OKLAHOMA
Transportation

AASHTOWare®
Mechanistic Empirical (M-E) Pavement Design Workshop

Presenters:

Nur Hossain, PhD, PE

Matt Coen, EI

Conducted by:

GEOCAL

SOUTHERN PLAINS TRANSPORTATION CENTER

Our History

Geocal, Inc.
Geosciences & Engineering

GEOCAL

GEOCAL 30 YEARS

1989

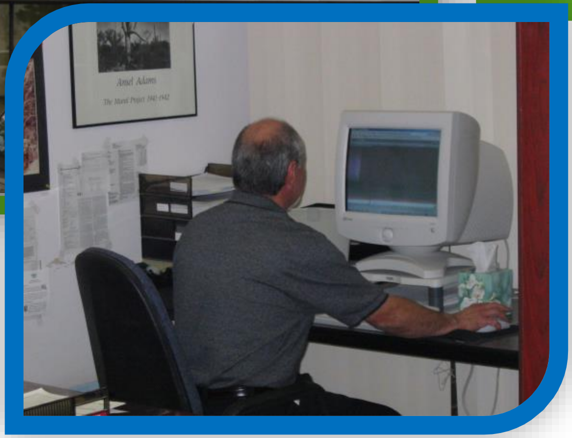
- Ron Vasquez establishes Geocal

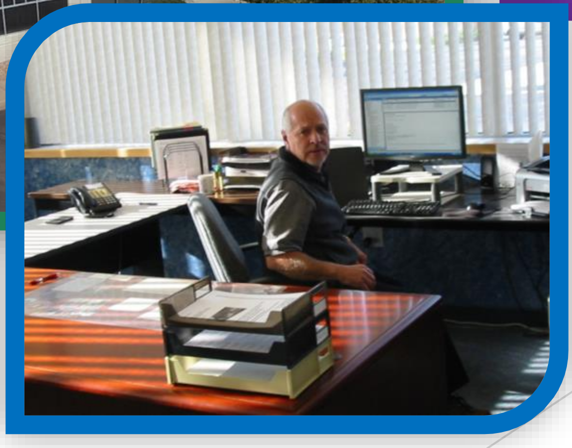
2013

- Natural Growth
- Fresh office
- Fresh logo

2019

- Celebrates 30 years
- Ron retires and…





… Someh
guys

Company Overview

- 50+ Employees across 3 locations along Colorado's Front Range:
  - Centennial
  - Colorado Springs
  - Loveland
  - *Established an OKC presence*
- Markets:
  - Transportation (Our bread)
  - Infrastructure (Our butter)
  - Airports
  - Transit
  - Water
- Clients:
  - Federal Agencies
  - Colorado
  - Oklahoma
  - Counties, Cities, other municipalities
  - Prime designers

Our Philosophy

The Stakeholder Mentality

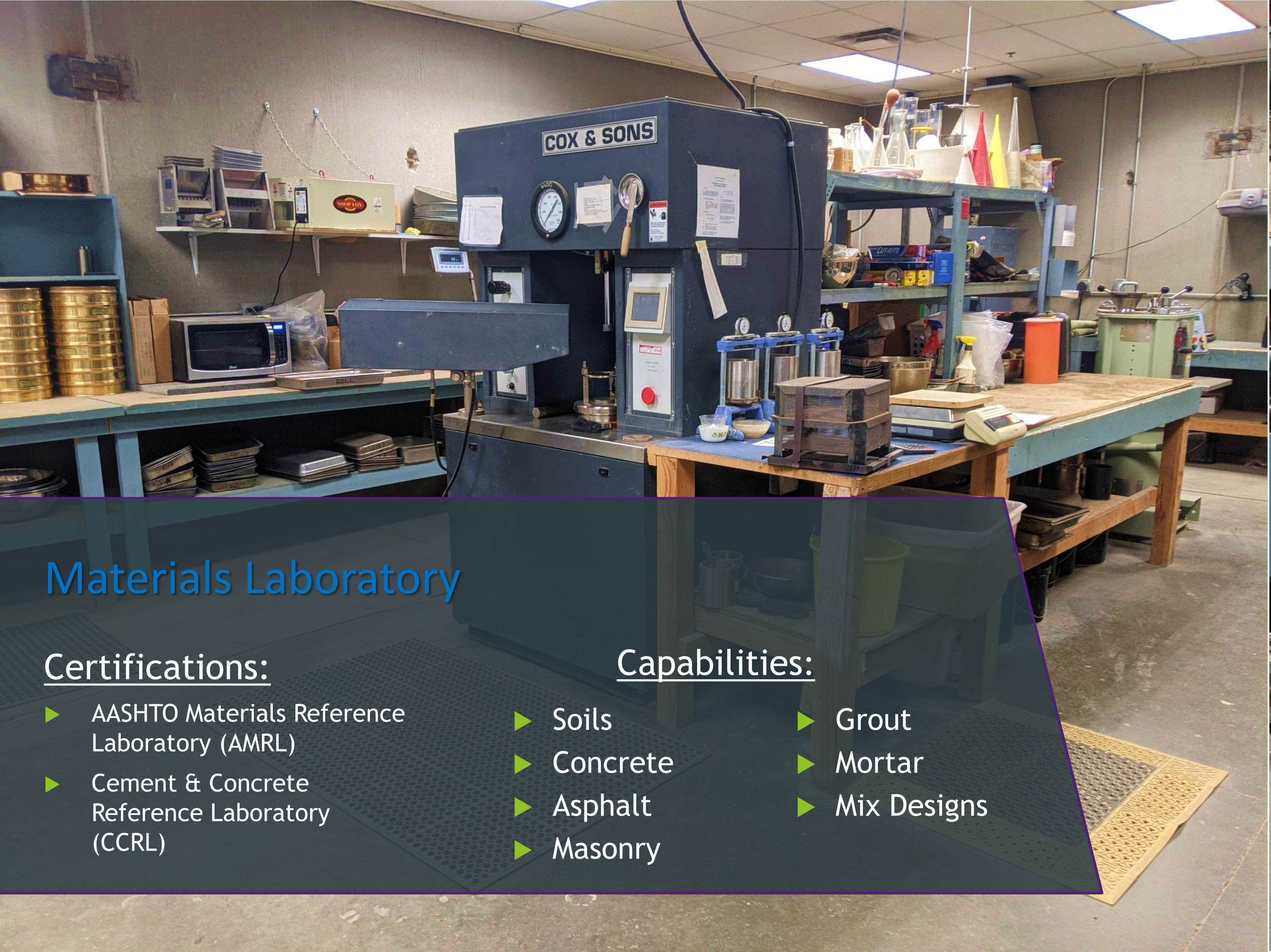
- Manage things; Lead people
- Stakeholders not employees
  - Take ownership and responsibility
  - Self-motivate
  - Be capable of making decisions

Keys To Success

- OPERATE AS AN EXTENSION OF THE CLIENT
- BE RESPONSIVE
- BE PROACTIVE, NOT REACTIVE
- WORK WITH INTEGRITY
- LET OUR PASSION DRIVE OUR WORK
- FOSTER A COHESIVE TEAM

Our Services

- Geotechnical Engineering
  - Site Exploration
  - Pavement Design
  - Foundations
  - Slope Stability and Settlement Analyses
- Material Testing
  - Full-service materials laboratory
  - Concrete testing
  - Asphalt testing
  - Quality Assurance
  - Quality Control
- Bridge Inspection
- Construction Management & Inspection



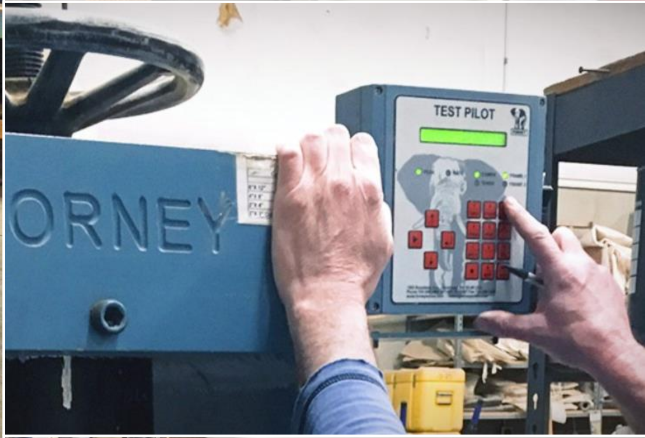
Materials Laboratory

Certifications:

- AASHTO Materials Reference Laboratory (AMRL)
- Cement & Concrete Reference Laboratory (CCRL)

Capabilities:

- Soils
- Concrete
- Asphalt
- Masonry
- Grout
- Mortar
- Mix Designs



And now… The Main Event!

Your Presenters

Nur Hossain, PhD, PE
President/Principal

- 14 years in industry
- PhD & Masters from
- Dissertation was on the MEPDG
- Published numerous peer-reviewed journals on MEPDG

Matt Coen, EI
Staff Engineer

- 4 years in industry
- Masters in Geological Engineering

Oklahoma Experience:
- US 270 over Carter Creek
- I-35 & Main Street Interchange
- Northeast Oklahoma County Loop
- SH 34 over Canadian River

Major ME Design Experience in Colorado:
- US 34 Resurfacing, Ft. Morgan to Brush
- US 85 & Weld CR 44 (Peckham) Interchange
- 56th Ave Widening, Peña Blvd to Peoria St
- I-25 Exit 11 (Raton Pass)

Notable Experience:
- I-25 North Culverts
- 48th Street Levee Improvements
- National Western Center, Equestrian Center Retaining Wall Design

Major ME Design Experience in Colorado:
- US 85 & Weld CR 44 (Peckham) Interchange
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- US 34 Resurfacing, Ft. Morgan to Brush

Nur/Matt's Contact Information

NUR HOSSAIN

MATT COEN

Our Goals for You:

- Understand the AASHTO Mechanistic-Empirical (M-E) Pavement Design procedure
- Understand how this methodology differs from previous pavement design methodologies
- Recognize the importance of accurate design inputs
- Be aware of the versatility of M-E design in both new construction and rehabilitated pavement design projects
- **Get Hands-On Training**

Workshop Schedule

Day 1

Morning Session

- ME Design Methodology, Software, and Process

Afternoon Session

- Discuss Design Outputs and Adequacy of Design
- New Asphalt/Concrete Pavement Design

Day 2

Morning Session

- Asphalt/Concrete Overlay Design
- Oklahoma Project Examples

Afternoon Session

- Classroom Exercises (Asphalt/Concrete/Overlay Design)

Day 3

Morning Session

- Calibration/Sensitivity Analysis/Backcalculation
- Q&A, Reviewing Topics

Day 1: Morning Session

- Introduction to M-E Design
- M-E vs AASHTO-93
- Overview of AASHTOWare® M-E software
- Outline the internal design process
- Elaborate on the design methodology
- Inputs/Outputs
- Analysis of Results

The thick red outline indicates where we are in the session

What is M-E Pavement Design?

M-E Design software uses the methodology and pavement models described in the AASHTO Interim Mechanistic-Empirical Pavement Design Guide (MEPDG) Manual of Practice.

The AASHTO Pavement M-E Design Procedure is based on mechanistic-empirical design concepts….which means what!?

- Mechanistic – uses mathematical models to calculate the pavement responses to stresses, strains, and deflections under traffic loads and climatic conditions and accumulates the damage over the design analysis period.
- Empirical - the procedure empirically relates calculated damage over to pavement distresses and smoothness based on performance criteria from actual projects.

AASHTO 1993	M-E Pavement Design
• Empirical design method • Data obtained from AASHO road test in the 1960s	• Mechanistic-Empirical Pavement Design Method • 'Mechanistic' refers to the incorporation of the principles of engineering mechanics
• Estimated Single Axle Load (ESAL) based design (highly empirical)	• Axle Load Spectra (ALS) based design (utilization of stress and strain into design)
• Does not account for climatic conditions as well as variety of vehicle types	• Developed from 20+ years of data regarding actual traffic, materials, and climate data
• One type of subgrade was utilized in the AASHO Road Test	• Many versions of M-E pavement design exist nationally
• Interstate pavements were designed for 5 to 15 million vehicles	• Modern interstates can be designed for 50 to 200 million vehicles

EXAMPLE: East 56th Avenue – Pena Boulevard to Peoria Street

- Widening East 56th Avenue for a length of approximately 3 miles to a 4-lane roadway

EXAMPLE: East 56th Avenue – Pena Boulevard to Peoria Street

	Current (2020) ADT	% Trucks	2023 ADTT
56th Avenue East of Peoria Street	23,900	13.3	3,741
56th Avenue West of Chambers Avenue	21,100	15.7	3,902

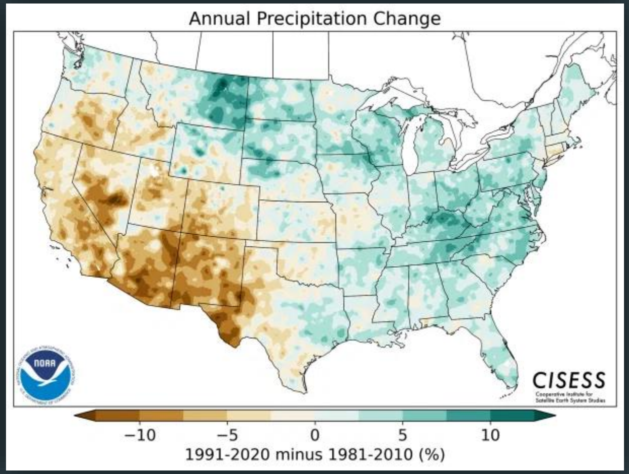
	M-E Pavement Design	AASHTO 1993
56th Avenue East of Peoria Street	8¾ in HMAP over 6 in ABC	10¾ in HMAP over 6 in ABC
56th Avenue West of Chambers Avenue	9 in HMAP over 6 in ABC	12.6 in HMAP over 6 in ABC

- Generally, we have seen that the asphalt pavement thicknesses generated using the AASHTO 1993 procedure is about ½-inch to roughly 3½ inches thicker than the passing designs achieved using the M-E Pavement Design software.

Overview

- Pavement design software that follows the methodology outlined in the AASHTO MEPDG Manual of Practice and is designed to simplify the design process while resulting in improved, cost-effective designs.
- There are three input categories (to be discussed later in detail):

Traffic



Climate

Materials

Introduction to M-E Design | M-E vs AASHTO-93 | Overview of AASHTOWare® M-E software | **Outline the internal design process** | Elaborate on the design methodology | Inputs/Outputs | Analysis of Results

Inputs

- Foundation Analysis
- Climate
- Materials Properties
- Traffic Analysis
- Performance Criteria & Reliability

Analysis

- Trial Design
- Pavement Response Model
- Damage Accumulation over Time
- Calibrated Damage-Distress/IRI Models

Outputs

- Thermal Cracking
- Longitudinal Cracking
- Alligator Cracking
- Rutting
- IRI

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Meets Performance Criteria?

