A Simple Empirical Guide to Low-Volume Road Pavement Design in Indiana

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Acknowledgment

- Indiana Local Technical Assistance Program
- Co-authors
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Low-Volume Road

Organization	Criteria
FHWA	ADT<500
AASHTO	50,000<ESAL<1,000,000
Asphalt Institute	ESAL<10,000
Washington DOT	ESAL<100,000

Background

- Low-volume roads are important to the nation's transportation infrastructure
- Many local agencies have no pavement design expertise
- Local agencies have little or no pavement data acquisition and materials testing capabilities

Objective

- Develop empirical low-volume road design method
  - Minimal input requirements
  - Simple to use
  - Account for weather and subgrade conditions

Procedure	ESAL	ADT	Index	Design Period	Growth
AASHTO	•				
USACE	•				
NCSA	•		•		
AI	•				
CA	•		•		
MN (GE)		•			
MN (R-value)	•				
MS	•			•	
NY	•				
PA	•				
VT	•				
VA		•			•

Procedure	MR	CBR	Soil Type	R-Value	Frost	Drainage
AASHTO	•					
USACE		•				
NCSA		•	•		•	•
AI	•					
CA				•		
MN (GE)			•			
MN (R-value)				•	•	
MS		•				
NY	•				•	•
PA		•			•	
VT	•				•	
VA		•				

Procedure	Traffic	Subgrade	Complexity
AASHTO	Not available	Not available	Complex
USACE	Available	Available	Simple
NCSA	Available	Available	Simple
AI	Not available	Not available	Simple
CA	Available	Not available	Moderate
MN (GE)	Not available	Not available	Simple
MN (R-value)	Not available	Not available	Moderate
MS	Not available	Available	Simple
NY	Not available	Not available	Complex
PA	Not available	Available	Moderate
VT	Not available	Not available	Complex
VA	Not available	Available	Moderate

USACE Design Procedure

- Three main pavement categories
  - Unsurfaced roads (natural soil)
  - Aggregate surface
  - Bituminous pavements
- Three basic steps
  - Class designation-based on daily traffic
  - Design category-based on traffic composition
  - Design index-based on class and design category
- Determine required thickness over given CBR

NCSA Design Method

- Required inputs
  - CBR-measured or estimated
  - Design index-based on traffic (average ESAL per lane per day over 20 years)
- Design charts

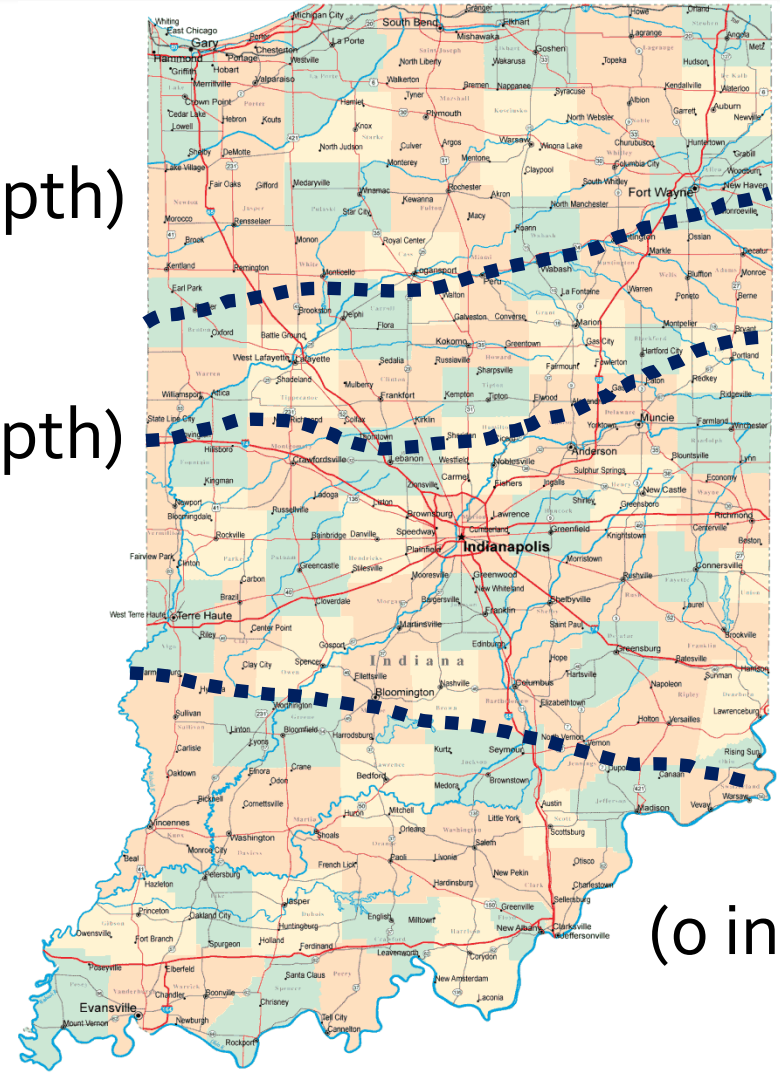
Proposed Design Method

- Based on NSCA and USACE methods
- Assumptions
  - 1,000 vpd or less
  - Life expectancy 15-20 years, regular maintenance
  - All trucks have 3 or more axles (all expected to be tandem axles, except for steering axle)
  - Pickup trucks and light duty vehicles not considered as trucks, considered as general traffic
  - Frost depth per USACE frost zone map

Frost Zone Map

Zone D
(20 in. frost depth)

Zone C
(10 in. frost depth)



Zone B
(5 in. frost depth)

Zone A
(0 in. frost depth)

Proposed Design Method

- Assumptions-continued
  - Subgrade strength given in either CBR or DCP (in./blow) values
  - DCP values can be converted to CBR according to ASTM D6951

Subgrade Strength

- Weak
  - CBR<6%, DCP>1.34 in./blow
- Medium
  - CBR of 6-10%, DCP of 0.83-1.34 in./blow
- Strong
  - CBR of 10-15%, DCP of 0.55-0.83 in./blow
- High strength
  - CBR>15%, DCP<0.55 in./blow

Subgrade Strength

- Pavement in a frost zone
  - Poor/weak-clay gravels, plastic sand clays, silts, silty sand, silty clay
  - Medium-sand, sandy clays, silty gravel
  - High-gravely soils

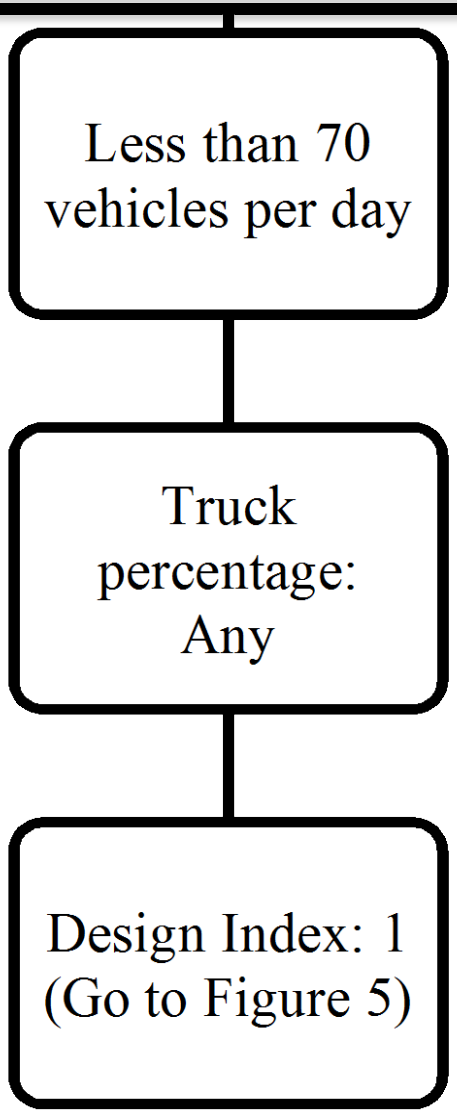
Traffic Data

- Traffic
  - Low (less than 70 vpd)
  - Medium (70-200 vpd)
  - High (201-1,000 vpd)
- Truck percentages
  - Less than 1 percent
  - Between 1 and 10 percent
  - Greater than 10 percent

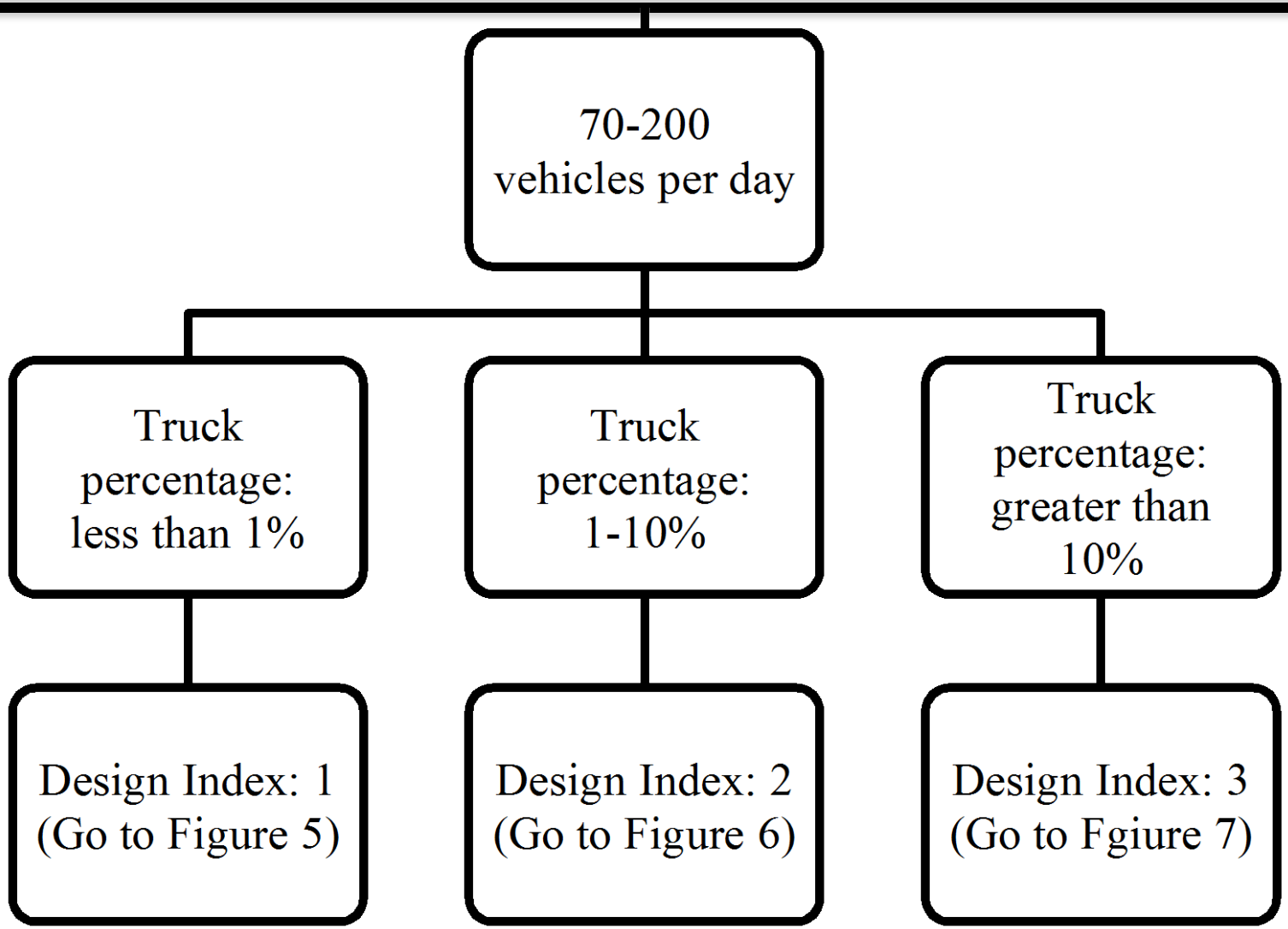
Pavement Design Index

Traffic Volume (vpd)	Percent Trucks		
	<1	1-10	>10
<70	1	1	1
70-200	1	2	3
201-1,000	2	3	4

