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

With Application to Rural Roads in Michigan

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Outline of Presentation

- Background
- DCP Design Method
- Material Selection and Specification
- Compaction Quality Control Using the DCP
- Strengths and Limitations of DCP Design Method
- Additional Sources of Information:
  ASTM D 6951, User Guide to the Dynamic Cone Penetrometer (MnDOT), Saskatchewan Highways and Transportation-STP 240-20, AASHTO Interim Structural Pavement Design Procedure, Chapter 5-Geotechnical Inputs for Pavement & Design-FHWA, NHI-05-037.

Details Worth Sweating

- Soil investigation
  - Appropriate number and type of borings
  - Verify limits of existing poor soil
  - Include appropriate pay items for soil removal
    - (i.e. subgrade undercutting, earth excavation, etc.)
  - Include boring logs on either the plans or in the GI submittal documents
  - DO NOT include the geotechnical report
- Pavement cores?
  - Good idea!
  - Should extend at least 1-inch beyond the proposed removal/ replacement thickness
  - Example-project proposing milling 4” of existing 5” HMA depth, actual depth was less than 4”

Background

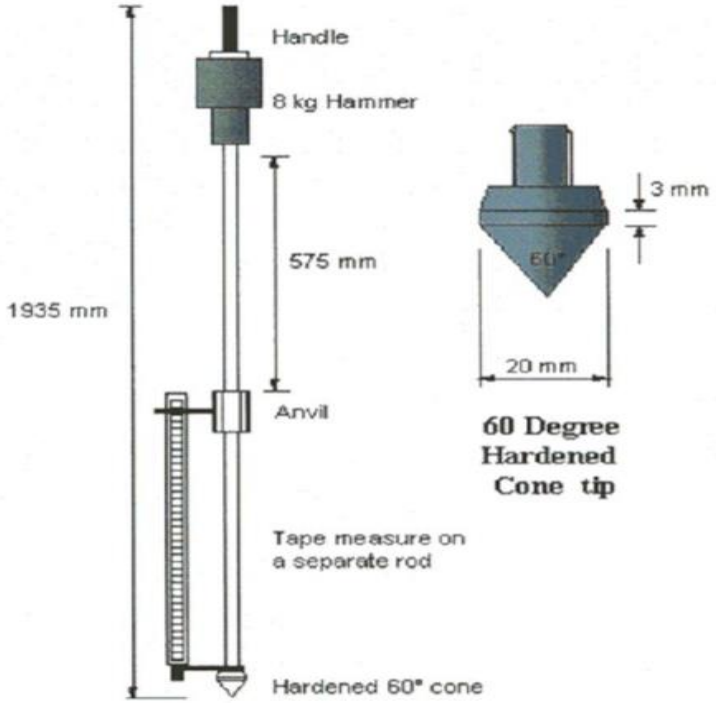
- Increasingly difficult to maintain:
  - Constraints: Financial, logistical, and technical burden coupled with depletion of non-renewable resource (gravel)
  - Consequences: Lack reliable access to many rural communities

- 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)

