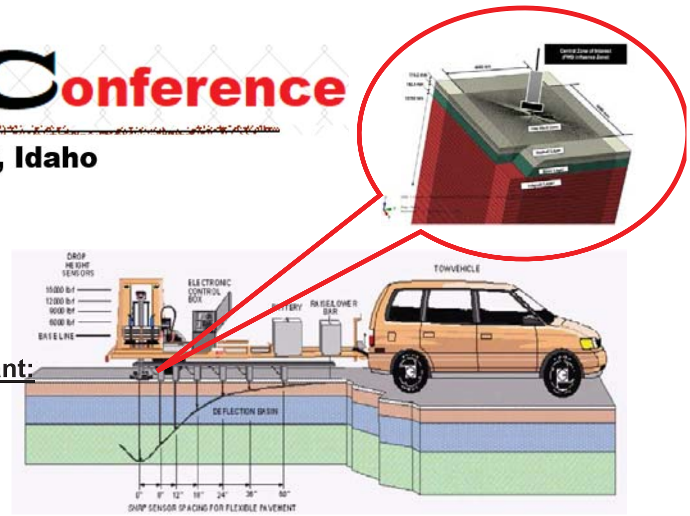
Idaho Asphalt Conference

Boise State University
College of Engineering

Use of Visual Distress Survey and Deflection Data for Rehabilitation Decisions in Idaho

57th Idaho Asphalt Conference
October 26, 2017, Moscow, Idaho



Presented By:
Deb Mishra, Ph.D., P.E.
Assistant Professor
Dept. of Civil Engineering
Boise State University

Graduate Research Assistant:
Md. Fazle Rabbi
Grad. Research Assistant
Dept. of Civil Engineering
Boise State University

Initial Version of Paper Presented at the 96th Annual Meeting of the Transportation Research Board

Boise State University
College of Engineering

Use of Visual Distress Survey Data and Deflection Basin Parameters for Network-Level Pavement Rehabilitation Decisions in Idaho

96th Annual Meeting of the Transportation Research Board

Author:
Deb Mishra, Ph.D., P.E.
Assistant Professor
Dept. of Civil Engineering
Boise State University

Co-Author:
Md. Fazle Rabbi
Grad. Research Assistant
Dept. of Civil Engineering
Boise State University

Co-Author:
John Arambarri, PE,
Materials Engineer,
District 3
ITD

Co-Author:
Dan Harelson, PE,
Engineering Manager,
District 5
ITD

Project Background and Scope

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING

"Over the year the transportation department has routinely repaired the pavement but even with this routine maintenance the pavement has reached the end of its life; it's time to invest in a new surface".

-Dan Harelson,
ITD project manager

- Total length of I-15 In Idaho= 190 mils
- Replacing around 44 miles

Project No	Limits		Project Length		
	Start	End	Start	End	Length
1	Arimo Interchange	McCammon Interchange	39.8	47.5	7.7
2	Baseline	Bonneville	106.7	111.9	5.2
3	Chubbuck	Milepost 76.01	72.6	76.01	3.4
4	Lava Bed crosover	Baseline road	100.4	106.7	6.3
5	McCommon Interchange	South 5th Pocatello	47.5	66.8	19.3
6	Milepost 76.01	Burns Road	76.01	81.9	5.9
7	South Blackfoot	west Blackfoot	89.3	92.5	3.2
8	Sand Road	Blackfoot	85.6	89.3	3.7
9	West Blackfoot	Lava Beds	92.5	100.4	7.9

Several sections were initially selected for Full-Depth Reclamation (CRABS); In-Depth Analysis of Structural Condition can lead to more educated decisions

Pavement Sections Analyzed

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING

Projects: (District -3) *Thank you John Arambarri!*

1. US-95 Payette NCL to Weiser River Bridge
   - MP 70.28 to 81.52
2. SH-55 Pride Lane to Middleton Road
   - MP 7.1 to MP 15.6
3. I-84, Sand Hollow to Caldwell
   - MP 17 to MP 26

Projects: (District -5)

1. I-15, Sand Road to South Blackfoot
   - MP 85.6 to MP 89.3

Objective and Motivation

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING

1. Recurrent Pavement Distresses
2. Unprecedented Construction and Maintenance Costs
3. Frequent Traffic Interruption
4. Increased in User Costs

Full Reconstruction?
or
Partial Reconstruction?
or
Rehabilitation?
or
Successive Maintenance Approach??

What is the Probable Solution????

en.wikipedia.org
color.ngmnexpo.com
www.qespavements.com
https://www.fhwa.dot.gov/publications/transporter/96aug/index.cfm

Functional vs. Structural Pavement Evaluation

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING

Surface Assessment Maintenance Purpose

Surface and Subgrade Assessment for Design and Evaluation purpose

Pavement Evaluation
- Functional Evaluation
  - Present Serviceability Index
  - Pavement Roughness Index
  - Skid Resistance
- Structural Evaluation
  - Destructive Testing
    - Flexible Pavement
      - Coring/Bitumen Extraction
    - Rigid Pavements
      - Crushing Strength, flexural strength
  - Non-Destructive Testing
    - Static Creep Deflection Method
    - Steady State Deflections
    - Wave propagation Method
    - Impulse Loading

X **Comparatively Expensive**
X **Time Consuming**
X **Labor-Intensive**
X **Traffic Interruption**
X **Discontinuous Assessment**
X **Damage to pavements**

✓ **Cost Efficient**
✓ **Noninvasive**
✓ **Rapid**
✓ **Limited Traffic Obstruction**

FWD (Impulse Loading Devices)

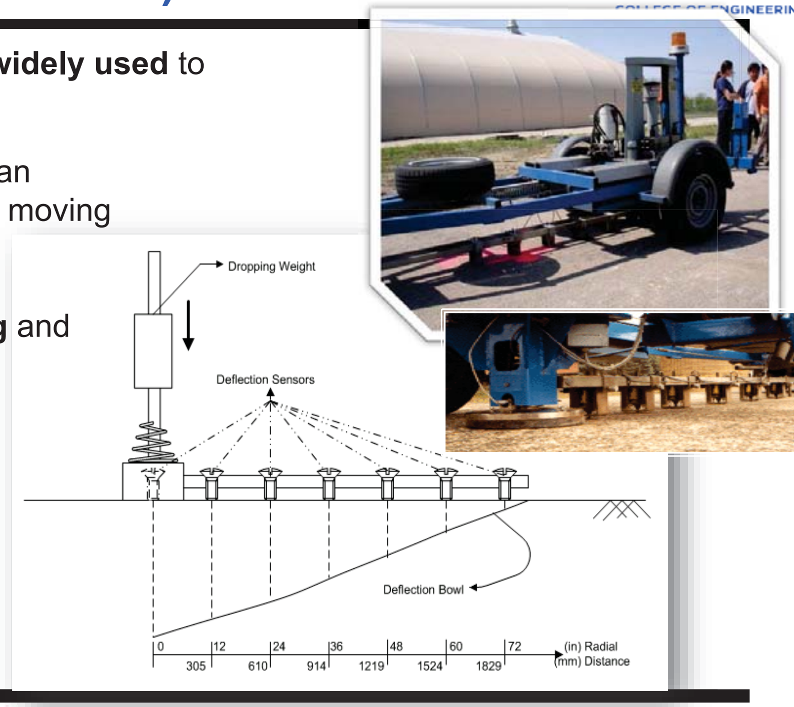
BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING

Falling Weight Deflectometer (FWD) is **widely used** to measure pavement surface deflections

- FWD measures surface deflections by an **impact loading** to simulate a vehicular moving load.
- The system applies **controlled loading** and measures deflections.

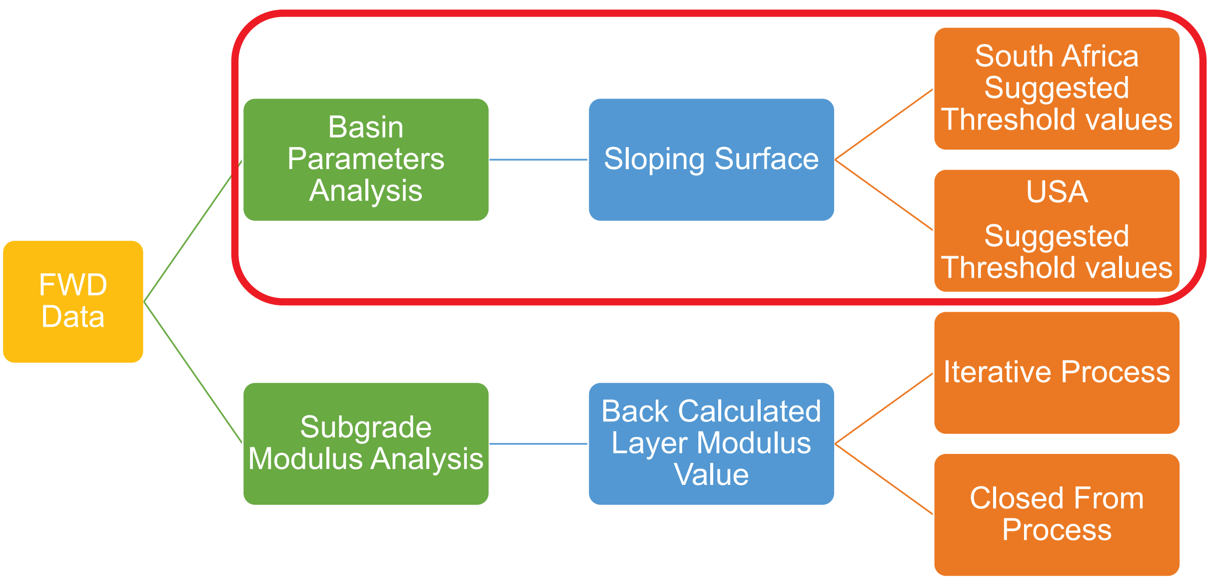
Advantages:

- ✓ **Comparatively Fast**
- ✓ **Economical**



FWD Data Assessment Process

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING



Backcalculation – A Challenge

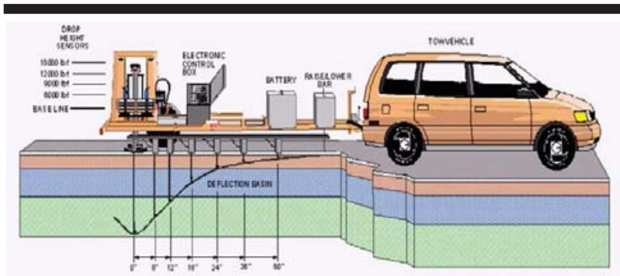
BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING

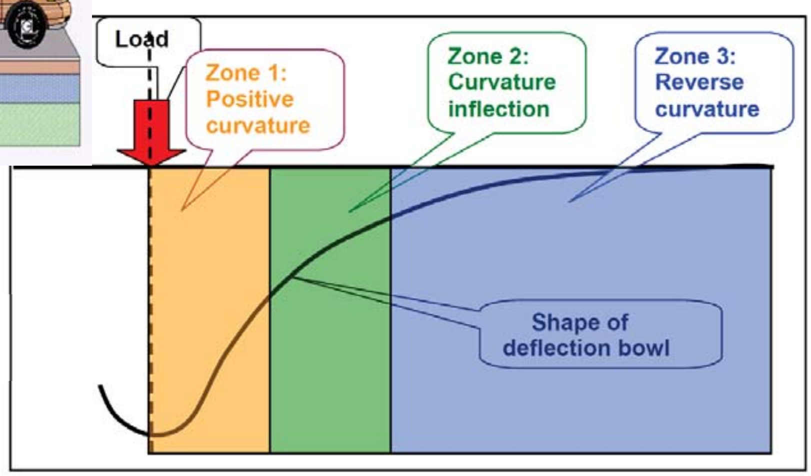
- ✓ Very powerful concept – needs good understanding of the procedure
- ✓ Pavement layer thicknesses – Important Input
- ✓ Not something that DOTs do on a daily basis

Is it possible to utilize FWD data at a network level without going through detailed back-calculation approaches?

