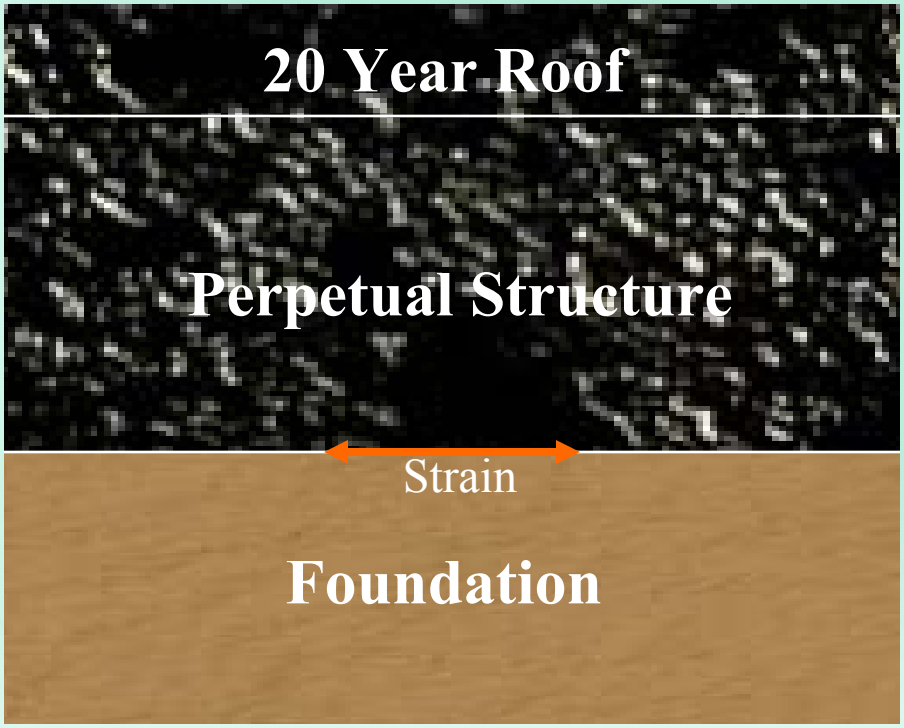
TF1 = 200 Trucks/Day

FAILURE MODES

Eventual Distress

Perpetual Pavement



Advantages

- Thinner Sections
- No Full-Depth Patching
- Rapid/Inexpensive Rehab
- Permanent Elevations

Dollars & Days

Dollars & Days

30 Year Concrete

Year	Activity	$ (millions)	Days
0	New Construction	4.0	60
10			
20			
30	Patch/Overlay	0.4	60
40	Patch/Overlay	0.4	60
50	Reconstruction	4.0	60
60			
70			
80	Patch/Overlay	0.4	60
90	Patch/Overlay	0.4	60
100	Reconstruction	4.0	60
	TOTAL	$13.6	420