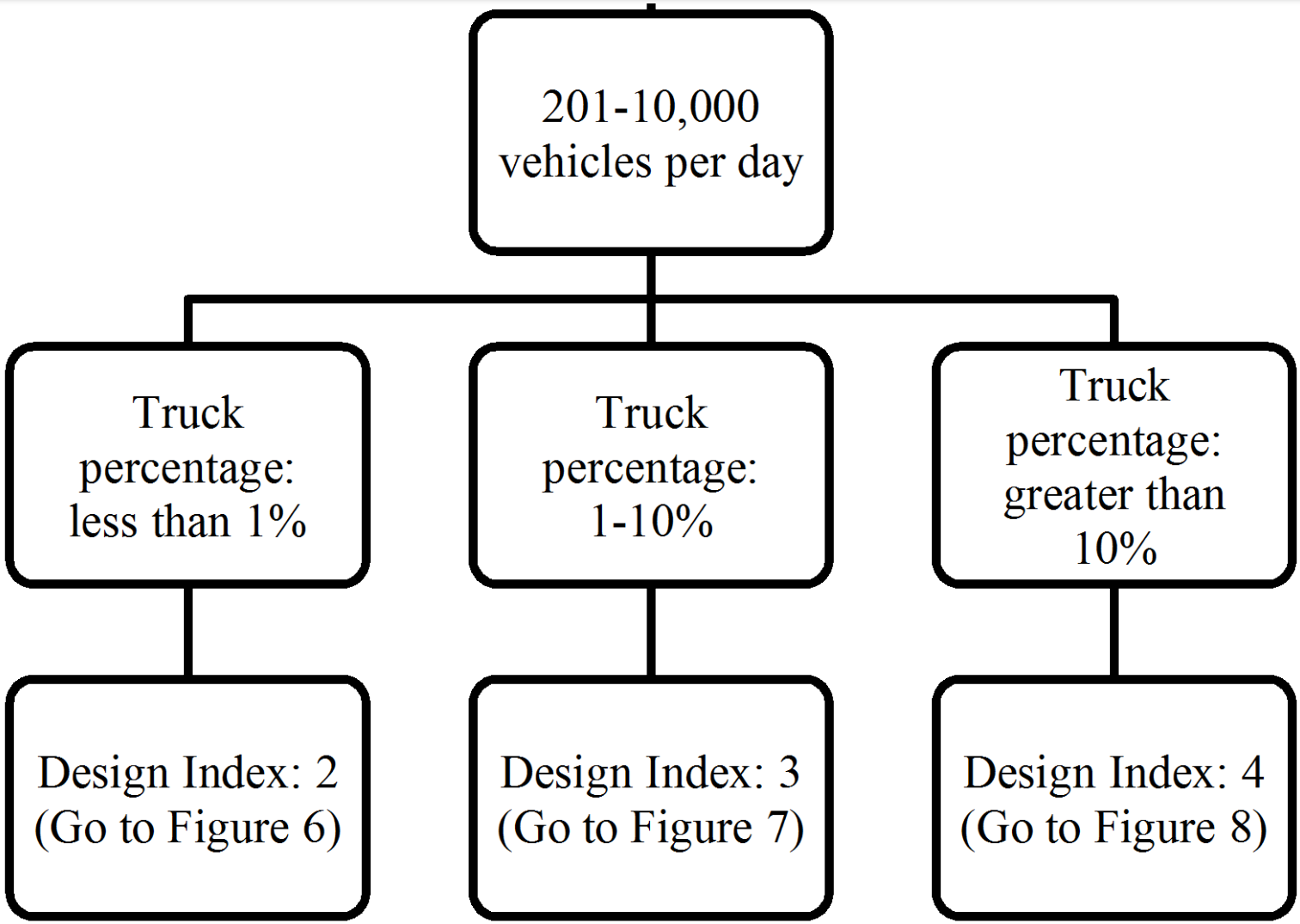
Pavement Design Index



Pavement Design Index



Pavement Design Index

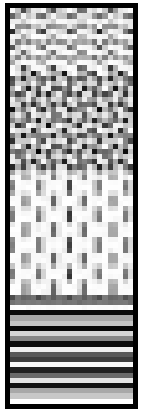


Design Example

- 400 vpd, 4% trucks
- Frost zone B
- Medium strength soil

Results in a design index of 3

Design Example



Aggregate Road Option

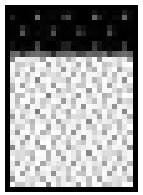
4 in. wearing course*

6 in. subbase

6 in. clean soil filter

10 in. compacted soil

*using crushed stone



Flexible Road Option

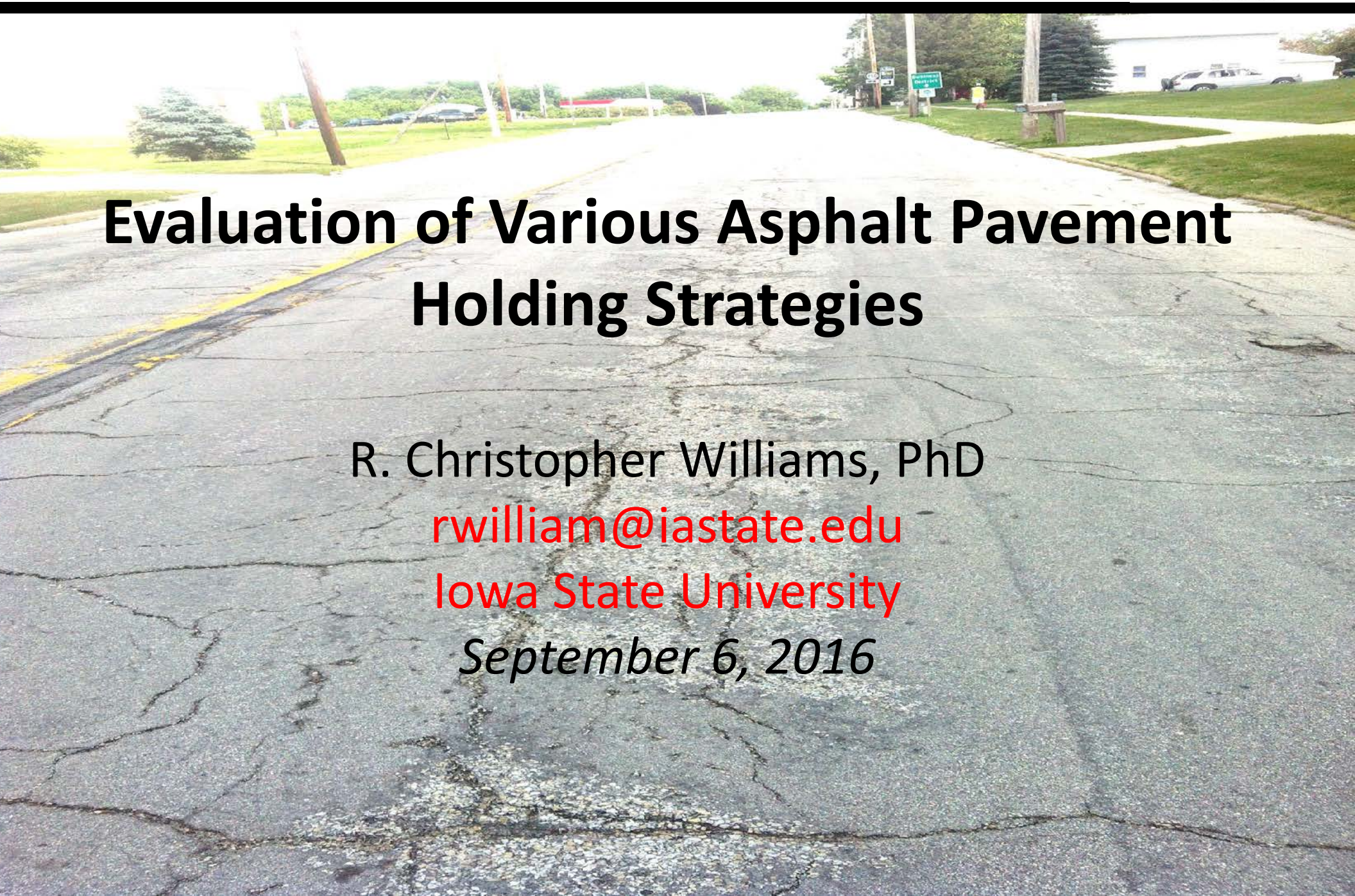
3 in. asphalt surface course

11 in. base

Method Summary

- Minimal inputs
  - Traffic count and truck percentage
  - Subgrade strength
  - Frost zone (location)
- Simple
- Accounts for weather and subgrade conditions
- Design for aggregate surfaced or bituminous surfaced roads
- Allows for timely design

Thank You!



Evaluation of Various Asphalt Pavement Holding Strategies

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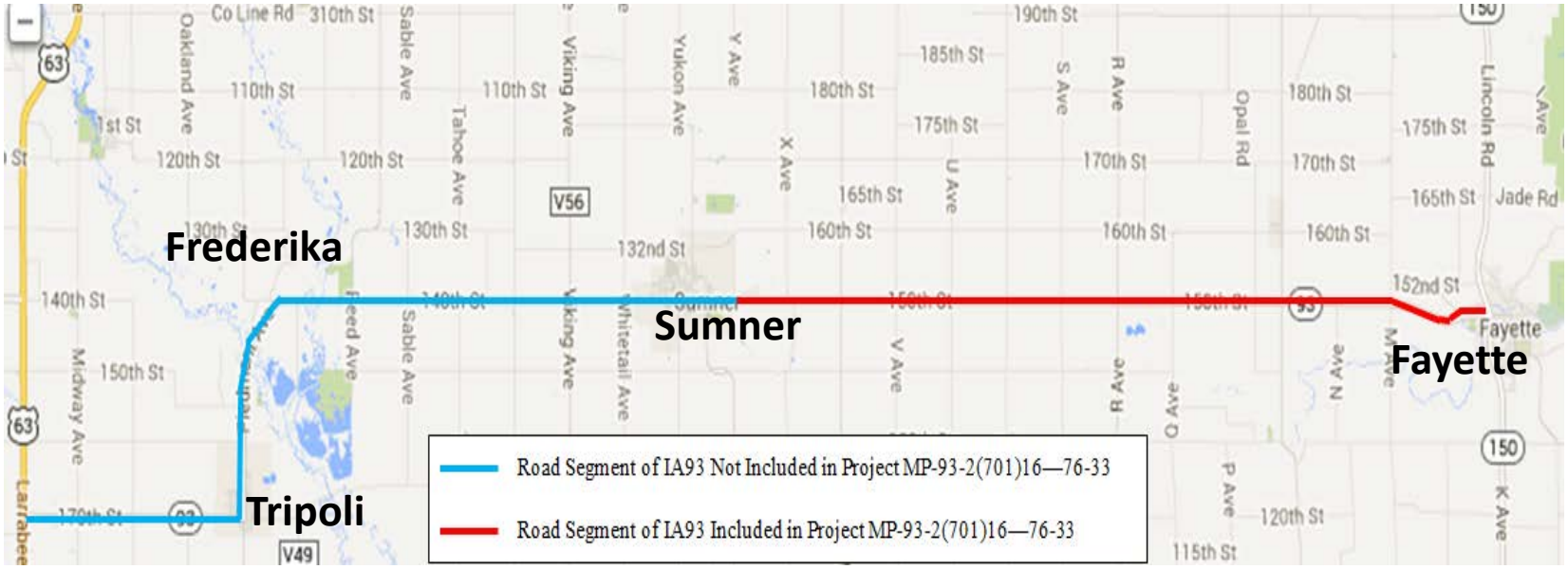
September 6, 2016

Iowa DOT MP-93-2(701)16-76-33 Project (IA 93)

- **Objective(s)**
  - Evaluate the cost-effectiveness of various pavement preservation technologies.
  - Develop pavement holding strategies for low-volume roads.
- **Methodology**
  - Construct test sections and monitor the material physical properties and pavement performance.
  - Employ performance evaluation and life-cycle-cost-analysis.

Test Sections

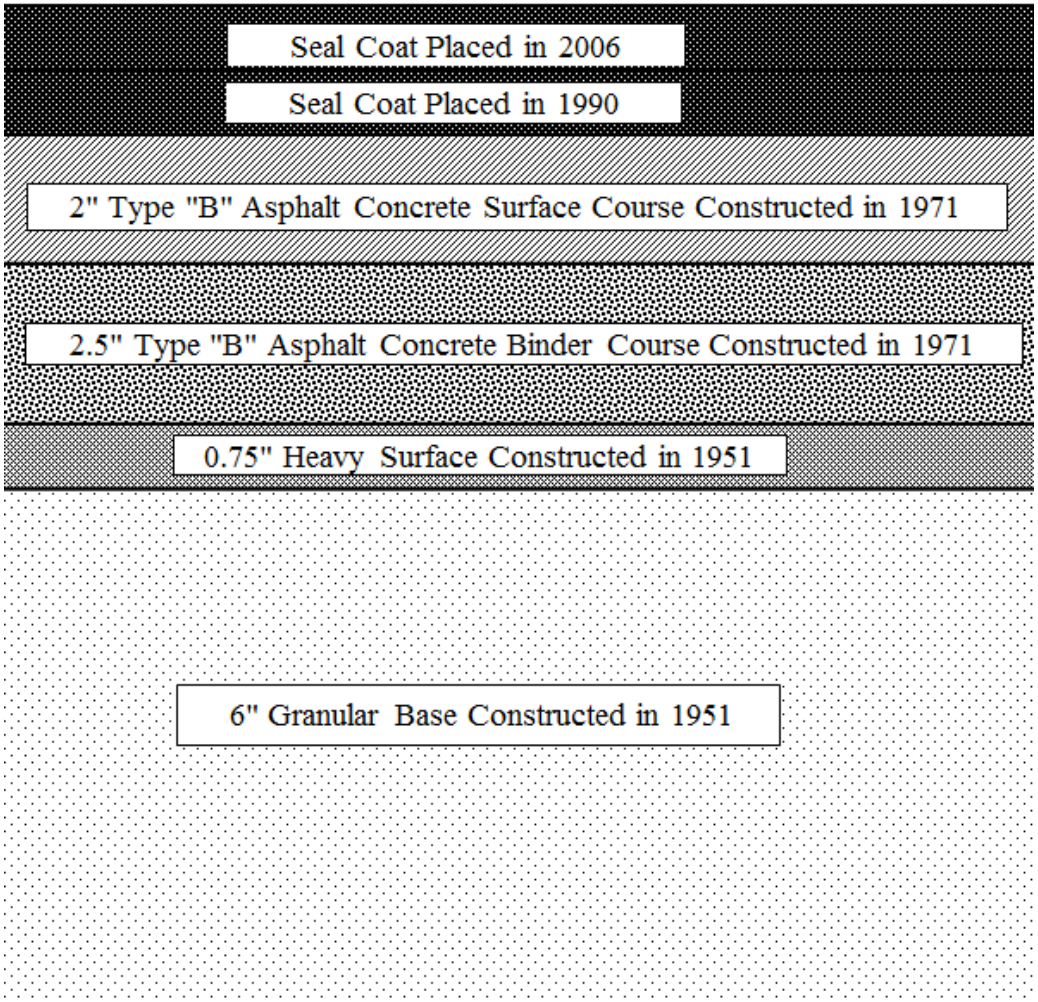


- 10 different combinations of base and surface treatments.
- Total project length = 13.6 miles
- Project started in June 2013 and commenced in September.

Challenging Issues

- **Aged highway system**
- **Increasing financial difficulties**
- **Low funding priority for low-volume roads**
  - No performance target was set by the *Moving Ahead for Progress in the 21st Century Act* (MAP-21) for Non-NHS roads.