1 Mile= 1.61 Kilometers

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

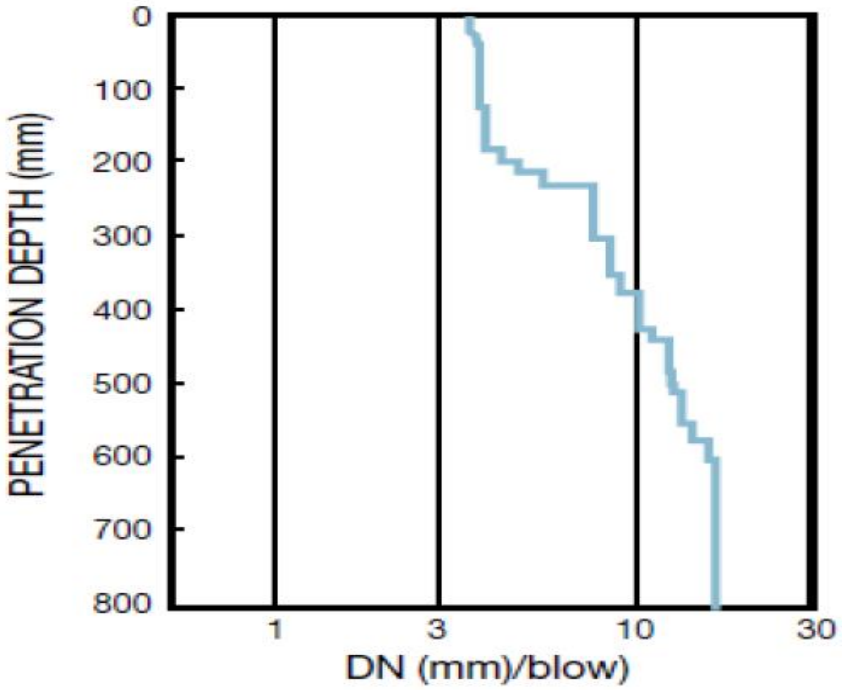


1 Inch= 25.4 mm
1 Pound= 0.454 kg

DCP Test

DCP test in progess

1 INCH= 25.4 mm



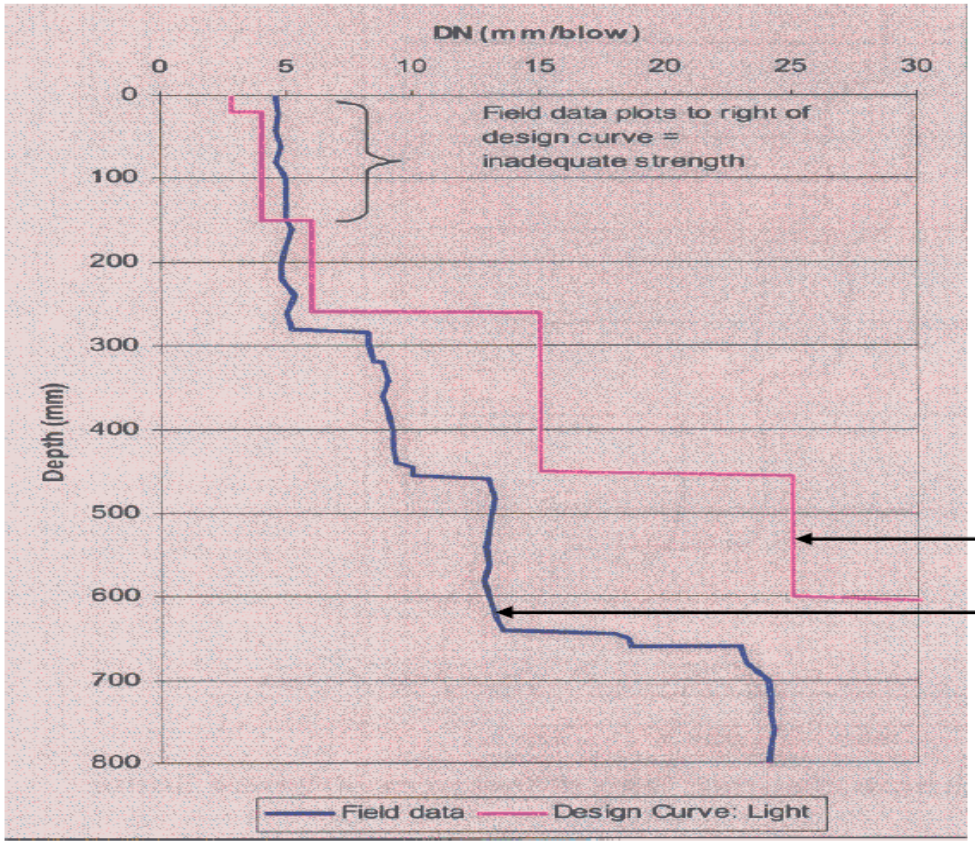
DCP resistance to penetration versus depth

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