Dollars & Days

30 Year Concrete

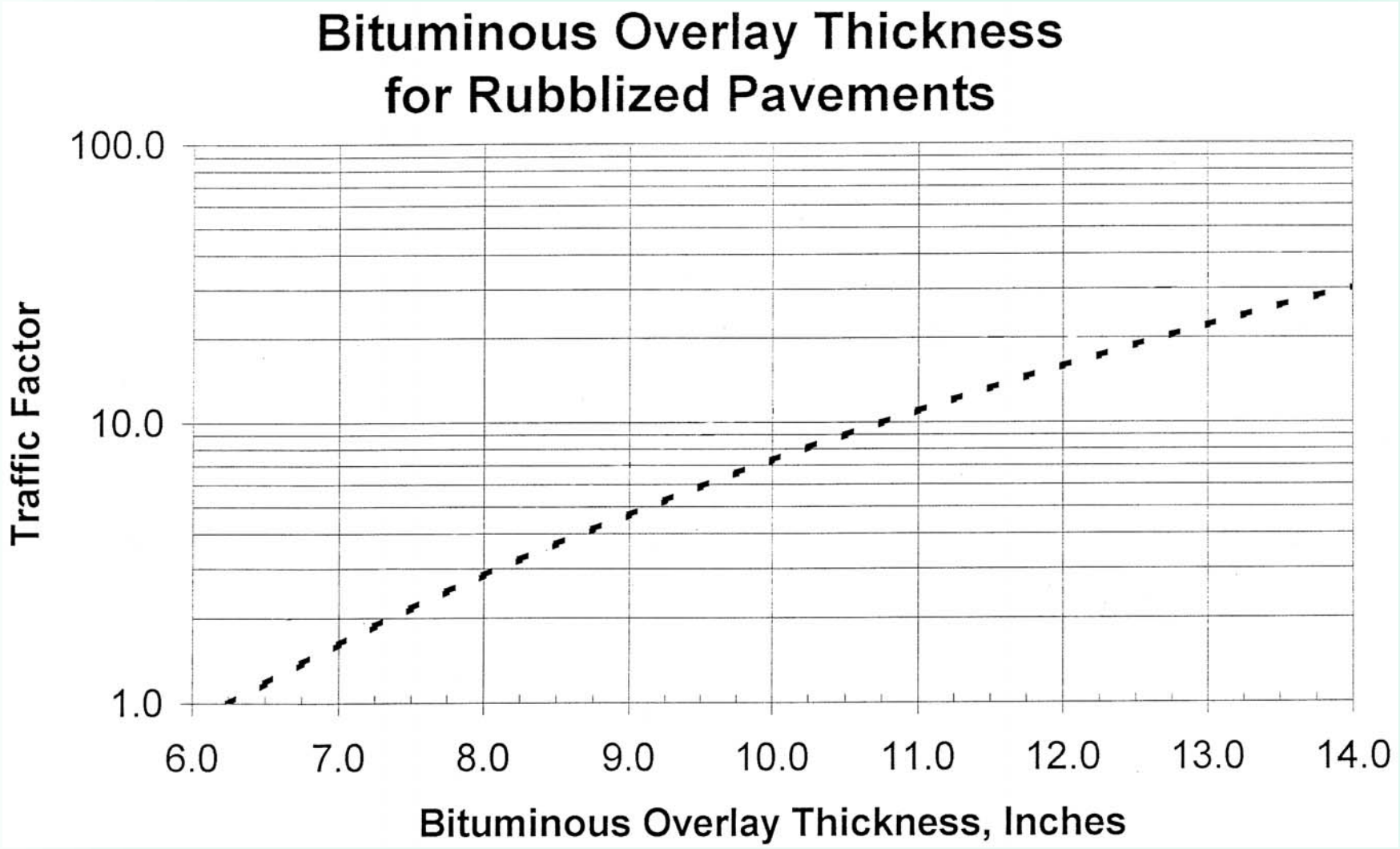
Year	Activity	$ (millions)	Days
0	New Construction	4.0	60
10			
20			
30	Patch/Overlay	0.4	60
40	Patch/Overlay	0.4	60
50	Reconstruction	4.0	60
60			
70			
80	Patch/Overlay	0.4	60
90	Patch/Overlay	0.4	60
100	Reconstruction	4.0	60
	TOTAL	$13.6	420