Existing Pavement Structure



Existing Pavement Conditions

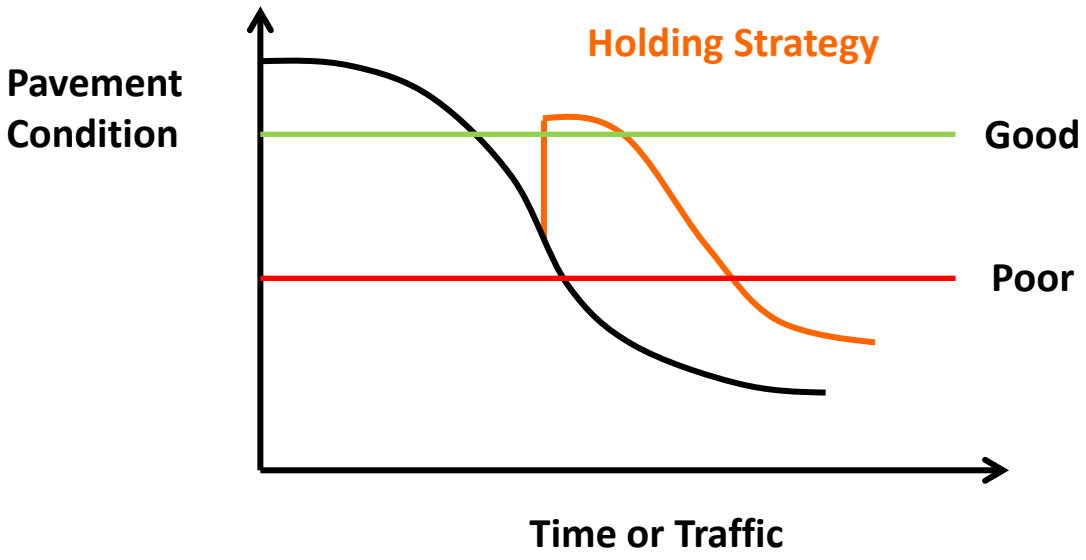
- **Pavement Management Information System Data:**
  - AADT: 1040 (8% trucks)
  - PCI: 32
  - IRI: 246 inches per mile
  - Structural rating: 3.63
  - K-value: 46

Conditions (Cont.)

- **Pre-construction Pavement Survey:**
  - All cracks are top-down cracking.
  - Transverse cracking: 9015 ft./mi.
  - Longitudinal cracking: 489 ft./mi. (wheel path); 1390 ft./mi. (center)
  - Some potholes.
  - Severe raveling at intersections.
  - Severe edge breaks.

Holding Strategy

- Relative low-cost pavement maintenance methods for significantly deteriorated low-volume roads.
- Promote and maintain pavement conditions at acceptable level.
- Delay major rehabilitation or reconstruction.
- Allow more flexible budget allocation.



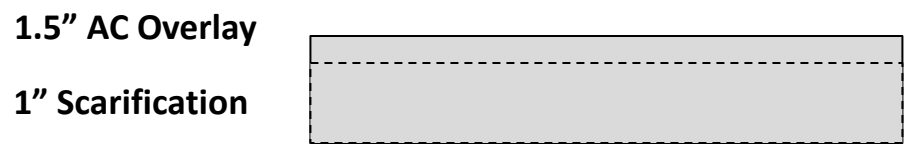
Technologies for Holding Strategies

- Full-Depth Reclamation
- In-place Recycling
- Thin Interlayer
- Strengthening and Leveling Course
- Thin Surfacing Treatments

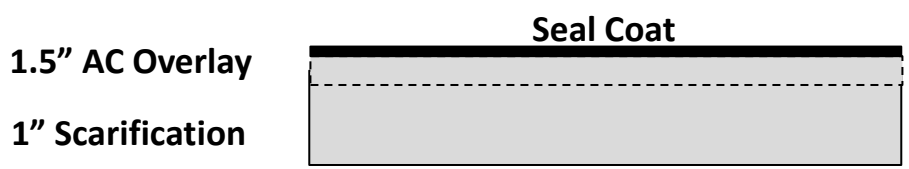
Treatments

- **Test Section #1:**
  - mill and fill
  - 1.3 miles
- **Test Section #2:**
  - mill and fill with seal coat
  - 2.0 miles
- **Test Section #3:**
  - scarification and interlayer with ultra-thin asphalt overlay
  - 2.2 miles

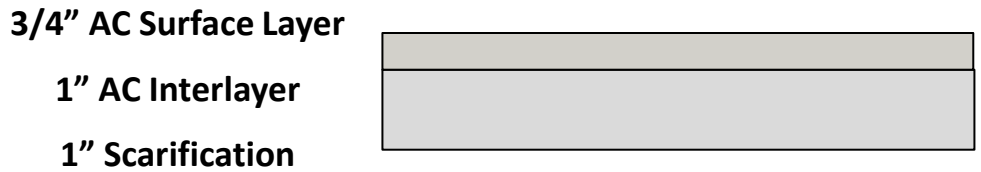
Section #1



Section #2



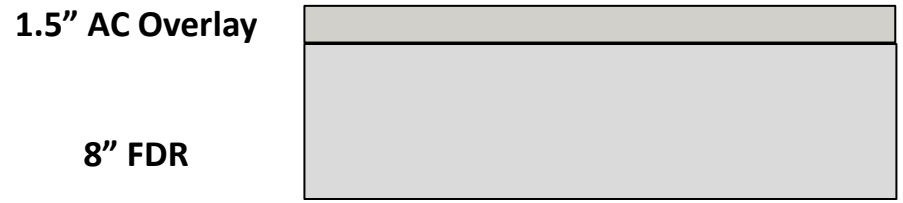
Section #3



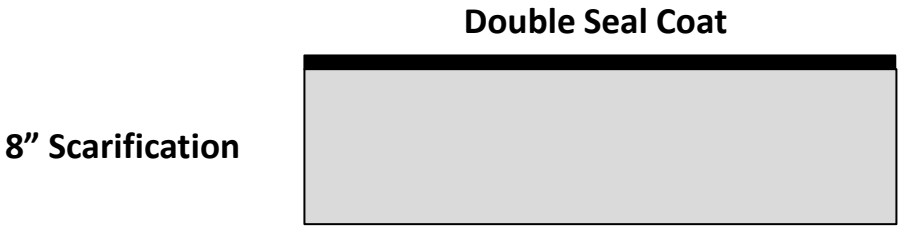
Treatments (Cont.)

- **Test Section #4:**
  - Full depth reclamation (FDR) with AC overlay
  - 1.0 mile
- **Test Section #5:**
  - FDR with double seal coat
  - 0.4 miles
- **Test Section #6:**
  - Cold-in-place recycling (CIR) with double seal coat
  - 1.4 miles

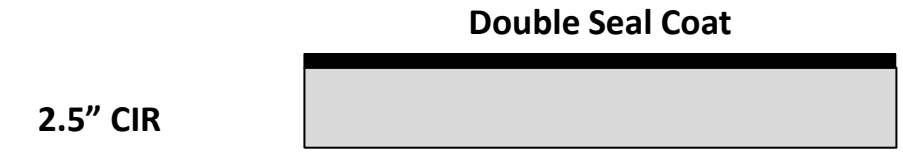
Section #4



Section #5



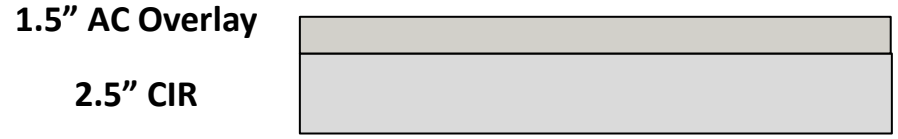
Section #6



Treatments (Cont.)

- **Test Section #7:**
  - CIR with AC overlay
  - 1.6 miles
- **Test Section #8:**
  - HMA overlay
  - 1.4 miles
- **Test Section #9:**
  - Leveling and strengthening course with seal coat
  - 1.9 miles

Section #7



Section #8

Section #9

Treatments (Cont.)

- **Test Section #10:**
  - Scarification with seal coat
  - 0.3 miles
  - “Urban” section in Fayette

Section #10

Scarification

- **Process**
  - Mill the pavement surface with a profiler.
  - Transport RAP using trucks.
  - Control dusts with water.
  - Sweep scarified surface.

Scarification (Cont.)

- **Quality Control**
  - Slope check: between 2% to 3%

Scarification (Cont.)

Cold-in-place Recycling

➢ Process

(a) Milling machine

(b) Crushing and screening unit

(c) Pug mill

(d) Oil tank trailer

Cold-in-place Recycling Train

➢ Material

- Virgin binder content = 2.3%
- Binder: foamed PG52-34 asphalt binder

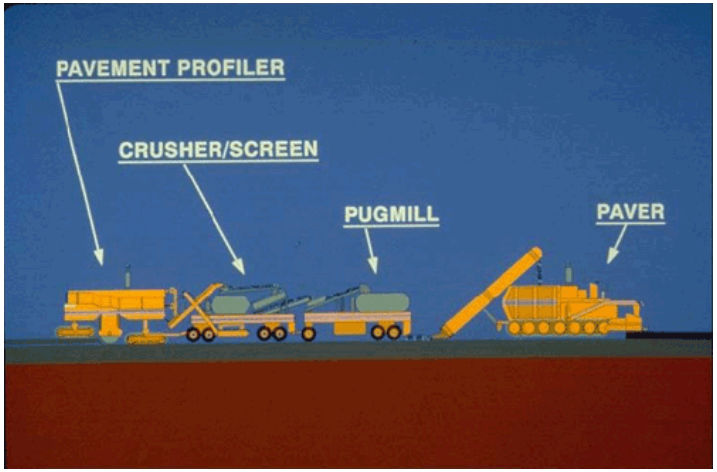


Image from FHWA website

Cold-in-place Recycling (Cont.)

Quality Control

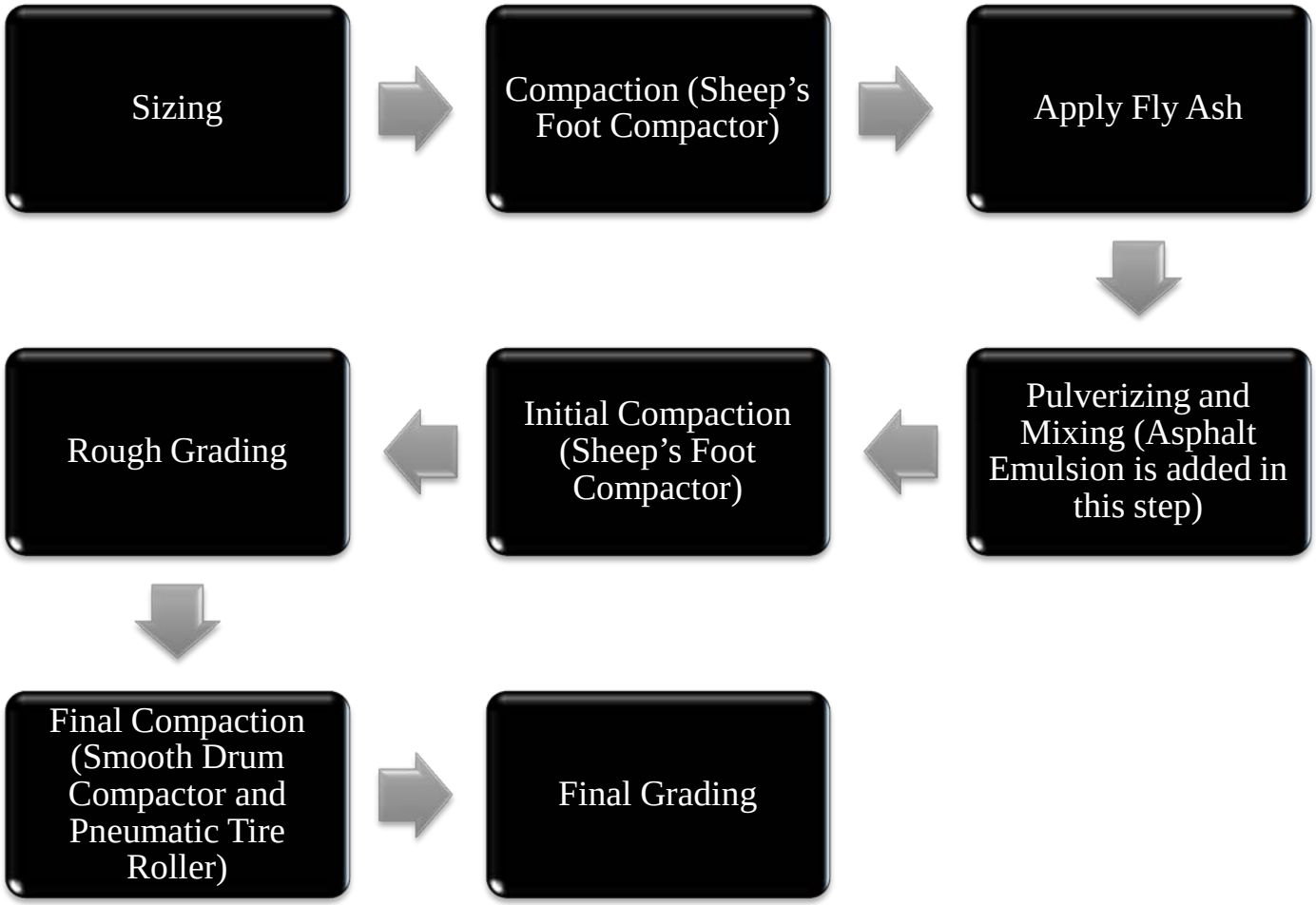
- Field dry density: ≥ 94% of lab sample density (corrected with moisture content)

Test Date	7/23	7/24	7/25	7/26
Corrected Laboratory Dry Density, pcf	126.6	127.1	127.1	127.1
Average Corrected Field Dry Density, pcf	122.9	123.7	123.3	121.0
Percent of Laboratory Density, %	97.1	97.3	97.0	95.2
Percent moisture, %	5.2	4.8	4.7	5.1

Cold-in-place Recycling (Cont.)