No → Revise Trial Design

Yes → Final Design (Optimize)

Structural Response Calculation

- Flexible Pavements - Layered Elastic Analysis (JULEA/TCMODEL programs)
  - Assumptions:
    - Pavement layers extend indefinitely in the horizontal direction
    - The bottom layer (typically subgrade extends indefinitely downward)
    - Materials are not stressed beyond their elastic ranges
  - Inputs:
    - Material Properties of each layer
    - Pavement Layer Thickness
    - Loading Conditions
  - Outputs:
    - Stress - intensity of internally distributed forces experienced within the pavement
    - Strain - unit displacement due to stress (typically expressed in terms of microstrain (10^{-6}))
    - Deflection - linear change in dimension

Structural Response Calculation

- Rigid Pavements – Finite Element Modeling (FEM) (ISLAB2000 program)
  - Assumptions:
    - Element geometry (size and shape)
    - Interpolation functions
  - Inputs:
    - Discretization of the region of interest
    - Boundary Conditions
  - Outputs:
    - Stress – intensity of internally distributed forces experienced within the pavement
    - Strain – unit displacement due to stress (typically expressed in terms of microstrain (10^{-6}))
    - Deflection – linear change in dimension


TIME FOR A
BREAK

Input Parameters

- One challenging aspect of M-E design is determining your inputs.
- There are three levels of input data:
  - Level 1
  - Level 2
  - Level 3
- Research is being conducted all over the country to develop traffic and materials input parameters, as well as to calibrate distress models

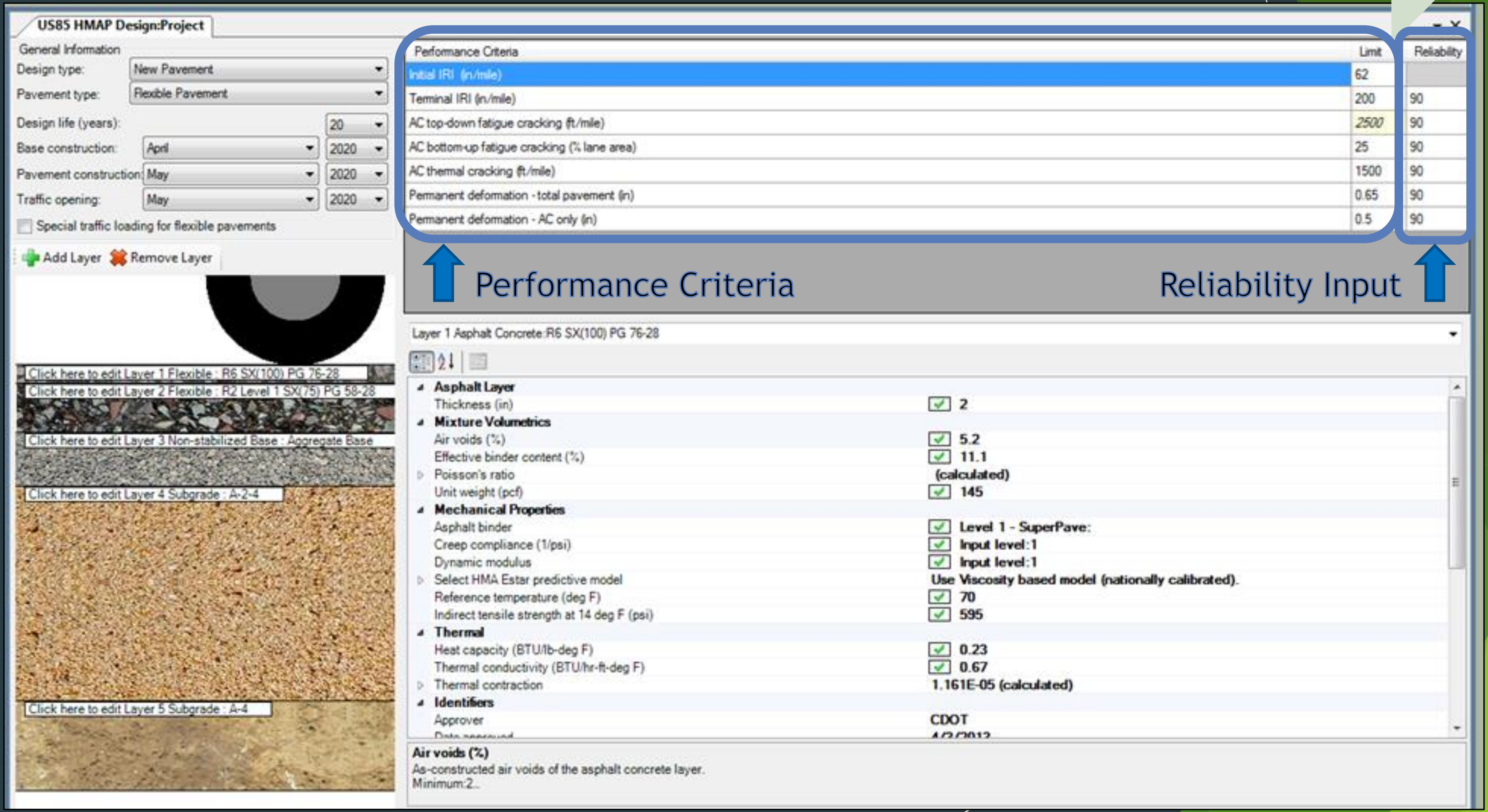
Input Parameters

- Level 1 Inputs
  - Highest Accuracy Level
  - Lowest Level of Input Errors
  - Site Specific data (based off lab and field testing)
  - Used for designing heavily trafficked areas or where there are high safety and economical consequences of failure
- Level 2 Inputs
  - Intermediate Accuracy Level
  - Information derived from agency database or limited lab testing
- Level 3 Inputs
  - Lowest Accuracy Level
  - Default values typically used (best estimates)

Reliability and Performance Criteria

- Design thickness depends heavily upon the Design Reliability & Performance Criteria
- Must be considered together, not independently.
- Reliability (Risk): dependent upon roadway classification and intent of the project
- Design Performance: represents the “level of deterioration” that a designer expects or anticipates a pavement to be at when major rehabilitation is needed
- Too LOW of distress criteria in conjunction with high reliability could result in a very conservative design with a high initial construction cost

User Interface



- Table 2.3 - Design Reliability *(from CDOT Design Guide)*

Functional Classification	Value for Reliability
Interstate	80-95
Principal Arterial (freeways/expressways)	75-95
Principal Arterials (other)	75-95
Minor Arterial	70-95
Major Collectors	70-90
Minor Collectors	50-90
Local	50-80

- Higher Reliability Levels – greater traffic volume, more costly projects

Traffic

https://www.oklahoman.com/gallery/6034612/unsustainable-okcs-growing-pains

Traffic Inputs in ME Design

Traffic Volume
- Annual Average Daily Truck Traffic
- Growth Factor (by truck class)
- Highway Capacity Limits

Traffic Volume Adjustment
- Vehicle Class Distribution
- Monthly Adjustment
- Hourly Truck Distribution

Axle Load Distribution
- Load Distribution by Axle Type

Design Lane Features
- Number of Lanes in Design Direction
- Directional Distribution Factor
- Lane Distribution Factor
- Operational Speed

General Traffic Inputs
- Number of Axles Per Truck
- Axle Spacing
- Truck Class Wheelbase
- Lateral Wander
- Tire Spacing and Pressure

Traffic Inputs

Input Hierarchy	Description
Level 1	Site-specific traffic data determined from weigh-in-motion data • Volume Counts • Traffic Adjustment Factors • Axle Load Distribution
Level 2	Site-specific traffic volume counts • Historical data • State Agency-derived averages
Level 3	M-E Design software defaults

See Table 3.2 from *CDOT Pavement Design Guide* for recommendations

Table 3.2 Recommendations of Traffic Inputs at Each Hierarchical Level

Input	Level 1	Level 2	Level 3
AADT	Use project specific historical traffic volume data **Section 3.1.3 Volume Counts**		
Traffic Growth Rate Distribution Factor	Use project specific historical traffic volume data **Section 3.1.5 Growth Factors for Trucks**		
Lane and Directional Distribution Factor	Use project specific values	**Section 3.1.4 Lane and Directional Distributions**	
Vehicle Class Distribution	Use project specific values	Use CDOT averages **Table 3.5 Level 2 Vehicle Class Distribution Factors**	Use M-E Design software defaults
Monthly Adjustment Factor	Use project specific values	Use CDOT averages **Table 3.7 Level 2 Monthly Adjustment Factors**	
Hourly Distribution Factor	Use project specific values	Use CDOT averages **Table 3.8 Hourly Distribution Factors**	
Axle Load Distribution	Use project specific values	Use CDOT averages **Section 3.1.10 Axle Load Distribution**	
Operational Speed	Use posted or design speed (Levels 1 and 2 not available)		
Number of Axles Per Truck	Use project specific values	Use CDOT averages **Table 3.6 Level 2 Number of Axles Per Truck**	
Lateral Traffic Wander	Use M-E Design software defaults (Levels 1 and 2 not available) **Section 3.1.12 Lateral Wander of Axle Load**		
Axle Configuration	Use M-E Design software defaults (Levels 1 and 2 not available) **Section 3.1.13 Axle Configuration and Wheelbase**		
Wheelbase	Use project specific values	Use national defaults **Section 3.1.13 Axle Configuration and Wheelbase**	
Tire Pressure	Use M-E Design software defaults (Levels 1 and 2 not available) **Section 3.1.14 Tire Pressure**		

Level 2 Vehicle Class Inputs *(from CDOT Design Guide)*

Cluster	Class 5 Distribution (%)	Class 9 Distribution (%)	Most Common Highway Functional Class
Cluster 1	40-75	10-30	• 4-lane rural principal arterial (non-interstate) • Some urban freeways
Cluster 2	5-35	40-80	• 4-lane rural principal arterial (other) • Interstate Highways
Cluster 3	15-50	15-50	• 2-lane rural principal arterial (other) • 2-lane rural major collector • 4-lane urban principal arterial

- Table 3.5 - Class 5 and Class 9 Distribution Per Cluster Type

Traffic Interface

US85 HMAP Design:Project | US85 HMAP Design:Traffic | US85 HMAP Design:Climate

AADTT	
Two-way AADTT	2200
Number of lanes	2
Percent trucks in design direction	50
Percent trucks in design lane	90
Operational speed (mph)	65
Traffic Capacity	
Traffic Capacity Cap	Not enforced
Axle Configuration	
Average axle width (ft)	8.5
Tandem axle spacing (in)	51.6
Dual tire spacing (in)	12
Quad axle spacing (in)	49.2
Tire pressure (psi)	120
Tridem axle spacing (in)	49.2
Lateral Wander	
Design lane width (ft)	12
Mean wheel location (in)	18
Traffic wander standard deviation (in)	10
Wheelbase	
Average spacing of long axles (ft)	18
Average spacing of medium axles (ft)	15
Percent trucks with long axles	61
Percent trucks with medium axles	22
Percent trucks with short axles	17
Average spacing of short axles (ft)	12
Identifiers	
Approver	
Date approved	4/3/2013
Author	AASHTOWare
Date created	4/3/2013
County	
Description of object	CDOT Traffic
Direction of travel	
Display name/identifier	CDOT Spectra
District	
From station (miles)	
Item Locked?	False
Highway	

Display name/identifier
Display name of object/material/project for outputs and graphical interface

Vehicle Class Distribution and Growth — Load Default Distribution

Vehicle Class	Distribution (%)	Growth Rate (%)	Growth Function
Class 4	2.5	1.59	Compound
Class 5	28.7	1.59	Compound
Class 6	14.1	1.59	Compound
Class 7	0	1.59	Compound
Class 8	3.8	1.59	Compound
Class 9	38.1	1.59	Compound
Class 10	12.8	1.59	Compound
Class 11	0	1.59	Compound

Monthly Adjustment — Import Monthly Adjustment

Month	Class 4	Class 5	Class 6	Class 7	Class 8	Class 9	Class 10	Class 11	Class 12	Class 13
January	0.885	0.82	0.765	0.745	0.822	0.93	0.889	0.905	0.918	0.862
February	0.899	0.824	0.782	0.771	0.873	0.938	0.888	0.888	0.976	0.83
March	0.963	0.9	0.843	1.066	0.993	0.99	0.997	0.983	0.919	0.925
April	1.037	1.007	0.941	1.023	1.009	1.029	1.06	0.987	1.031	1.05
May	1.078	1.102	1.03	1.266	1.095	1.043	1.088	1.091	1.123	0.999
June	1.054	1.147	1.203	1.149	1.146	1.029	1.067	0.976	1.083	1.035
July	1.103	1.209	1.467	1.279	1.175	0.995	1.09	1.057	1.082	1.255
August	1.117	1.158	1.275	1.034	1.148	1.049	1.089	1.101	1.055	0.968

Axles Per Truck

Vehicle Class	Single	Tandem	Tridem	Quad
Class 4	1.53	0.45	0	0
Class 5	2.02	0.16	0.02	0
Class 6	1.12	0.93	0	0
Class 7	1.19	0.07	0.45	0.02
Class 8	2.41	0.56	0.02	0
Class 9	1.16	1.88	0.01	0
Class 10	1.05	1.01	0.93	0.02
Class 11	4.35	0.13	0	0
Class 12	3.15	1.22	0.09	0

Climate

Climate

- Climate data is derived from statewide weather stations and are used to predict the temperature and moisture profiles within the pavement structure during the design life.

- Variables like temperature, precipitation, wind speed, percent sunshine, and relative humidity

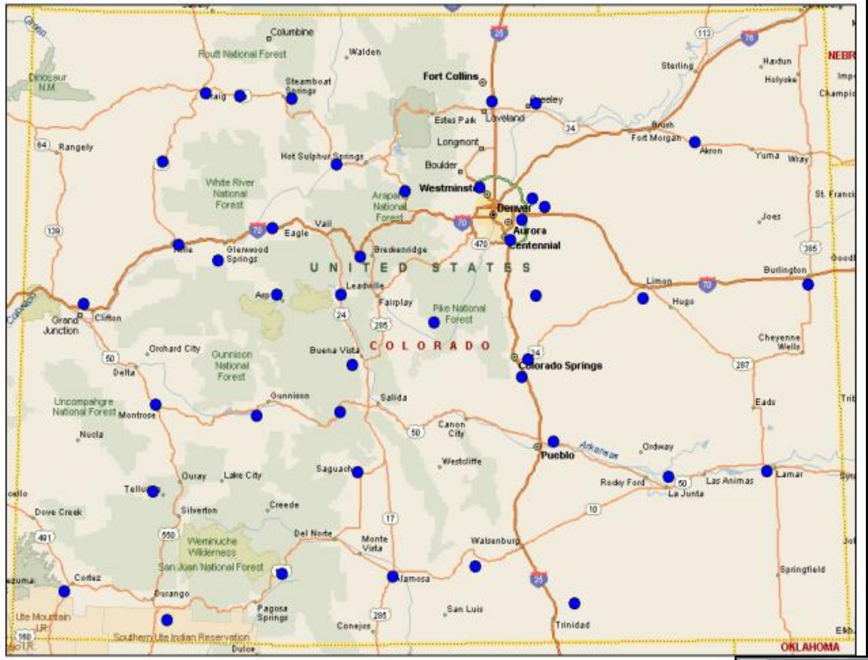
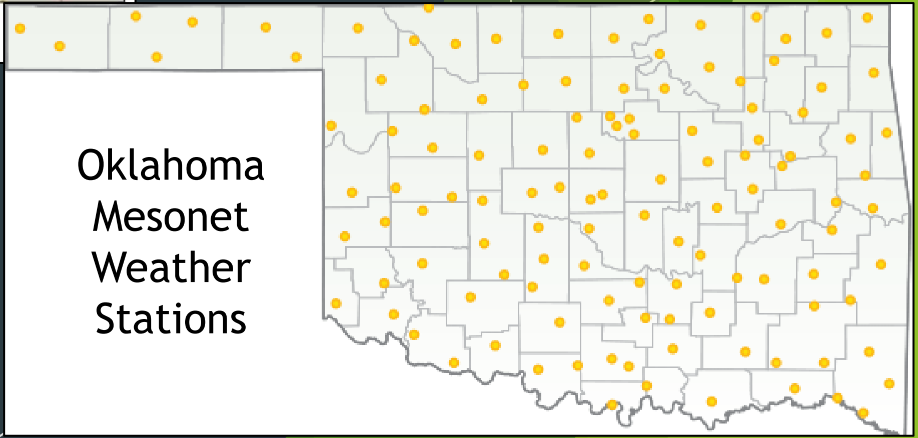
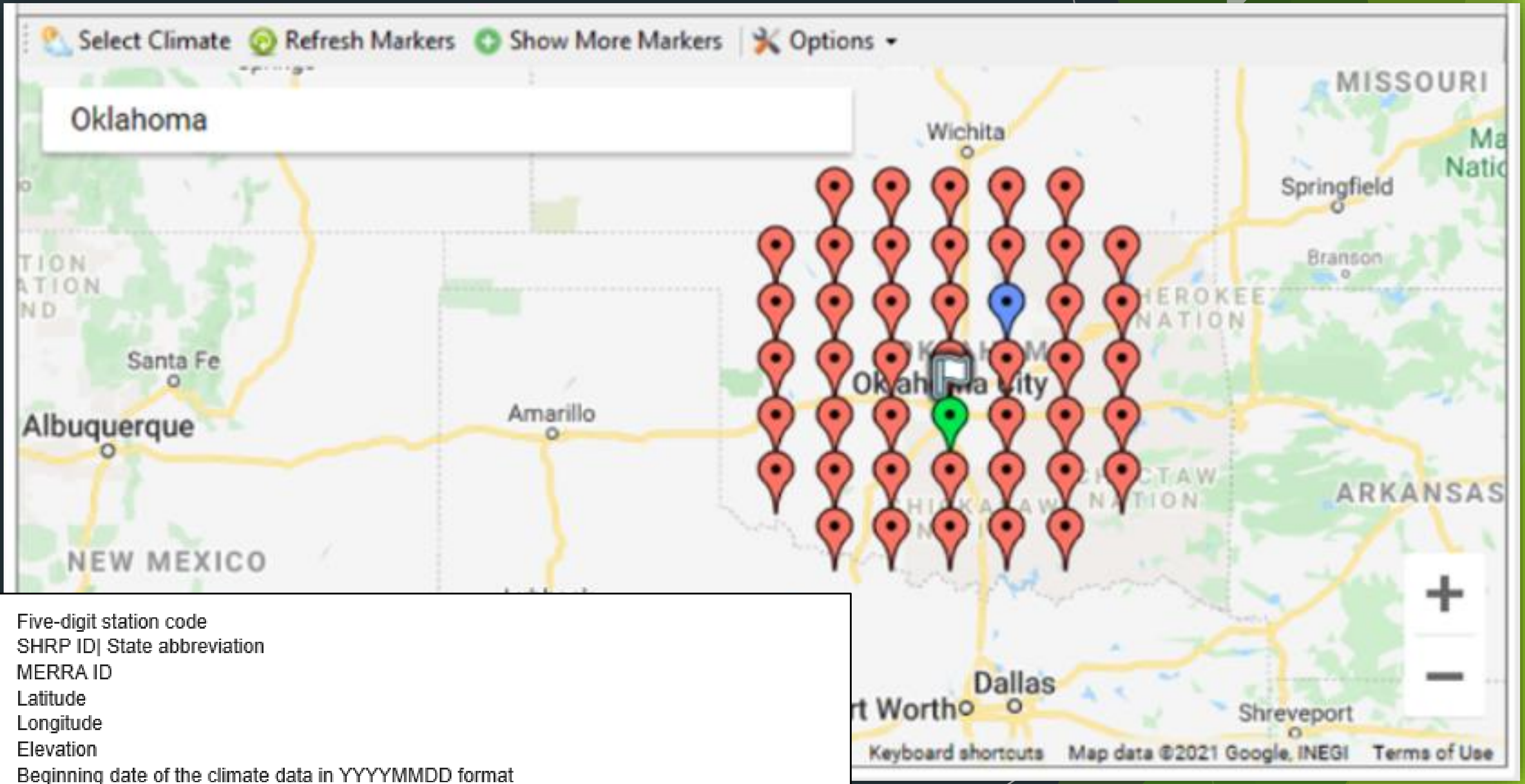


Figure 3.25 Location of Colorado Weather Stations



Climate

- Version 2.6 of the AASHTOWare® uses data from the Modern-Era Retrospective Analysis for Research and Applications (MERRA) climate database.
- There are 59 climate stations in Oklahoma (portrayed in grid pattern).