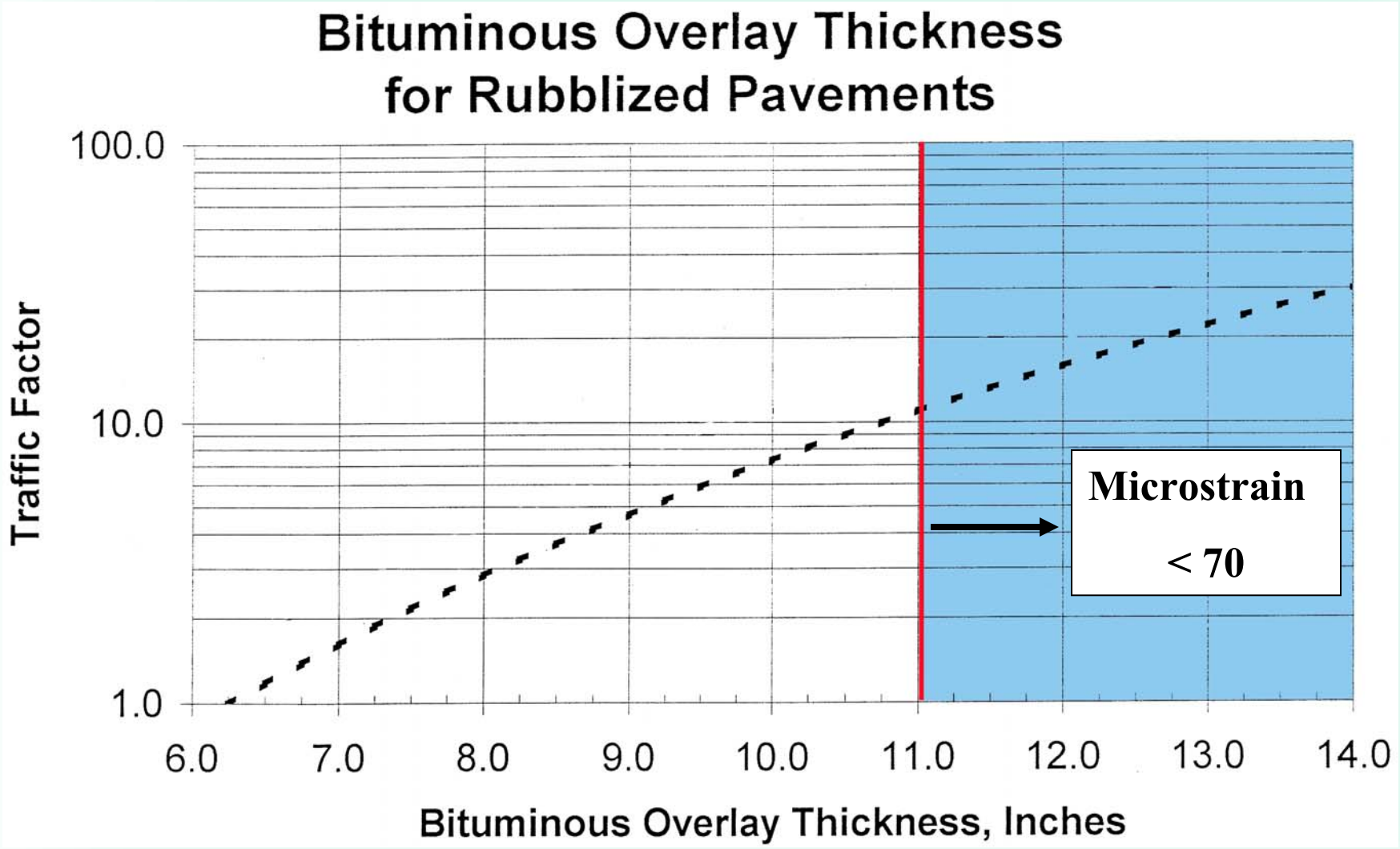
Perpetual Pavement

Year	Activity	$ (millions)	Days
0	New Construction	3.0	30
10			
20	Mill/Overlay	0.3	15
30			
40	Mill/Overlay	0.3	15
50			
60	Mill/Overlay	0.3	15
70			
80	Mill/Overlay	0.3	15
90			
100	Mill/Overlay	0.3	15
	TOTAL	$4.8	105

Rubblizing


ANTIGO
LANE


Bituminous Overlay Thickness
for Rubblized Pavements
100.0
10.0
1.0
Traffic Factor
6.0
7.0
8.0
9.0
10.0
11.0
12.0
13.0
14.0
Bituminous Overlay Thickness, Inches


Bituminous Overlay Thickness
for Rubblized Pavements
100.0
10.0
1.0
Traffic Factor
6.0
7.0
8.0
9.0
10.0
11.0
12.0
13.0
14.0
Bituminous Overlay Thickness, Inches
Microstrain
< 70