Full-Depth Reclamation

Process

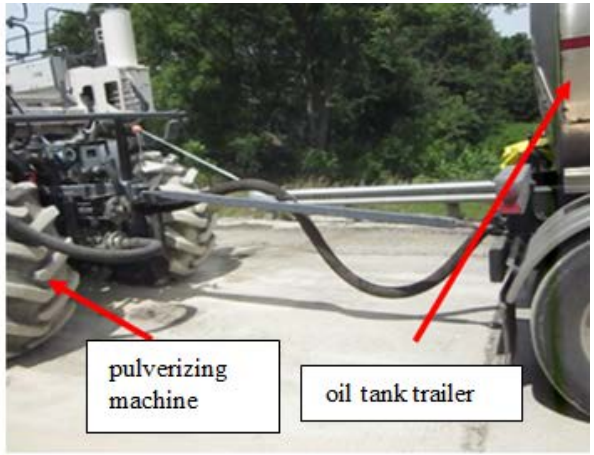


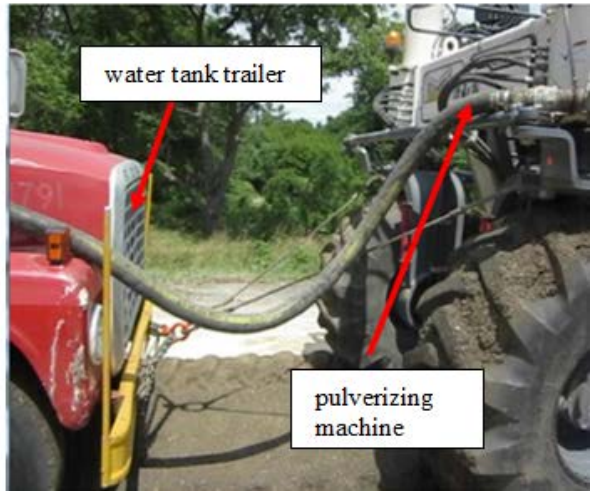
Full-Depth Reclamation (Cont.)

- **Process: Sizing**

Full-Depth Reclamation (Cont.)

- **Process (Pulverizing and Mixing)**





Full-Depth Reclamation (Cont.)

- **Process (Grading and Compaction)**

Full-Depth Reclamation (Cont.)

Material

- Virgin binder content: 2.8%
- Binder: foamed PG52-34 asphalt binder
- Fly ash content: 2%

Quality Control

- Field density at 3/4 of the FDR thickness ≥ 94% lab sample density (corrected with moisture content)
- Field density at 1/4 of the FDR thickness ≥ 97% of the field density at 3/4 of the FDR thickness

Interlayer, Leveling & Strengthening Course

- Thin interlayer and leveling and strengthening course were constructed with conventional HMA paving techniques.
- Interlayer was placed on the scarified surface.
- Leveling and strengthening course was placed on existing pavement directly.
- Tack coat was applied to ensure bonding at the interface of the existing pavement and the newly constructed layer.

Interlayer, Leveling & Strengthening Course (cont.)

➢ Material

1" Interlayer Course Mix		1" Leveling and Strengthening Course Mix	
Aggregate	**Percent in Aggregate**	**Aggregate**	**Percent in Aggregate**
3/8" ACC Stone	40	3/8" ACC Stone	30
3/16" Washed Manufactured Sand	20	3/8" Washed Chips	15
Washed Concrete Sand	25	3/8" Washed Manufactured Sand	30
Aggregate Lime	15	Washed Concrete Sand	25
Binder	**Percent in Mixture**	**Binder**	**Percent in Mixture**
PG64-34	7.4%	PG58-28	6.3%

HMA Overlay

- **2 inches HMA Overlay**
  - Serves as the control section
  - Test Section #8

- **Thin Overlay**
  - Layer thickness ≤ 1.5 inches (sometimes a 2” overlay is still called thin overlay)
  - Test Sections #1, #2, #4, #7

- **Ultra-thin Overlay**
  - Layer thickness ≤ 1 inch (most states), ≤ 1.25 inches (California)
  - Test Section #3

HMA Overlay (Cont.)

➢ Material

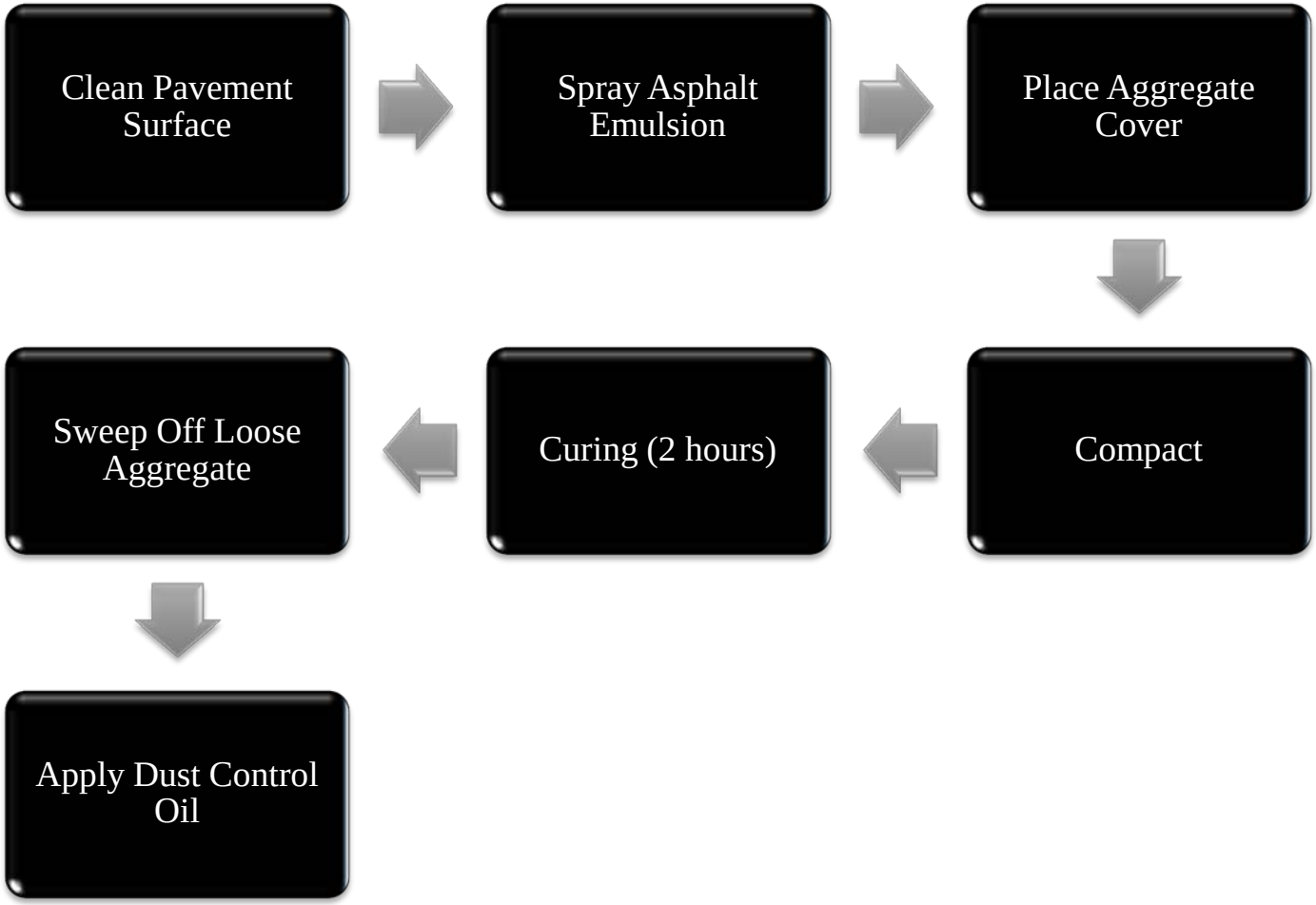
1.5" and 2" Surface Course Mix		0.75" Ultra-thin Surface Course Mix	
Aggregate	**Percent in Aggregate**	**Aggregate**	**Percent in Aggregate**
1/2" ACC Stone	15	3/8" ACC Stone	48
1/2" Washed Chips	25	3/16" Washed Manufactured Sand	32
3/16" Washed Manufactured Sand	10	Washed Concrete Sand	7
Washed Concrete Sand	30	3/8" Washed Chip	13
RAP	20		
Binder	**Percent in Mixture**	**Binder**	**Percent in Mixture**
PG58-28	5.3%	PG76-34	6.7%

HMA Overlay (Cont.)

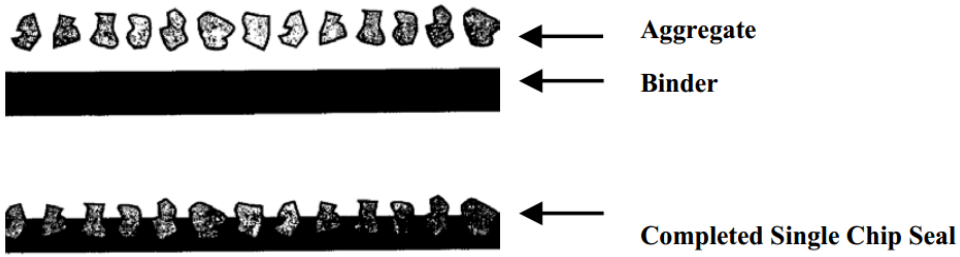
- **Concerns for thin and ultra-thin overlays**
  - Temperature drops fast.
  - Compaction needs to be done carefully and quickly.
  - Difficult to recover cores.
  - In-situ density measurements are problematic.

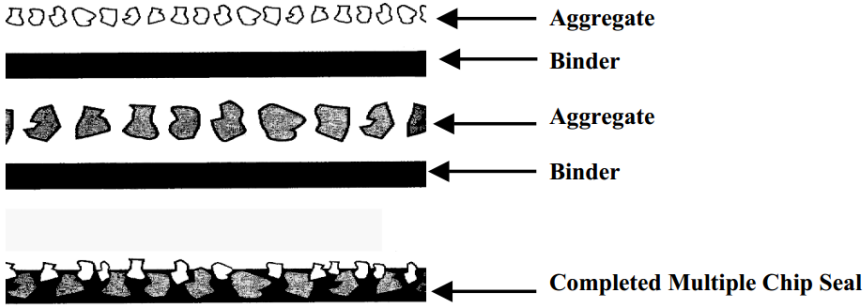
Seal Coat (Chip Seal)

Process



Seal Coat (Cont.)





(Figures were retrieved from California DOT Pavement Maintenance Technical Advisory Guide)

Seal Coat (Cont.)

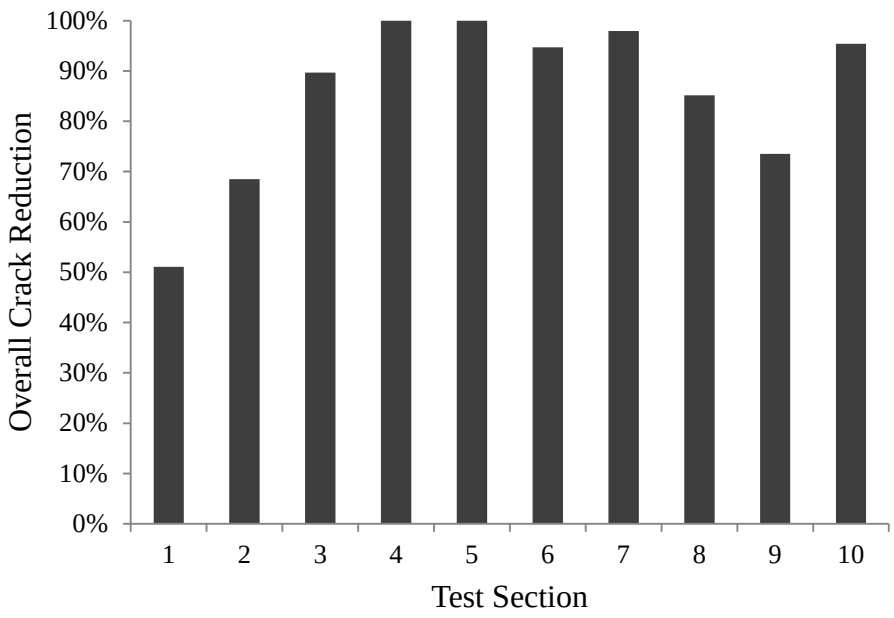
Pavement Survey

- **Right after construction**
  - No distresses were observed; quality of construction was confirmed.
- **October, 2013**
  - No distresses were observed; FWD test was performed.
- **Other Surveys**

Pre-construction survey	**July 2013**
Project construction	August and September 2013
1st post-construction survey	September 2013
2nd post-construction survey	April 2014
3rd post-construction survey	October 2014
4th post-construction survey	April 2015