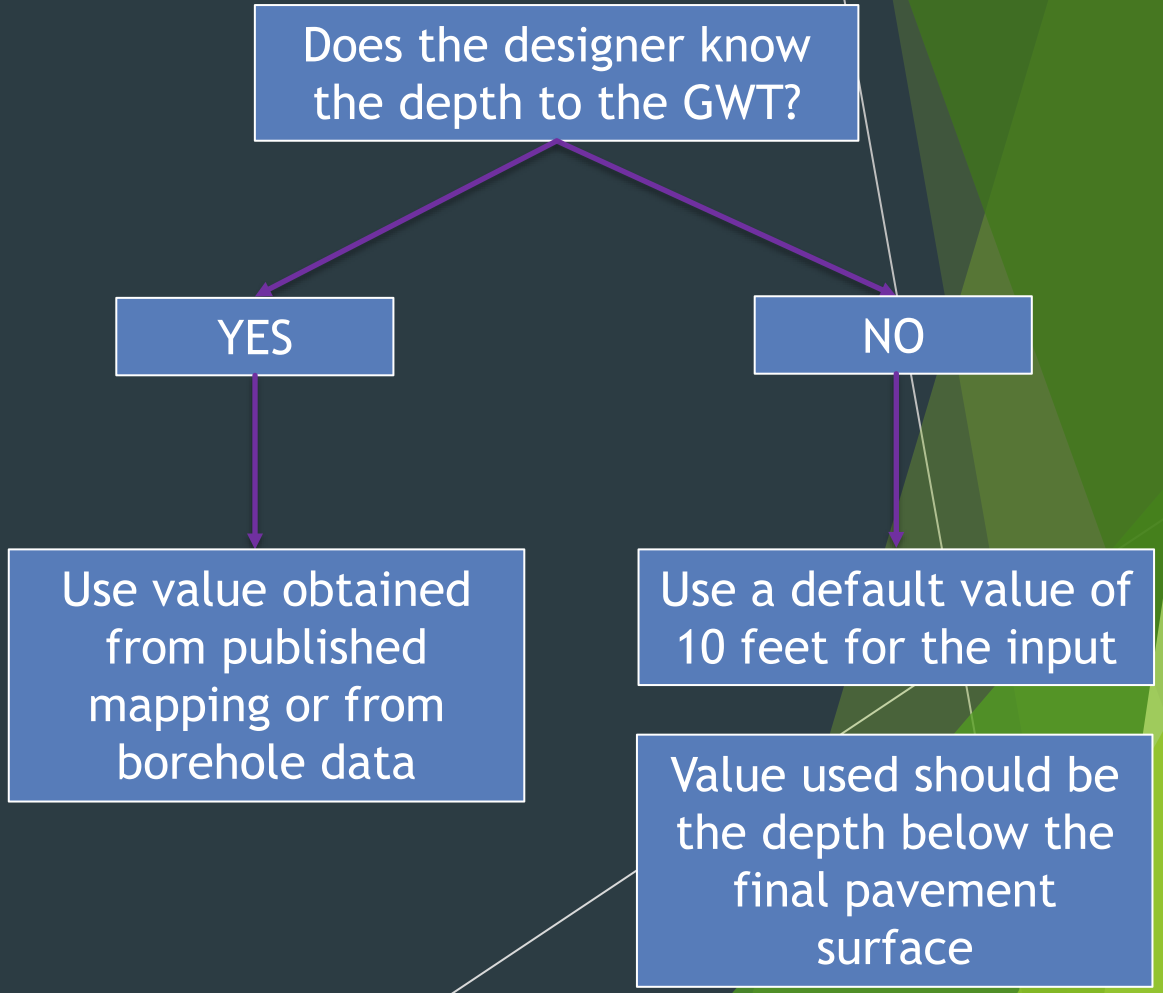
- Five-digit station code
- SHRP ID| State abbreviation
- MERRA ID
- Latitude
- Longitude
- Elevation
- Beginning date of the climate data in YYYYMMDD format
- Code "C" for complete climate data
- End date of the climate data in YYYYMMDD format

https://infopave.fhwa.dot.gov/Tools/MEPDGInputsFromMERRA

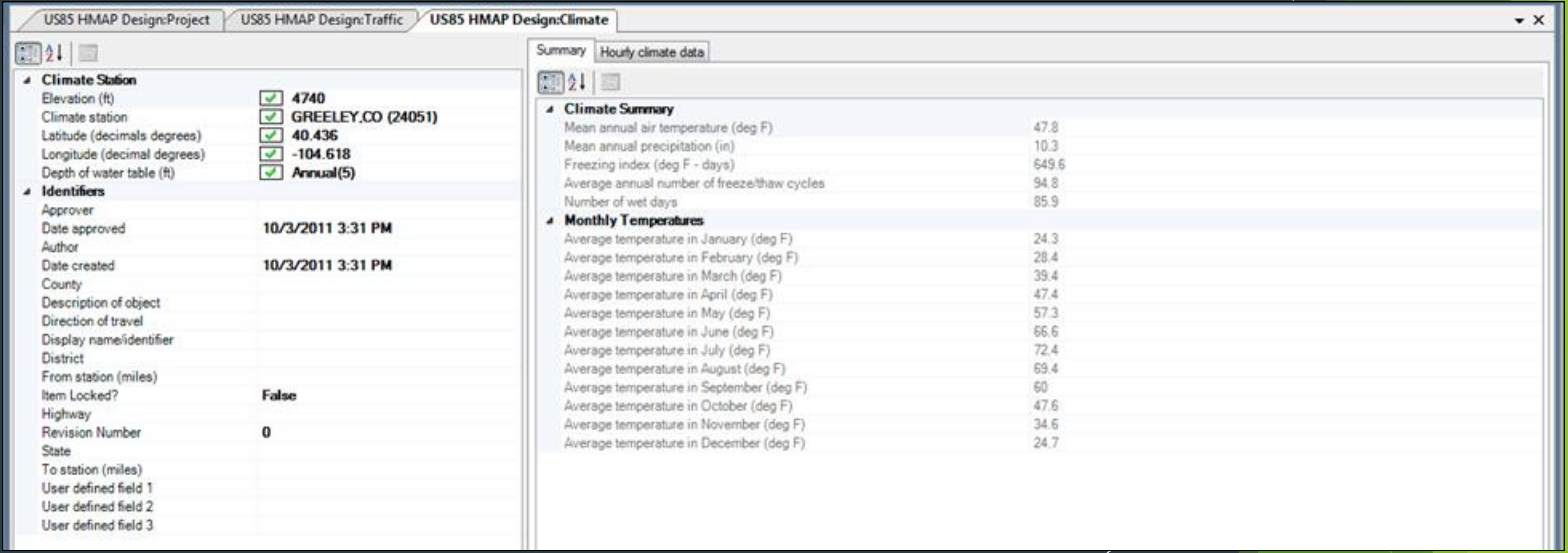
137222,SHRP 404161| OK,MERRA_ID_137222,34,-96.875,751.12, 19800101,C,20201231

Climate (Groundwater)

- M-E Design requires the depth to groundwater as an input.
- Groundwater Table (GWT) may shift seasonally due to precipitation events and seasonal weather variations.
- Shallower GW could equate to a thicker pavement section



Climate Data Interface



Material Characterization

Unbound Materials – Data Inputs

Pavement Response Model Material Inputs	EICM Material Inputs	Other Properties
Resilient Modulus (M_r)	Gradation	Coefficient of Lateral Earth Pressure (K_0)
Poisson's Ratio (μ)	Atterberg Limits	
Elastic Modulus (for bedrock)	Hydraulic Conductivity (k)	

- CDOT Resilient Modulus, R-value Correlation:
  - Equation 4.1: $M_r = 3438.6 \times R^{0.2753}$
    - Mr = Resilient Modulus (psi)
  - R = R-value obtained from the Hveem stabilometer
- This equation is only valid for the AASHTO T 190 procedure and should be used for R-values of 50 or less.

Unbound Material Interface

Unbound		
Coefficient of lateral earth pressure (k0)	☑	0.5
Layer thickness (in)	☑	24
Poisson's ratio	☑	0.35
Modulus		
Resilient modulus (psi)	☑	9494
Sieve		
Gradation & other engineering properties	☑	A-2-4
Identifiers		
Approver		
Date approved		1/1/2011
Author		AASHTO
Date created		1/1/2011
County		
Description of object		Default material
Direction of travel		
Display name/identifier		A-2-4
District		
From station (miles)		
Item Locked?		False

Sieve

Unbound		
Coefficient of lateral earth pressure (k0)	☑	0.5
Layer thickness (in)	☐	Semi-infinite
Poisson's ratio	☑	0.35
Modulus		
Resilient modulus (psi)	☑	7844
Sieve		
Gradation & other engineering properties	☑	A-4
Identifiers		
Approver		
Date approved		1/1/2011
Author		AASHTO
Date created		1/1/2011
County		
Description of object		Default material
Direction of travel		
Display name/identifier		A-4
District		
From station (miles)		
Item Locked?		False

Sieve

Table 4.4 from *CDOT Pavement Design Guide* for recommendations

Table 4.4 Recommended Subgrade Inputs for HMA Overlays of Existing Flexible Pavement

Pavement and Design Type	Material Property	Input Hierarchy		
		Level 1	Level 2	Level 3
HMA Overlays of Existing Flexible Pavement	Resilient modulus	FWD deflection testing and backcalculated resilient modulus	CDOT lab testing	AASHTO soil classification
	Gradation	Colorado Procedure 21-08		Use CDOT defaults
	Atterberg limit[1]	AASHTO T 195		Use CDOT defaults
	Poisson's ratio	Use software defaults		Use M-E Design software default of 0.4
	Coefficient of lateral pressure	Use software defaults		Use M-E Design software default of 0.5
	Maximum dry density	AASHTO T 180		Estimate internally using gradation, plasticity index, and liquid limit.[2]
	Optimum moisture content	AASHTO T 180		
	Specific gravity	AASHTO T 100		
	Saturated hydraulic conductivity	AASHTO T 215		
	Soil water characteristic curve parameters	Not applicable		

Note:
[1] For drainage reasons if non-plastic use PI = 1
[2] The M-E Design software internally computes the values of the following properties based on the inputs for gradation, liquid limit, plasticity index, and if the layer is compacted. If the designer chooses, they may modify the internally computed default values. The software updates the default values to user-defined values once the user clicks outside the software's input screen.

Flexible Pavement Material Types

- Stone Matrix Asphalt (SMA)
- Hot Mix Asphalt (HMA)
  - Dense to Open Graded
  - Asphalt Stabilized Base Mixes
  - Sand Asphalt Mixtures
- Cold Mix Asphalt
  - Central Plant Processed

Flexible Pavement Input Categories

Physical Properties
- Asphalt Binder
- Aggregate Gradations
- Mix Volumetric Properties

Engineering Properties
- Dynamic Modulus
- Creep Compliance

Predicted Distresses
- Load-Related Fatigue Cracking and Rutting
- Thermal or Transverse Cracking

Time/Seasonal Effects
- Temperature
- Aging

Responses
- Load-related Stresses/Strain/Deflection
- Non-load Related Tensile Stress

Flexible Pavement Inputs

Asphalt Layer	
Thickness (in)	✓ 2
Mixture Volumetrics	
Air voids (%)	✓ 5.2
Effective binder content (%)	✓ 11.1
Poisson's ratio	(calculated)
Unit weight (pcf)	✓ 145
Mechanical Properties	
Asphalt binder	✓ Level 1 - SuperPave:
Creep compliance (1/psi)	✓ Input level:1
Dynamic modulus	✓ Input level:1
Select HMA Estar predictive model	Use Viscosity based model (nationally calibrated).
Reference temperature (deg F)	✓ 70
Indirect tensile strength at 14 deg F (psi)	✓ 595
Thermal	
Heat capacity (BTU/lb-deg F)	✓ 0.23
Thermal conductivity (BTU/hr-ft-deg F)	✓ 0.67
Thermal contraction	1.161E-05 (calculated)
Identifiers	
Approver	CDOT
Date approved	4/3/2013
Author	CDOT
Date created	4/3/2013

Concrete Pavement Material Types

- Surface Layers
  - Concrete or CRCP
- Cementitious Base Layers
  - Lean Concrete
  - Cement Stabilized Base
  - Soil Cement
  - Lime Stabilized Base

Concrete Pavement Material Properties

Strength/Deformation Properties
Flexural Strength
Elastic Modulus
Poisson's Ratio
Split Tensile Strength (CRCP Only)

Thermal Properties
Coefficient of Thermal Expansion
Setting Temperature of Concrete
Thermal Conductivity
Heat Capacity

Additional Properties
Unit Weight
Reversible Shrinkage
Ultimate Shrinkage
Time to Reach 50% of Ultimate Shrinkage

- The M-E Design Manual goes into detail regarding how to estimate these parameters based on the desired Input Level.

Calibration/Performance Prediction Model Coefficients

- CDOT has their own local calibration coefficients for each pavement design:
  - New Asphalt
  - Asphalt overlay over existing Asphalt
  - New Concrete
  - Concrete overlay over existing Concrete
- To be discussed during Day 3

Optimization Function

- Built-in tool that allows a user to find the minimal thickness of a strata layer while maintaining a constant thickness of all other pavement layers.
- The user can define a minimum and maximum thickness for a strata layer. The program will then run the designs changing the design thickness of that strata until the thinnest, passing thickness is determined.

Design Layers

Use	Layer	Default Thickness	Minimum Thickness	Maximum Thickness
☑	Layer 1 Flexible : R6 SX(100) PG 76-28	2	1	5
☐	Layer 2 Flexible : R2 Level 1 SX(75) PG ...	5.5		
☐	Layer 3 Non-stabilized Base : Aggregate ...	6		
☐	Layer 4 Subgrade : A-2-4	24		

LUNCH TIME!

Workshop Schedule

Day 1

Morning Session
- ME Design Methodology, Software, and Process

Afternoon Session
- Discuss Design Outputs and Adequacy of Design
- New Asphalt/Concrete Design

Day 2

Morning Session
- Asphalt/Concrete Overlay Design
- Oklahoma Project Examples

Afternoon Session
- Classroom Exercises (Asphalt/Concrete/Overlay Design)

Day 3

Morning Session
- Calibration/Sensitivity Analysis/Backcalculation
- Q&A, Reviewing Topics

Outputs

- The results of running the M-E Design software gives the user insight into how their pavement section performs over time.
- The M-E Design Software does not generate a pavement thickness.
- After the trial run has been completed, the M-E Design will generate a report in the form of a PDF or Microsoft Excel File.