Dollars & Days*

	Rubblize	20 Yr. PCC	30 Yr. PCC
$	1.9	3.5	3.9
Days	55	90	105

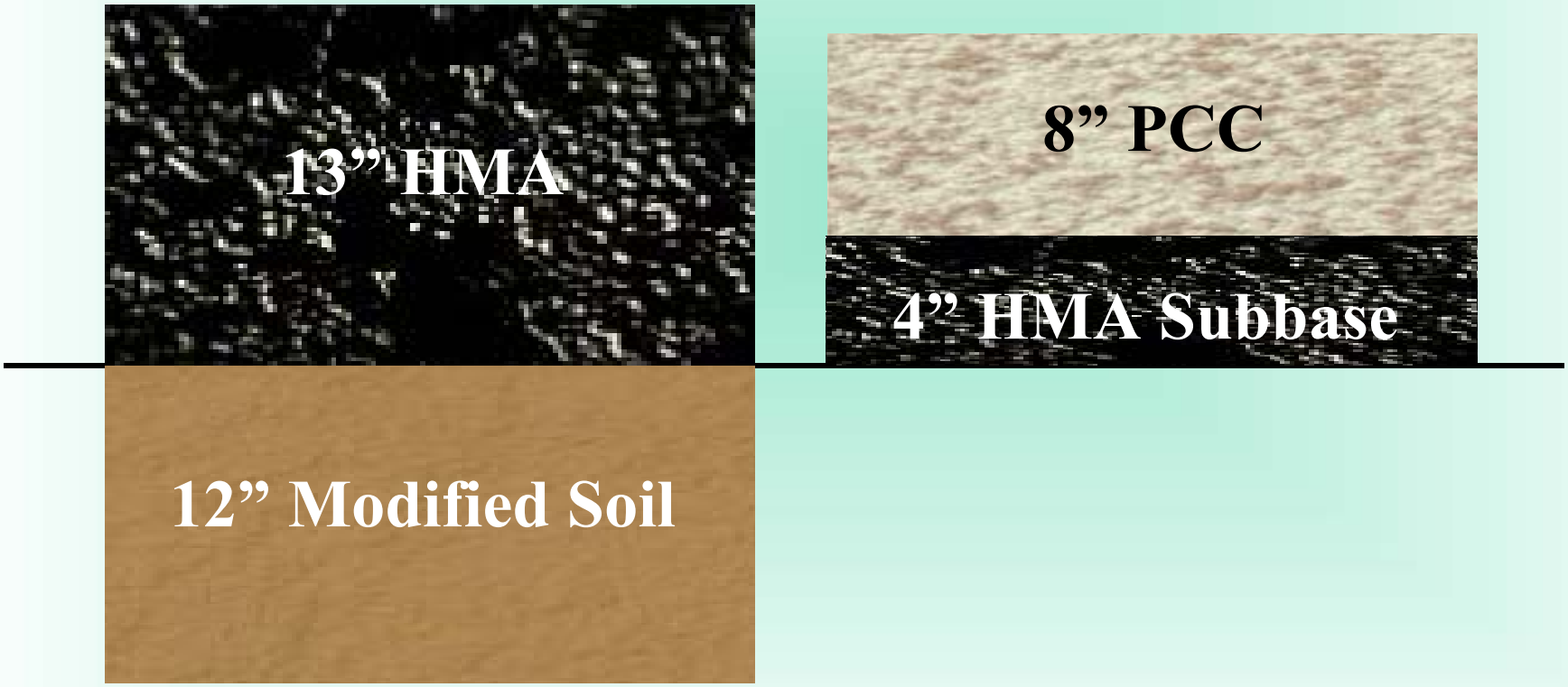
* All figures for One Mile of 4-Lane Divided Pavement

Score Card

	PCC	HMA
Initial Costs		
Out Year Costs		
User Delay Costs		

Initial Costs

Alternate Pavements



Engineer's Estimate
(Total Project)

WHITE	BLACK
$2,445,407	$2,331,134

5% Difference

Actual Bids
(Total Project)