E 80 x 10^6 kN= 18,000 x10^3 LBS (Single) AXLE LOAD)

DCP Design Principle

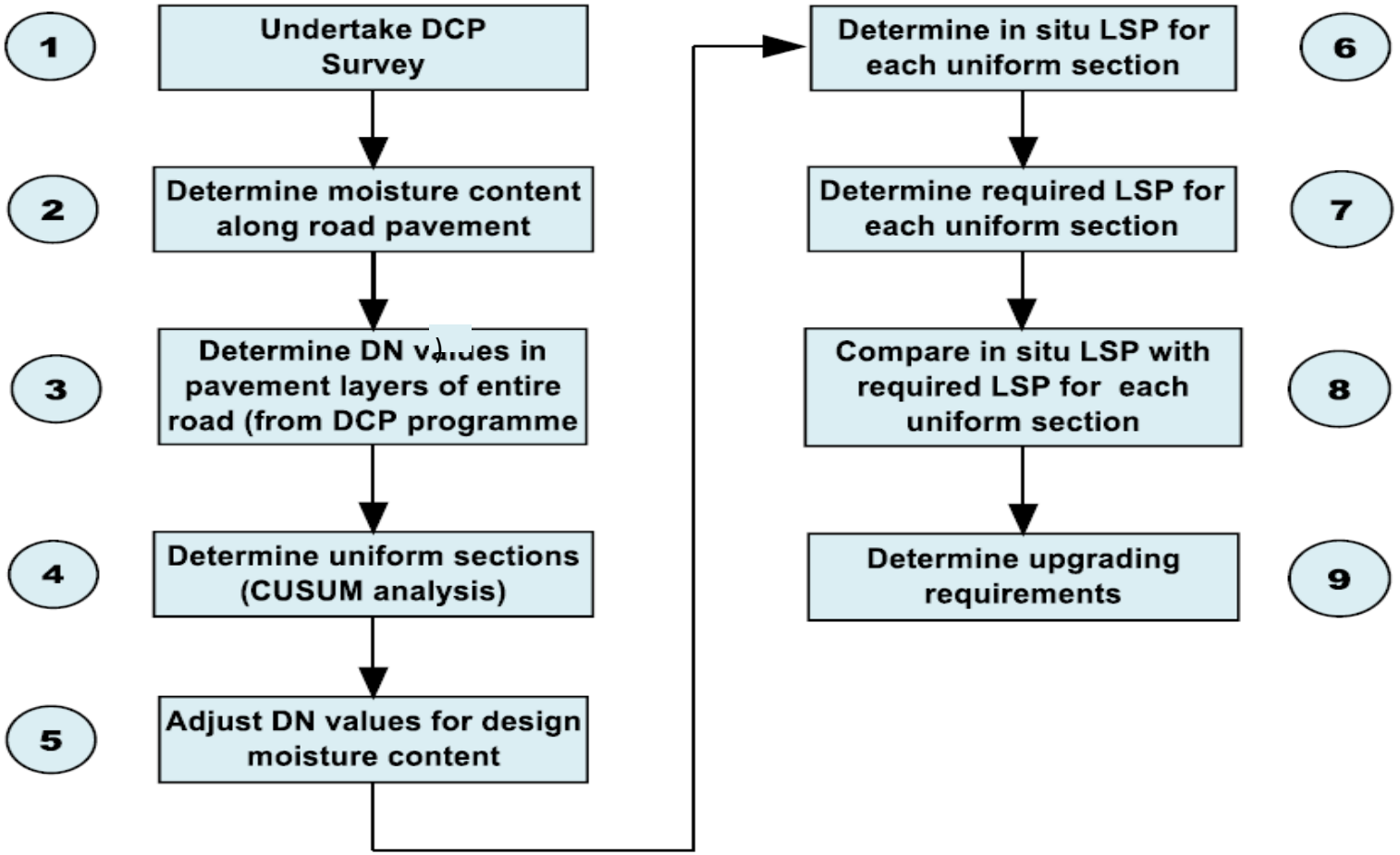


- To achieve a balanced pavement structure whilst optimizing the utilization of the in situ material strength.
  - Determining design strength profile needed
  - Integrating strength profile with in situ strength profile