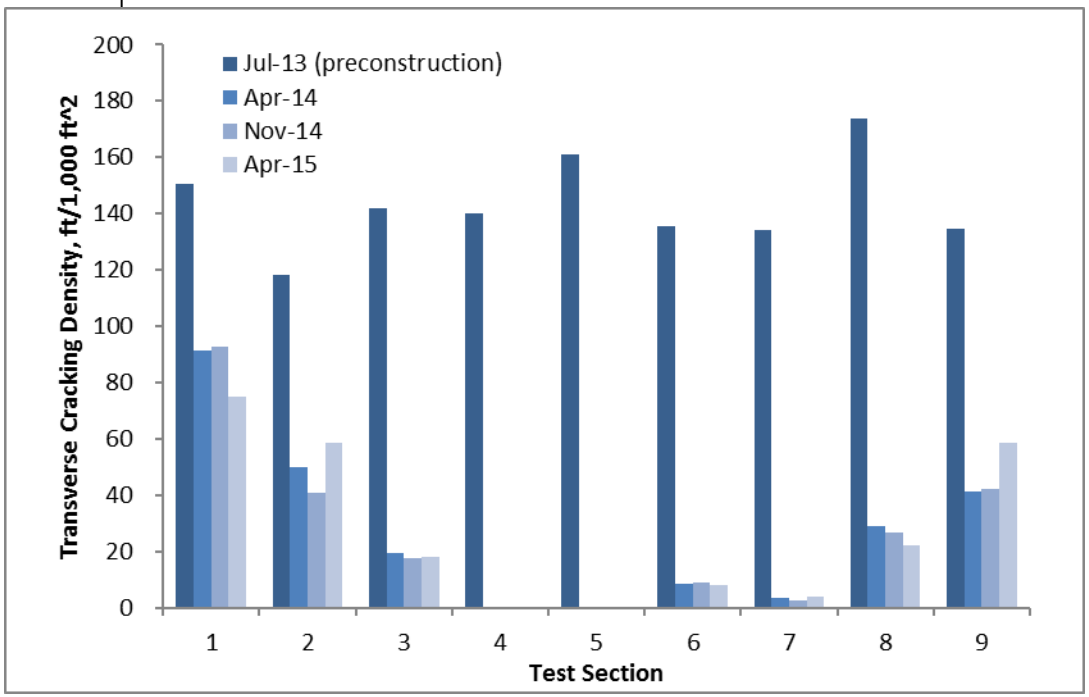
Test Section Performance

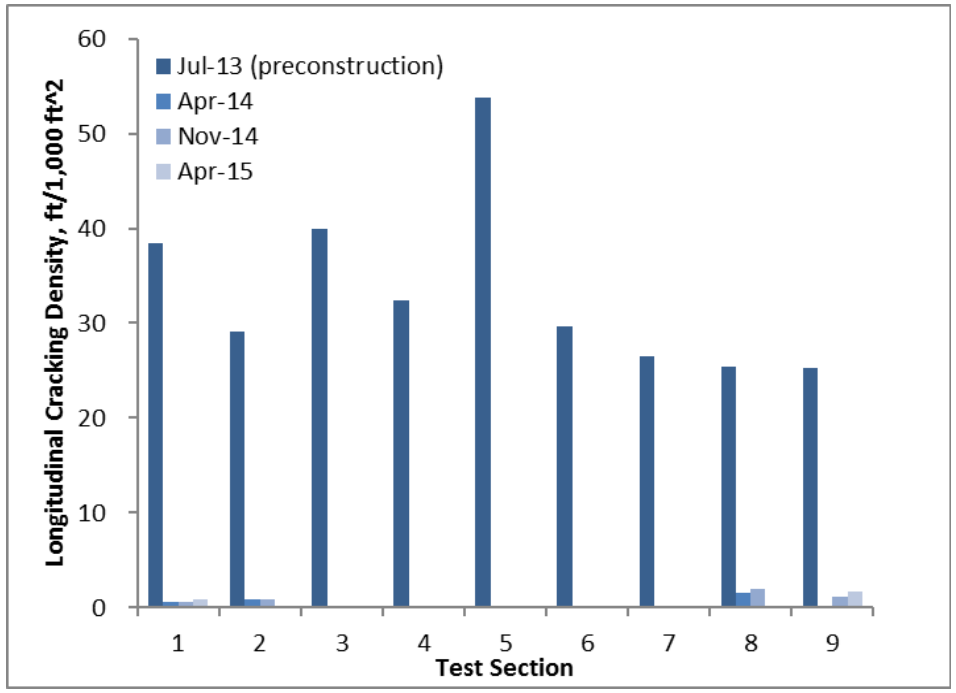
- Predominating distress type is transverse cracking.
- Other observed distresses: pothole, stripping of chip seal.
- FDR and CIR were the most effective treatments for cracking mitigation.
- Chip seal surface seems not to decrease the ability of base treatment to correct cracking; however, it has a higher chance to mitigate surface defects than AC overlay.



Test Section	Surface Type	Pothole		Chip Seal Stripping
		2013/7	2014/10	
1	AC	X		
2	Chip Seal			
3	AC			
4	AC			
5	Double Chip Seal		X	X
6	Double Chip Seal			
7	AC			
8	AC			
9	Chip Seal	X		
10	Chip Seal		X	X

Test Section Performance





1	1” Scar. + 1.5” AC Overlay	6	2.5” Cold In-place Recycling + 2XSeal Coat
2	1” Scar. + 1.5” AC Overlay + Seal Coat	7	2.5” Cold In-place Recycling + 1.5” Overlay
3	1” Scar. + 1” Interlayer + 0.75” Ultrathin	8	2.0” Overlay
4	Full-Depth Reclamation + 1.5” Overlay	9	1.0” Leveling/Strengthening + Seal Coat
5	Full-Depth Reclamation + 2XSeal Coat	10	1.0” Scar. + Seal Coat

Test Section Performance

- Snow plowing impose significant damage to chip seal surface. Base treatment type seems to have influence on the damage level of chip seal surface.

Double chip seal surface on FDR layer

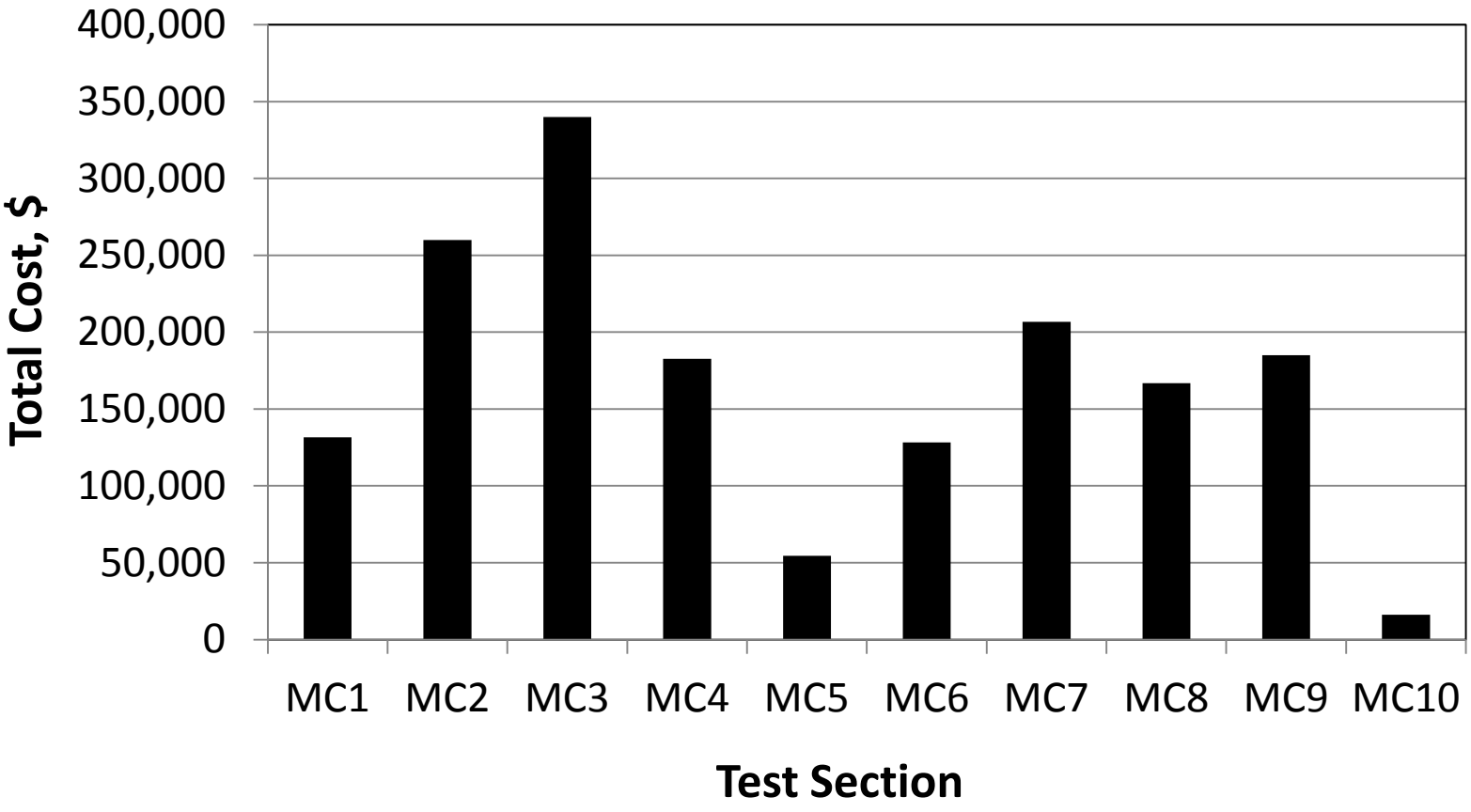
Double chip seal surface on CIR layer

Chip seal surface on scarified surface

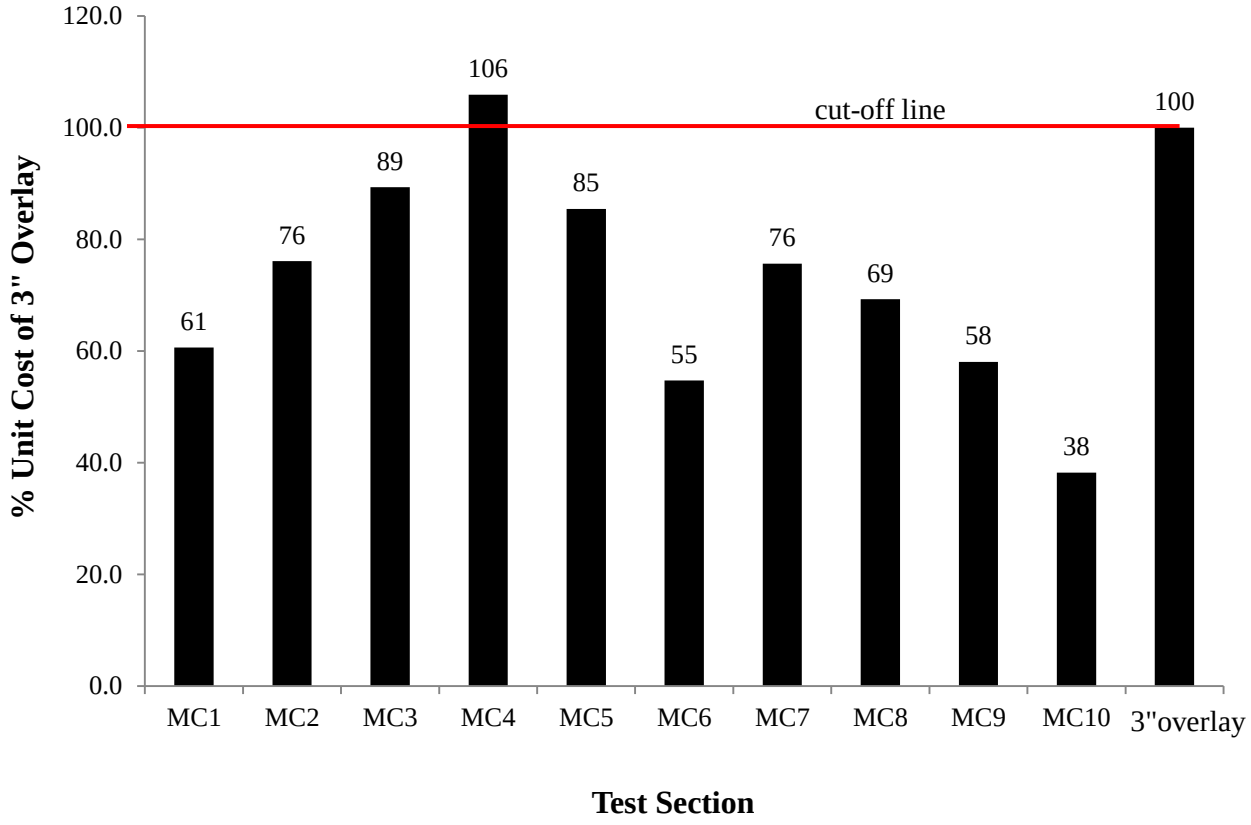
Chip seal surface on 1.5” AC overlay

Cost of Construction

Total construction cost: **$1,692,157 ($124,423/mile)**



Cost of Construction



1	1” Scar. + 1.5” AC Overlay	6	2.5” Cold In-place Recycling + 2XSeal Coat
2	1” Scar. + 1.5” AC Overlay + Seal Coat	7	2.5” Cold In-place Recycling + 1.5” Overlay
3	1” Scar. + 1” Interlayer + 0.75” Ultrathin	8	2.0” Overlay
4	Full-Depth Reclamation + 1.5” Overlay	9	1.0” Leveling/Strengthening + Seal Coat
5	Full-Depth Reclamation + 2XSeal Coat	10	1.0” Scar. + Seal Coat

References

- Yu, J., Jahren, C.T., and Williams, R.C. “Development of Holding Strategies for Deteriorated Low-Volume Roads: Introduction to Test Sections in Iowa”, Transportation Research Record: Journal of the Transportation Research Board, Volume 2474, pages 217-224, June 2015.
- http://trrjournalonline.trb.org/doi/pdf/10.3141/2474-26
- Forthcoming Iowa DOT Research Report

Questions?

Thank You!

New Approaches for Upgrading Gravel Roads to a Low Volume Sealed Standard Based on the Use of the Dynamic Cone Penetrometer

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Africa Community Access Programme

Outline of Presentation

- Background
- DCP Design Method
- Material Selection and Specification
- Compaction Quality Control Using the DCP
- Strengths and limitations of DCP design method
- Summary

Background

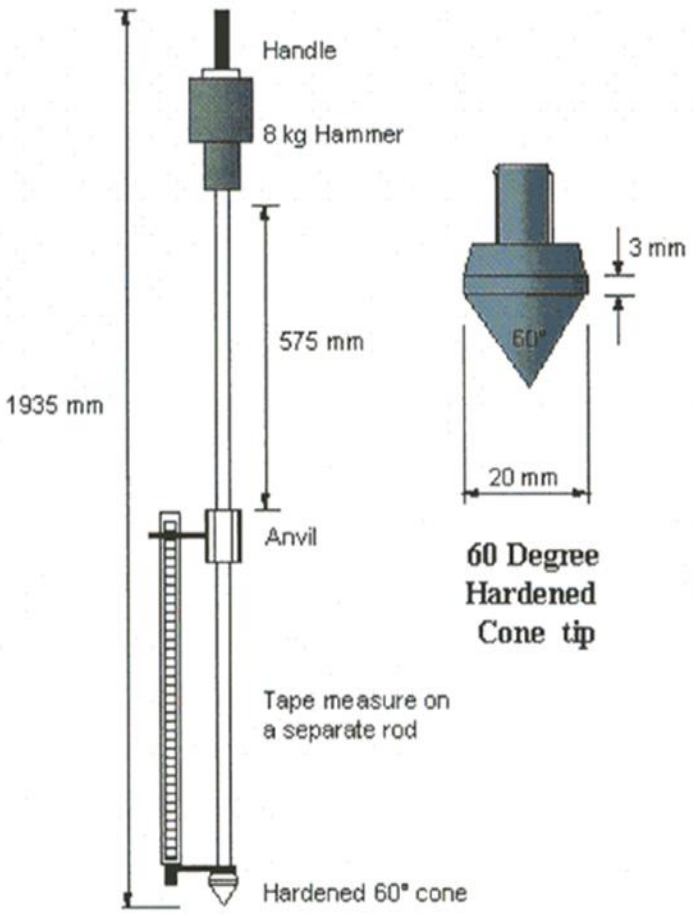
- Approximately 1 million km of unsealed roads on African continent
- Increasingly difficult to maintain:
  - Constraints: financial, logistical, and technical burden coupled with depletion of non-renewable resource (gravel)
  - Consequence: lack reliable access to many rural communities
- Solution: Upgrade unpaved roads to a paved standard
- Problem: Cost of upgrading following traditional approaches is prohibitively expensive
- Way forward: Research has led to development of new approach for upgrading gravel roads to a paved standard based on the use of the Dynamic Cone Penetrometer (DCP)

DCP Outline Details

- DCP measures in situ shear strength which is a function of material moisture, density, grading and plasticity at time of testing.