Asphalt Output Example

Design Inputs

Design Life: 20 years
Design Type: FLEXIBLE

Base construction: April, 2020
Pavement construction: May, 2020
Traffic opening: May, 2020

Climate Data Sources (Lat/Lon): 40.436, -104.618

Design Structure

Layer type	Material Type	Thickness (in)
Flexible	R6 SX(100) PG 76-28	2.0
Flexible	R2 Level 1 SX(75) PG 58-28	5.5
NonStabilized	Aggregate Base	6.0
Subgrade	A-2-4	24.0
Subgrade	A-4	Semi-infinite

Volumetric at Construction:	
Effective binder content (%)	11.1
Air voids (%)	5.2

Traffic

Age (year)	Heavy Trucks (cumulative)
2020 (initial)	2,200
2030 (10 years)	3,885,980
2040 (20 years)	8,435,960

Design Outputs

Distress Prediction Summary

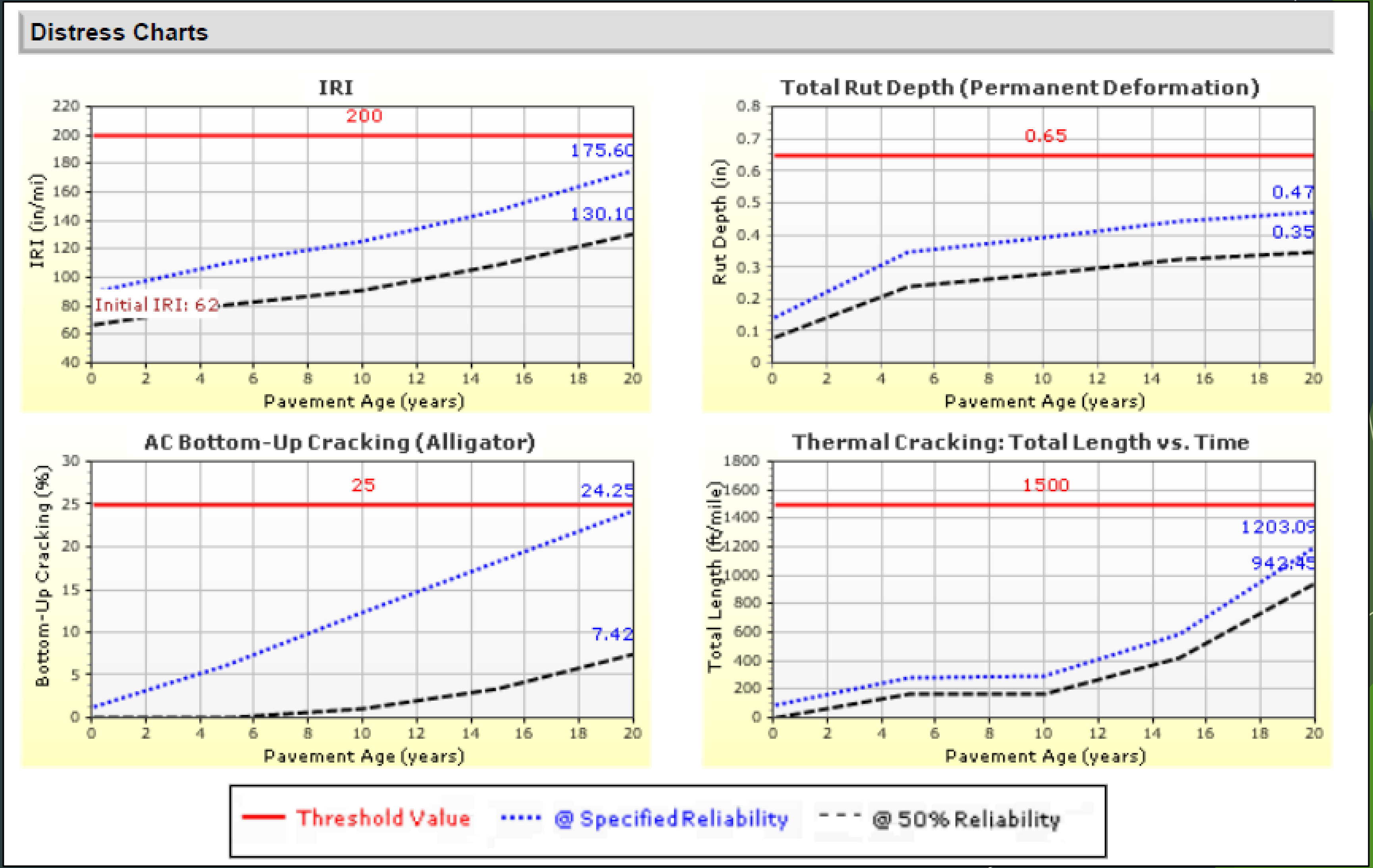
Distress Type	Distress @ Specified Reliability		Reliability (%)		Criterion Satisfied?
	Target	Predicted	Target	Achieved	
Terminal IRI (in/mile)	200.00	175.62	90.00	97.55	Pass
Permanent deformation - total pavement (in)	0.65	0.47	90.00	99.91	Pass
AC bottom-up fatigue cracking (% lane area)	25.00	24.25	90.00	90.96	Pass
AC thermal cracking (ft/mile)	1500.00	1203.09	90.00	99.69	Pass
AC top-down fatigue cracking (ft/mile)	2500.00	269.65	90.00	100.00	Pass
Permanent deformation - AC only (in)	0.50	0.29	90.00	99.99	Pass

OR

Criterion Satisfied?
Pass
Pass
Pass
Fail
Pass
Fail
Pass

Results dependent upon input parameters as well as reliability.

Asphalt Output Example



Concrete Output Example

Design Inputs

Design Life: 30 years
Design Type: JPCP

Existing construction: -
Pavement construction: May, 2020
Traffic opening: May, 2020

Climate Data Sources (Lat/Lon): 40.436, -104.618

Design Structure

Layer type	Material Type	Thickness (in)
PCC	R4 Level 1 Lawson	8.5
NonStabilized	A-1-a	6.0
Subgrade	A-2-4	24.0
Subgrade	A-4	Semi-infinite

Joint Design:	
Joint spacing (ft)	15.0
Dowel diameter (in)	1.25
Slab width (ft)	12.0

Traffic

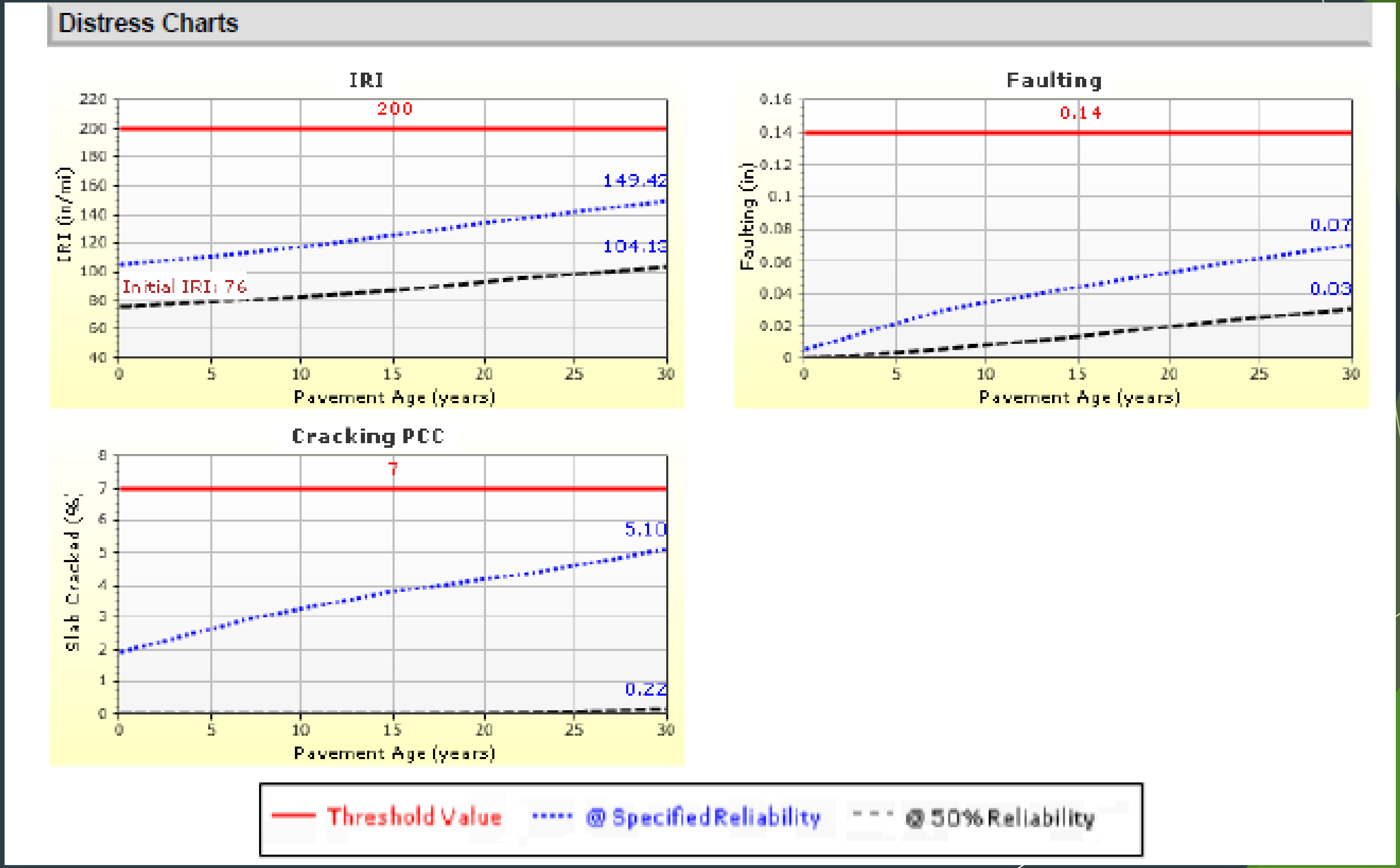
Age (year)	Heavy Trucks (cumulative)
2020 (initial)	2,200
2035 (15 years)	6,071,300
2050 (30 years)	13,763,400

Design Outputs

Distress Prediction Summary

Distress Type	Distress @ Specified Reliability		Reliability (%)		Criterion Satisfied?
	Target	Predicted	Target	Achieved	
Terminal IRI (in/mile)	200.00	149.42	90.00	99.67	Pass
Mean joint faulting (in)	0.14	0.07	90.00	99.98	Pass
JPCP transverse cracking (percent slabs)	7.00	5.10	90.00	96.26	Pass

Concrete Output Example



Evaluate the Adequacy of the Trial Design

- Once the trial run is complete, the designer should review all inputs and outputs for accuracy and reasonableness before accepting the trial design.
- For flexible pavement, as per Section 6.8 of the CDOT M-E Design Manual, if alligator fatigue cracking or transverse cracking criteria have not been met, the trial design is deemed unacceptable and revised accordingly to produce a satisfactorily design.
- If any of the criteria have not been met, the trial design is deemed unacceptable and should be revised.

- **BIG QUESTION:** CAN YOU LIVE WITH THE RESULTS?

Modifying Trial Design

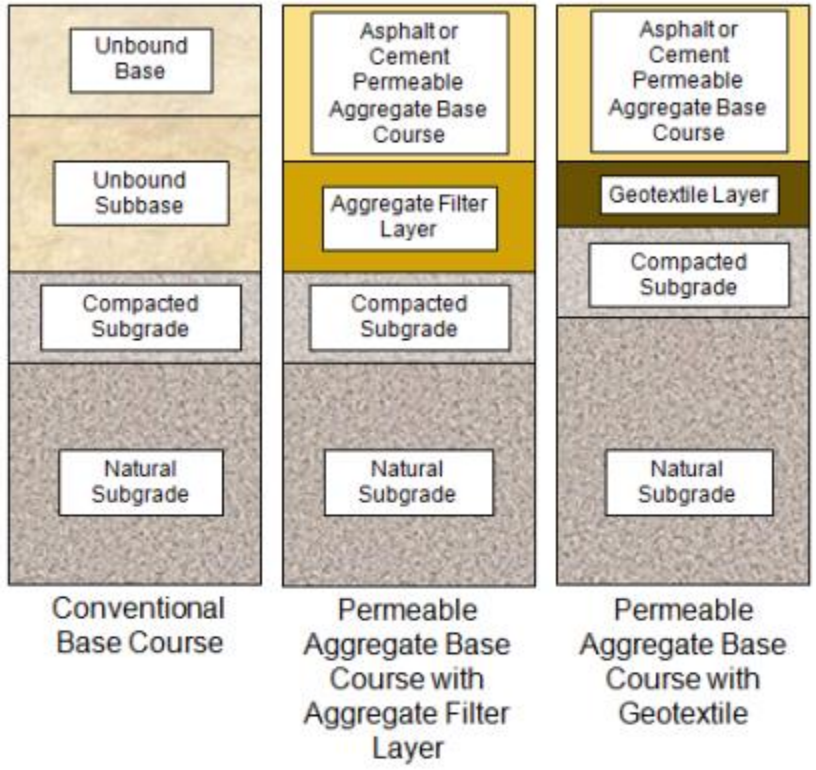


Figure 5.6 Structural Permeable Aggregate Base Course Layers

- Layer thickness may not be the only influencer to whether the design passes.
- To modify the design, the designer needs to identify the performance indicator(s) that failed to meet the performance target.
- Geogrid may be an option.

Modifying Trial Design

- Potential strategies to improve the design:
  - Pavement layer considerations
  - Increasing layer thickness
  - Modifying layer type and layer arrangement
  - Foundation improvements (stabilize subgrade with geogrid, chemical stabilization, etc.)
  - Use higher quality materials for the pavement
  - Modify the material design
  - Improve the construction quality
- Table 6.3 (flexible pavement) and 7.2 (rigid pavement) of the M-E Pavement Design Manual provide guidance on plausible methods for modifying trials so as to address the distress indicator that negatively impacted the trial run.

Design Approach Summary

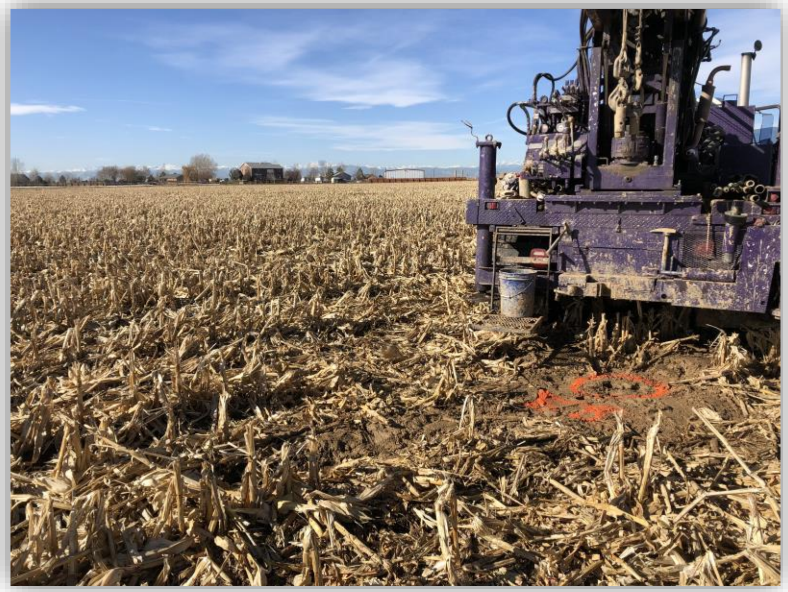
1. Trial Design Strategy
2. Determine Mean Project Inputs
3. Run M-E Design Software
4. Check Outputs and Analyze Results
5. Modify Design and Rerun Design
6. Conduct Cost Analysis (Independent of M-E Design)


TIME FOR A
BREAK

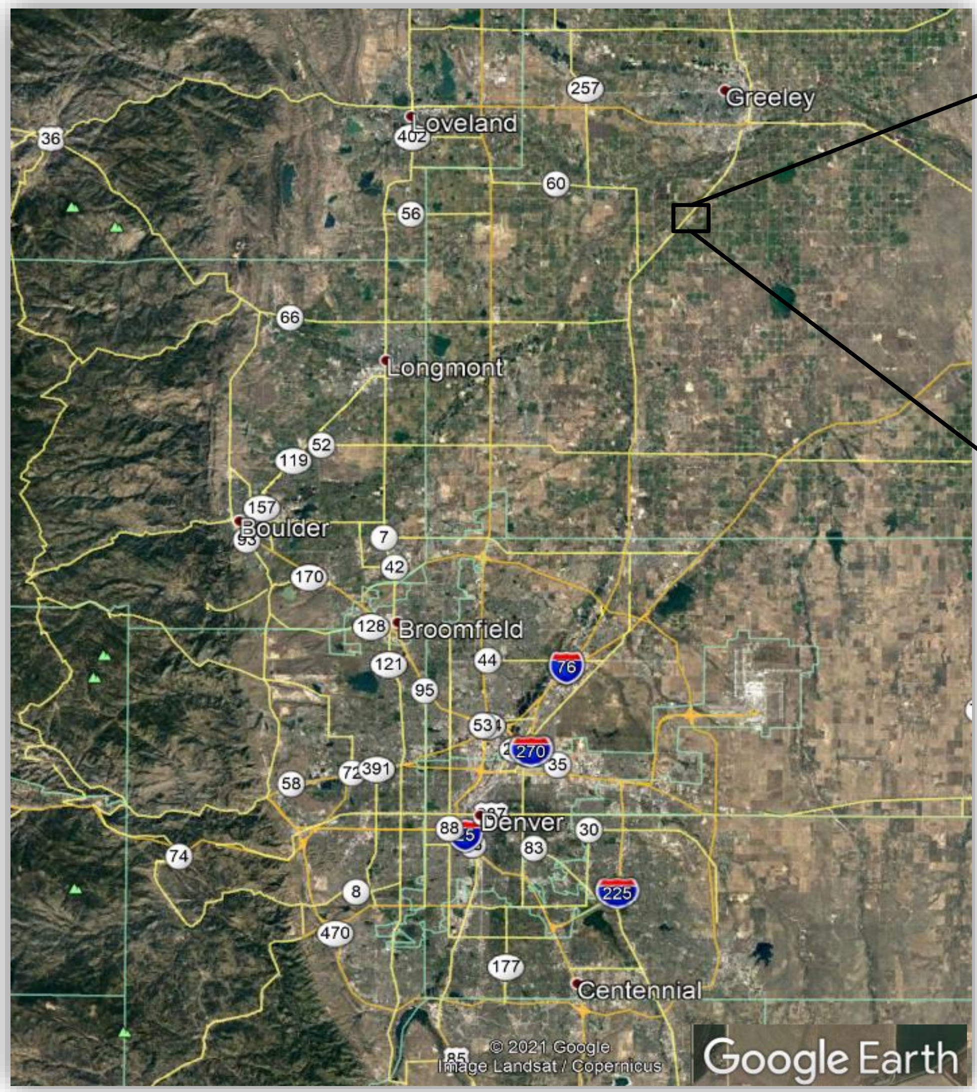
Geocal Project Examples

Example 1: US-85 & Weld CR 44 Interchange (Asphalt Design)

- This project involved the realignment of Weld County Road (WCR) 44 over US-85 with new pavement being required for the realigned section of US-85 as well as the new on/off ramps.
- 4-lane, rural highway
- Existing: asphalt pavement



Example 1: US-85 & Weld CR 44 Interchange (Asphalt Design)



Project located approx. 9 miles southwest of Greeley, CO with a ground elevation of approx. 4,730 feet.