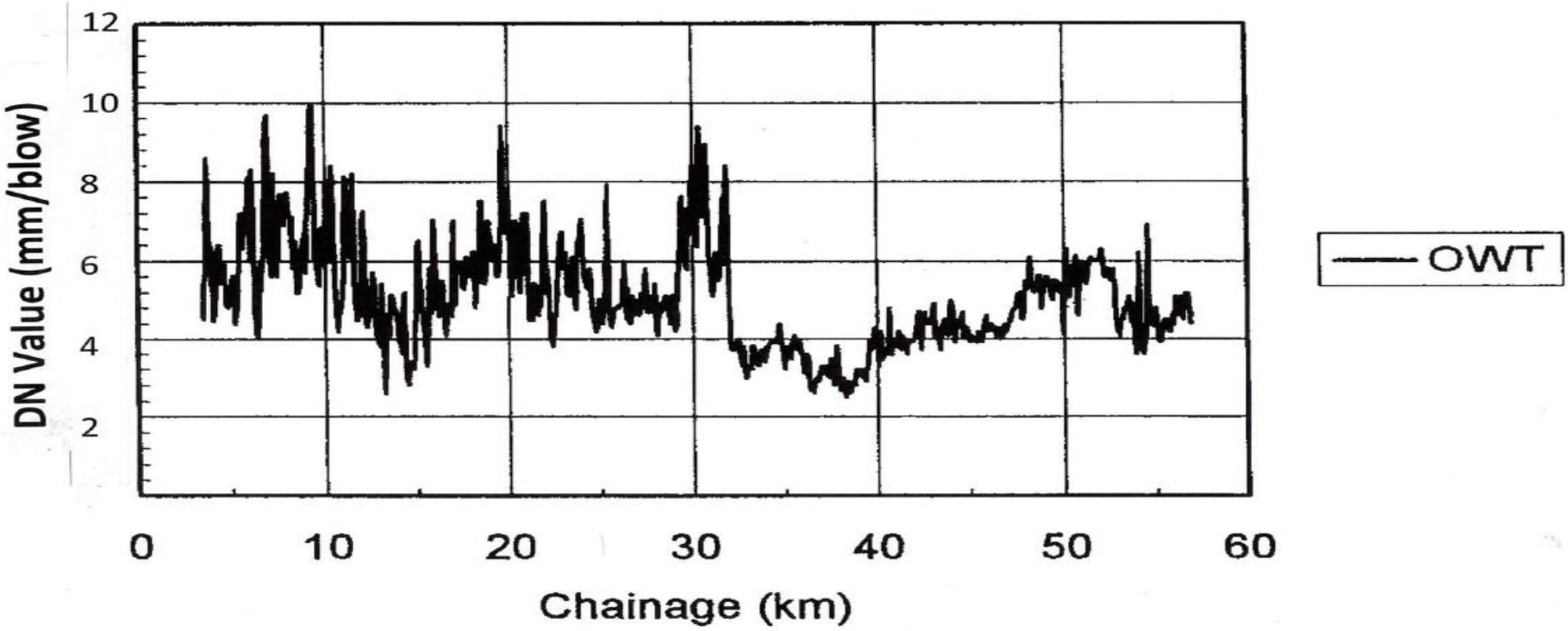
Required strength profile

In situ strength profile

DCP Design Procedure



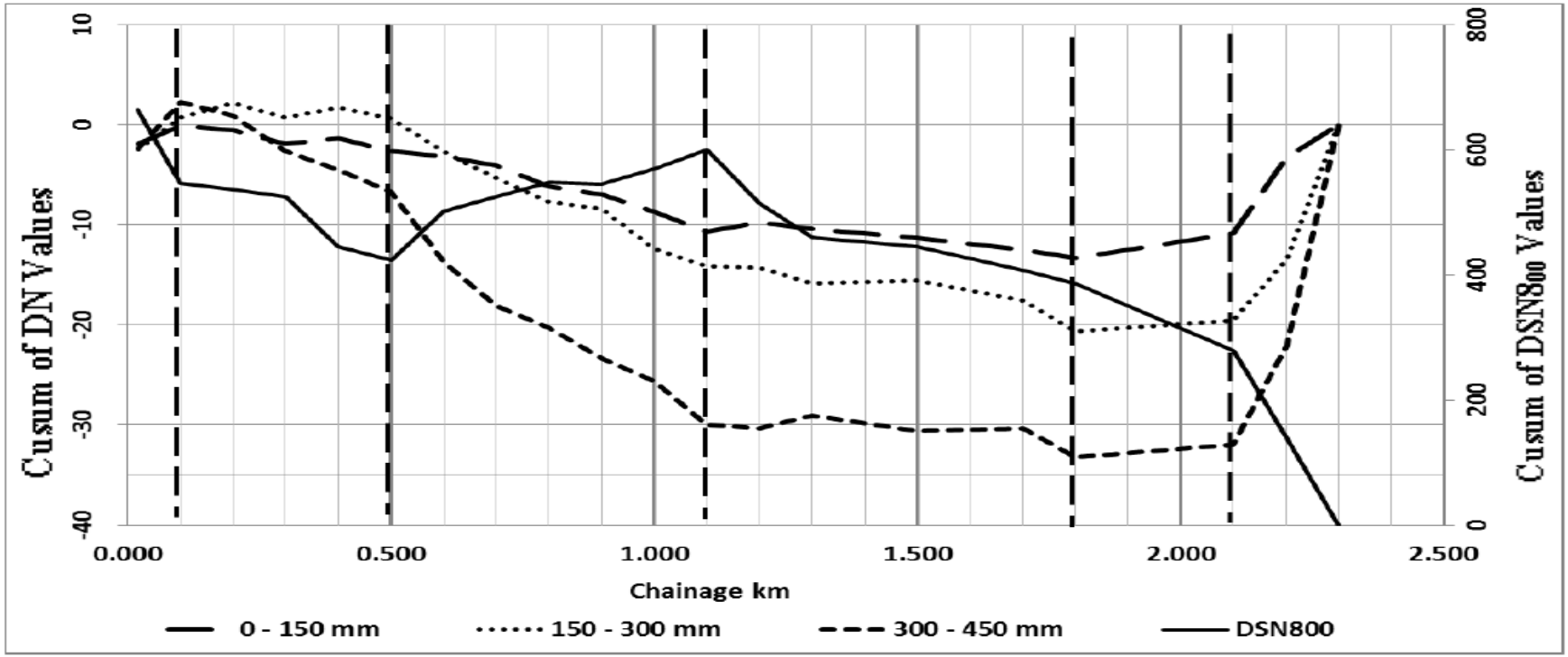
Step 1: Undertake DCP Survey Along Road



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

1 Mile = 1.61 Kilometers

Step 4: Determine Uniform Sections



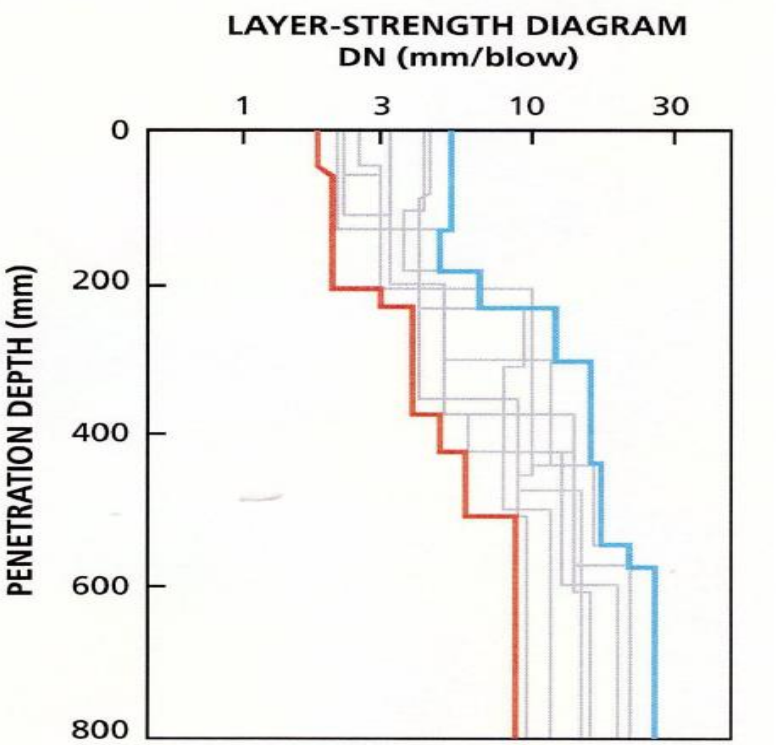
Step 5 – Adjust DN Values for Design Moisture Content