Deflection Basin Shape – Relevant Inferences

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING





Not a replacement for backcalculation ! Just a tool to help engineers

Ref: Horak, E. (2008), "Benchmarking the Structural Condition of Flexible Pavements with Deflection Bowl Parameters"

Deflection Basin Parameters Used in the US

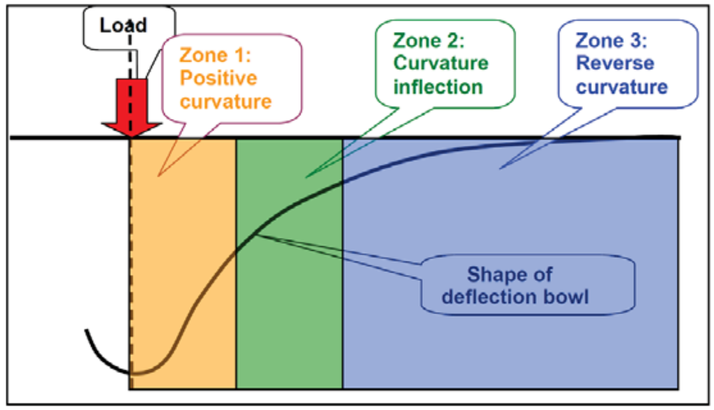
BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING

Surface Curvatutre Index (SCI)
(also known as Base Layer Index, BLI)
$SCI = D_0 - D_{300}$

Middle Layer Index (MLI)
(also known as Base Damage Index, BDI)
$MLI = D_{300} - D_{600}$

Lower Layer Index (LLI)
(also known as Base Curvature Index, BCI)
$LLI = D_{600} - D_{900}$

Shape of the deflection basin is governed by structural condition of individual pavement layers



Different Countries; Different Names

Ref: Horak, E. (2008), "Benchmarking the Structural Condition of Flexible Pavements with Deflection Bowl Parameters"

Deflection Bowl Parameters - South African Practice

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING

Parameter	Formula	Structural indicator
Maximum Deflection	D_o as measured	ALL Layers
Radius of Curvature (RoC)	$RoC = \frac{L^2}{2 \times D_0 \left(1 - \frac{D_0}{D_{200}}\right)}$ $L = 200$ mm (for FWD)	Surface and Base Layer
Base Layer Index (BLI)	$BLI = D_0 - D_{300}$	Base Layer
Middle Layer Index (MLI)	$MLI = D_{300} - D_{600}$	Subbase/ Subgrade Layer
Lower Layer Index (LLI)	$MLI = D_{600} - D_{900}$	Subbase/ Subgrade Layer

Ref: Horak, E., Emery, S., & Maina, J. Review of Falling Weight Deflectometer Deflection Benchmark Analysis on Roads and Airfields. In Proc. 11th Conf. on Asphalt Pavements for Southern Africa.

Deflection Bowl Parameters and Thresholds

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING

Base Type	Structural Condition Rating	Deflection Bowl Parameters (700 kPa)				
		Do (µm)	RoC (m)	BLI (µm)	MLI (µm)	LLI (µm)
Granular Base	Sound	< 625	> 90	< 250	< 115	< 65
	Warning	625 to 925	42-90	250-475	115-225	65-120
	Severe	> 925	< 42	> 475	> 225	> 120

Parameter	Formula	Structural indicator
Maximum Deflection	D_o as measured	ALL Layers
Radius of Curvature (RoC)	$RoC = \frac{(L)^2}{2Do(1-\frac{Do}{D200})}$ L= 200mm (FWD)	Surface and Base Layer
Base Layer Index (BLI)	$BLI = D_o - D_{300}$	Base Layer
Middle Layer Index (MLI)	$MLI = D_{300} - D_{600}$	Subbase/ Subgrade Layer
Lower Layer Index (LLI)	$LLI = D_{600} - D_{900}$	Subbase/ Subgrade Layer

Need to use consistent FWD load levels

Idaho Uses a Load Level of 12 kips for FWD Testing

Ref: Horak, E., Emery, S., & Maina, J. Review of Falling Weight Deflectometer Deflection Benchmark Analysis on Roads and Airfields. In Proc. 11th Conf. on Asphalt Pavements for Southern Africa.

Deflection Bowl Parameters & Thresholds

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING

Deflection Basin Parameters Range		Remarks
SCI / BLI (mils)	< 4.00	Very Good Asphalt Layer
	4.00 - 6.00	Good Asphalt Layer
	6.00 - 8.00	Fair Asphalt Layer
	8.00 - 10.00	Poor Asphalt Layer
	> 10.00	Very Poor Asphalt Layer
MLI (mils)	< 2.00	Very Good Base Layer
	2.00 - 3.00	Good Base Layer
	3.00 - 4.00	Fair Base Layer
	4.00 - 5.00	Poor Base Layer
	> 5.00	Very Poor Base Layer
W_{60} (mils)	< 1.00	Very Good Subgrade Layer
	1.00 - 1.14	Good Subgrade Layer
	1.40 - 1.80	Fair Subgrade Layer
	1.80 - 2.20	Poor Subgrade Layer
	> 2.20	Very Poor Subgrade Layer

Ref: Chang C, D. Saenz , S. Nazarian, I. N. Abdallah, A. Wimsatt, T. Freeman, and E. G. Fernando (2014) "TxDOT Guidelines to Assign PMIS Treatment Levels" (Table)

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING

Structural Evaluation of I-15, I-84, SH-55 & US-95 Sections using Deflection Basin Parameters

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING

Different Pavement Sections Considered

1. US-95 Payette NCL to Weiser River Bridge
   - MP 70.28 to 81.52
   - FWD data collected in 2011
2. SH-55 Pride Lane to Middleton Road
   - MP 7.1 to MP 15.6
   - FWD data collected on 29 June 2016
3. I-84, Sand Hollow to Caldwell
   - MP 17 to MP 26
   - FWD data collected on 14 October 2015
4. I-15, Sand Road to South Blackfoot
   - MP 85.6 to MP 89.3
   - FWD data collected on 15 June 2011

$$d_{0n} = \left(\frac{L_{norm}}{L_{applied}}\right) d_0 \quad [1]$$

Where:
d_{0n} = Normalized deflection
L_{norm} = Normalized load
$L_{applied}$ = Applied load
d_0 = Measured deflection at selected sensor location

Normalized to "12000" lb Load

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING

Functional Condition Assessment

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING

Condition Assessment Based on Rutting and International Roughness Index (IRI)

http://pathweb.pathwayservices.com/idaho/) (edited)

Rutting Index	
Category	Rut Depth (in.)
Excellent	< 0.25
Good	0.25-.037
Fair	0.38-0.50
Poor	>0.50

	Classification Based on IRI	
	Criteria	Classification
IRI Range	IRI ≤ 95	Good
	95 ≤ IRI ≤170	Fair / Acceptable
	IRI >170	Poor / Not Acceptable

Identifying the "source" of the problem is important for the selection of suitable rehabilitation measures

Ref: http://pathweb.pathwayservices.com/idaho/) (edited)

Threshold Values used to Classify Pavements Based on Distress Extent and severity

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING

Distress Type	Distress Severity / Magnitude							
Pavement Section	I-15		I-84		US-95		SH-55	
	Value	Rating	Value	Rating	Value	Rating	Value	Rating
Cracking Index	2.6	Fair	3.8	Good	2.2	Poor	1.6	Poor
International Roughness Index (IRI, in/mi)	< 95	Good	56 (avg.)	Excellent	90.5 (avg.)	Good	156 (avg.)	Poor
Roughness Index (RI)	3.40	Good	3.95	Good	3.33	Good	2.51	Fair
Average Rut Depth (inch)	0.43”	Fair	0.24”	Good	0.46”	Fair	0.24”	Good

*The data was taken from ITD's visual distress survey database.
IRI values for the I-84, US-95, and SH-55 segments were extracted from reports prepared by ITD. IRI values for the I-15 segment are extracted from the visual distress survey database*

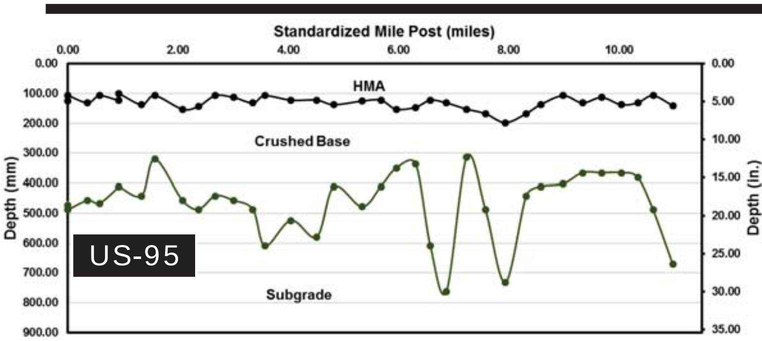
Condition: Cracking Index	
Pavement Condition	Functional Class Interstate and Arterials
Good	CI > 3.0
Fair	2.5 ≤ CI ≤ 3.0
Poor	2.0 ≤ CI ≤ 2.5
Very Poor	CI < 2.0
Condition: Roughness Index	
Pavement Condition	Functional Class Interstate and Arterials
Good	RI > 3.0
Fair	2.5 ≤ RI ≤ 3.0
Poor	2.0 ≤ RI ≤ 2.5
Very Poor	RI < 2.0
Condition: Rutting	
Pavement Condition	Functional Class Interstate and Arterials
Good	0.00” – 0.24”
Fair	0.25” – 0.49”
Poor	0.50” – 0.74”
Very Poor	≥ 0.75”
Condition: IRI (inch/mile)	
Pavement Condition	Functional Class Interstate and Arterials
Excellent	<60
Good	60-99
Fair	100-139
Poor	140-199
Very Poor	≥200

57th Idaho Asphalt Conference
October 26, 2017, Moscow, Idaho

19

Pavement Layer Profiles of US-95, SH-55 & I-15

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING

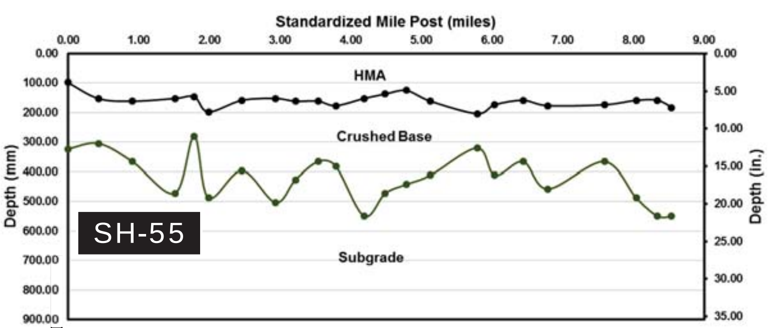


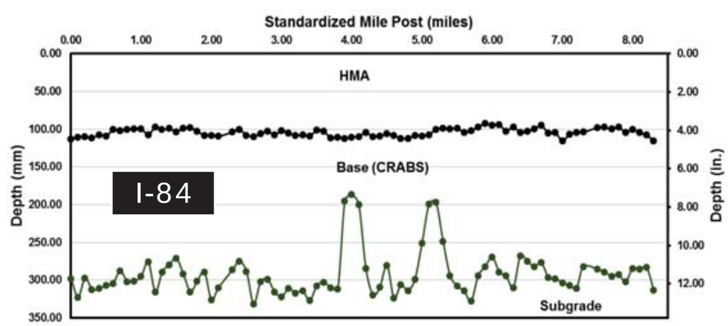
Pavement Layer Profiles

(a) I-84 (Ground Penetrating Radar)

(b) US-95 (Boring logs)

(c) SH-55 (Boring logs)



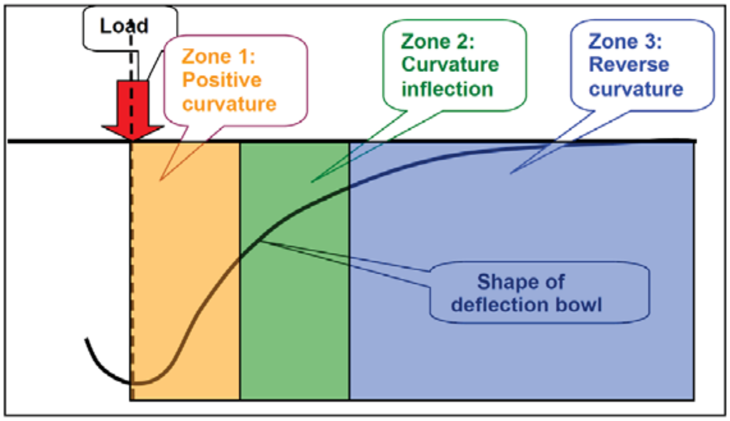


57th Idaho Asphalt Conference
October 26, 2017, Moscow, Idaho

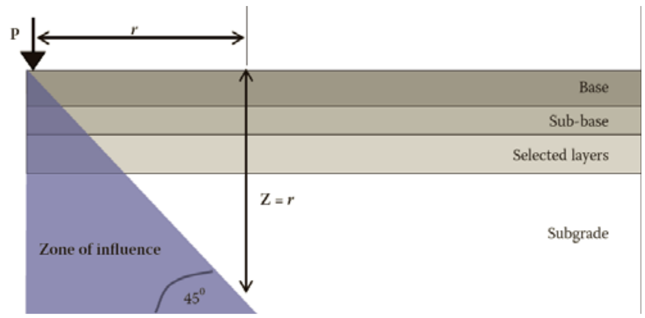
20

Inferences based on Deflection Basin – Zone 1

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING

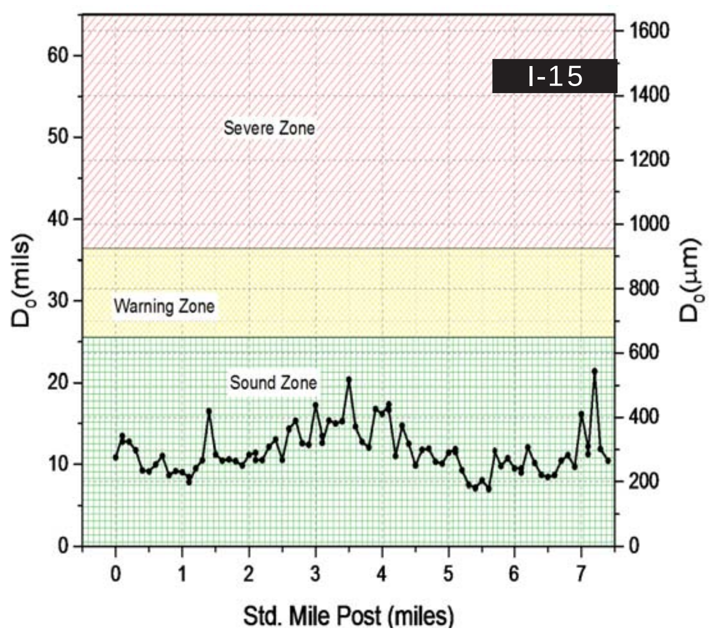


Inferences based on Shape of Stress Dissipation Curve



Pavement Assessment Based on Deflection Bowl Parameters

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING



Base Type	Structural Condition Rating	Deflection Bowl Parameter
		Do (µm)
Granular Base	Sound	< 625
	Warning	625-925
	Severe	> 925