Example 1: US-85 & Weld CR 44 Interchange (Asphalt Design)

- Key Inputs
  - Reliability: 90%
  - Nearest Weather Station: Greeley, CO
  - GWT: 5 feet
  - AADTT: 2,200 trucks per day
- Working Pavement Section
  - 7½ inches Asphalt
  - 6 inches ABC
  - 24 inches A-2-4
  - A-4 Subgrade

Example 2: US-85 & Weld CR 44 Interchange (Concrete Design)

- Key Inputs
  - Reliability: 90%
  - Nearest Weather Station: Greeley, CO
  - GWT: 5 feet
  - AADTT: 2,200 trucks per day

- Working Pavement Section
  - 8½ inches Concrete
  - 6 inches ABC (A-1-a)
  - 24 inches A-2-4
  - A-4 Subgrade

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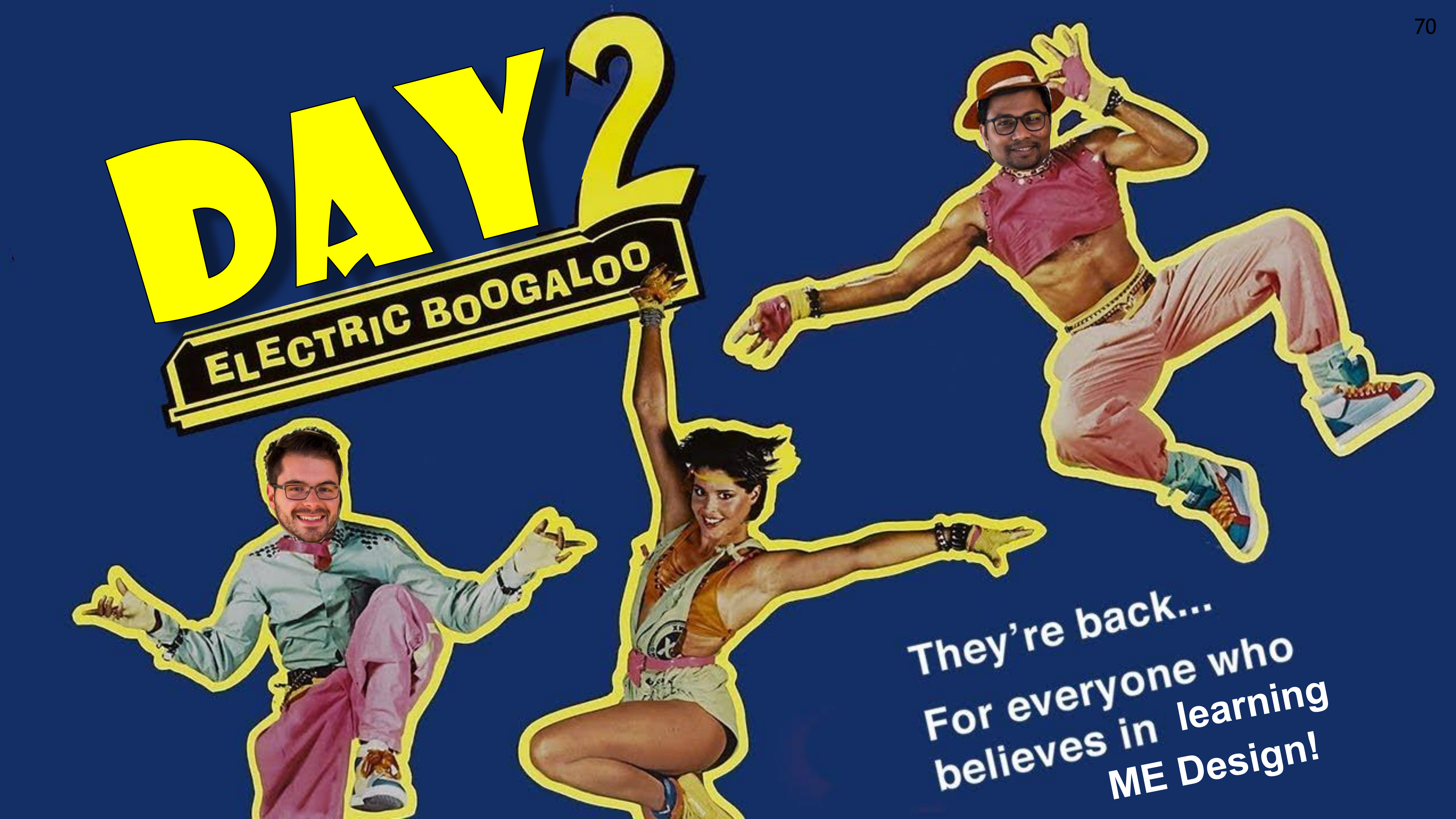
End of Day 1 Session


DAY 2
ELECTRIC BOOGALOO
They're back...
For everyone who believes in learning ME Design!

Workshop Schedule

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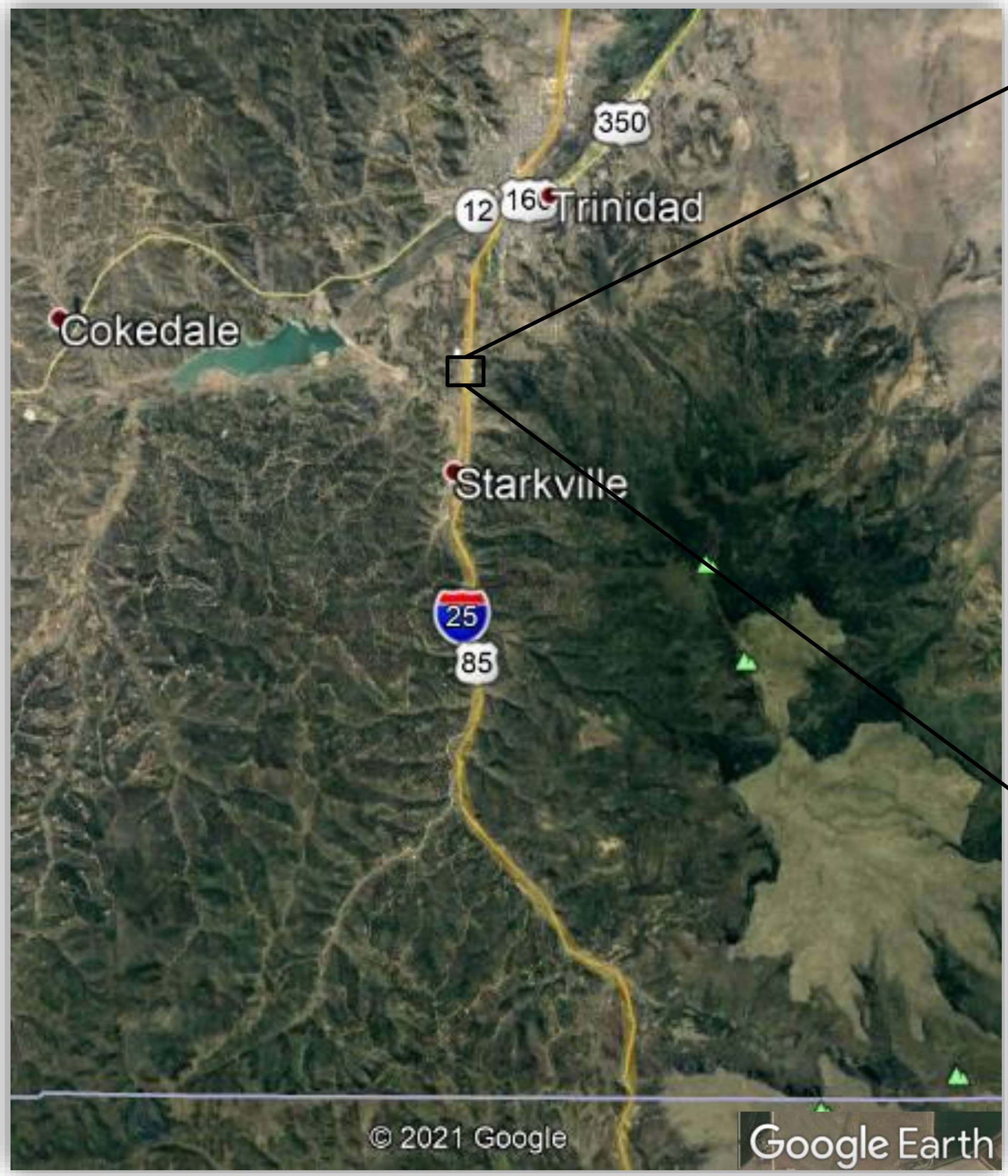
Example 3: Raton Pass, I-25 Exit 11 Roundabouts (Concrete Design)

- This project involved the reconstruction of the Exit 11 interchange carrying CR 18.9 over I-25. Two new circular roundabouts are planned (one at each approach). The reconstruction involves the reconstruction of the frontage roads and on and off ramps.
- Existing: asphalt pavement

Example 3: Raton Pass, I-25 Exit 11 Roundabouts (Concrete Design)



Project located approx. 2½ miles south of Trinidad, CO with a ground elevation of approx. 6,320 feet.

Example 3: Raton Pass, I-25 Exit 11 Roundabouts (Concrete Design)

- Key Inputs
  - Reliability: 90%
  - Nearest Weather Stations: Trinidad, CO and La Veta Pass
    - Weather station is approximately 500 feet lower in elevation than where the project was, so a virtual weather station was used.
  - GWT: 10 feet
  - AADTT: 380 trucks per day
- Working Pavement Section
  - 8 inches Concrete
  - 6 inches ABC
  - 12 inches A-6
  - A-6 Subgrade

Example 4: US-34 Resurfacing (Asphalt Overlay Design)

- This project involved the rehabilitation of the existing US-34 pavement, extending from Fort Morgan to Brush, Colorado.
- The rehabilitation efforts included either a structural overlay (where feasible) and a functional overlay where a structural overlay is not feasible.
- Existing: asphalt-paved, two- to four-lane, rural highway
- Classifies as a Principal Arterial (Other)
- Concrete pavement was encountered beneath the existing asphalt pavement and base layer along part of the roadway (difficult to model in M-E Design)

Example 4: US-34 Resurfacing (Asphalt Overlay Design)

Western Terminus

Eastern Terminus

Fort Morgan is located approximately 70 miles northeast of Denver. The project extends east along US-34 from I-76 to the intersection with SH-71 (approx. length of 13 miles). The approximate ground elevation is 4,330 feet.

Example 4: US-34 Resurfacing (Asphalt Overlay Design)

- Key Inputs
  - Project divided into five sections
  - Reliability: 90%
  - Nearest Weather Station: Akron, CO
  - GWT: 10 feet
  - AADTT: 304 to 1,118 trucks per day (depending on road section)

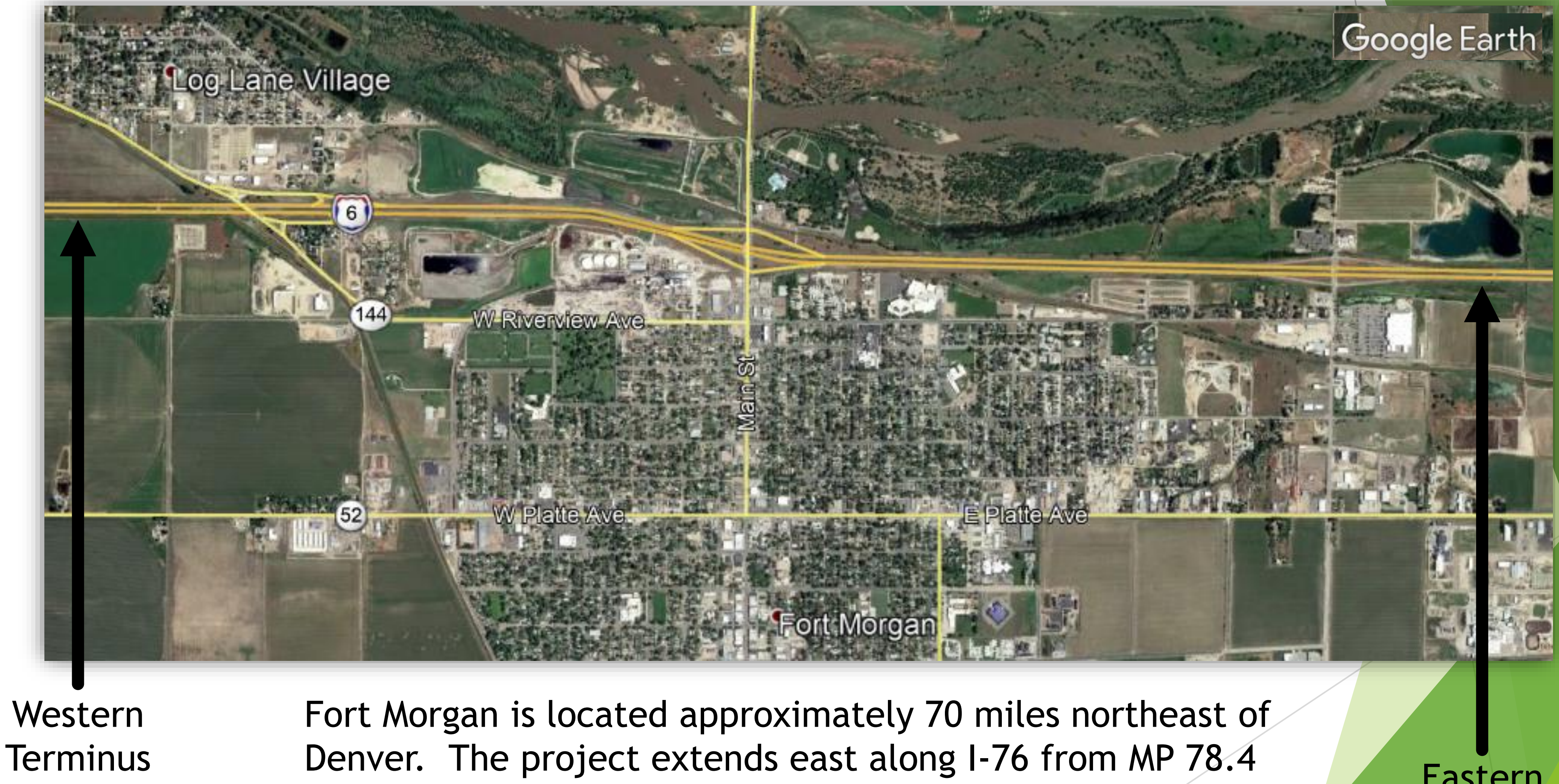
- Working Pavement Section (10-year Design)
  - Depth of Milling: 2 inches to 3 inches
  - Thickness of Overlay: 2 inches to 4 inches
  - Structural overlay is not feasible in some areas.


TIME FOR A
BREAK

Example 5: I-76 Phase V (Concrete Overlay Design)

- This project involved the rehabilitation of the pavement on I-76 between MP 78.4 and MP 82.16 in Fort Morgan, CO.
- Improvements include either an unbonded Concrete overlay or full-depth replacement
- 4-lane, interstate
- Existing: 2¼ inches to 4½ inches asphalt overlay on 8 inches to 9 inches of concrete

Example 5: I-76 Phase V (Concrete Overlay Design)



Fort Morgan is located approximately 70 miles northeast of Denver. The project extends east along I-76 from MP 78.4 and MP 82.16 in Fort Morgan, CO (approx. length of 3¾ miles). The approximate ground elevation is 4,320 feet.