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

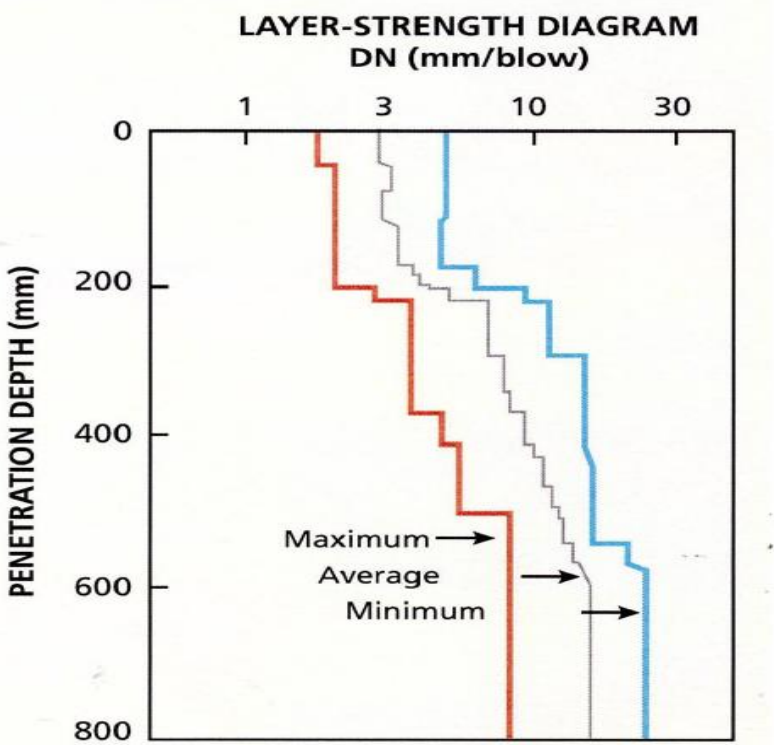
Adjustment of DN Values for Moisture

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

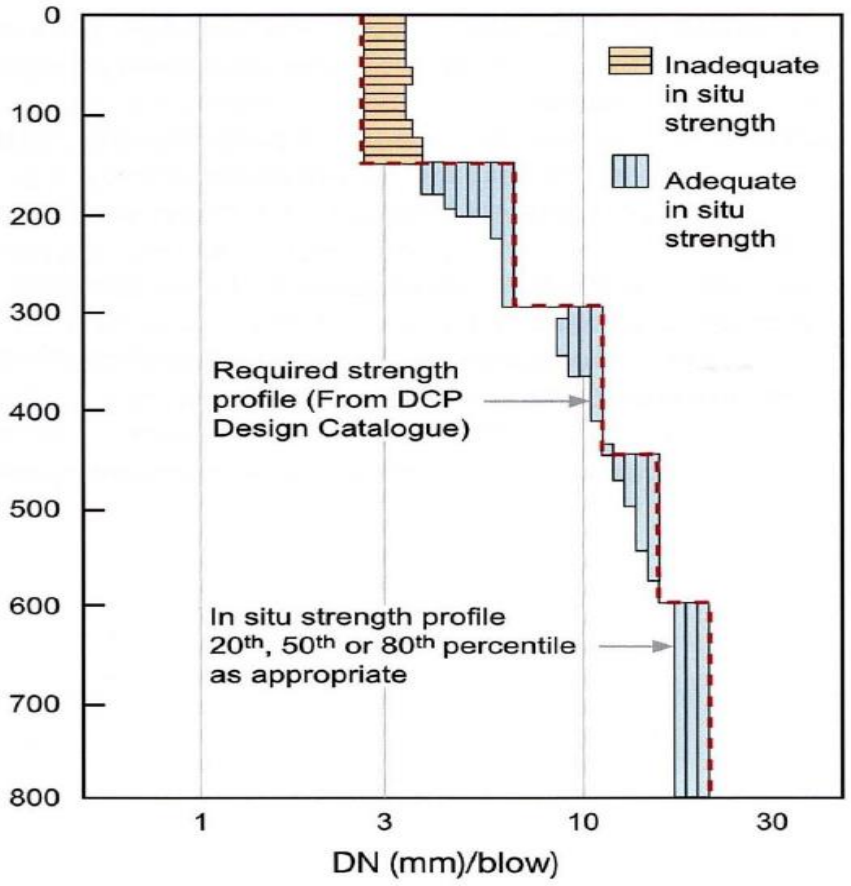


Collective DCP strength profiles



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 (Low Volume Sealed Roads) pavement.

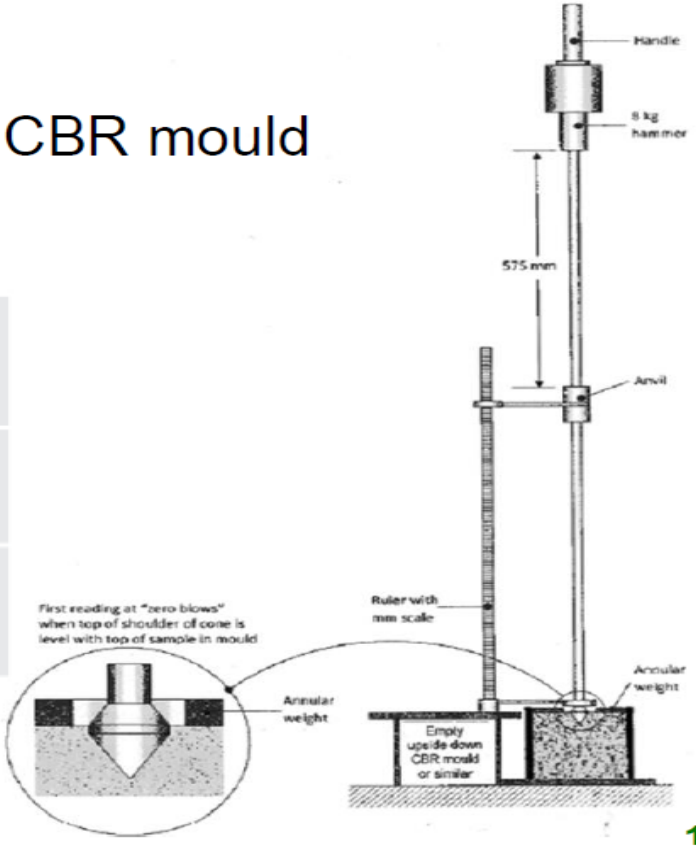
- Provided design DN value is achieved, then in service performance indirectly takes account of actual grading and plasticity at given moisture and density which do not need to be separately specified.
  - DN value provides a composite measure of materials resistance to penetration (= shear strength) 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”.