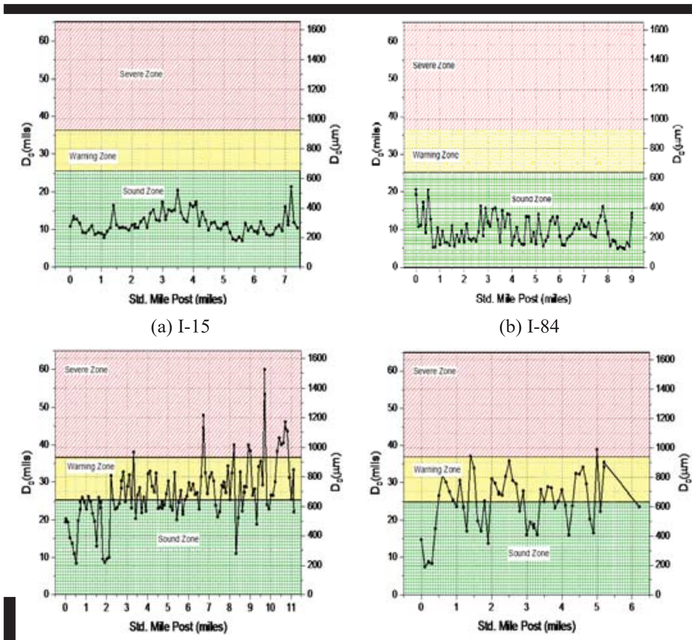
Deflection under the Load

Central Deflection as an Indicator of Overall Pavement Structural Condition

Ref: Levi, G. (2016), Horak, E., Emery, S., & Maina, J. Review of Falling Weight Deflectometer Deflection Benchmark Analysis on Roads and Airfields. In Proc. 11th Conf. on Asphalt Pavements for Southern Africa.

Pavement Assessment Based on Deflection Bowl Parameters

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING



(a) I-15 (b) I-84 (c) US-95 (d) SH-55

Base Type	Structural Condition Rating	Deflection Bowl Parameter Do (μm)
Granular Base	Sound	< 625
	Warning	625-925
	Severe	> 925

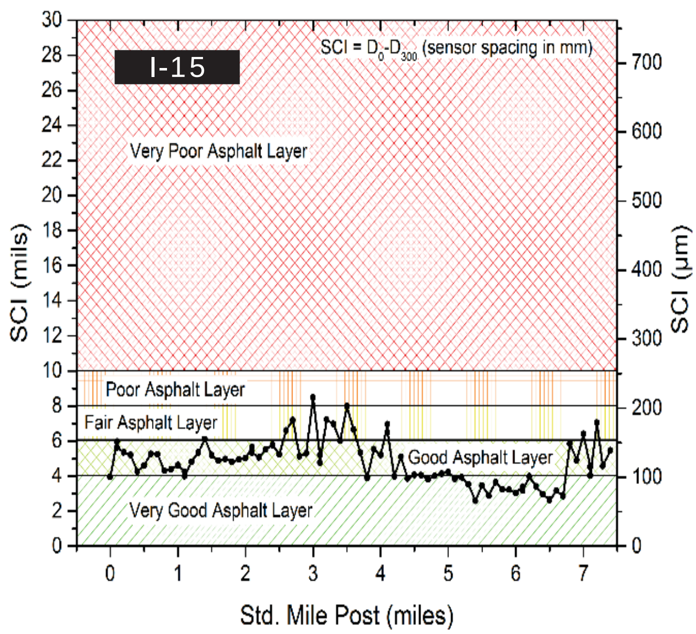
Deflection under the Load

Central Deflection as an Indicator of Overall Pavement Structural Condition

Ref: Levi, G. (2016), Horak, E., Emery, S., & Maina, J. Review of Falling Weight Deflectometer Deflection Benchmark Analysis on Roads and Airfields. In Proc. 11th Conf. on Asphalt Pavements for Southern Africa.

Pavement Assessment Based on Deflection Bowl Parameters

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING



SCI (BLI)	Remarks
< 4.00	Very Good Asphalt Layer
4.00 -- 6.00	Good Asphalt Layer
6.00 -- 8.00	Fair Asphalt Layer
8.00 -- 10.00	Poor Asphalt Layer
> 10.00	Very Poor Asphalt Layer

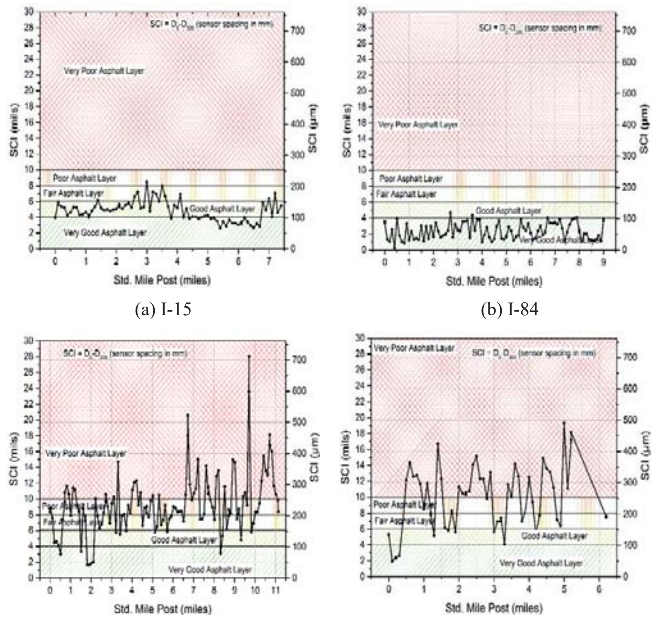
Surface Curvature Index

Structural Condition Indicator for HMA Layer

Ref: Chang C, D. Saenz , S. Nazarian, I. N. Abdallah, A. Wimsatt, T. Freeman, and E. G. Fernando (2014) “Txdot Guidelines to Assign PMIS Treatment Levels” (Table)

Pavement Assessment Based on Deflection Bowl Parameters

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING



(a) I-15 (b) I-84 (c) US-95 (d) SH-55

SCI / BLI (mils)	Inference
< 4.00	Very Good Asphalt Layer
4.00 -- 6.00	Good Asphalt Layer
6.00 -- 8.00	Fair Asphalt Layer
8.00 -- 10.00	Poor Asphalt Layer
> 10.00	Very Poor Asphalt Layer

Surface Curvature Index

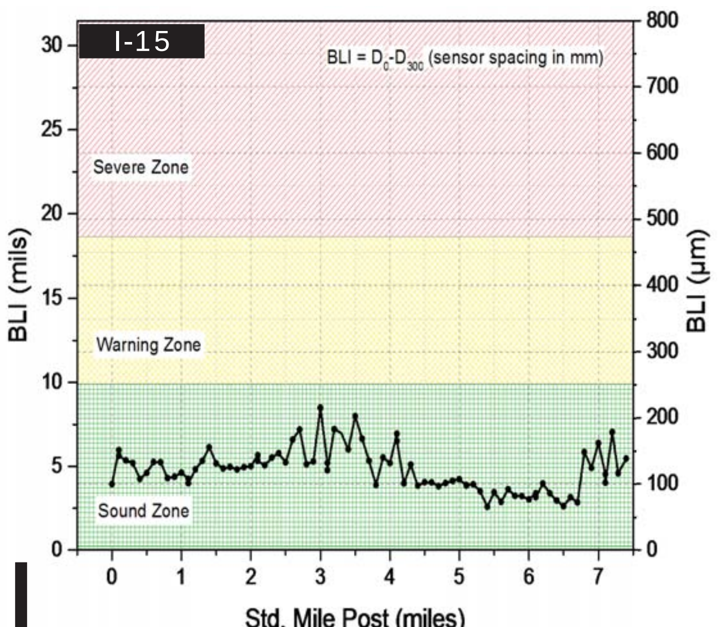
Structural Condition Indicator for HMA Layer

57th Idaho Asphalt Conference
October 26, 2017, Moscow, Idaho

Ref: Chang C, D. Saenz , S. Nazarian, I. N. Abdallah, A. Wimsatt, T. Freeman, and E. G. Fernando (2014) "Txdot Guidelines to Assign PMIS Treatment Levels" (Table)

Pavement Assessment Based on Deflection Bowl Parameters

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING



Base Type	Structural Condition Rating	Deflection Bowl Parameter BLI (μm)
Granular Base	Sound	< 250
	Warning	250 - 475
	Severe	> 475

Base Layer Index

Numerically equivalent to SCI

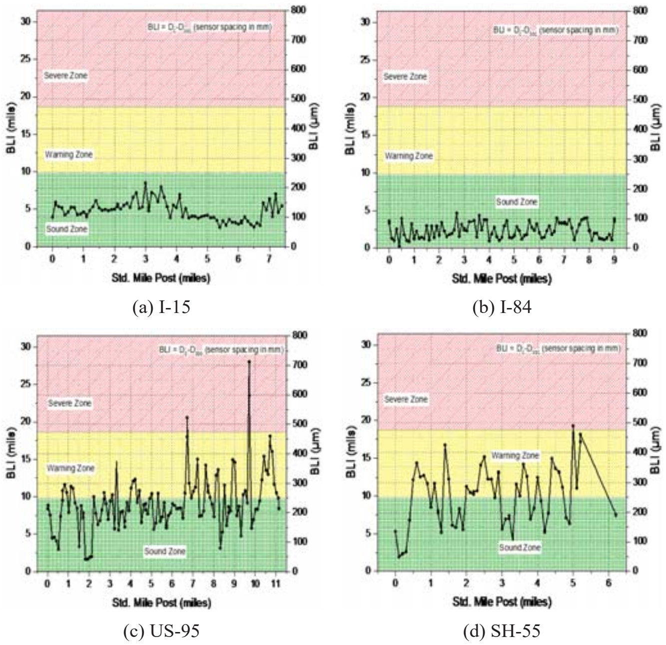
However, used to Assess Base Layer Condition

57th Idaho Asphalt Conference
October 26, 2017, Moscow, Idaho

Ref: Horak, E., Emery, S., & Maina, J. Review of Falling Weight Deflectometer Deflection Benchmark Analysis on Roads and Airfields. In Proc. 11th Conf. on Asphalt Pavements for Southern Africa.

Pavement Assessment Based on Deflection Bowl Parameters

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING



(a) I-15 (b) I-84 (c) US-95 (d) SH-55

Base Type	Structural Condition Rating	Deflection Bowl Parameter BLI (μm)
Granular Base	Sound	< 250
	Warning	250 - 475
	Severe	> 475

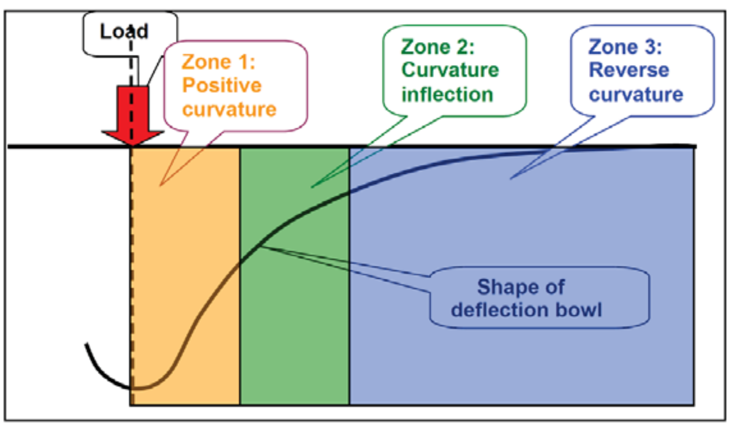
Base Layer Index

Base Condition Indicator

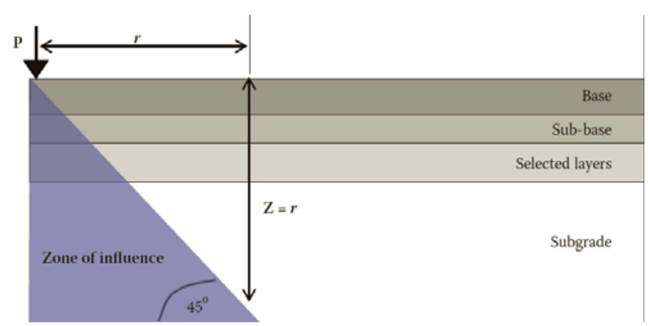
Ref: Horak, E., Emery, S., & Maina, J. Review of Falling Weight Deflectometer Deflection Benchmark Analysis on Roads and Airfields. In Proc. 11th Conf. on Asphalt Pavements for Southern Africa.