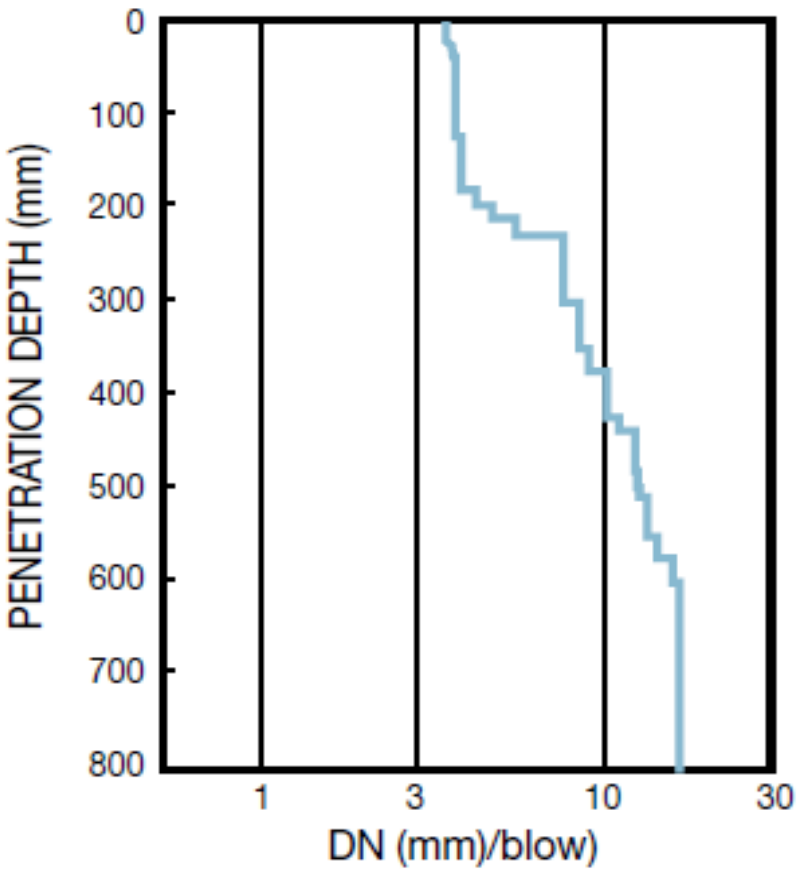
- Test entails dropping an 8 kg mass from 575 mm height, recording the penetration of the cone in the material per number of blows and evaluatinge the weighted average of the rate of penetration in mm/blow (DN value)

- DCP structure number: number of DCP blows required to penetrate a pavement structure or layer, e.g. DSN_{800} = number of blows to penetrate 800mm of pavement



DCP Test

DCP test in progess



DCP resistance to penetration versus depth

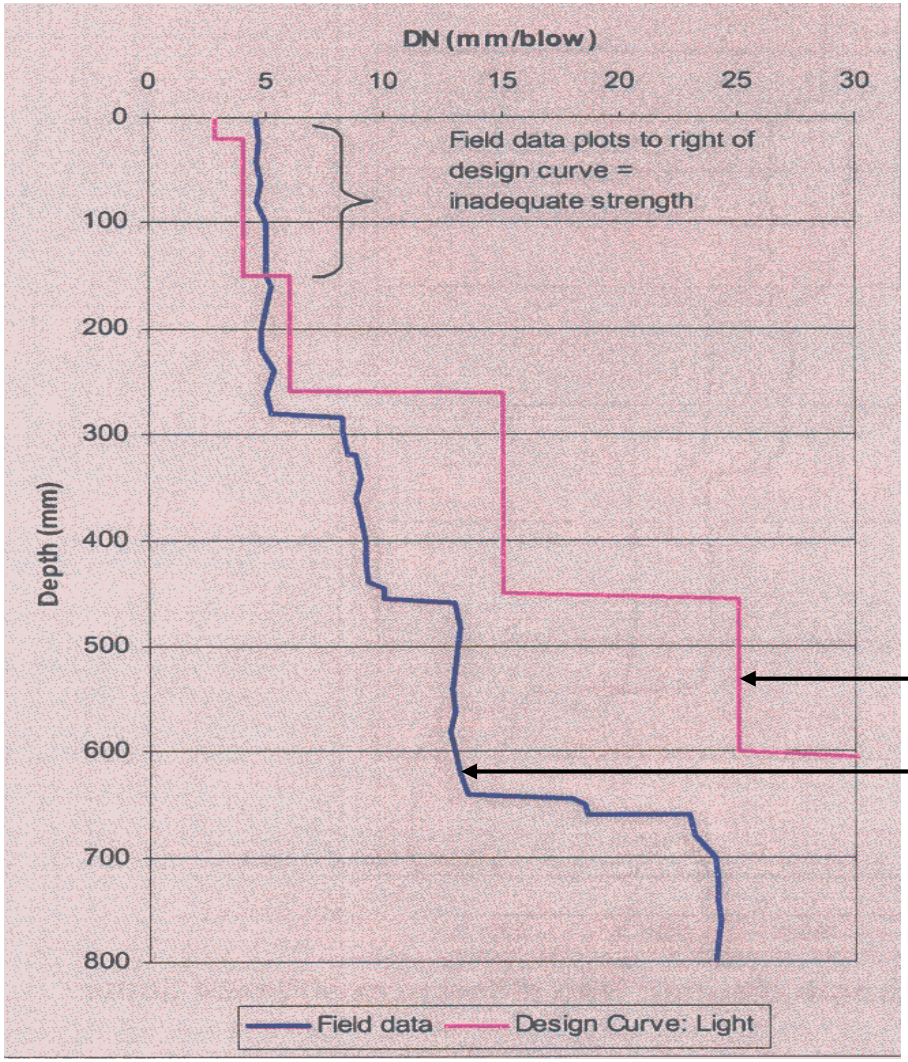
Development of DCP Design Method

- Original development dates back to mid-1950s in Australia
- Used initially as non-destructive device to evaluate shear strength of material in pavement
- Further developed in S. Africa in mid 1970s as an empirical method of LVR design on basis of extensive back-analysis of existing pavements in conjunction with Heavy Vehicle Simulator (HVS) testing
- Allowed relationships to be developed between DCP penetration curves and life of pavements.
- Further enhanced under AfCAP to include material selection and specification and laboratory DN testing.

DCP Design Catalogue

Traffic Class E80 x 10^6	TLC 0.01 < 0.010	TLC 0.03 0.010 – 0.030	TLC 0.1 0.030 – 0.100	TLC 0.3 0.100 – 0.300	TLC 0.7 0.300–0.700	TLC 1.0 0.700 – 1.0
0- 150mm Base ≥ 98% MAASHTO	DN ≤ 8	DN ≤ 5.9	DN ≤ 4	DN ≤ 3.2	DN ≤ 2.6	DN ≤ 2.5
150-300 mm Subbase ≥ 95% MAASHTO	DN ≤ 19	DN ≤ 14	DN ≤ 9	DN ≤ 6	DN ≤ 4.6	DN ≤ 4.0
300-450 mm subgrade ≥ 95% MAASHTO	DN ≤ 33	DN ≤ 25	DN ≤ 19	DN ≤ 12	DN ≤ 8	DN ≤ 6
450-600 mm In situ material	DN ≤ 40	DN ≤ 33	DN ≤ 25	DN ≤ 19	DN ≤ 14	DN ≤ 13
600-800 mm In situ material	DN ≤ 50	DN ≤ 40	DN ≤ 39	DN ≤ 25	DN ≤ 24	DN ≤ 23
DSN 800	≥ 39	≥ 52	≥ 73	≥ 100	≥ 128	≥ 143

DCP Design Principle

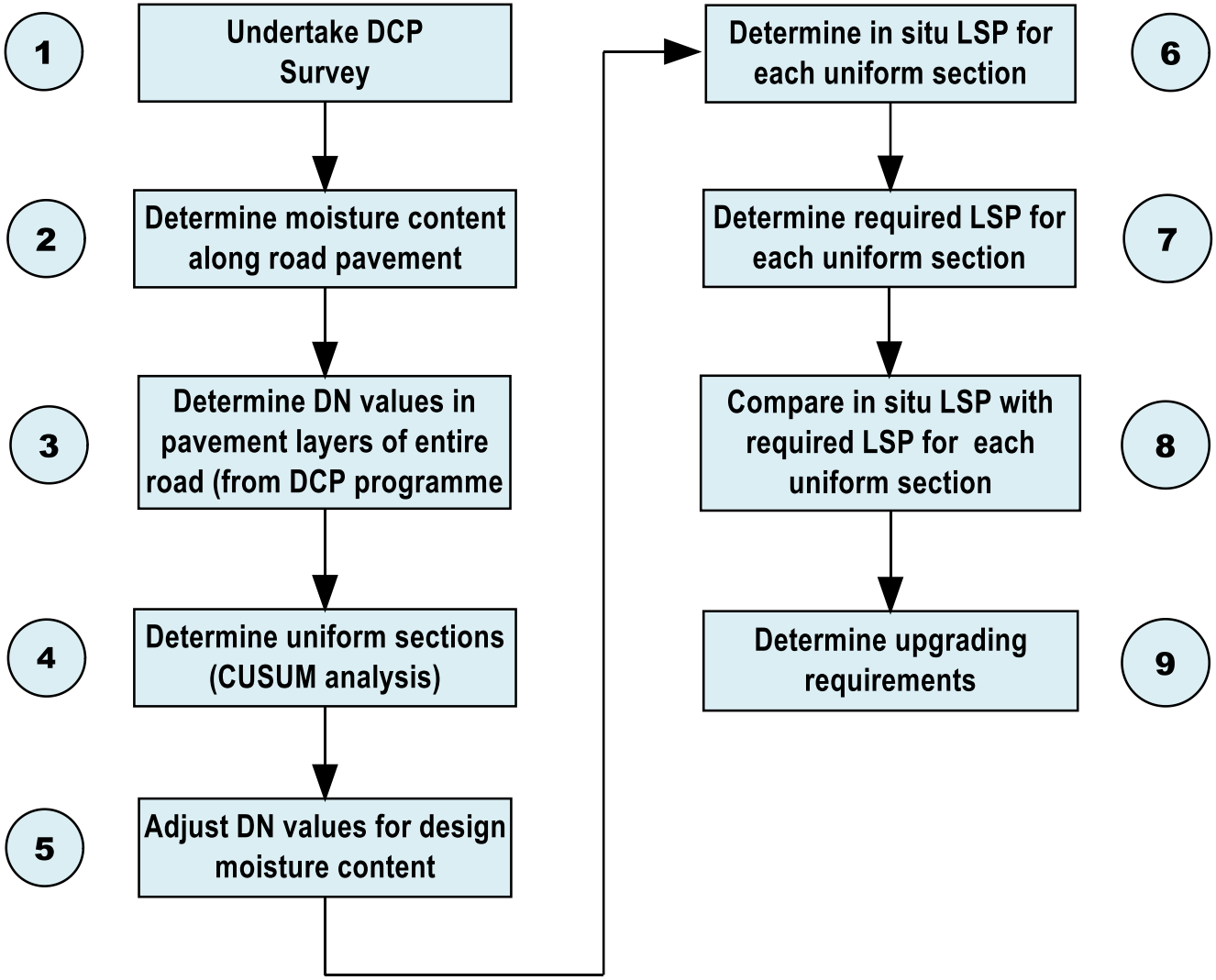


- To achieve a balanced pavement structure whilst optimizing the utilization of the in situ material strength.
  - Determining design strength profile needed
  - Integrating strength profile with in situ strength profile