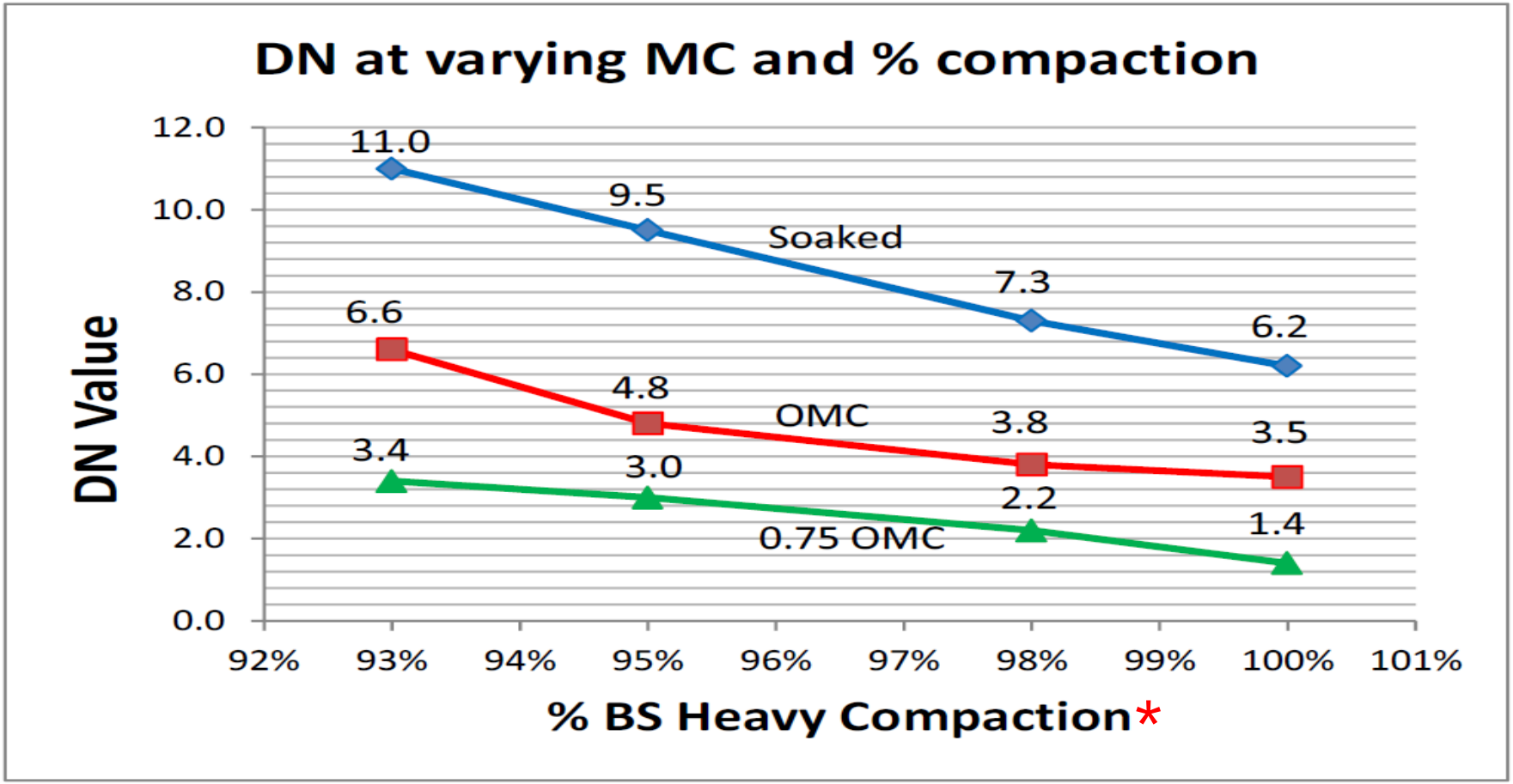
Laboratory Determination of DN value

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



*= AASTO T180 (Modified Proctor)

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 characterizing existing gravel road, testing pavement materials and undertaking compaction quality control.
- Is based on a relatively simple design procedure that produces cost-effective environmentally optimized designs
- 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

Chip Seal Road
10 Years After Construction

Gravel Road 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

1 Mile = 1.61 Kilometers

USER GUIDE TO THE DYNAMIC CONE PENETROMETER

MnROAD
Office of Minnesota Road Research

Building a Better Foundation for the Future

MnDOT

- Correlation of Data

  log CBR = 2.46-1.12 log DPI

  Where DPI = mm/Blow
- MnDot 2502 Acceptance Specification of Pavement Edge Drain Backfill Material
- Locating Layers in Pavement Structures and Pavement Rehabilitation Strategy Determination
- Supplementing Foundation Testing for Design
- Identifying Weak Spots in Constructed Embankments
- Locating Boundaries of Required Subcuts
- Determining Thaw/Freeze Depth During Spring