Example 5: I-76 Phase V (Concrete Overlay Design)

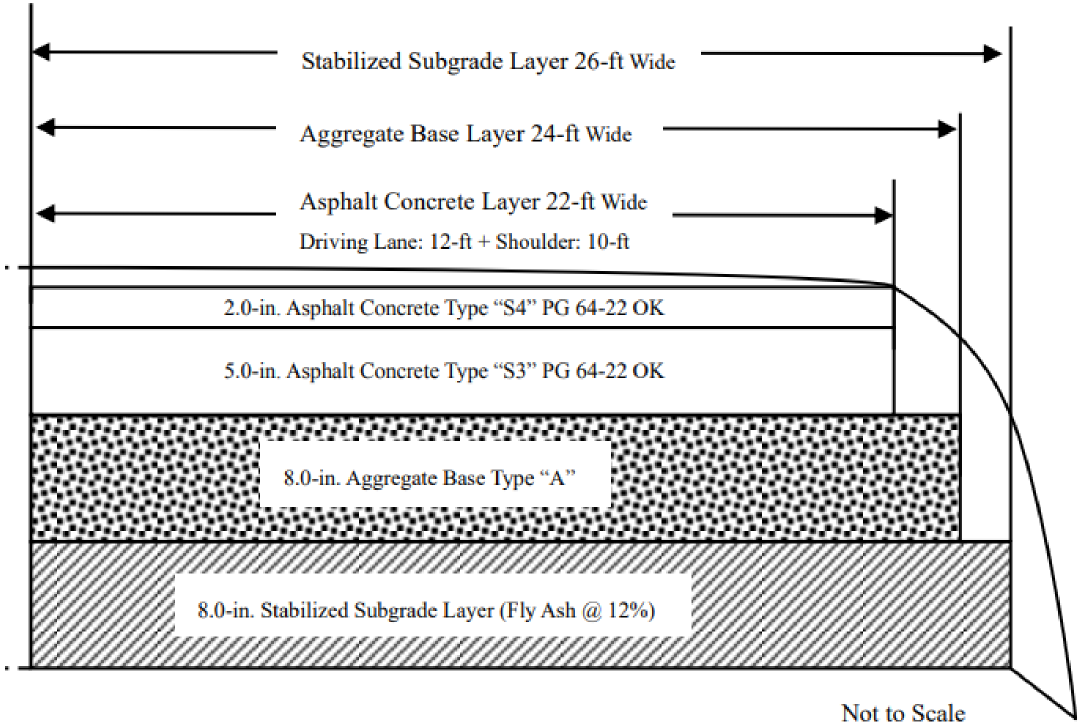
- Key Inputs
  - Reliability: 90%
  - Nearest Weather Station: Akron, CO
  - GWT: 10 feet
  - AADTT: 2,678 trucks per day
- Working Pavement Section (Overlay)
  - 9½ inches Concrete
  - 1-inch Asphalt separator layer
  - 8 inches existing Concrete
  - 12 inches A-2-4
  - A-2-4 Subgrade

Oklahoma Example 1: I 35 (New Pavement Design)

- An instrumented Test Section was constructed in McClain County, Oklahoma, on the southbound (right) lane of Interstate-35.
- To record the traffic data, a weigh-in-motion (WIM) station was installed approximately 1,200-meter south of the Test Section. The Test Section and the WIM site start at approximately Mile Post 95 and ends at Mile Post 91.

Oklahoma Example 1: I 35 (New Pavement Design)

- The Test Section consists of five pavement layers.
- The top layer is 2-inch thick constructed with a HMA mix having a NMAS of 12.5-mm. The mix is prepared with a PG 64-22 asphalt binder.
- The second layer is 5-inch thick and is constructed with a HMA mix having a NMAS of19-mm. This layer incorporates a recycled mix involving a PG 64-22 binder and 25% reclaimed asphalt pavement (RAP).
- Third layer is a 200-mm thick aggregate base layer having ODOT type “A” gradation.
- The fourth layer consists of an 8-inch-thick subgrade layer stabilized with 12% Class C fly ash.
- The bottom layer is natural subgrade soil, consisting of lean clay with a liquid limit of 33 and a plasticity index of 15.



Oklahoma Example 1: I 35 (New Pavement Design)

General

- Design Life = 10 years
- Design Reliability: 90%
- Base Construction: May 2008
- Pavement Construction : June 2008
- Traffic Open: June 2008

Analysis Parameters:

- Terminal IRI: 172
- AC top-down fatigue cracking: 25% lane area
- AC bottom-up fatigue cracking: 25% lane area
- AC thermal cracking: 1000 ft/mile
- Permanent deformation: total 0.75, AC 0.25 in

Oklahoma Example 1: I 35 (New Pavement Design)

- Traffic:
  - Initial two-way AADTT (8,219), Lanes in design direction (2), % truck in design direction (50), %truck in DSN lane (80), operational speed (70).
- Traffic Adjustment Factors:
  - Monthly (level 1), Vehicle class (level 1), Hourly truck distribution (Level 1), and Traffic Growth Factor (Linear 2.7%).
- Axle Load Distribution Factors:
- Level 1
- Number of Axle per Truck:
  - Level 1
- Mean wheel location (15.5 in), Traffic wander deviation (10.2 in), and design lane width (12 ft).

Oklahoma Example 1: I 35 (New Pavement Design)

Volume Monthly Adjustment Factors

Month	Vehicle Class									
	4	5	6	7	8	9	10	11	12	13
January	0.9	0.9	1.2	0.7	0.9	1.1	1.0	1.1	1.0	1.3
February	0.9	0.8	1.3	0.8	0.9	1.0	1.1	1.1	1.0	1.1
March	1.0	0.9	1.2	1.0	1.0	1.1	1.1	1.0	1.0	1.0
April	1.0	0.9	1.3	1.0	1.1	1.1	1.1	1.1	1.1	1.3
May	1.0	0.9	1.0	1.2	1.1	1.1	1.0	1.1	1.1	1.2
June	1.0	1.0	0.9	1.2	1.2	1.1	1.2	1.2	1.1	1.1
July	2.2	2.5	0.8	1.0	1.0	0.6	0.8	0.6	0.7	0.7
August	0.9	1.0	0.8	1.3	1.1	1.2	1.1	1.1	1.2	0.9
September	0.9	0.9	0.8	0.9	1.1	1.1	1.1	1.1	1.1	1.0
October	1.1	0.9	1.2	1.2	1.2	1.1	1.2	1.3	1.2	1.2
November	0.6	0.7	0.7	0.9	0.7	0.7	0.6	0.6	0.7	0.5
December	0.7	0.8	0.8	0.9	0.8	0.9	0.8	0.9	1.1	0.8

Oklahoma Example 1: I 35 (New Pavement Design)

Distributions by Vehicle Class

Vehicle Class	AADTT Distribution (%) (Level 3)
Class 4	5.7%
Class 5	15.5%
Class 6	6.3%
Class 7	0.2%
Class 8	9.9%
Class 9	58.5%
Class 10	0.6%
Class 11	2.2%
Class 12	1%
Class 13	0.1%

Number of Axles per Truck

Vehicle Class	Single Axle	Tandem Axle	Tridem Axle	Quad Axle
Class 4	1.61	0.4	0	0
Class 5	2	0	0	0
Class 6	1.02	0.97	0	0
Class 7	1.69	0.05	0.68	0
Class 8	2.38	0.26	0	0
Class 9	1.2	2	0	0
Class 10	1.07	0.98	0.87	0.08
Class 11	5	0	0	0
Class 12	4	1	0	0
Class 13	1.47	0.6	1.1	0

Oklahoma Example 1: I 35 (New Pavement Design)

Layer 1 (S-4 Asphalt):

- Asphalt concrete, 2 in thick.
- Unit Weight: 135.9 pcf
- Effective Binder Content: 10.6%
- Air Voids: 9%
- Thermal Conductivity: 0.67 BTU/hr-ft-F)
- Heat Capacity: 0.23 BTU/lb-F)
- Asphalt content by weight: 4.5%
- Aggregate Parameter: 0.4021

Asphalt Dynamic Modulus (Input Level: 1)

T (ºF)	0.1 Hz	0.5 Hz	1 Hz	5 Hz	10 Hz	25 Hz
10	1976749	2248836	2361669	2610177	2710590	2836667
40	761210	1059477	1180146	1404441	1513592	1662424
70	210084	352080	416131	600179	659885	745122
100	65742	95197	115086	181825	213554	261165
130	30947	43577	49294	71907	85008	98958

Asphalt Binder

Temperature (ºF)	Binder Gstar (Pa)	Phase angle (deg)
142	6153	77
147	3930	78
153	2713	79

Oklahoma Example 1: I 35 (New Pavement Design)

Layer 2 (S-3 Asphalt):

- Asphalt concrete, 5 in thick.
- Unit Weight: 138.1 pcf
- Effective Binder Content: 9.5%
- Air Voids: 10%
- Thermal Conductivity: 0.67 BTU/hr-ft-F)
- Heat Capacity: 0.23 BTU/lb-F)

Asphalt Dynamic Modulus (Input Level: 1)

T (ºF)	0.1 Hz	0.5 Hz	1 Hz	5 Hz	10 Hz	25 Hz
10	2194482	2395862	2472903	2629875	2688509	2758336
40	995548	1307273	1464214	1817892	2013348	2025775
70	306328	494014	571255	822116	901579	948270
100	86215	126454	156197	255138	301891	361526
130	40825	51128	60620	86963	121483	153106

Asphalt Binder

Temperature (ºF)	Binder Gstar (Pa)	Phase angle (deg)
142	6153	77
147	3930	78
153	2713	79

Oklahoma Example 1: I 35 (New Pavement Design)

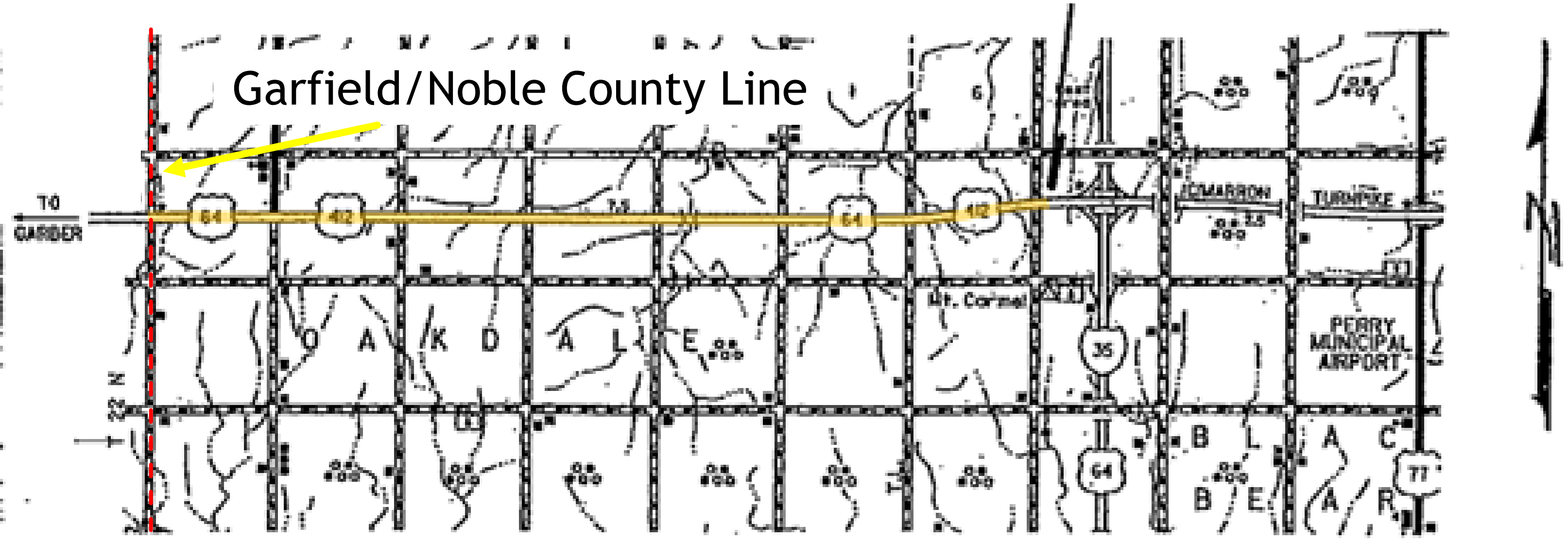
- **Layer 3 (Non-stabilized Base : Crushed gravel)**
  - Resilient Modulus: 30,000 psi
  - Thickness: 8 inch
  - Liquid Limit: 6, Plasticity Index: 1
- **Layer 4 (Subgrade)**
  - Subgrade: A-5
  - Resilient Modulus: 20,000 psi
  - Thickness: 8 inch.
  - Liquid Limit: 45, Plasticity Index: 5
- **Layer 5 (Subgrade)**
  - Subgrade A-7-5,
  - Strength properties: Modulus 10,000 psi.
  - Liquid Limit: 57, Plasticity Index: 24

Oklahoma Example 2: US 412(Asphalt Overlay Design)

- Extensive **Fatigue Cracking o**n US 412 in Noble County starting from Garfield/Noble County line and continuing for 7.08 miles East.
- **Transverse, Block Cracking,** and **Rutting** on the wheel path were observed.

Oklahoma Example 2: US 412(Asphalt Overlay Design)

Project Information

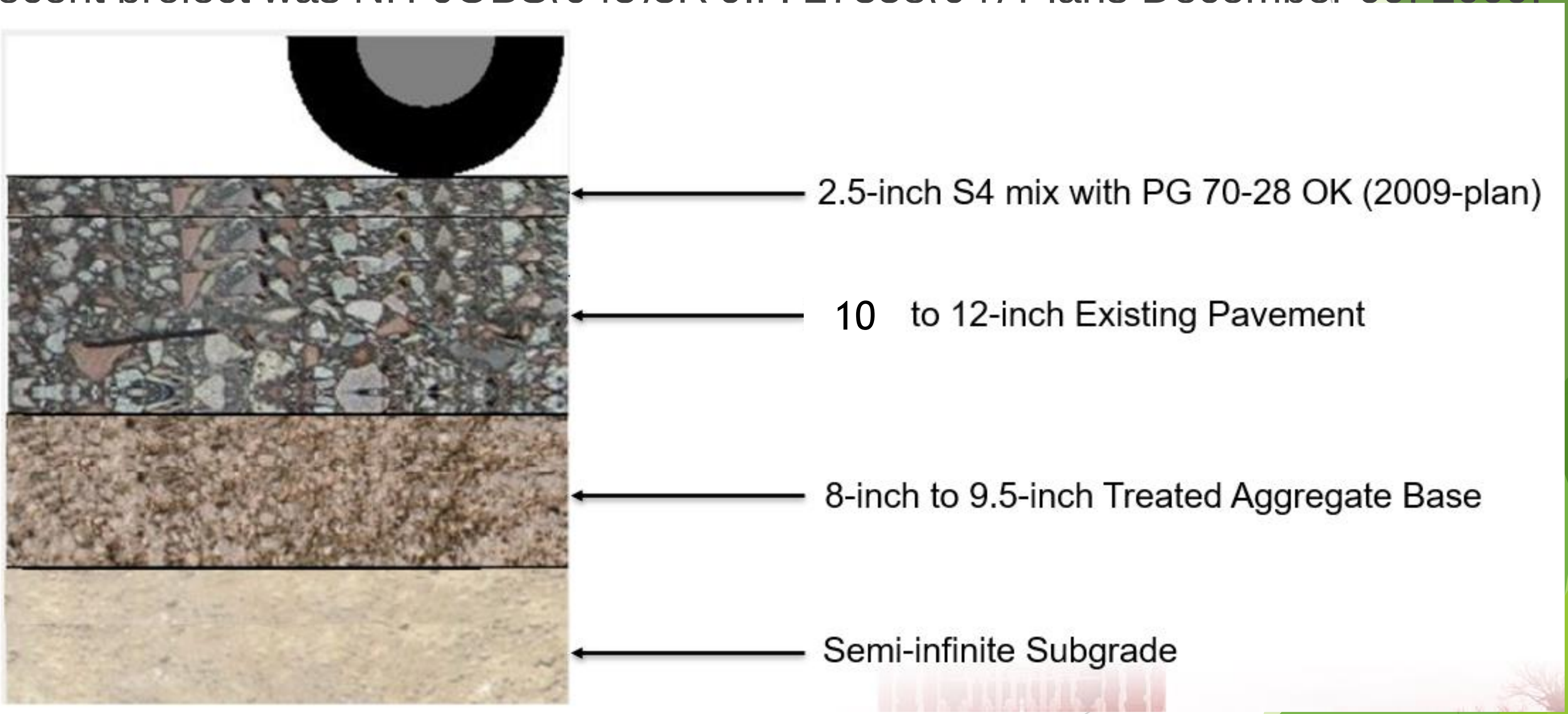


- A 2500-ft. long test site was selected for detailed investigation.
- The test site for US 412 from (36.397838, -97.416591) to (36.397864, -97.408843).
- 6.7M ESAL's

Oklahoma Example 2: US 412(Asphalt Overlay Design)

Pavement Structure

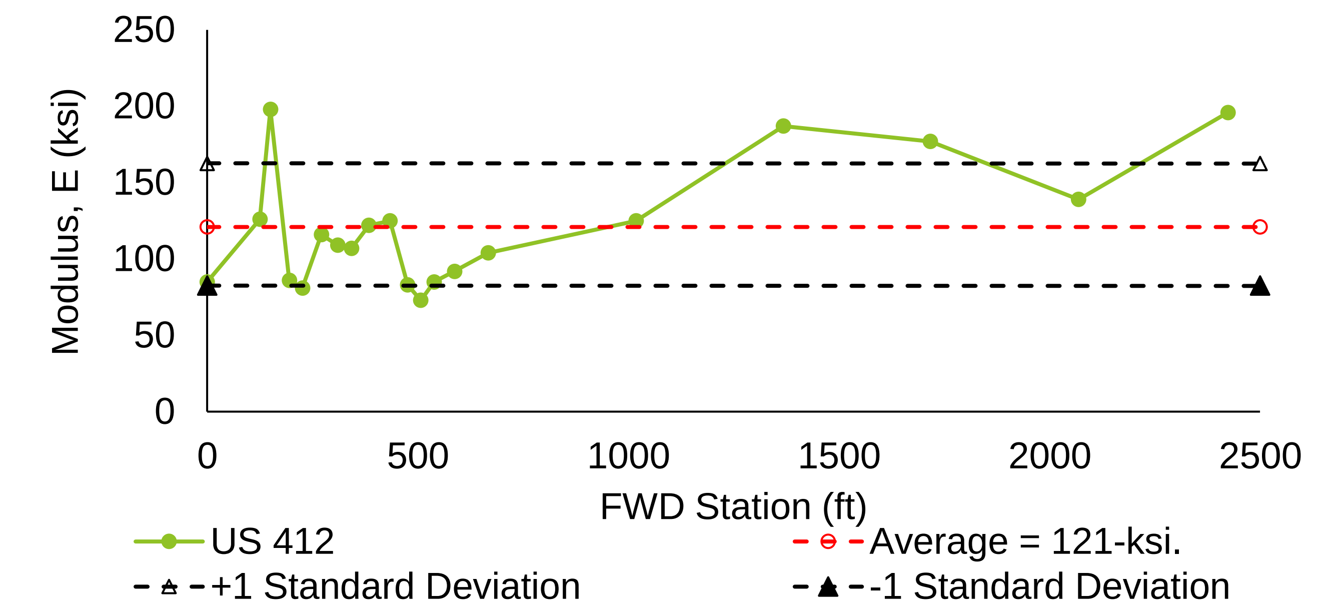
- The original pavement section is from Project No RF – 396(8) dated June 27, 1969.
- Most Recent project was NH-JOBS(045)3R J.P. 27358(04) Plans December 09, 2009.