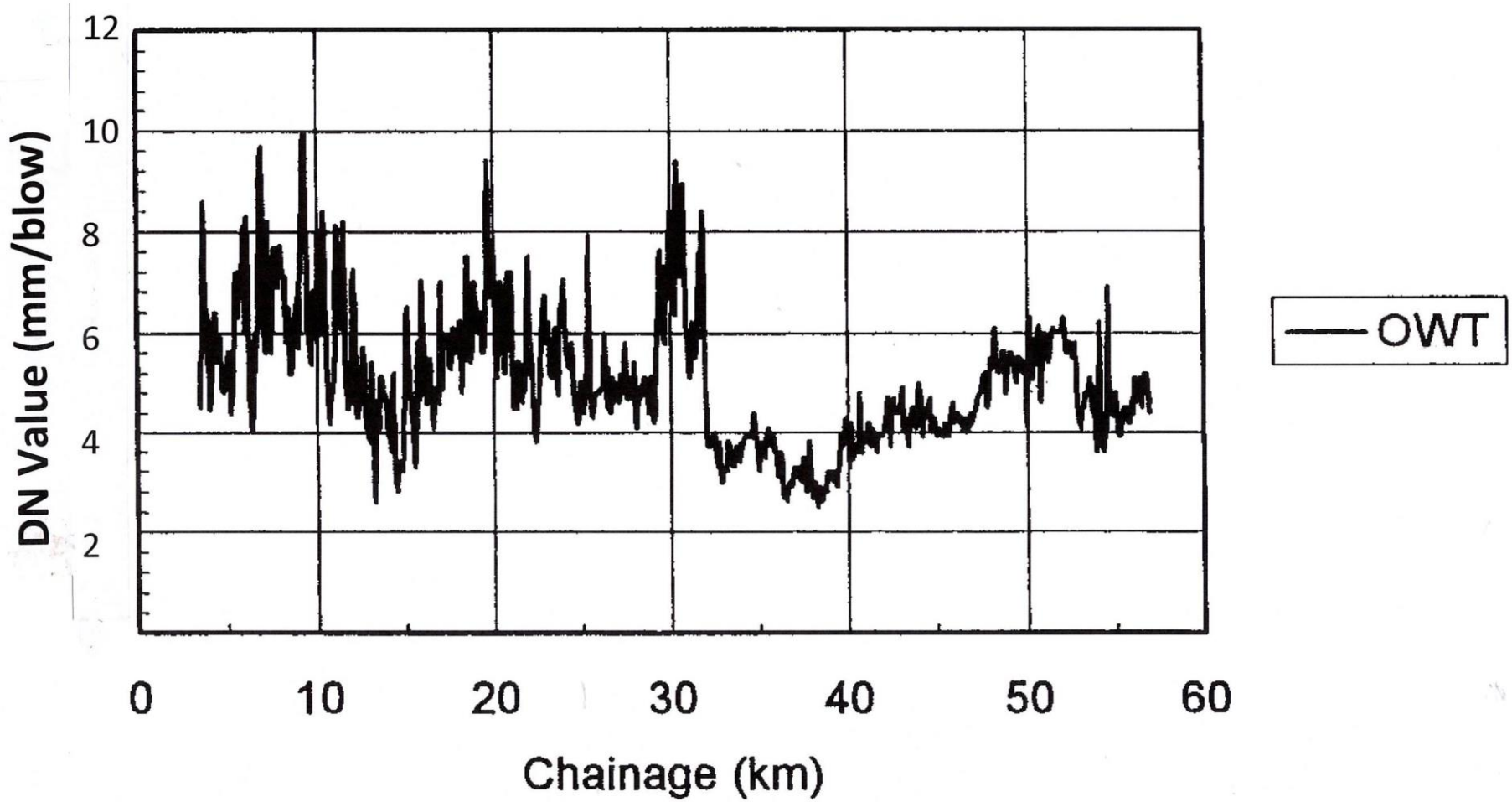
Required strength profile

In situ strength profile

DCP Design Procedure

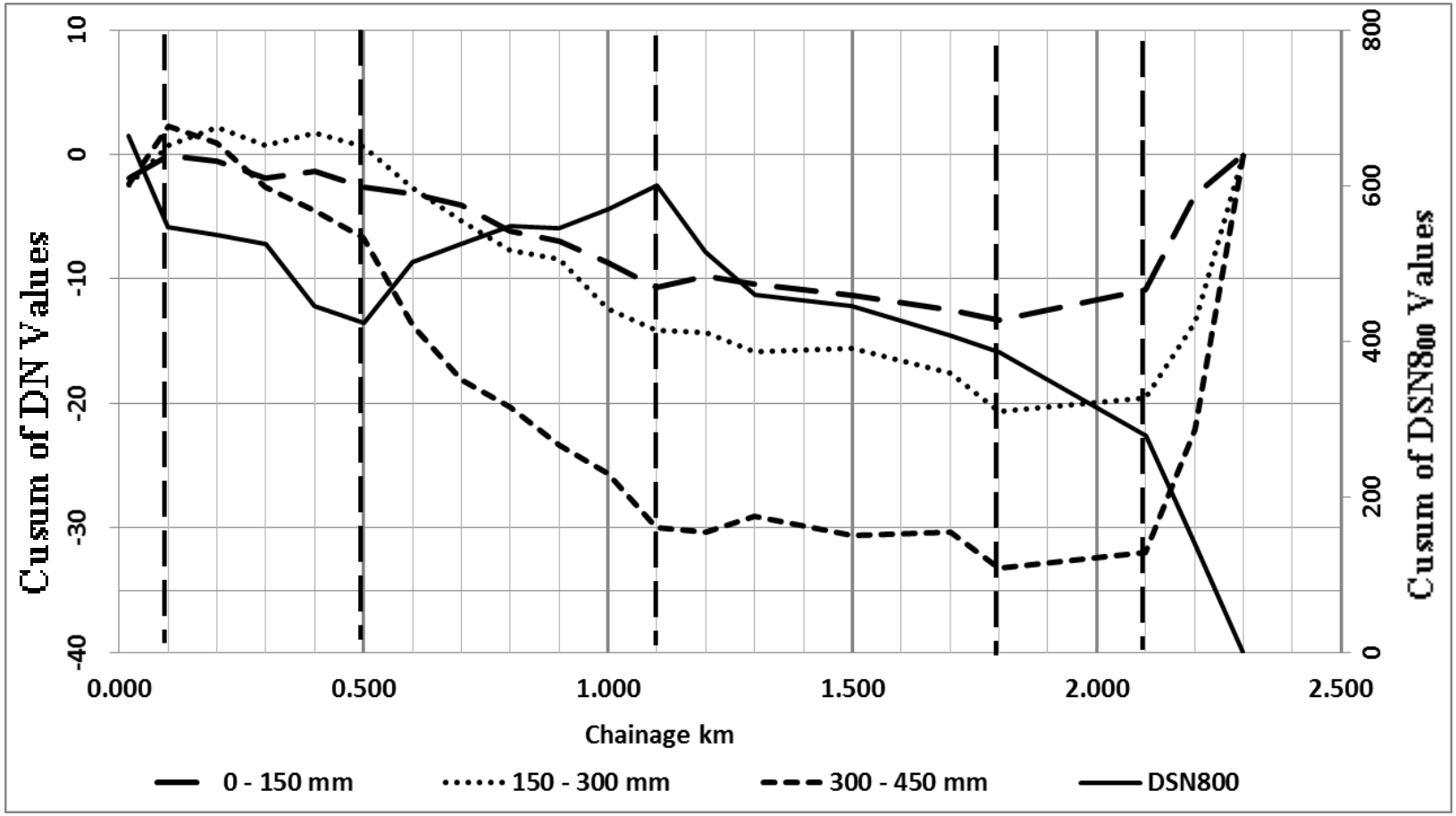


Step 1: Undertake DCP Survey Along Road



DCP provides a good "picture" of in situ ground conditions

Step 4: Determine Uniform Sections



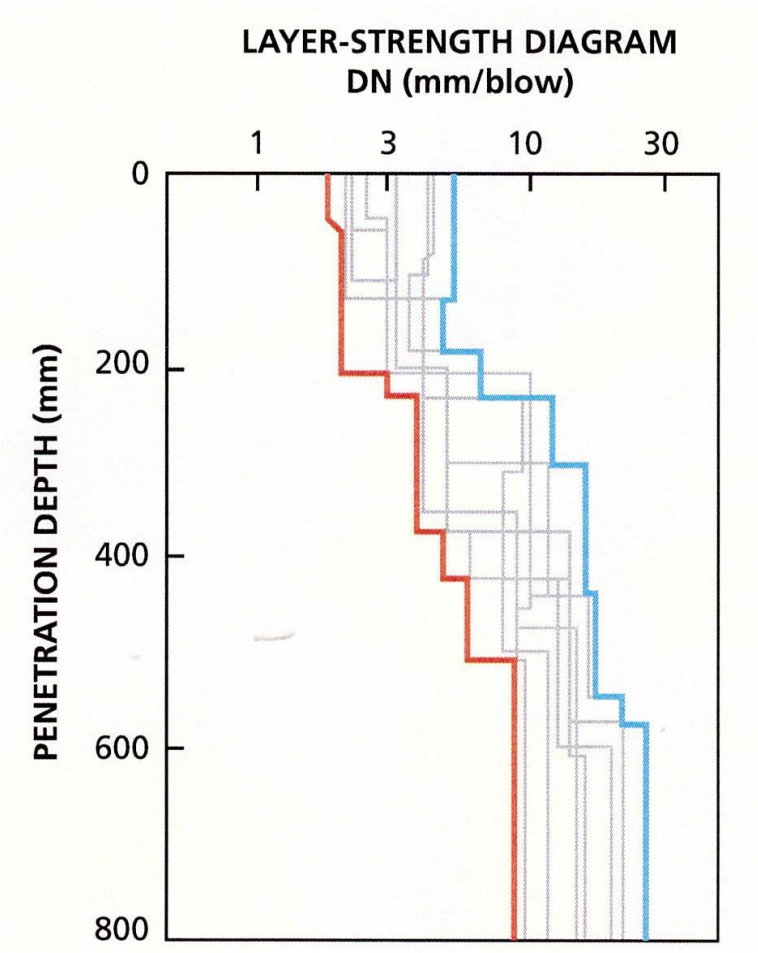
Step 5 – Adjust DN Values for Design Moisture Content

Anticipated long-term in-service moisture content in pavement	Percentile of minimum strength profile (maximum penetration rate – DN mm/blow)	
	Design traffic < 0.5 MESA	Design traffic 0.5 – 1.0 MESA
Drier than at time of DCP survey	20	30
Same as at time of DCP survey	50	65
Wetter than at time of DCP survey	80	90

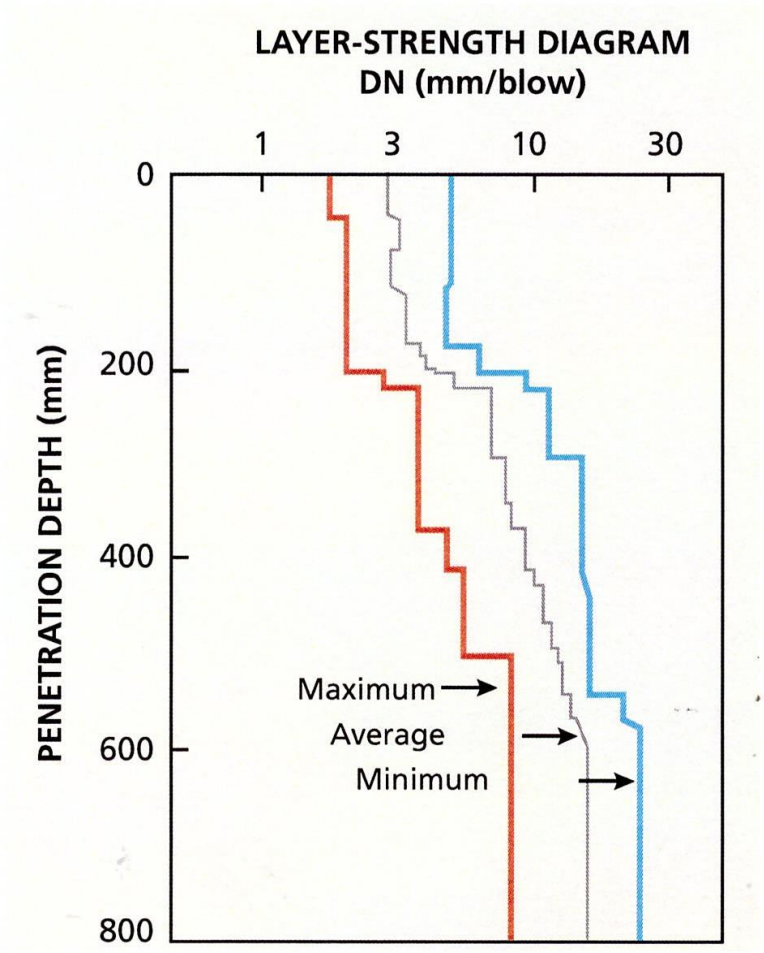
Adjustment of DN Values for Moisture

Chainage (km)	Point No	DN 0-150 (Base)	Percentile of minimum strength Profile (max. penetration rate – DN)		
			20th	50th (Mean)	80th
0.00	1	2.29	3.46	5.24	8.19
0.25	2	4.44			
0.50	3	2.00			
0.75	4	8.67			
1.00	5	3.75			
1.25	6	8.07			
1.50	7	5.11			
1.75	8	5.37			
2.00	9	6.60			
2.25	10	10.12			
Anticipated long-term in-service moisture content in pavement					
Drier than at time of DCP survey			3.46	N/A	N/A
Same as at time of DCP survey			N/A	5.24	N/A
Wetter than at time of DCP survey			N/A	N/A	8.19

Step 6-Determine In Situ LSP For Each Uniform Section

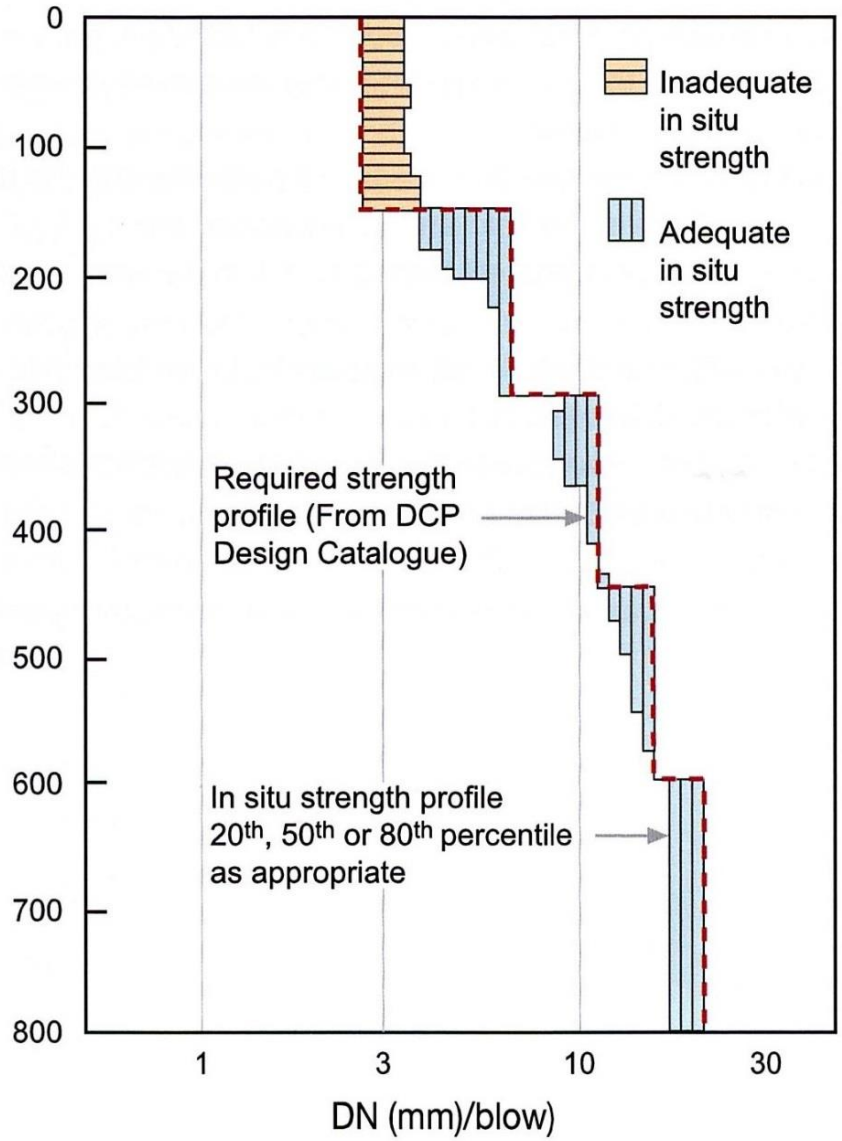


Collective DCP strength profiles



Average and extreme DCP strength profiles

Step 8:Compare In Situ & Required LSP for Uniform Section



Step 9: Determine Upgrading Requirements

- **Reworking the existing layer**
  - if only the density is inadequate and the required DN value can be obtained at the specified construction density and anticipated in-service moisture content.
- **Replacing the existing layer**
  - if material quality (DN value at specified construction density and anticipated in-service moisture content) is inadequate, then appropriate quality material will need to be imported to serve as the new upper pavement layer(s).
- **Augmenting the existing layer**
  - if material quality (DN value) is adequate but the layer thickness is inadequate, then imported material of appropriate quality will need to be imported to make up required thickness prior to compaction.