	WHITE	BLACK
FREESEN	$2,114,322	$1,599,532
FLATT		$1,599,992
SANKEY		$1,772,477
MERRILL		$1,779,209
CALHOUN	$2,343,458	

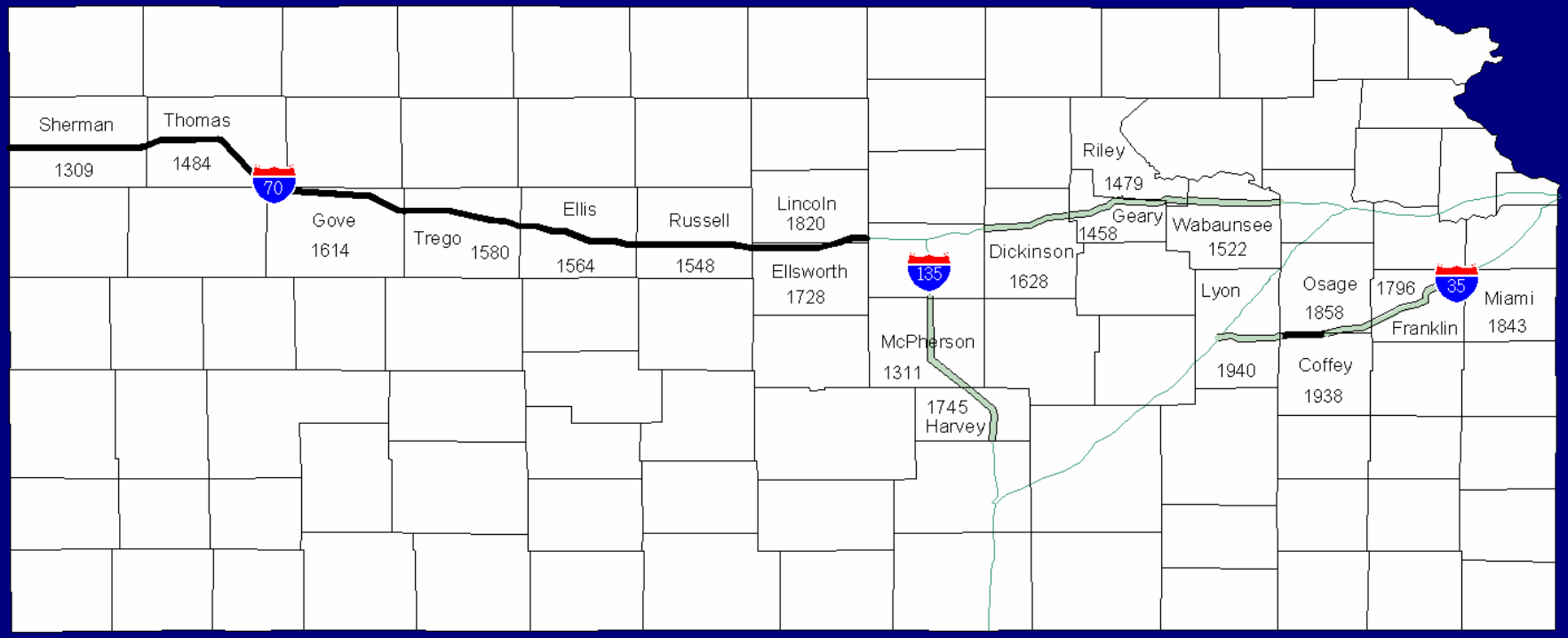