Inferences based on Deflection Basin – Zone 2

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING

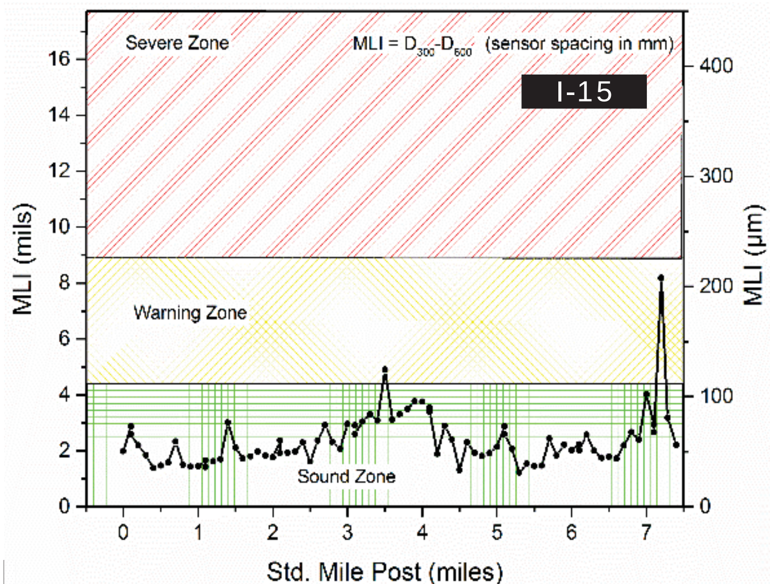


Inferences based on Shape of Stress Dissipation Curve



Pavement Assessment Based on Deflection Bowl Parameters

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING



Base Type	Structural Condition Rating	Deflection Bowl Parameters MLI (µm)
Granular Base	Sound	< 115
	Warning	115-225
	Severe	> 225

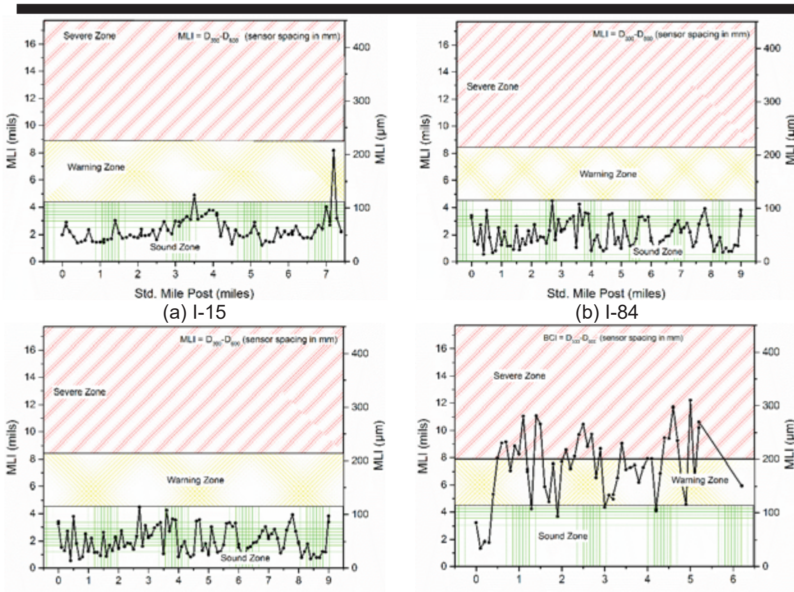
Middle Layer Index

Inferences Concerning Intermediate Pavement Layers

Ref: Horak, E., Emery, S., & Maina, J. Review of Falling Weight Deflectometer Deflection Benchmark Analysis on Roads and Airfields. In Proc. 11th Conf. on Asphalt Pavements for Southern Africa.

Pavement Assessment Based on Deflection Bowl Parameters

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING



(a) I-15 (b) I-84

(c) US-95 (d) SH-55

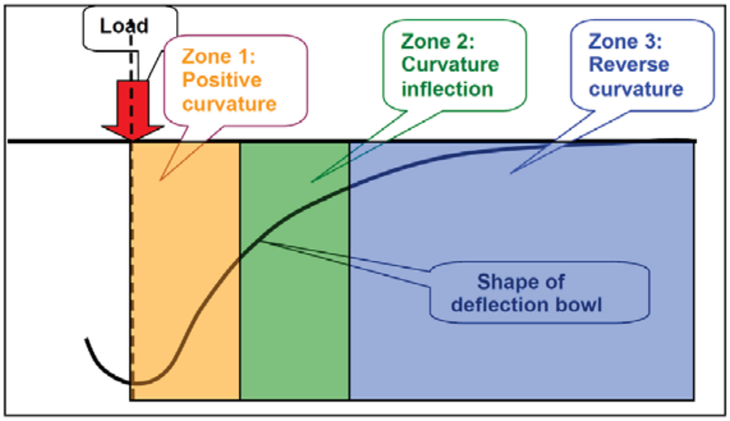
Base Type	Structural Condition Rating	Deflection Bowl Parameters MLI (µm)
Granular Base	Sound	< 115
	Warning	115-225
	Severe	> 225

Middle Layer Index

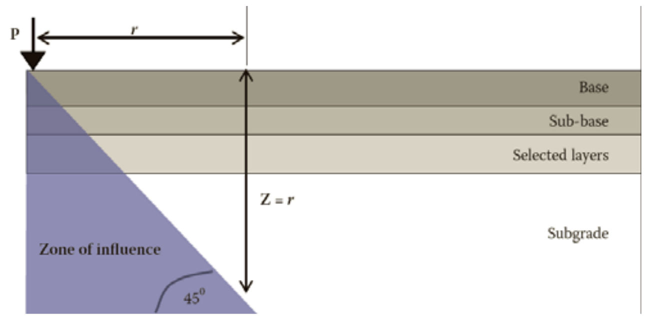
Ref: Horak, E., Emery, S., & Maina, J. Review of Falling Weight Deflectometer Deflection Benchmark Analysis on Roads and Airfields. In Proc. 11th Conf. on Asphalt Pavements for Southern Africa.

Inferences based on Deflection Basin – Zone 3

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING

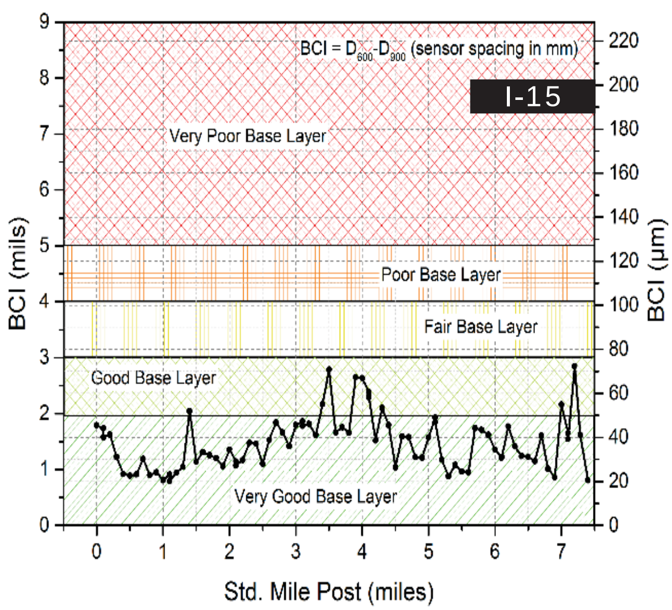


Inferences based on Shape of Stress Dissipation Curve



Pavement Assessment Based on Deflection Bowl Parameters

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING



BCI / LLI (mils)	Inference
< 2.0	Very Good Base Layer
2.0 -- 3.0	Good Base Layer
3.0 -- 4.0	Fair Base Layer
4.0 -- 5.0	Poor Base Layer
> 5.0	Very Poor Base Layer

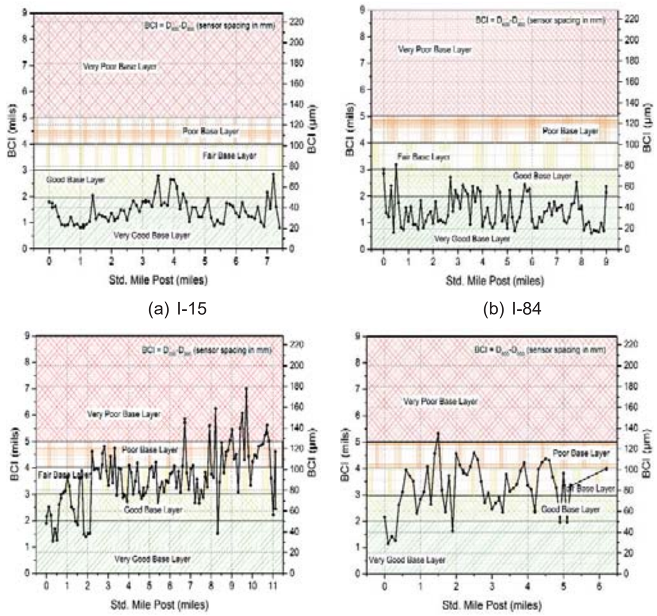
Base Curvature Index

Inferences Concerning Lower Pavement Layers

Ref: Chang C, D. Saenz , S. Nazarian, I. N. Abdallah, A. Wimsatt, T. Freeman, and E. G. Fernando (2014) "Txdot Guidelines to Assign PMIS Treatment Levels" (Table)

Pavement Assessment Based on Deflection Bowl Parameters

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING



(a) I-15 (b) I-84 (c) US-95 (d) SH-55

BCI / LLI (mils)	Inference
< 2.0	Very Good Base Layer
2.0 -- 3.0	Good Base Layer
3.0 -- 4.0	Fair Base Layer
4.0 -- 5.0	Poor Base Layer
> 5.0	Very Poor Base Layer

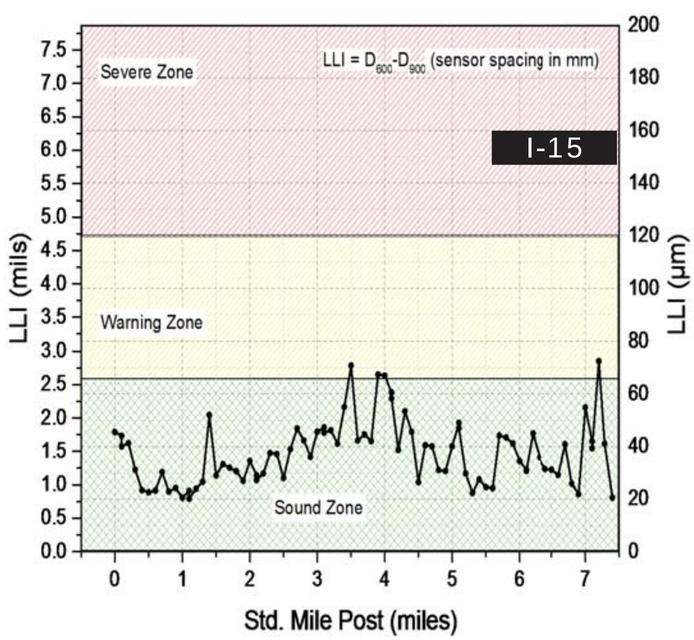
Base Curvature Index

Base/Subgrade Condition Indicator

Ref: Chang C, D. Saenz , S. Nazarian, I. N. Abdallah, A. Wimsatt, T. Freeman, and E. G. Fernando (2014) "Txdot Guidelines to Assign PMIS Treatment Levels" (Table) http://pathweb.pathwayservices.com/idaho/) (Picture)

Pavement Assessment Based on Deflection Bowl Parameters

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING



Base Type	Structural Condition Rating	Deflection Bowl Parameter LLI (µm)
Granular Base	Sound	< 65
	Warning	65 – 120
	Severe	> 120

Lower Layer Index

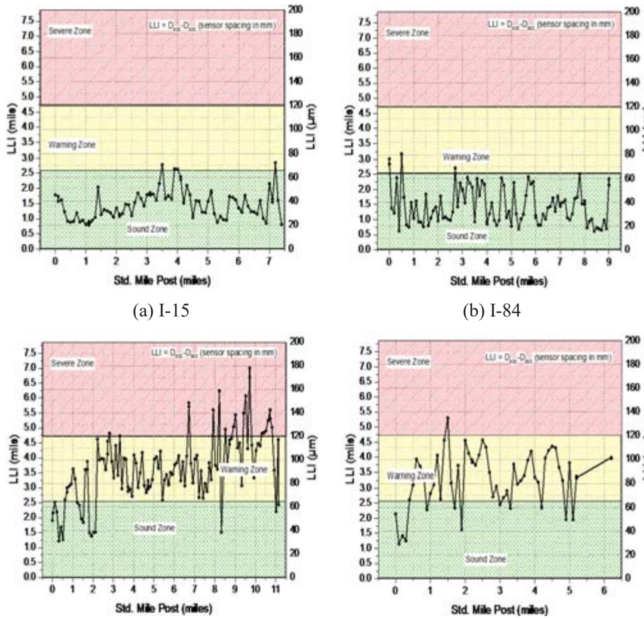
Subgrade Condition Indicator

57th Idaho Asphalt Conference
October 26, 2017, Moscow, Idaho

Ref: Horak, E., Emery, S., & Maina, J. Review of Falling Weight Deflectometer Deflection Benchmark Analysis on Roads and Airfields. In Proc. 11th Conf. on Asphalt Pavements for Southern Africa.