DCP TEST RESULT CS 5-04, Km 43.1

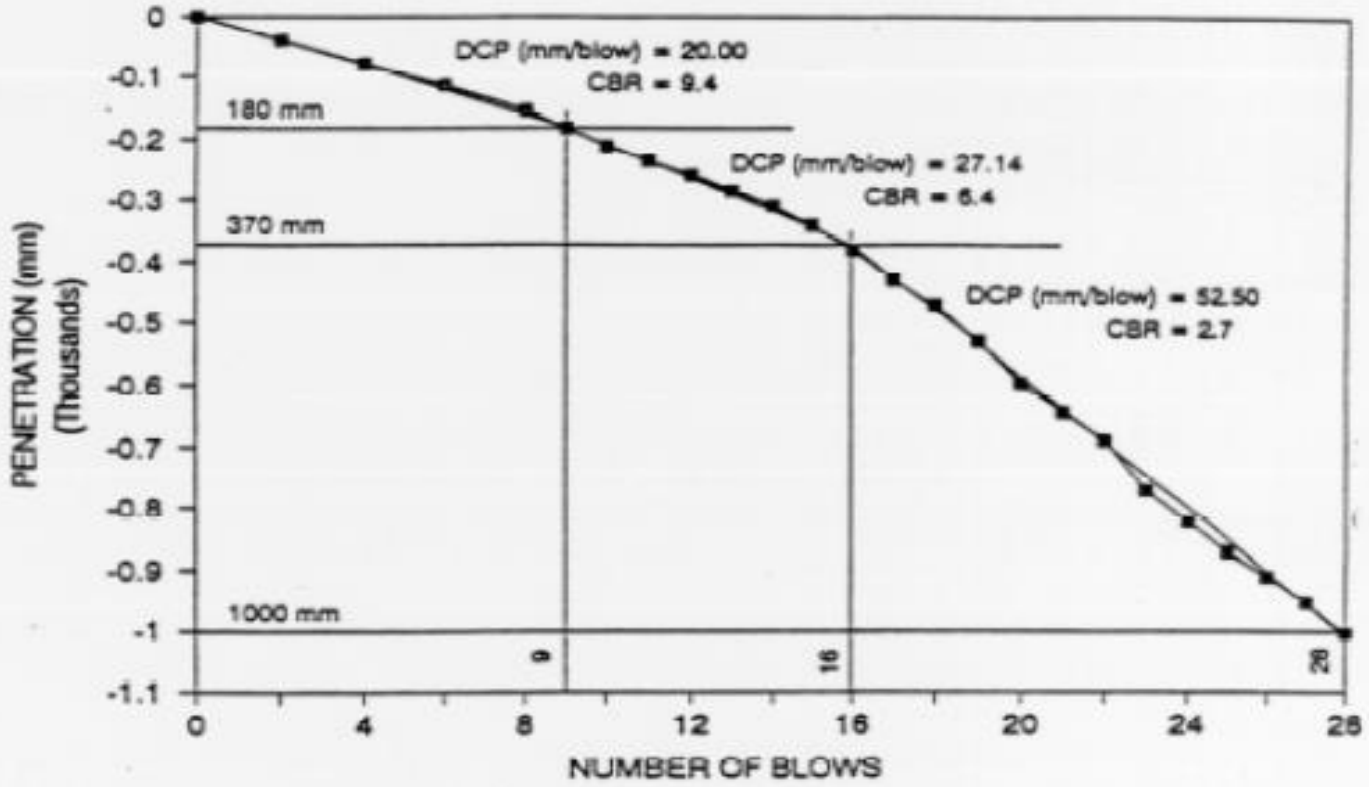


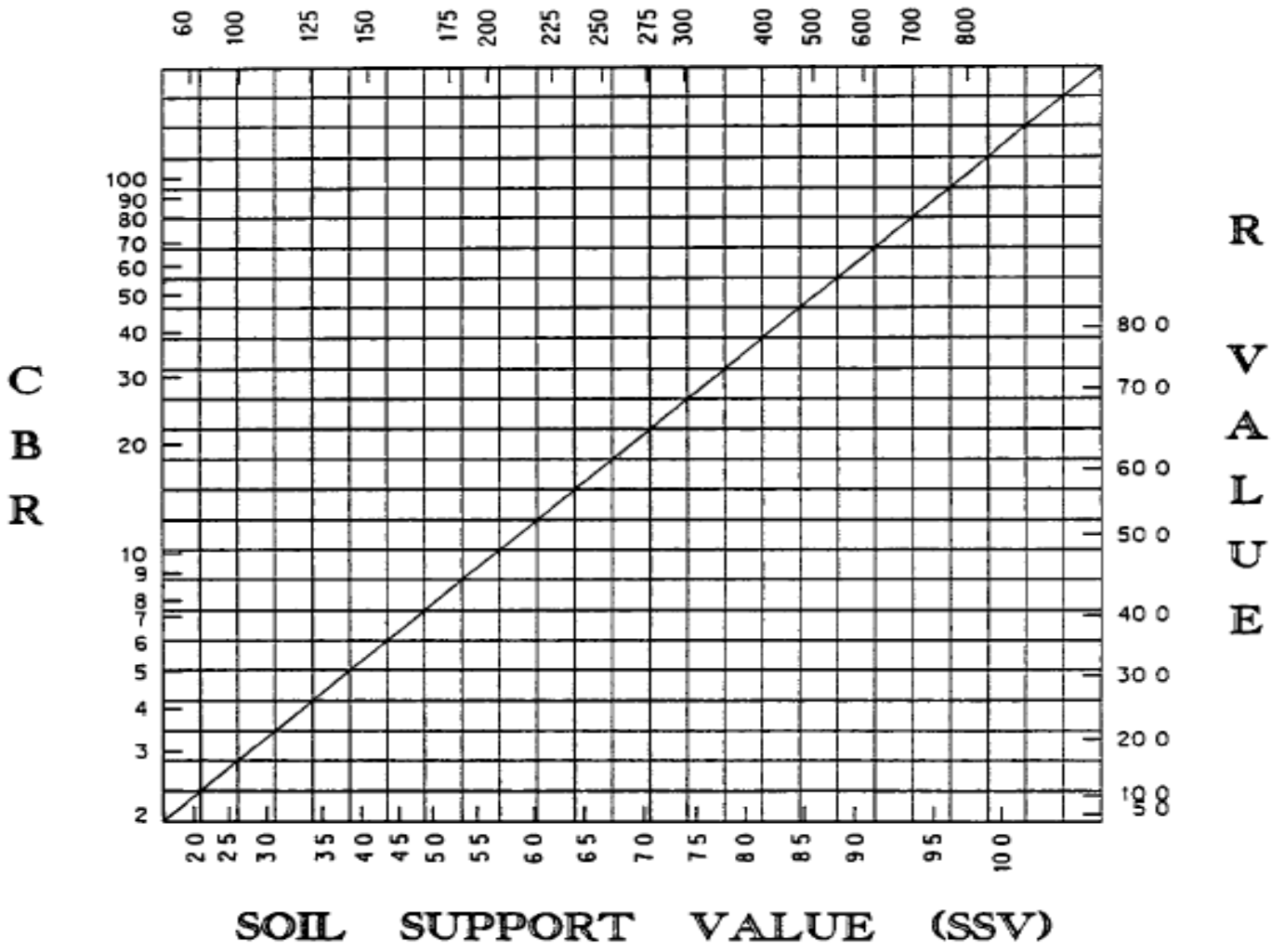
FIGURE 240-20-3

DETERMINATION OF CBR FROM DCP TEST RESULTS

C.S.	km	LAYER	FROM	TO	DEPTH	BLOW COUNT	No. of BLOWS	DCP mm/blow	LAYER Log CBR	LAYER CBR
5-04	42.1	1	0	180	180	9	9	20.00	0.97	9.4
		2	180	370	190	16	7	27.14	0.80	6.4
		3	370	1000	630	28	12	52.50	0.44	2.7