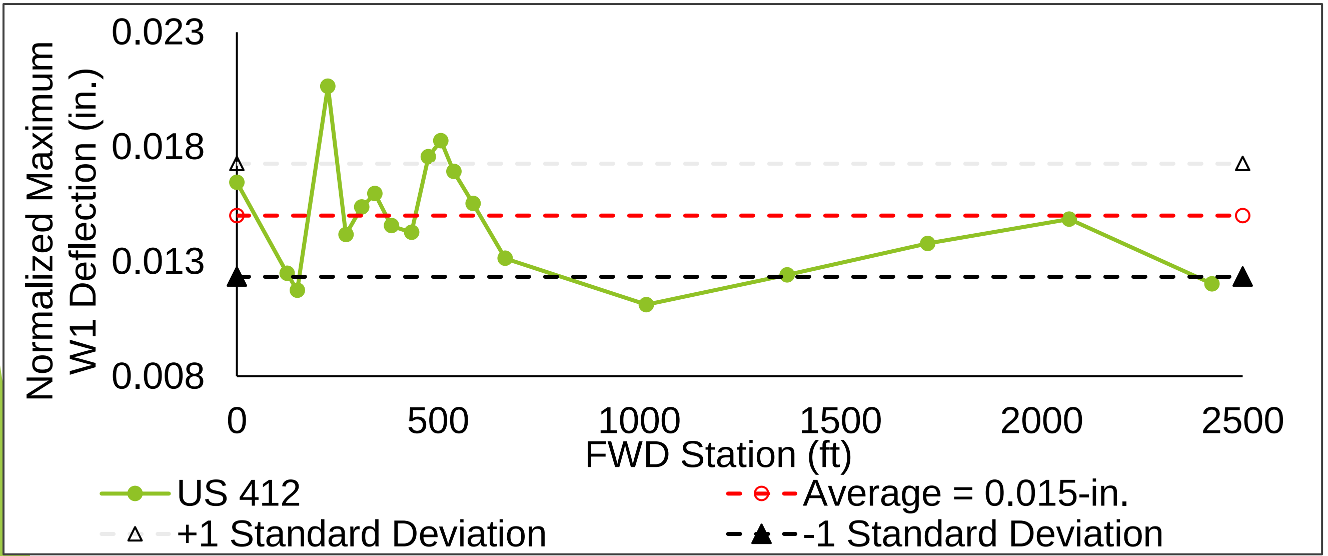


Oklahoma Example 2: US 412(Asphalt Overlay Design)

Falling Weight Deflectometer (FWD)

- 20 FWD tests using JILS-20-FWD equipment;
- Average normalized W1 deflection = 0.015-in;
- Average modulus = 121-ksi

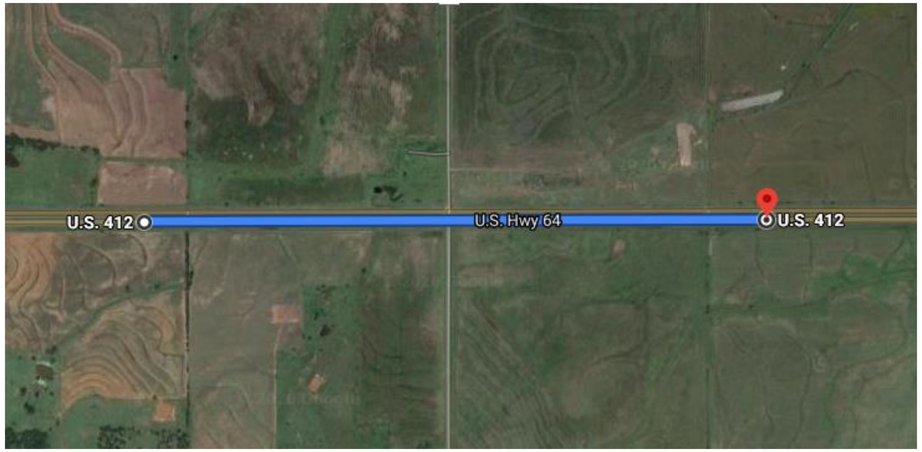




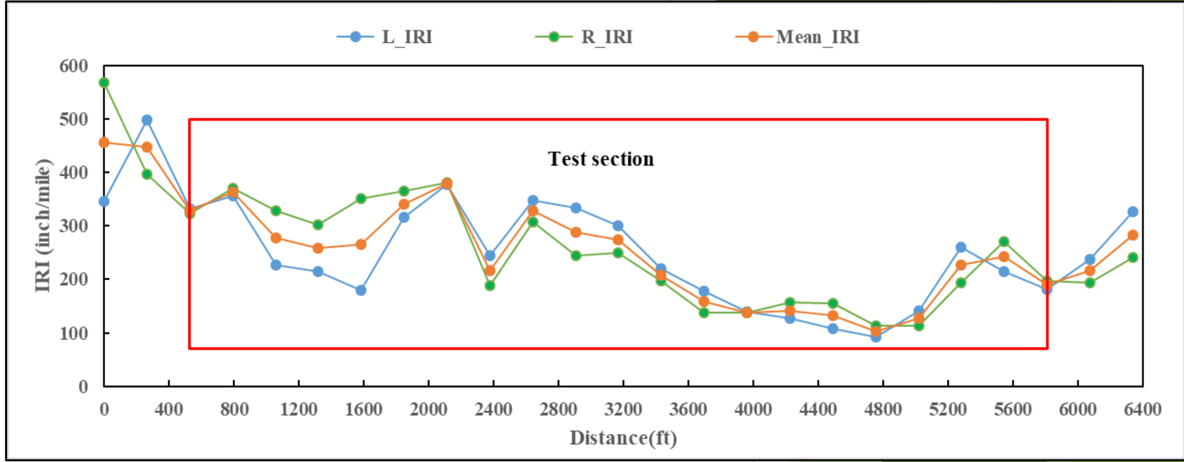
- **Pavement not structurally adequate**
- **Very low moduli**

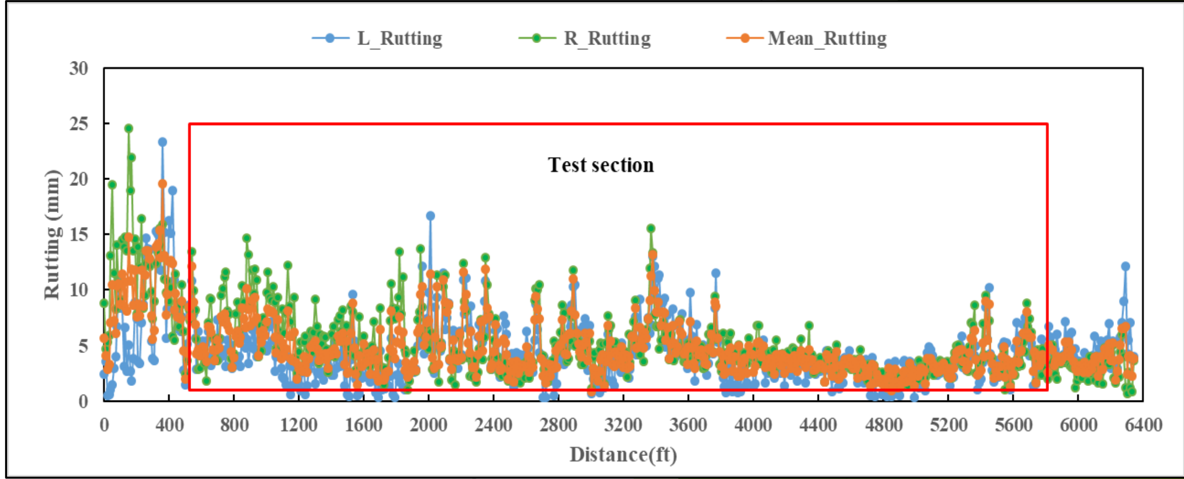
Oklahoma Example 2: US 412(Asphalt Overlay Design)

Pave3D 8K



Pave3D 8K Test Segment

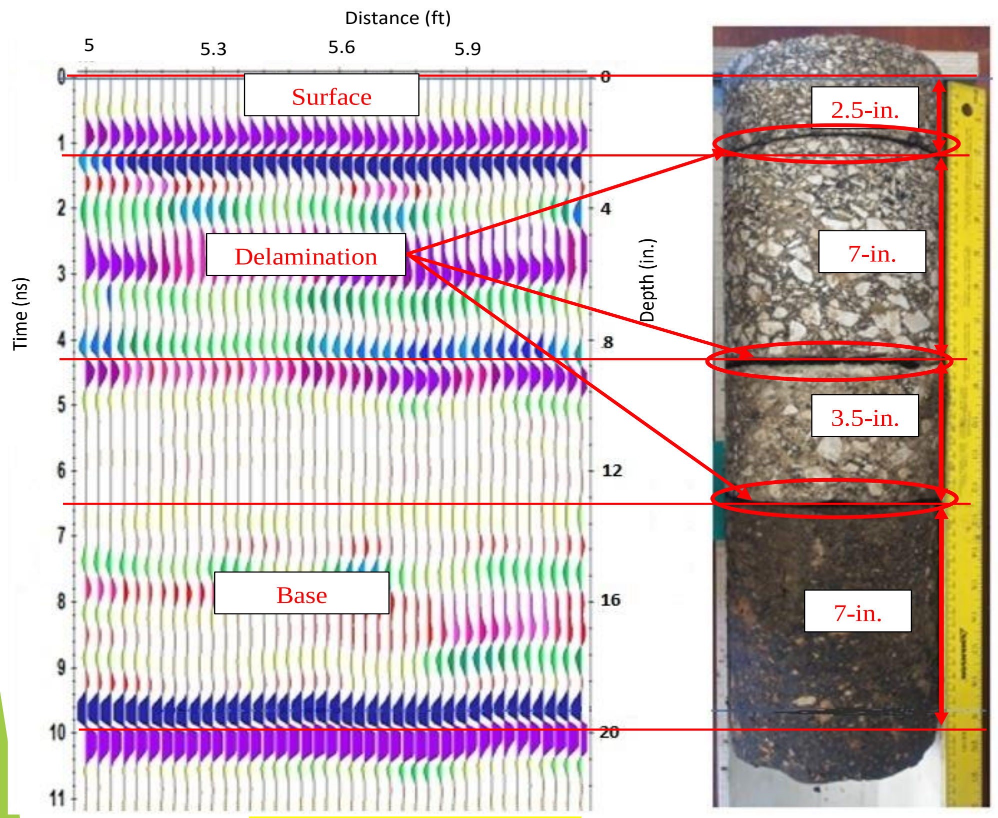




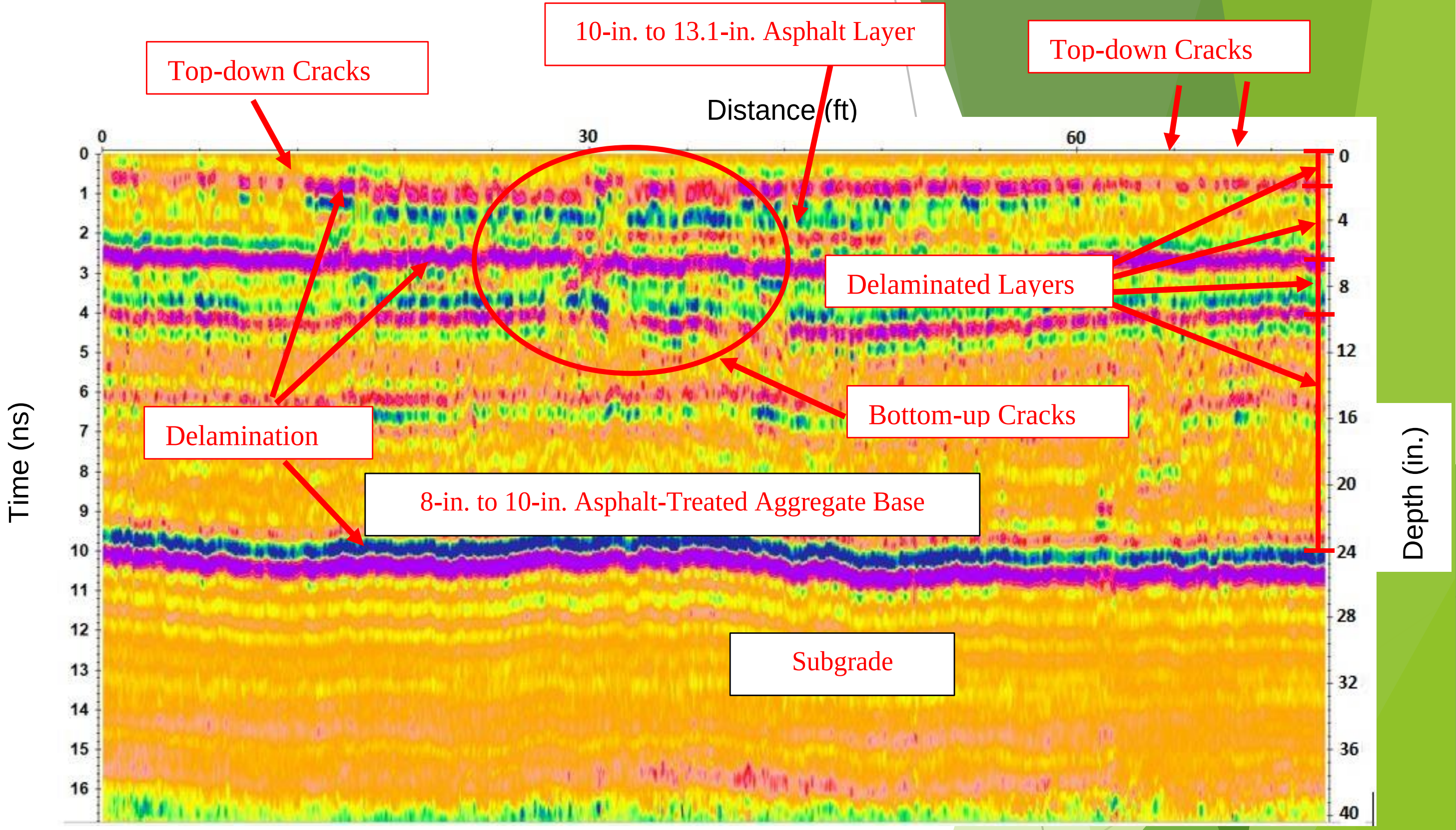
- 3D image were collected from a 1.2-mile-long pavement section.
- The left, right, and mean IRI numbers for the site ranged from 92.2-in/mi to 568.1-in/mi.
- Rut depths ranged from 0.3-mm to 24.56-mm

Oklahoma Example 2: US 412(Asphalt Overlay Design)

Ground Penetrating Radar (GPR)