Pavement Assessment Based on Deflection Bowl Parameters

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING



(a) I-15 (b) I-84

(c) US-95 (d) SH-55

Base Type	Structural Condition Rating	Deflection Bowl Parameter LLI (µm)
Granular Base	Sound	< 65
	Warning	65 – 120
	Severe	> 120

Lower Layer Index

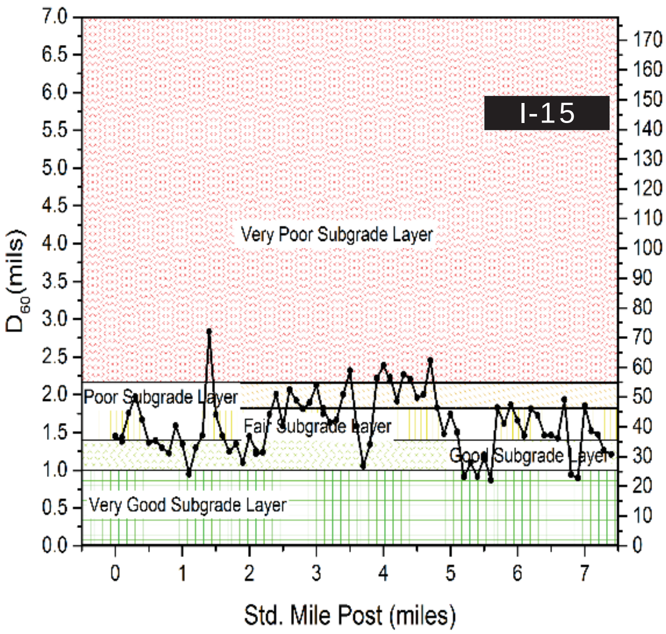
Subgrade Condition Indicator

57th Idaho Asphalt Conference
October 26, 2017, Moscow, Idaho

Ref: Horak, E., Emery, S., & Maina, J. Review of Falling Weight Deflectometer Deflection Benchmark Analysis on Roads and Airfields. In Proc. 11th Conf. on Asphalt Pavements for Southern Africa.

Pavement Assessment Based on Deflection Bowl Parameters

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING



D (60”)	Remarks
< 1.0	Very Good Subgrade Layer
1.0 -- 1.4	Good Subgrade Layer
1.4 -- 1.8	Fair Subgrade Layer
1.8 -- 2.2	Poor Subgrade Layer
> 2.20	Very Poor Subgrade Layer

Deflection at 60”

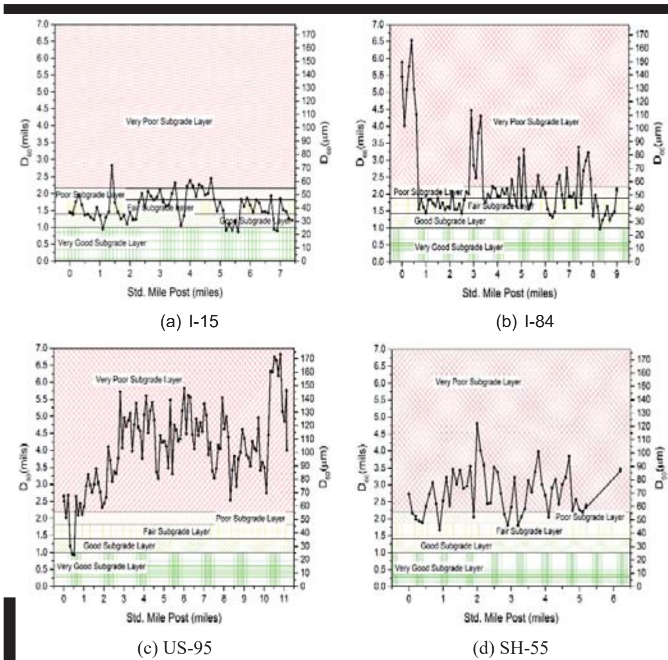
Structural Condition Indicator for Subgrade Layer

57th Idaho Asphalt Conference
October 26, 2017, Moscow, Idaho

Ref: Chang C, D. Saenz , S. Nazarian, I. N. Abdallah, A. Wimsatt, T. Freeman, and E. G. Fernando (2014) “Txdot Guidelines to Assign PMIS Treatment Levels” (Table)

Pavement Assessment Based on Deflection Bowl Parameters

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING



D (60”)	Remarks
< 1.0	Very Good Subgrade Layer
1.0 -- 1.4	Good Subgrade Layer
1.4 -- 1.8	Fair Subgrade Layer
1.8 -- 2.2	Poor Subgrade Layer
> 2.20	Very Poor Subgrade Layer

Deflection at 60”

Structural Condition Indicator for Subgrade Layer

57th Idaho Asphalt Conference
October 26, 2017, Moscow, Idaho

Ref: Chang C, D. Saenz , S. Nazarian, I. N. Abdallah, A. Wimsatt, T. Freeman, and E. G. Fernando (2014) “Txdot Guidelines to Assign PMIS Treatment Levels” (Table)

37

Summary of Assessment Results

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING

Distress Type	Distress Severity / Magnitude							
Pavement Section	I-15		I-84		US-95		SH-55	
	Value	Rating	Value	Rating	Value	Rating	Value	Rating
Cracking Index	2.6	Fair	3.8	Good	2.2	Poor	1.6	Poor
International Roughness Index (IRI, in/mi)	< 95	Good	56 (avg.)	Excellent	90.5 (avg.)	Good	156 (avg.)	Poor
Roughness Index (RI)	3.40	Good	3.95	Good	3.33	Good	2.51	Fair
Average Rut Depth (inch)	0.43”	Fair	0.24”	Good	0.46”	Fair	0.24”	Good

Distress Type	Structural Condition Assessed from FWD Data							
Pavement Section	I-15		I-84		US-95		SH-55	
	Percentage in Length	Rating	Percentage in Length	Rating	Percentage in Length	Rating	Percentage in Length	Rating
Surface	80	GOOD	100	GOOD	65	POOR	60	POOR
Base	100	GOOD	95	GOOD	40	GOOD	40	GOOD
Subgrade	25	POOR	25	POOR	75	POOR	65	POOR

Rehabilitation method should be selected based on detailed analysis of individual layer conditions

57th Idaho Asphalt Conference
October 26, 2017, Moscow, Idaho

38

Summary of Assessment Results

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING

Layer	I-15	I-84	US-95	SH-55
Surface	✓	✓	UPGRADE REQUIRED	WARNING ↓
Base	✓	✓	✓	Caution
Subgrade	Caution	Caution	UPGRADE REQUIRED	UPGRADE REQUIRED

✓ Caution UPGRADE REQUIRED WARNING

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING

Research Outcome

Research Does Pay Off !

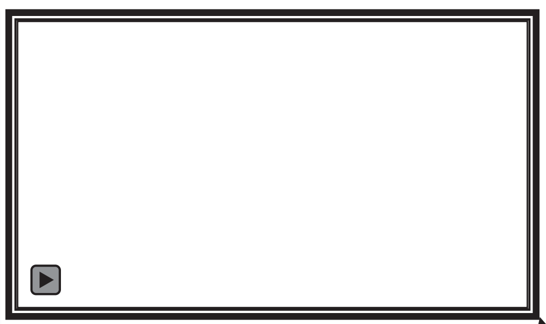
BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING

…collaboration between one of their (ITD D5) engineers and Boise State University will result in a savings of at least five million dollars from the original cost of the projects. Dan Harelson …asked Dr. Deb Mishra from Boise State University to review the consultant prepared pavement investigation report for the project and Dr. Mishra evaluated the data using a tool he has developed … he concluded that the consultant evaluation was extremely conservative and that much less costly rehabilitation options are available. Dan and Dr. Mishra applied the analysis to several additional projects and reached the same conclusion in their regard. The analysis will result in a savings of over five million dollars …

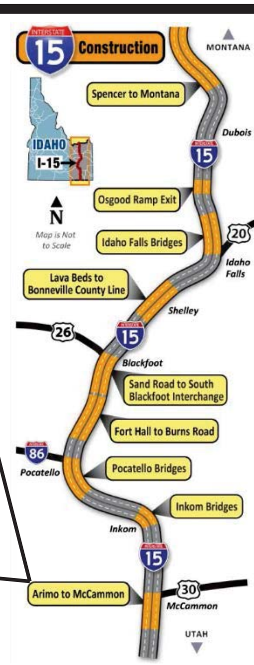
Report to Idaho Legislators

CIR Implementation on I-15

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING



"We are not bothering the traveling public as much and creating a road for cheaper that's actually goanna last longer"---Scott Redding, ITD Resident Engineer

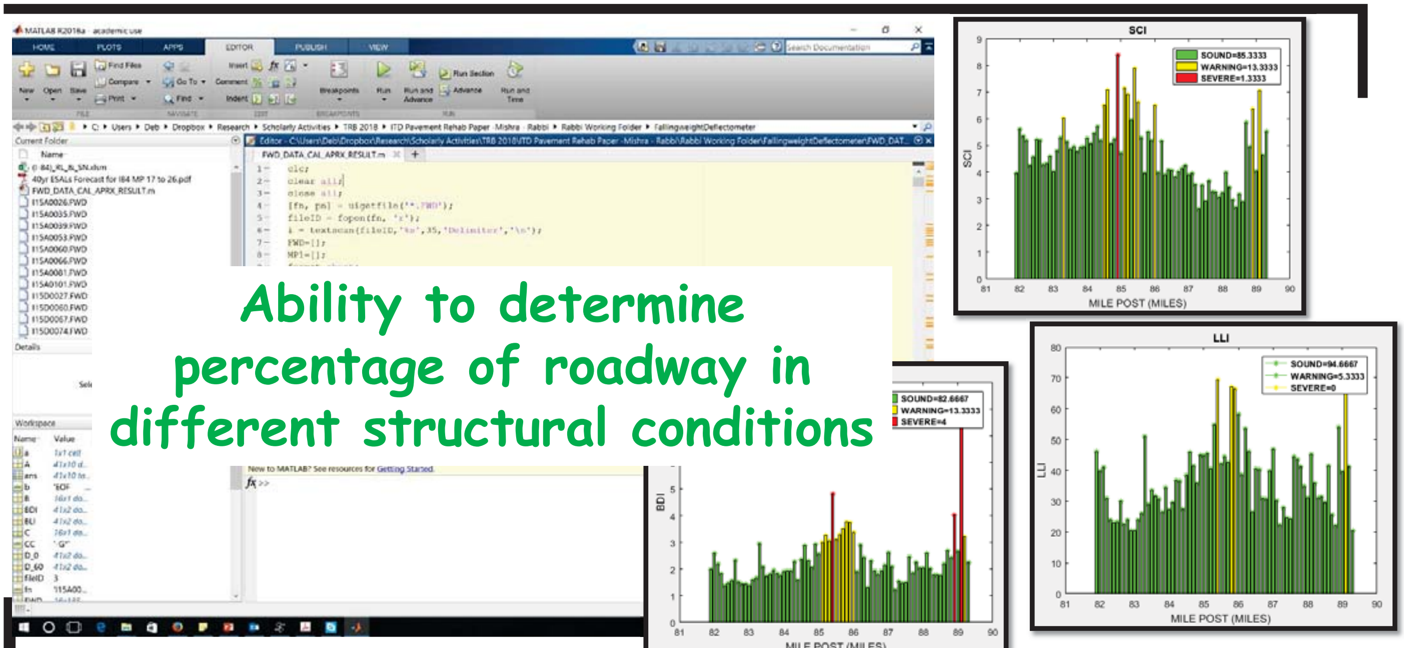


BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING

Developing a Tool for "Quick" Implementation

MATLAB Tool for Rapid Analysis of FWD Data

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING



Ability to determine percentage of roadway in different structural conditions

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING

Network-Level Application of FWD Data

[Structural Number, Layer Modulus, Service Life]