FIGURE 240-20-5

APPROXIMATE CORRELATION BETWEEN
K SSV CBR AND R-VALUE •



•COMPOSITE BASED ON INFORMATION FROM 13 AGENCIES
INVOLVED IN RIGID AND/OR FLEXIBLE PAVEMENT DESIGN

Designation: D6951/D6951M – 09

Standard Test Method for Use of the Dynamic Cone Penetrometer in Shallow Pavement Applications[1]

This standard is issued under the fixed designation D6951/D6951M; the number immediately following the designation year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

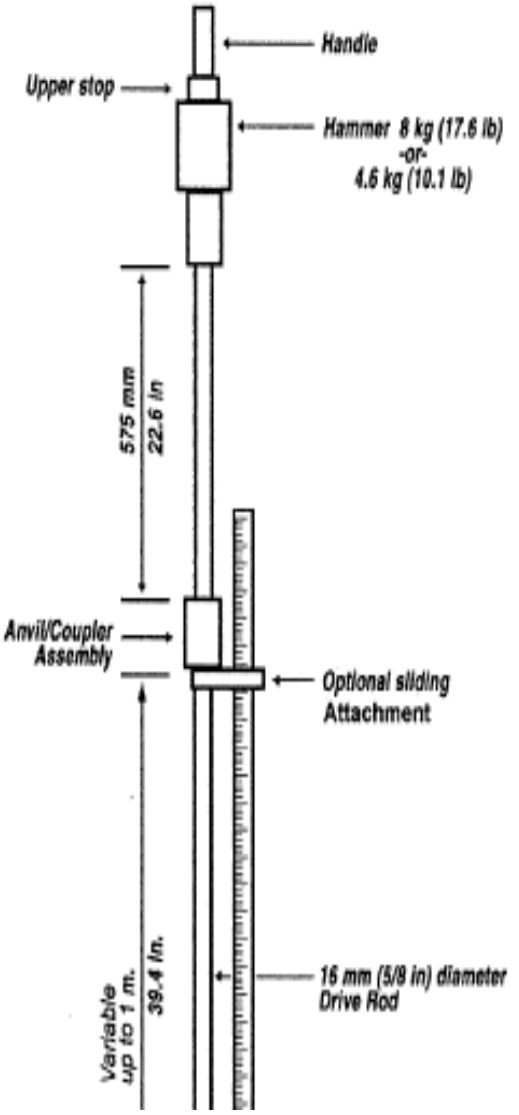
1. Scope

1.1 This test method covers the measurement of the penetration rate of the Dynamic Cone Penetrometer with an 8-kg [17.6-lb] hammer (8-kg [17.6-lb] DCP) through undisturbed soil or compacted materials, or both. The penetration rate may be related to in situ strength such as an estimated in situ CBR (California Bearing Ratio). A soil density may be estimated (Note 1) if the soil type and moisture content are known. The DCP described in this test method is typically used for pavement applications.

1.2 The test method provides for an optional 4.6-kg [10.1-lb] sliding hammer when the use of the 8-kg [17.6-lb] sliding mass produces excessive penetration in soft ground conditions.

1.3 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

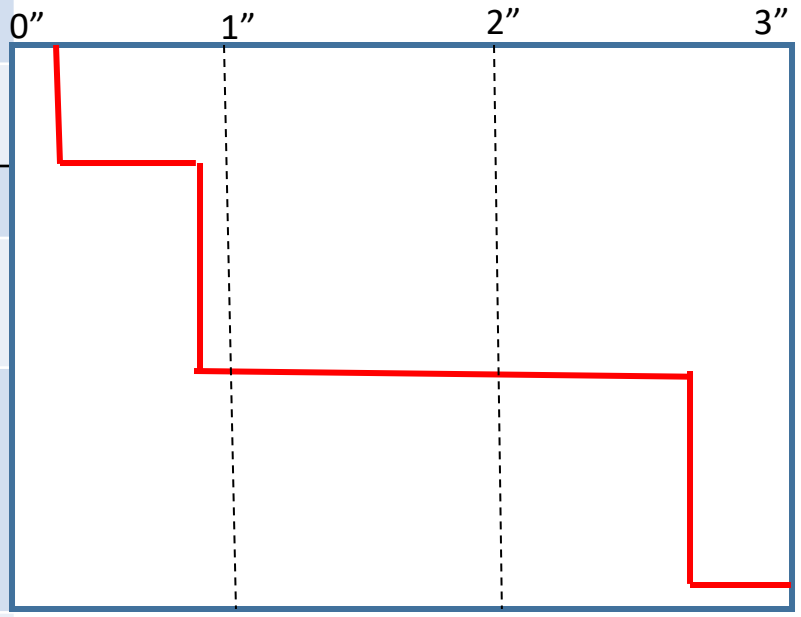
1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*



Pavement Design AASHTO '93 MOD. Crush & Shape Given: Reg. Factor = 4.5 Terminal Serv. =4.5 SSV=3.0
SN =4.63 ESAL=1,000,000 ADT =320 DES. Life =20yrs Comm. ADT =2% M_R (psi) =30,000 $(a_i/0.14)^3$
M_R (psi) =2555 $(CBR)^{0.64}$ CBR =292/($DCP^{1.12}$) mm/Blow

	Auger Sample	Pvmnt Des.	ai	M_R PSi	CBR %	IN/Blow
0		1.5 HMA 1.5 HMA 2.5 Recycle	0.42 0.42 0.20			
9	9" AGG Base	8" AGG Base	0.14	30,000	46.9	0.20
	24" Sand	12" Sand Subbase	0.10	10,900	9.7	0.83
33		13"Sand Subgrade SSV = 3 CBR 3.5	0.08	5,700	3.5	2.86
		SN = 5.12 › 4.63				

Required LSP



Thank you!

Questions?