32% Difference

Score Card

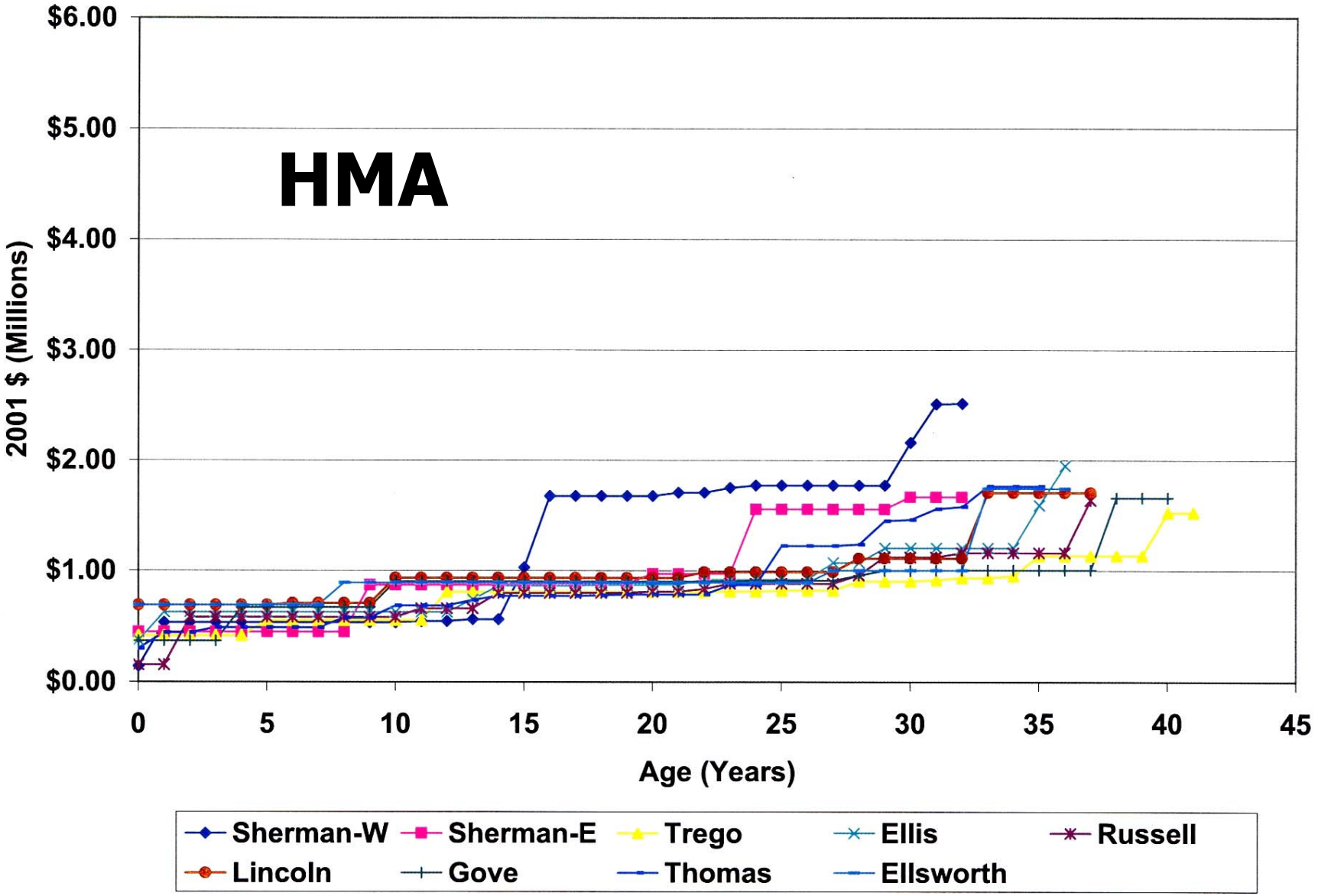
	PCC	HMA
Initial Costs		X
Out Year Costs		
User Delay Costs		