Structural Number & Remaining Life Calculations

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING

Normalized FWD Data

$$M_R = \frac{0.24 \times P}{d_r \times r}$$

Solve the Equation Iteratively to Determine Ep

$$d_0 = 1.5 \times P \times a \times \left\{ \frac{1}{M_R \times \sqrt{1 + \left(\frac{D}{a} \times \sqrt[3]{\frac{E_p}{M_R}} \right)^2}} + \frac{\left[1 - \frac{1}{\sqrt{1 + \left(\frac{D}{a} \right)^2}} \right]}{E_p} \right\}$$

$$E_p$$

$$SN_{eff} = 0.0045 \times D \sqrt[3]{E_p}$$

$$\log_{10} W_{18} = Z_R \times S_0 + 9.36 \times \log_{10}(SN - 1) - 0.20 + \frac{\log_{10}\left[\frac{\Delta PSI}{4.2 - 1.5}\right]}{0.40 + \frac{1094}{(SN + 1)^{5.19}}} + 2.32 \times \log_{10}(M_R) - 8.07$$

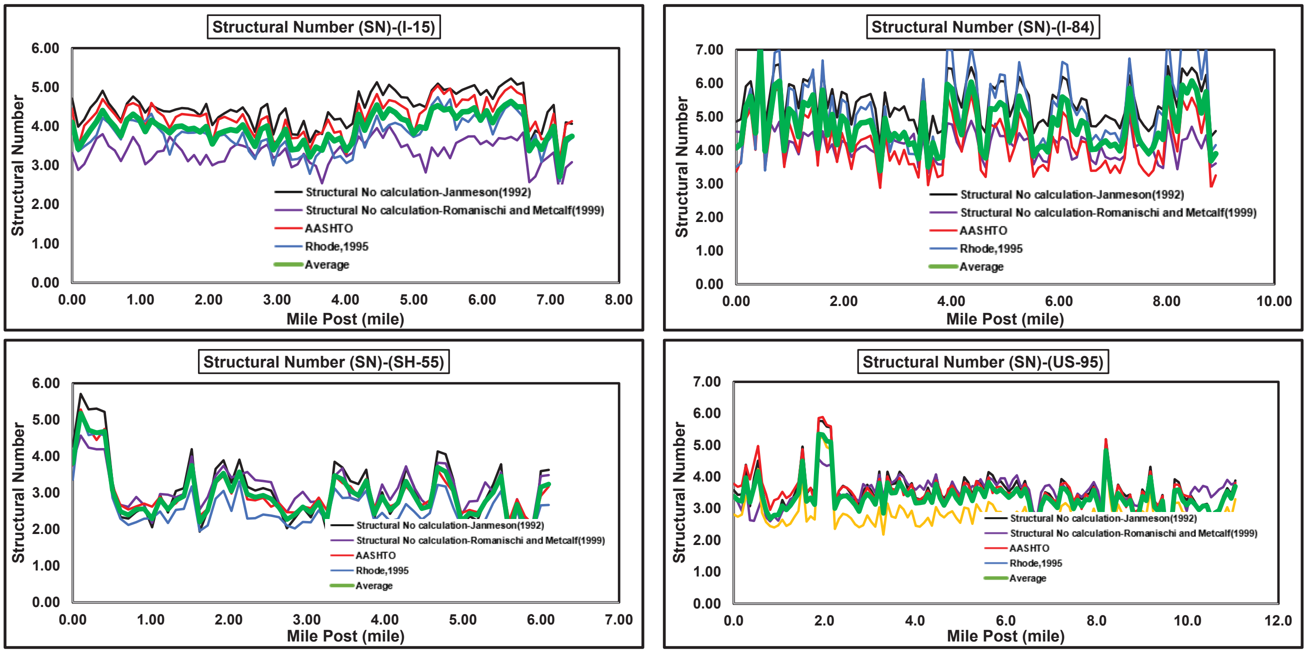
ESALs Experienced by the Existing Road

$$RL = 100 \times \left[1 - \left(\frac{N_p}{N_{1.5}} \right) \right]$$

Remaining Service Life(RL)

Sample Representation of Network-Level Pavement Condition

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING



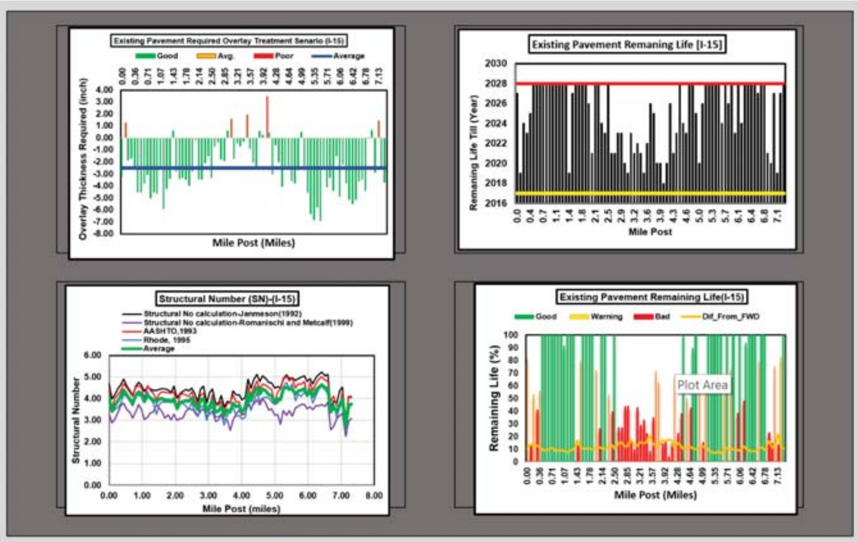
Excel Tool for Network-Level Sn_{eff} Calculations

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING

Input Data For Pavement Design	
Pavement Thickness GPR	18
Change in Present Serviceability Index Delta(PSI)	0.94208
ZR	-1.645
S0	0.45
Design_ESALs	24657
Reliability,R	95
IRI	95
Change in PSI	2
Rut Depth	0.43
Zr	-1.645
Structral Co-efficent of AC overlay	0.25

Please Click For SN_{eff} | Please Click For SN_{req}

Calculated Data		
Average Overlay pavement Required	-2.5189	
Average Remaining Life of Existing pavement	8.01205	year
Average SN	3.96	



BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING

Mechanistic Validation of Deflection Basin Parameters using Finite Element Modeling

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING

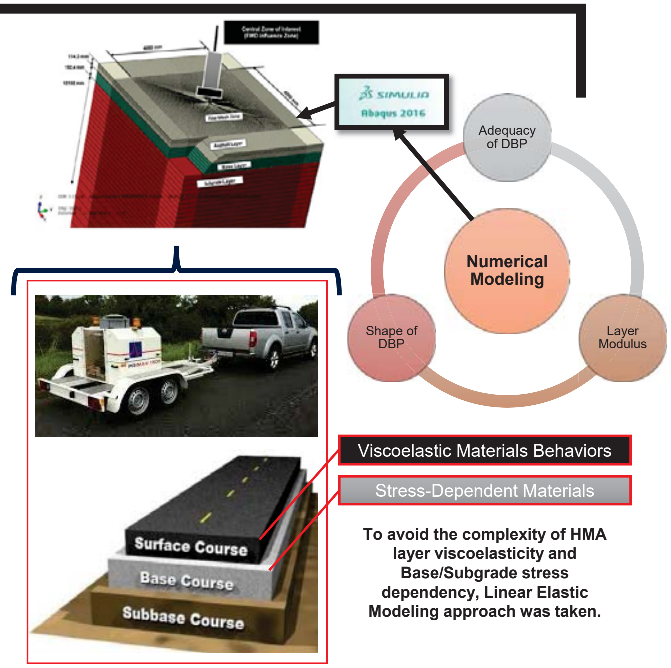
Numerical Pavement Modeling

Pavement Modeling Purpose:

- ❑ To determine the pavement responses like stresses, strains, and deflections due to the application of load.

The common structural models:

- ❑ Layered Elastic Models (All layers)
- ❑ Visco-Elastic Modeling. (HMA layer)
- ❑ Stress-Dependent Modulus (Base and Subgrade layers)



To avoid the complexity of HMA layer viscoelasticity and Base/Subgrade stress dependency, Linear Elastic Modeling approach was taken.

Ref: http://elibrary.bharathuniv.ac.in/NPTEL/105101087/Transportation%20Engg%201/20-Ltexhtml/nptel_ceTEI_L20.pdf

Numerical Pavement Modeling

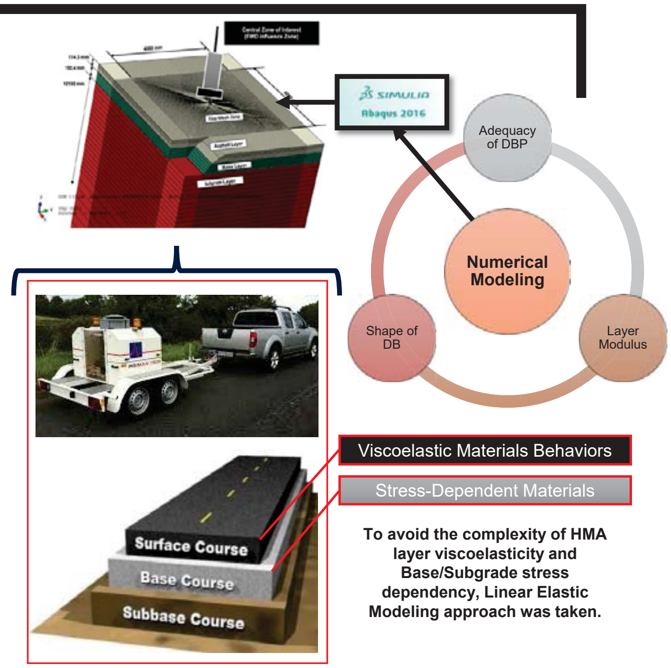
BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING

Layered elastic model:

- ❑ Computation of stresses, strains, and deflections at any point in a pavements are relatively simple.
- ❑ For the modeling only pavement layer configuration, elastic modulus and Poisson's Ratio values are required.

Layered elastic models assumption:

- ❑ Pavement structural layer is homogeneous, isotropic, and linearly elastic
- ❑ The layer will rebound to its original form once the load is removed.



To avoid the complexity of HMA layer viscoelasticity and Base/Subgrade stress dependency, Linear Elastic Modeling approach was taken.

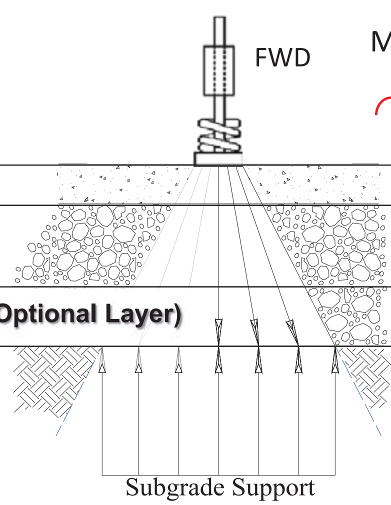
Ref: http://elibrary.bharathuniv.ac.in/NPTEL/105101087/Transportation%20Engg%201/20-Ltexhtml/nptel_ceTEI_L20.pdf

Flexible Pavement Typical Layer Input Parameters

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING

LAYERED ELASTIC METHOD

Layer	Parameters	Back-calculation
SURFACE	E_S, μ_S, h	*Modulus (M_R)
BASE	E_B, μ_B, h_B	Modulus (M_R)
SUBBASE	E_{SB}, μ_{SB} h_{SB} (Optional Layer)	Modulus (M_R)
SUBGRADE	E_{SG}, μ_{SG} h_{SG}	Modulus (M_R)



E = Elastic Modulus
h = thickness
μ = Poisson's Ratio

Ref: Rodney N. Joel,(2008), Civil Engineer / Airfield Pavement Airport Engineering Division, Presented to: 2008 Eastern Region Airport Conference(Picture Modified)

Flexible Pavement Typical Layer Input Parameters

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING

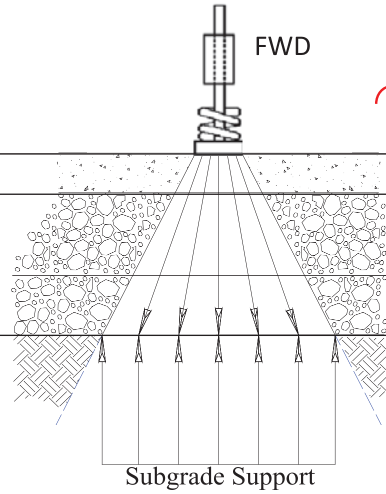
Flexible Pavement Typical Layer Parameters Required as Input

LAYERED ELASTIC METHOD

SURFACE E_S, μ_S, h

BASE E_B, μ_B, h_B

SUBGRADE E_{SG}, μ_{SG} h_{SG}



Model Input Parameters

E = Elastic Modulus

E_{HMA} = 4137~689 MPa

E_{Base} = 552~207 MPa

$E_{Subgrade}$ = 276~14 MPa

E = Elastic Modulus
h = thickness
μ = Poisson's Ratio

57th Idaho Asphalt Conference
October 26, 2017, Moscow, Idaho

Ref: Rodney N. Joel,(2008), Civil Engineer / Airfield Pavement Airport Engineering Division, Presented to: 2008 Eastern Region Airport Conference(Picture Modified)