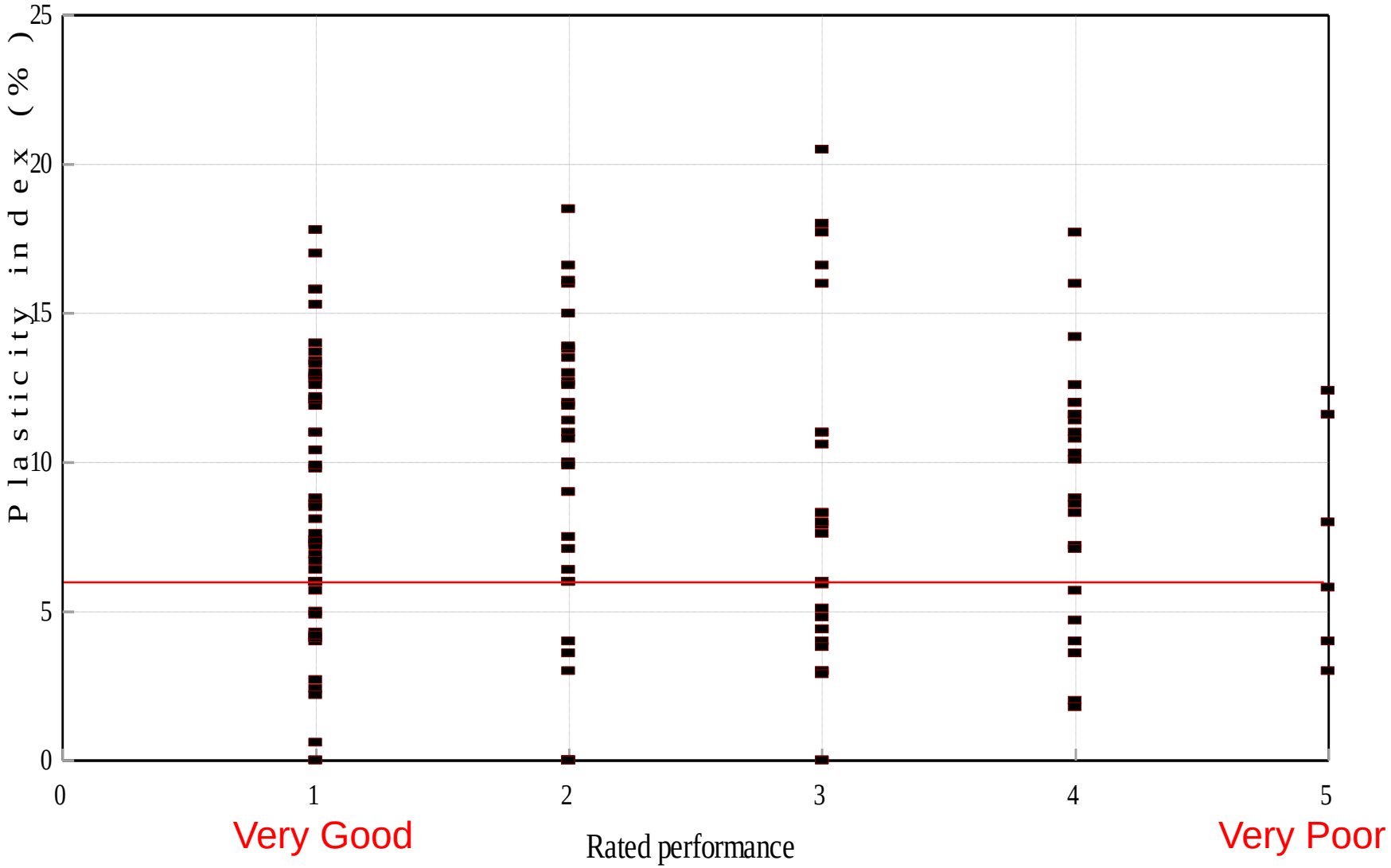
Material Selection and Specification

- DN value serves as criterion for selecting materials to be used in upper/base layer of LVSR pavement.

- Provided design DN value is achieved, then in service performance indirectly takes account of actual grading and plasticity at given moisture and density which do not need to be separately specified.
  - DN value provides a composite measure of materials resistance to penetration (= shear strength) at given moisture and density and is affected by material grading and plasticity.
  - Limits also placed on GM 1.0 – 2.2

- Criterion widens scope for more extensively utilising local materials that would otherwise be excluded, even though they are “fit for purpose”.

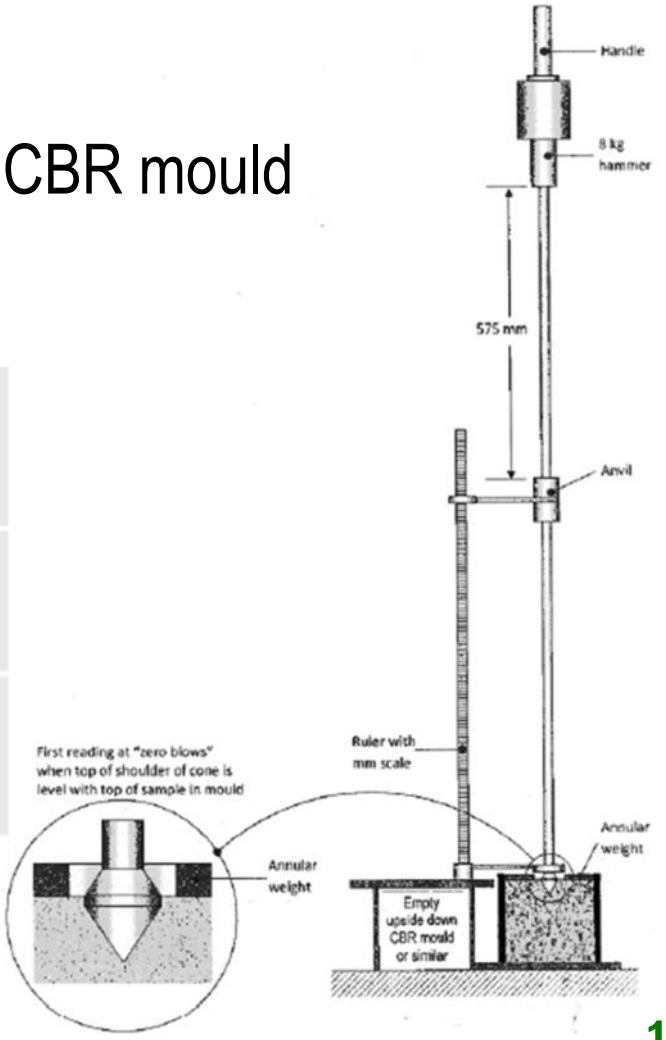
PI – Poor Correlation With Performance



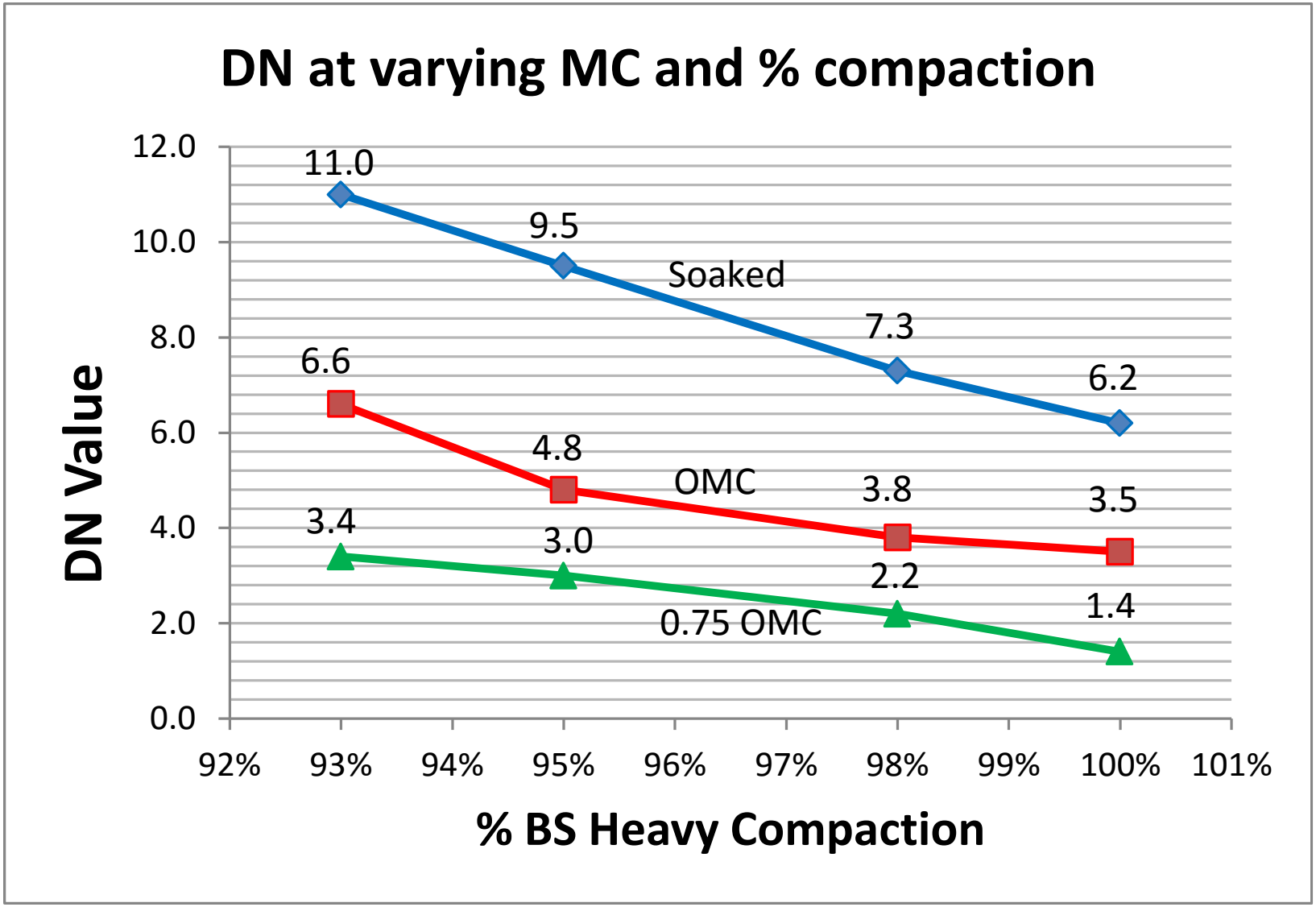
Laboratory Determination of DN value

DCP used to penetrate the CBR mould

4 days soaked sample , sealed for 4 days in plastic bag	Soaked DN
Sample at OMC, sealed for 4 to 7 days in plastic bag	OMC DN
Oven sample (0.75OMC), sealed for 4 days in plastic bag	0.75 OMC DN



DN/Density/Moisture Relationship



Compaction Quality Control Using DCP

- Traditional methods (Sand Replacement, core cutter, rubber balloon and nuclear density gauge): slow, hazardous, uncertain accuracy, and impractical for variation of material along tested section.

- Alternative method of compaction quality control with DCP:
  - level and uniformity of compaction
  - relatively simple and low cost compared
  - procedure is based on the DN value criterion, used in the pavement design
  - assessing compaction compliance, field DN versus required DN value using strength/density/moisture relationship and adjustment factor for confinement effect of mould.

Summary of DCP Method-Strengths

- Relatively low cost, robust apparatus that is quick and simple to use allowing comprehensive characterization of the in situ road conditions.
- Provides improved precision limits compared to the CBR test
- Very little damage is done to the pavement being tested (effectively non-destructive) and very useful information is obtained.
- The pavement is tested in the condition at which it performs and the test can be carried out in an identical manner both in the field and in the laboratory.
- The simplicity of test allows repeated testing to minimize errors and also to account for temporal effects.
- The laboratory DN value is determined over a depth of 150 mm and not just the top 2.5 – 5.0 mm as with the CBR test.
- The method is as good or better than any other method in taking into account variations in moisture content and provides data quickly for analysis.

Summary of DCP Method-Limitations

- Use in very coarse granular (> 37.5mm or lightly stabilized materials
- Very hard cemented layers in pavement structure
- Poorly executed tests (hammer not falling the full distance, non-vertical DCP, excessive movement of the depth measuring rod, etc.)

Conclusions

- The DCP-DN design method:
  - Makes use of a relatively inexpensive, multi-purpose device for characterising existing gravel road, testing pavement materials and undertaking compaction quality control.
  - Is based on a relatively simple design procedure that produces cost-effective, environmentally optimised designs.
  - Has been used successfully in the past two decades to design many kilometres of light pavement structures in the Southern African region.
  - Allows more extensive use to be made of local materials
  - Offers potential for economically upgrading a significantly greater length of gravel roads to a paved standard with similar risk as conventional pavement design techniques.
  - Need for full appreciation of the strengths and weaknesses of the DCP device

Examples of DCP Designed Roads

Danger Point road, South Africa (10 years after construction)

Road D379 Kiambu, Kenya (4 years after construction)

Benefits of Adopting New Approaches

- Application of locally derived, appropriate technology
- Reduced life cycle costs of LVR provision
- Facilitating socio-economic growth and development and poverty alleviation

LVR construction

Standard construction

Malawi experience

Thank you!