Out Year Costs

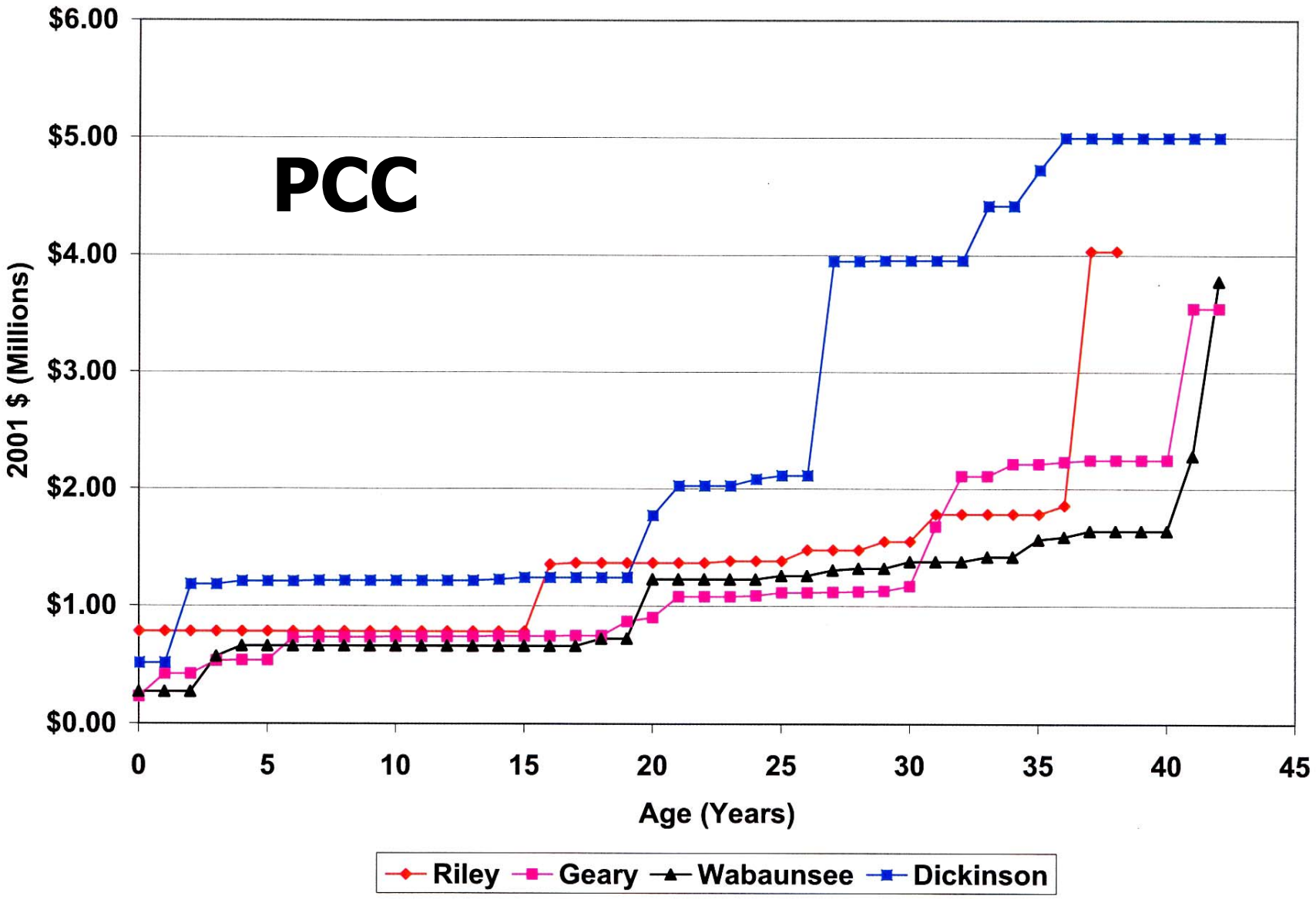
Kansas Interstate Study


Sherman
1309
Thomas
1484
70
Gove
1614
Trego
1580
Ellis
1564
Russell
1548
Lincoln
1820
Ellsworth
1728
135
McPherson
1311
1745
Harvey
Dickinson
1628
Riley
1479
Geary
1458
Wabaunsee
1522
Lyon
1940
Osage
1858
Coffey
1938
1796
35
Franklin
Miami
1843
70
Interstate/Kansas Turnpike
PCC Pavement (184 miles)
HMA Pavement (244 miles)

Total Expenditures Per 4-Lane Mile Per Year, HMA Pavements, I-70



Total Expenditures Per 4-Lane Mile Per Year, PCC Pavements, I-70



Expenditures per 4-Lane Mile, 2001 $

Pavement Type	Original Construction	Average Cost Per Year	
		0-20 Years	>20 Years
PCC	$823,872	$19,578	$94,632
HMA	$613,388	$23,358	$33,794