53

Flexible Pavement Typical Layer Input Parameters

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING

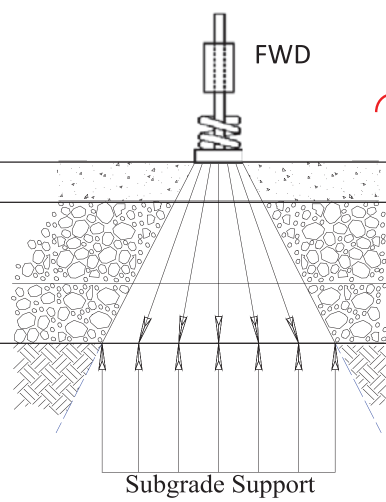
Flexible Pavement Typical Layer Parameters Required as Input

LAYERED ELASTIC METHOD

SURFACE E_S, μ_S, h

BASE E_B, μ_B, h_B

SUBGRADE E_{SG}, μ_{SG} h_{SG}



Model Input Parameters

H= Layer Thickness	μ = Poisson's Ratio
h_{HMA} = 114 mm	μ_{HMA} =0.30
h_{Base} = 152 mm	μ_{Base} =0.30
$h_{Subgrade}$ = 12192 mm	μ_{Sub} =0.35

E = Elastic Modulus
h = thickness
μ = Poisson's Ratio

57th Idaho Asphalt Conference
October 26, 2017, Moscow, Idaho

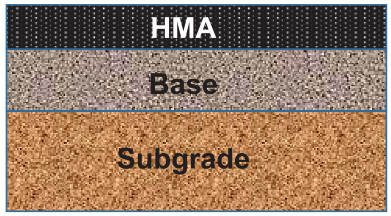
Ref: Rodney N. Joel,(2008), Civil Engineer / Airfield Pavement Airport Engineering Division, Presented to: 2008 Eastern Region Airport Conference(Picture Modified)

54

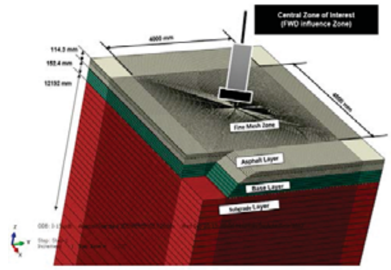
Details of the Numerical Model

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING

The physical structure



The idealized model



The discretized (approximate) model

Advantages of 3-D Model

- Provides the complete stress and displacement fields for the analyzed domain
- Not limited to linear elastic analysis

Disadvantages of 3D-FEM

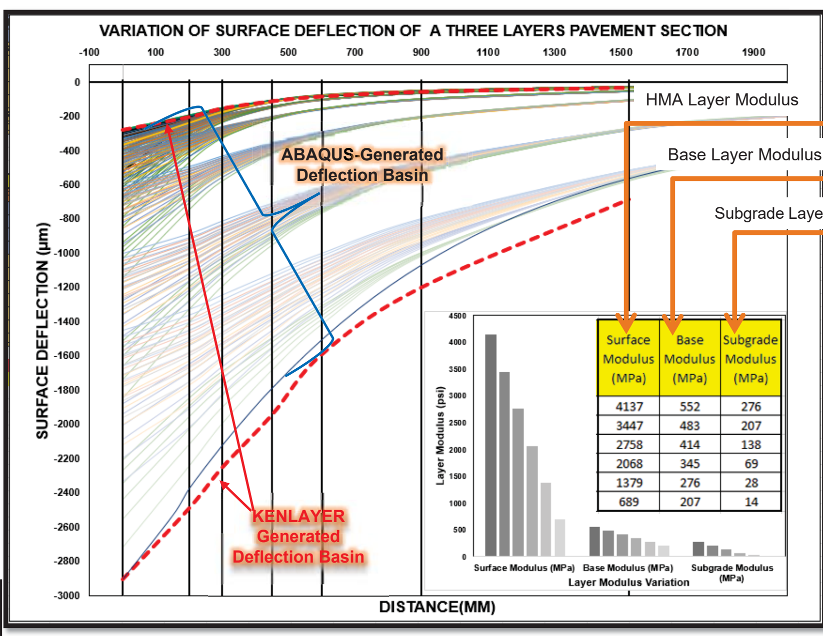
- Require long computation times
- Significant Pre-processing and post-processing requirements.
- Solution is mesh-dependent.
  - In theory, the solution can always be improved by refining the 3D mesh.
  - Improvement comes at the expense of time.

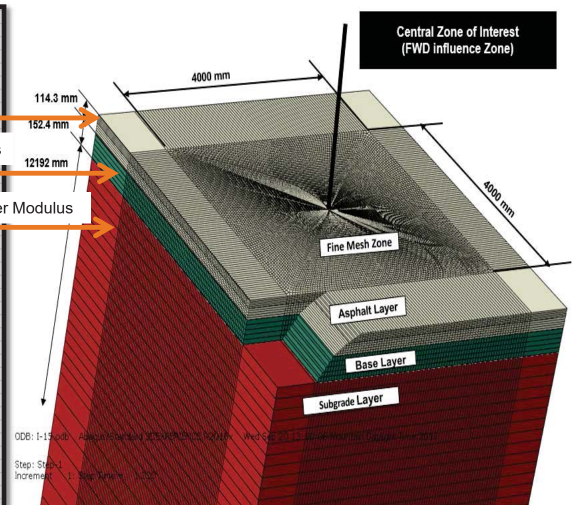
Model Dimensions	
Length	26.0 m (85.3 ft.)
Width	18.0 m (59.0 ft.)
Depth	12.7 m (41.5 ft.)

Ref: Rodney N. Joel,(2008), Civil Engineer / Airfield Pavement Airport Engineering Division, Presented to: 2008 Eastern Region Airport Conference

Model Optimization

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING



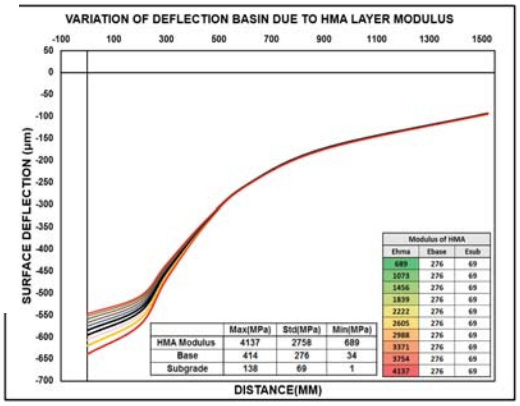


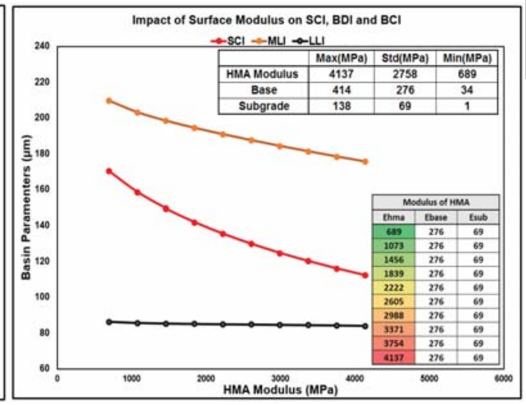
BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING

Sensitivity Analysis Using the Control Pavement Section

Observation:

- ✓ **Variation of SCI and MLI Significant**
- ✓ **Variation of LLI insignificant (~0)**
- ✓ **Effect are more prominent near the loading area.**





Layer	Elastic Modulus (MPa)			PI (%)	SCI/BLI (µm)		MLI/BDI (µm)		LLI/BCI (µm)		SCI (µm)	MLI (µm)	LLI (µm)
	Min.	Max.	Control		Max.	Min.	Max.	Min.	Max.	Min.	PD (%)	PD (%)	PD (%)
HMA	689	4137	2758	+500	170	112	210	176	86	85	-34	-16	-1
Base	34	414	276	+1118	422	242	349	177	162	105	-43	-49	-35
Subgrade	17	138	69	+712	360	238	377	139	297	61	-34	-63	-79

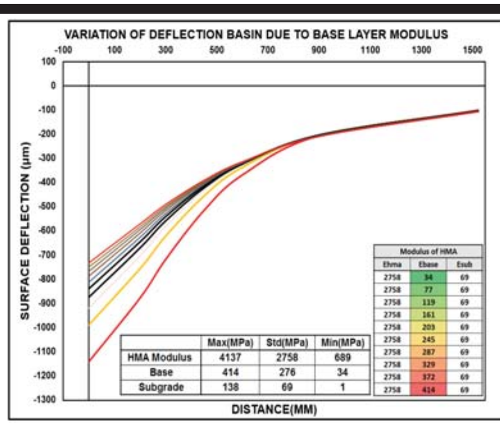
**PI= Percentage Increase from minimum to maximum, PD= Percentage Decrease from maximum to minimum

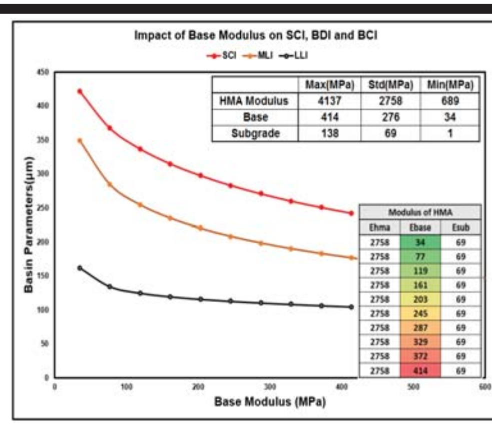
BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING

Sensitivity Analysis Using the Control Pavement Section

Observation:

- ✓ **Rate of change of slope noticable in SCI, MLI and LLI**
- ✓ **SCI and MLI are highly influenced by changes in Base Modulus**





Layer	Elastic Modulus (MPa)			PI (%)	SCI/BLI (µm)		MLI/BDI (µm)		LLI/BCI (µm)		SCI (µm)	MLI (µm)	LLI (µm)
	Min.	Max.	Control		Max.	Min.	Max.	Min.	Max.	Min.	PD (%)	PD (%)	PD (%)
HMA	689	4137	2758	+500	170	112	210	176	86	85	-34	-16	-1
Base	34	414	276	+1118	422	242	349	177	162	105	-43	-49	-35
Subgrade	17	138	69	+712	360	238	377	139	297	61	-34	-63	-79

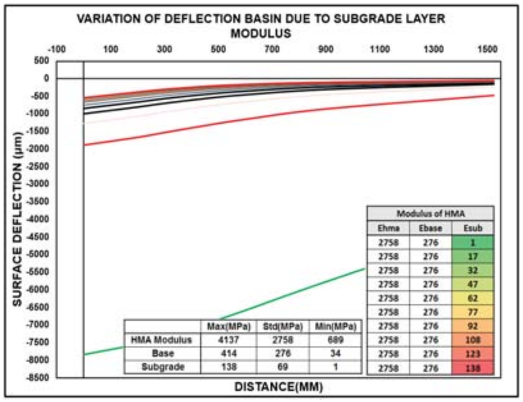
**PI= Percentage Increase from min. to max., PD= Percentage Decrease from max. to min.

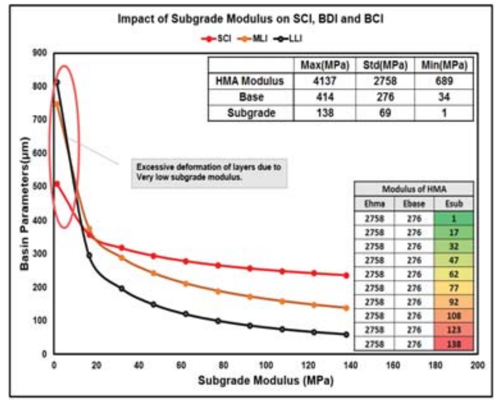
Sensitivity Analysis Using the Control Pavement Section

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING

Observation:

- ✓ Rate of change of slope noticeable in all three DBPs parameter such as SCI, MLI and LLI
- ✓ The variation of LLI are considerable high.
- ✓ Deflection of farthest sensor is highly influence by the variation of subgrade modulus.





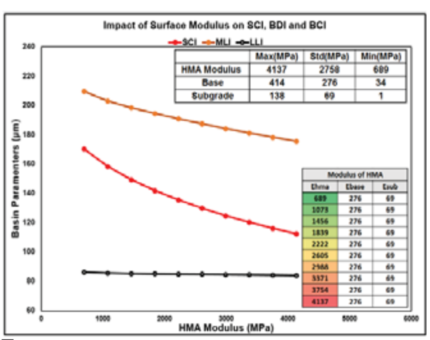
Layer	Elastic Modulus (MPa)			PI (%)	SCI/BLI (µm)		MLI/BDI (µm)		LLI/BCI (µm)		SCI (µm)	MLI (µm)	LLI (µm)
	Min.	Max.	Control		Max.	Min.	Max.	Min.	Max.	Min.	PD (%)	PD (%)	PD (%)
HMA	689	4137	2758	+500	170	112	210	176	86	85	-34	-16	-1
Base	34	414	276	+1118	422	242	349	177	162	105	-43	-49	-35
Sub.G	17	138	69	+712	360	238	377	139	297	61	-34	-63	-79

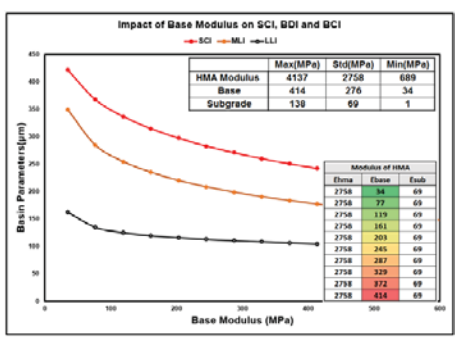
**PI= Percentage Increase from minimum to maximum, PD= Percentage Decrease from maximum to minimum

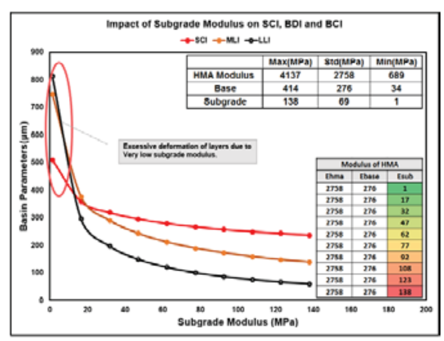
Sensitivity Analysis Using the Control Pavement Section

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING

Layer	Elastic Modulus(MPa)			PI (%)	SCI/BLI(µm)		MLI/BDI(µm)		LLI/BCI(µm)		SCI(µm)	MLI(µm)	LLI(µm)
	Mini.	Max.	Control		Max.	Mini.	Max.	Mini.	Max.	Mini.	PD (%)	PD (%)	PD (%)
HMA	689	4137	2758	+500	170	112	210	176	86	85	-34	-16	-1
Base	34	414	276	+1118	422	242	349	177	162	105	-43	-49	-35
Sub.G	17	138	69	+712	360	238	377	139	297	61	-34	-63	-79





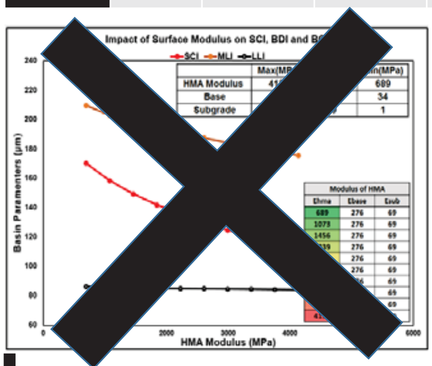


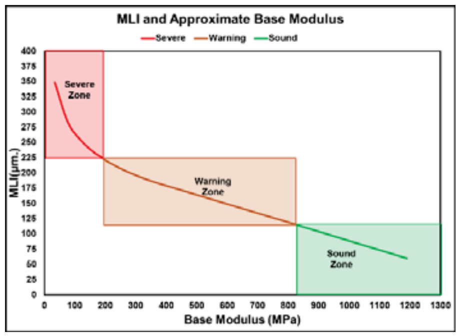
**PI= Percentage Increase from min. to max., PD= Percentage Decrease from max. to min.

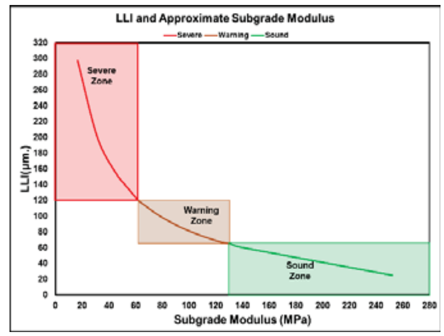
Sensitivity Analysis Using the Control Pavement Section

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING

Layer	Elastic Modulus(MPa)			PI (%)	SCI/BLI(μm)		MLI/BDI(μm)		LLI/BCI(μm)		SCI(μm)	MLI(μm)	LLI(μm)
	Mini.	Max.	Control		Max.	Mini.	Max.	Mini.	Max.	Mini.	PD (%)	PD (%)	PD (%)
HMA	689	4137	2758	+500	170	112	210	176	86	85	-34	-16	-1
Base	34	414	276	+1118	422	242	349	177	162	105	-43	-49	-35
Sub.G	17	138	69	+712	360	238	377	139	297	61	-34	-63	-79







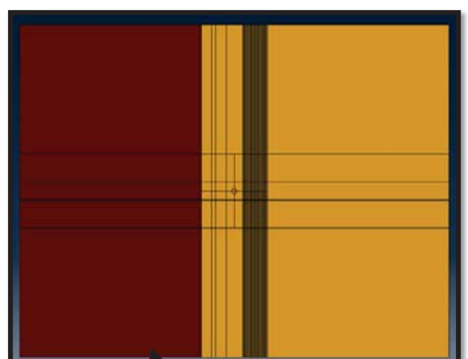
**PI= Percentage Increase f

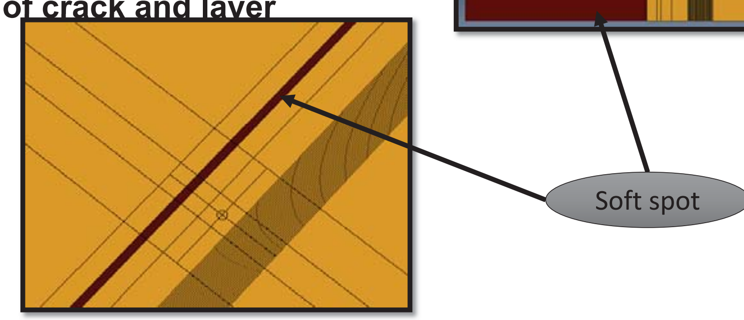
Modulus variation between 100-600 ksi not capturing full SCI thresholds

Current Research Tasks

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING

- ✓ Incorporation of viscoelastic behavior of HMA layer
- ✓ Preparation of a synthetic database of different pavement scenario and it's effect of DBPs.
- ✓ Investigate the effect of crack and layer thickness on DBPs



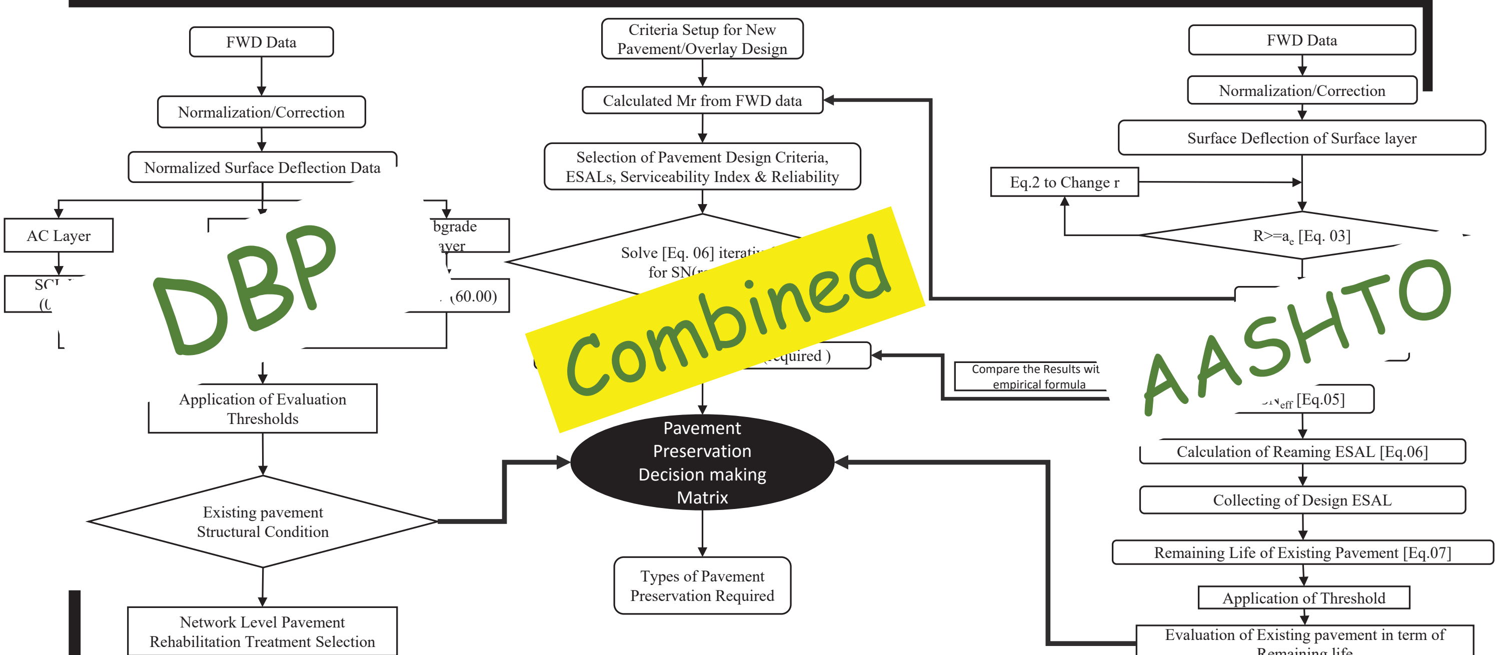


BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING

Moving Forward …

Framework for Rehabilitation Strategy Selection

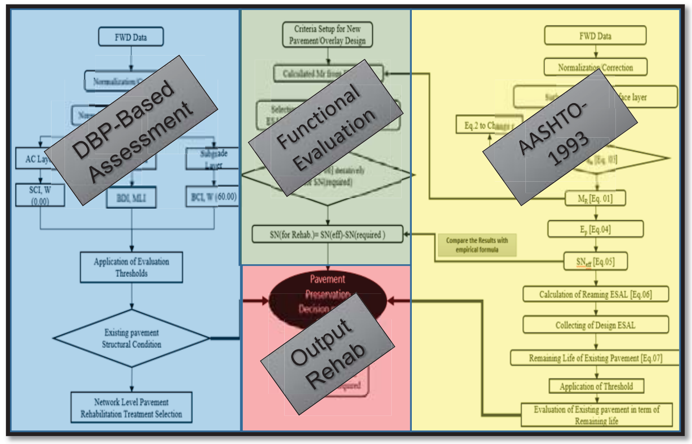
BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING



Framework for Rehabilitation Strategy Selection

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING

- ✓ This framework not only follows AASHTO-1993 guidelines, but also considers DBP evaluation along with the existing functional evaluation function process.
- ✓ Final results are presented as percent layer condition, SN and RL, which depict a complete picture of existing pavement conditions, and will assist engineers in selecting the best rehabilitation strategies.



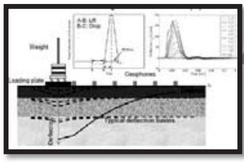
Futures Research Direction

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING

- ✓ Collaborate with ITD to gather as much data as possible concerning pavement layer depths (from cores) and corresponding FWD data.
  - ✓ This will facilitate the validation of the DBP approach for different pavement depths
  - ✓ Possible modification of DBP thresholds
  - ✓ The FWD Data Analysis Tool (currently under development) will be available for use by ITD districts for rapid assessment of network-level pavement structural condition

Envisioned Research Approach

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING

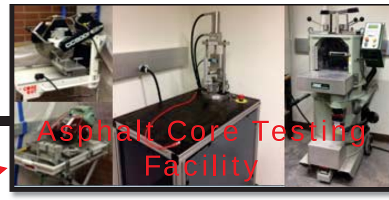


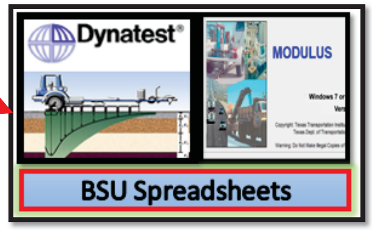
DBP Thresholds for Idaho

Asphalt, Base & Subgrade

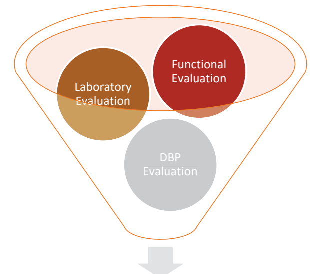
FWD Testing

Functional Evolution





A simple Initiative towards the Validation of DBP for Idaho



Idaho DBP Thresholds

- http://pathweb.pathwayservices.com
- ITD Function Survey Records

Acknowledgments

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING

Dan Harelson
John Arambarri
Mike Santi
Dave Richards
Ed Bala
Dr. Mandar Khanal

BOISE STATE UNIVERSITY

IDAHO TRANSPORTATION DEPARTMENT

Dynatest®

Thank You

BOISE STATE UNIVERSITY
COLLEGE OF ENGINEERING

Deb Mishra, Ph.D., P.E.
Assistant Professor
Department of Civil Engineering
Boise State University; ERB 3137
Tel: (208) 426-3710
Email: debmishra@boisestate.edu

Thanks to all organizers and sponsors agencies

WESTERN STATES CAT
Western States Asphalt, Inc.
Zydex
URETEK USA
IDAHO ASPHALT SUPPLY, INC.
InstroTek Inc.
SAGE SUPPLY, INC.
SPHALT INSTITUTE
IDAHO TRANSPORTATION DEPARTMENT
University of Idaho