Average Life Cycle Cost

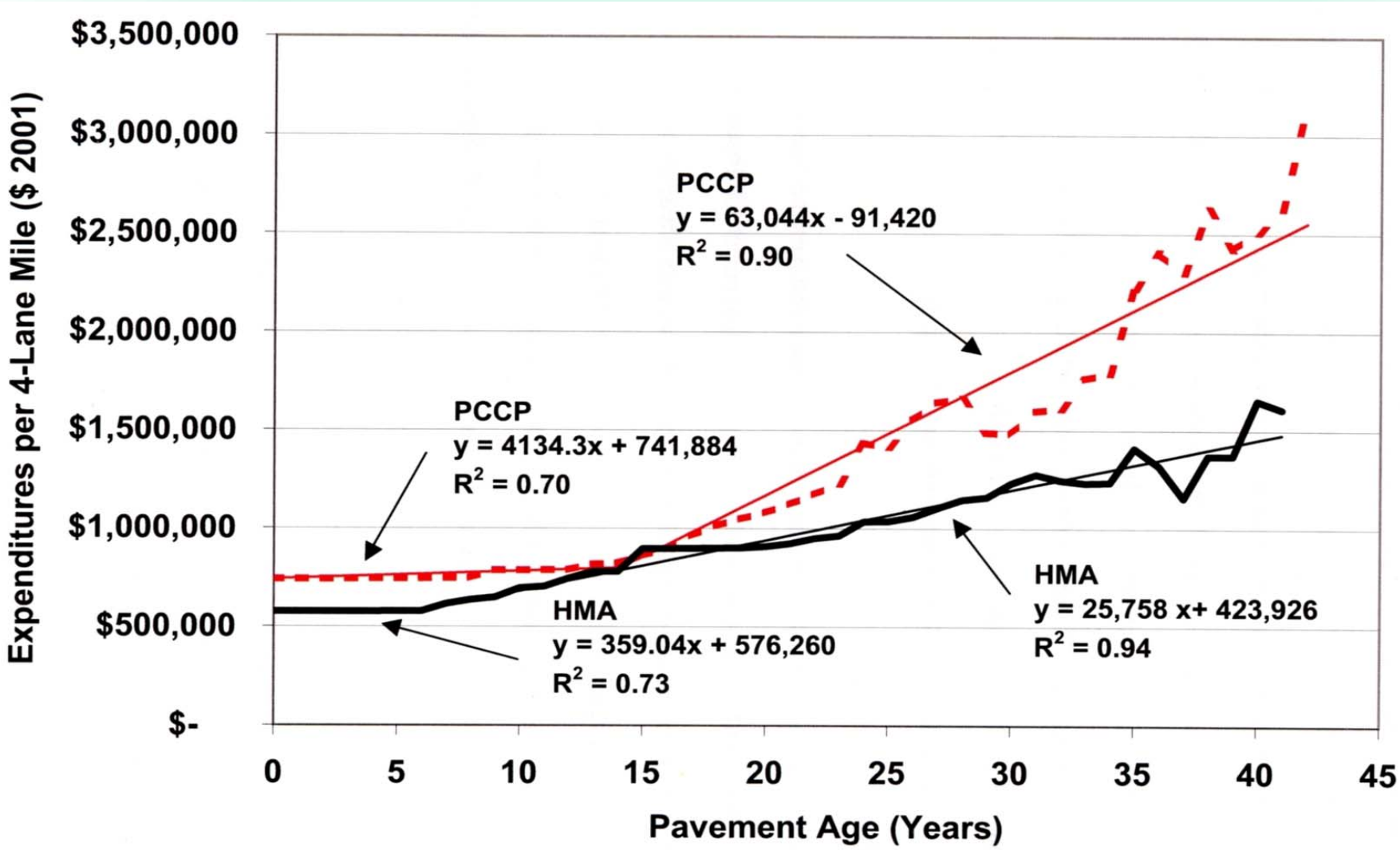


Figure 12. Regression Curves for Average Life-Cycle Cost

Score Card

	PCC	HMA
Initial Costs		X
Out Year Costs		X
User Delay Costs		

User Delay Costs

Score Card

	PCC	HMA
Initial Costs		X
Out Year Costs		X
User Delay Costs		X

Marvin Traylor