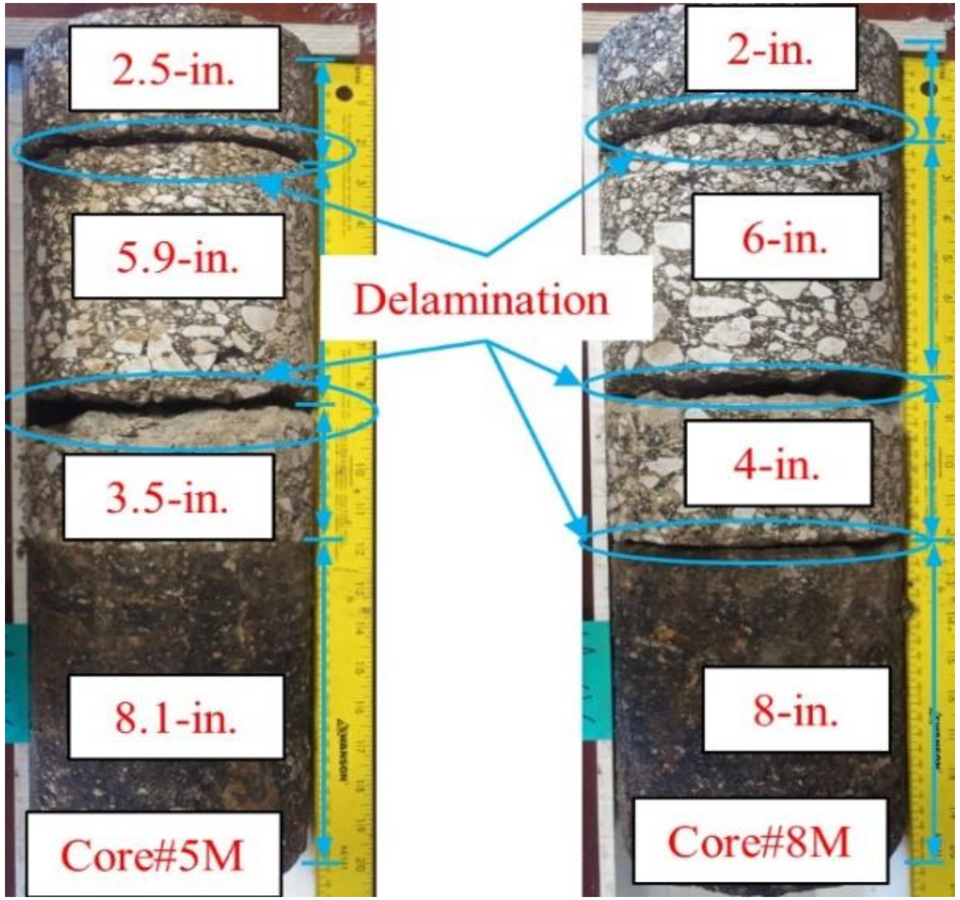
Calibration



- Delamination
- Top-down cracking
- Bottom-up cracking
- No disturbance in subgrade

Oklahoma Example 2: US 412(Asphalt Overlay Design)

Physical Inspection of Asphalt Cores



Oklahoma Example 2: US 412(Asphalt Overlay Design)

Dynamic Cone Penetration (DCP)

- 3 DCP tests at US 412

Parameters	Maximum	Minimum	Average	Standard Deviation
CBR	26.1	5.5	17.3	10.7
Modulus (ksi)	20.1	7.6	14.7	6.5

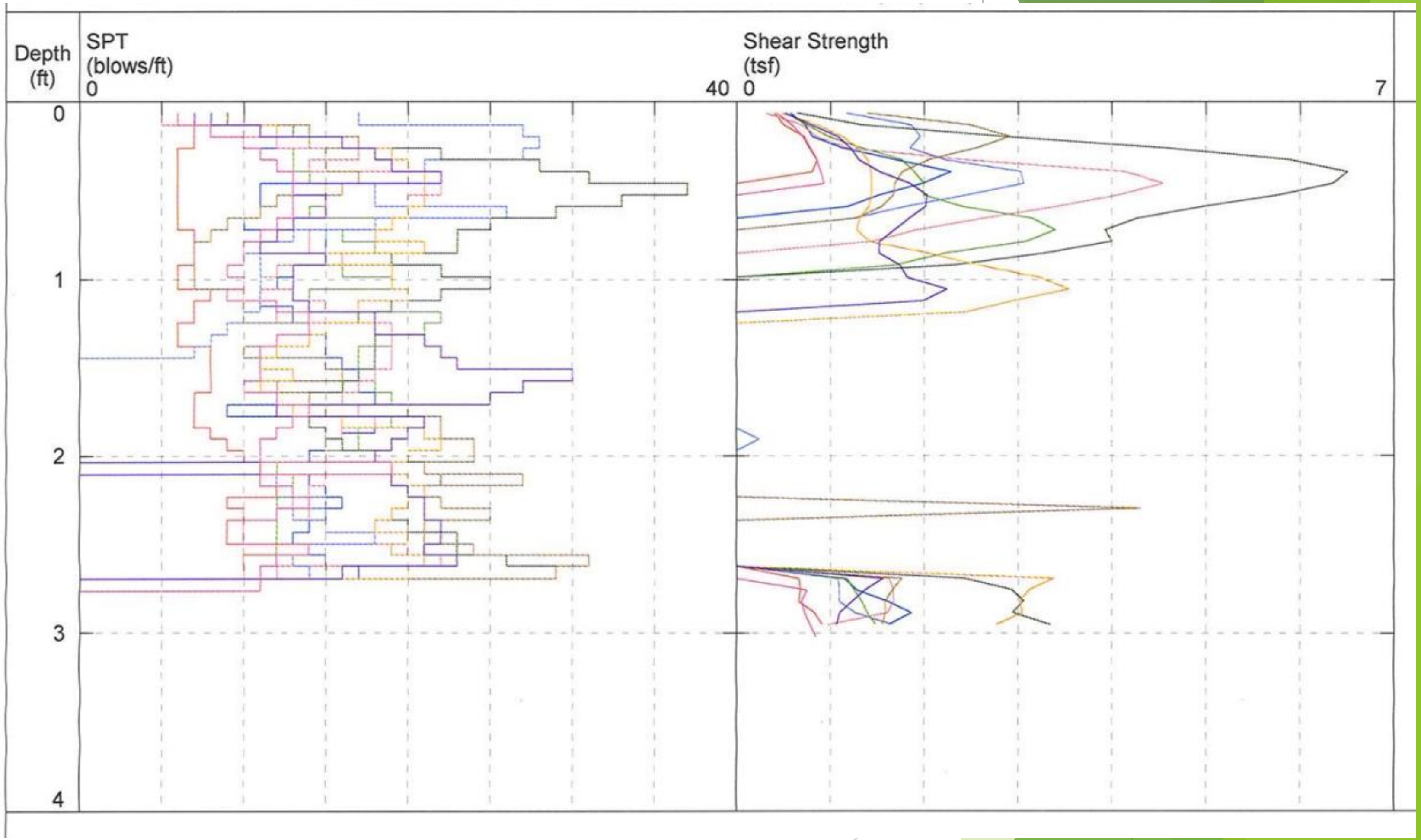
Subgrade Soil Properties

- Disturbed sample using hand auger
- The average LL, PL and PI was found as 29, 46 and 17%, respectively
- The percentage passing #200 sieve was determined as 65%
- The soil sample was categorized as A-7-6

Oklahoma Example 2: US 412(Asphalt Overlay Design)

Seismic Cone Penetration Test ($SCPT_u$)

- SCPTu Tests indicated relatively **stiff compacted in-place subgrade soils** based on the cone tip (q_t) and estimated SPT N-values.
- The SCPTu soundings revealed **good subgrade support**.



Oklahoma Example 2: US 412(Asphalt Overlay Design)

Illinois Flexibility Index Test (IFIT)

FI<8 → *Very poor cracking resistance (Ozer et al., 2016)*

Statistics	Flexibility Index (FI)
Average	0.15
Maximum	0.23
Minimum	0.07
Standard Deviation	0.06

Very low cracking resistance

Binder Extraction and Performance Grading (PG)

True Performance Grade (PG) = 112.9°C

Excessive aging of asphalt mix

Oklahoma Example 2: US 412(Asphalt Overlay Design)

Conclusions

1. Both the field and laboratory results show that the **subgrade soil is sound**.
2. Binder in top lift of asphalt pavement is **highly oxidized**. This translates to a stiff and brittle surface course.
3. **Delamination and stripping** were observed in the extracted cores in planes between asphalt lifts.
4. High **resistant to rutting** was observed on the collected cores.
5. Pavement is severely cracked. More cracking is expected which could damage subgrade.

Oklahoma Example 2: US 412(Asphalt Overlay Design)

Recommendations

Mitigation Options From Least to Most Cost:

1. Mill 1.5-in. and fill 1.5-in. with S5 (PG 70-28) mix.
2. Mill 2.5-in. and fill 2.5-in. with S4 (PG 70-28) mix.
3. Mill 2.5-in. and fill 2.5-in. with a SMA (PG 76-28) mix.
4. Mill 9.5-in. and fill 4-in. with a S4 (PG 70-28) mix and 5.5-in. with a S3(PG 64-22) mix.

Oklahoma Example 2: US 412(Asphalt Overlay Design)

Repair Option# 4: Mill 9.5-in. fill 4-in. with a S4 (PG 70-28) mix and 5.5-in. with a S3(PG 64-22) mix

- Key Inputs
  - Reliability: 90%
  - Nearest Weather Station: US, OK (36.5, -97.5)
  - GWT: 10 feet
  - AADTT: 1,280 trucks per day
- Working Pavement Section (Overlay)
  - 12 inches existing Asphalt
  - 9.5 inches Milling
  - 9.5 inches Asphalt Overlay
  - 8.5 inches A-3
  - A-7-6 Subgrade

Oklahoma Example 2: US 412(Asphalt Overlay Design)

General

- Design Life = 10 years
- Existing Construction: May 1986
- Pavement Construction Month: June 2021
- Traffic Open: June 2021

Analysis Parameters:

- Terminal IRI: 172
- AC top-down fatigue cracking: 25% lane area
- AC bottom-up fatigue cracking: 25%
- AC thermal cracking: 1000 ft/mile
- Permanent deformation: total 0.75, AC 0.25 in
- AC total fatigue cracking: bottom up + reflective: 25 % lane area
- AC total transverse cracking: thermal + reflective: 2500 ft/mile

Oklahoma Example 2: US 412(Asphalt Overlay Design)

- Traffic:
  - Initial two-way AADTT (1,280), Lanes in design direction (2), % truck in design direction (55), %truck in DSN lane (95), operational speed (70).
- Traffic Adjustment Factors:
  - Monthly (level 3), Vehicle class (level 3, default values), Hourly truck distribution (default values), and Traffic Growth Factor (compound 3%).
- Axle Load Distribution Factors:
  - Level 3, default values.
- Mean wheel location (18 in), Traffic wander deviation (10 in), and design lane width (12 ft).

Oklahoma Example 2: US 412(Asphalt Overlay Design)

Layer 1 (Overlay):

- Asphalt concrete, 4 in thick.
- Aggregate gradation: (Passing ¾ in: 100%, Passing 3/8 in: 77%, Passing #4: 60%, Passing 200: 6)
- Asphalt Binder: 70-28
- Asphalt General: (default values)

Layer 2 (Overlay):

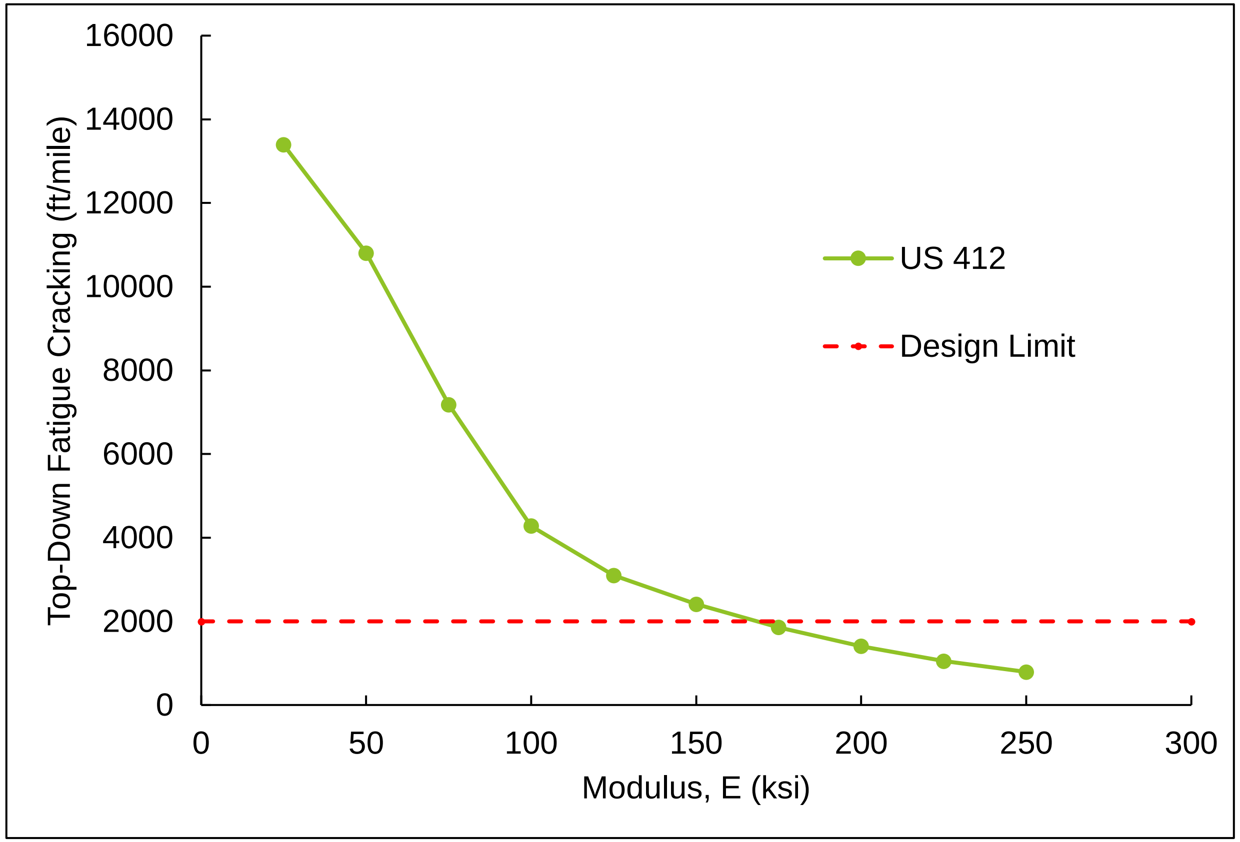
- Asphalt concrete, 5.5 in thick.
- Aggregate gradation: (Passing ¾ in: 100%, Passing 3/8 in: 77%, Passing #4: 60%, Passing 200: 6)
- Asphalt Binder: 64-22
- Asphalt General: (default values)

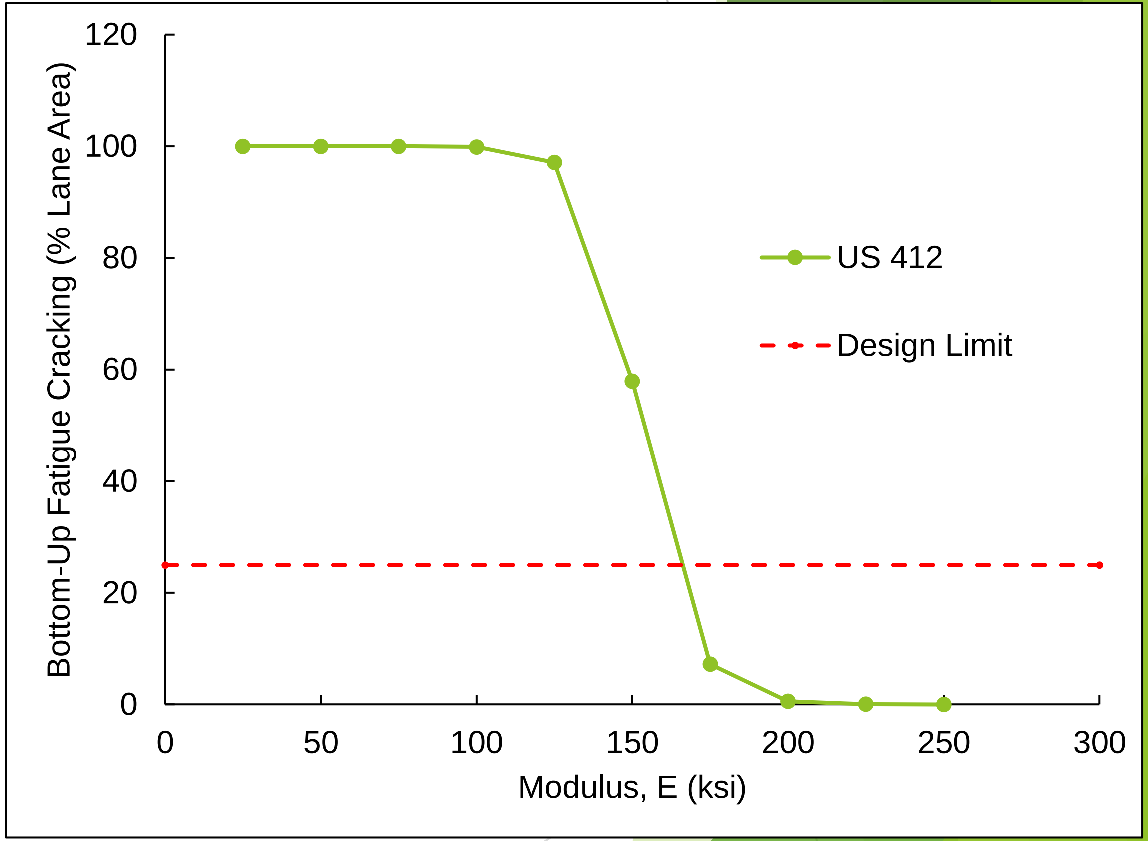
Oklahoma Example 2: US 412(Asphalt Overlay Design)

- **Layer 3 (Existing Asphalt):**
  - NDT Modulus: 250,000 psi
  - Thickness: 2.5 inch
  - Asphalt Binder: 64-22
  - Asphalt General: (default values)
- **Layer 4:**
  - Non-stabilize Base: A-3,
  - Thickness: 8.5 inch.
  - Strength properties: Modulus 15,000 psi.
- **Layer 5:**
  - Subgrade A-7-6,
  - Strength properties: Modulus 8,000 psi.

Oklahoma Example 2: US 412(Asphalt Overlay Design)

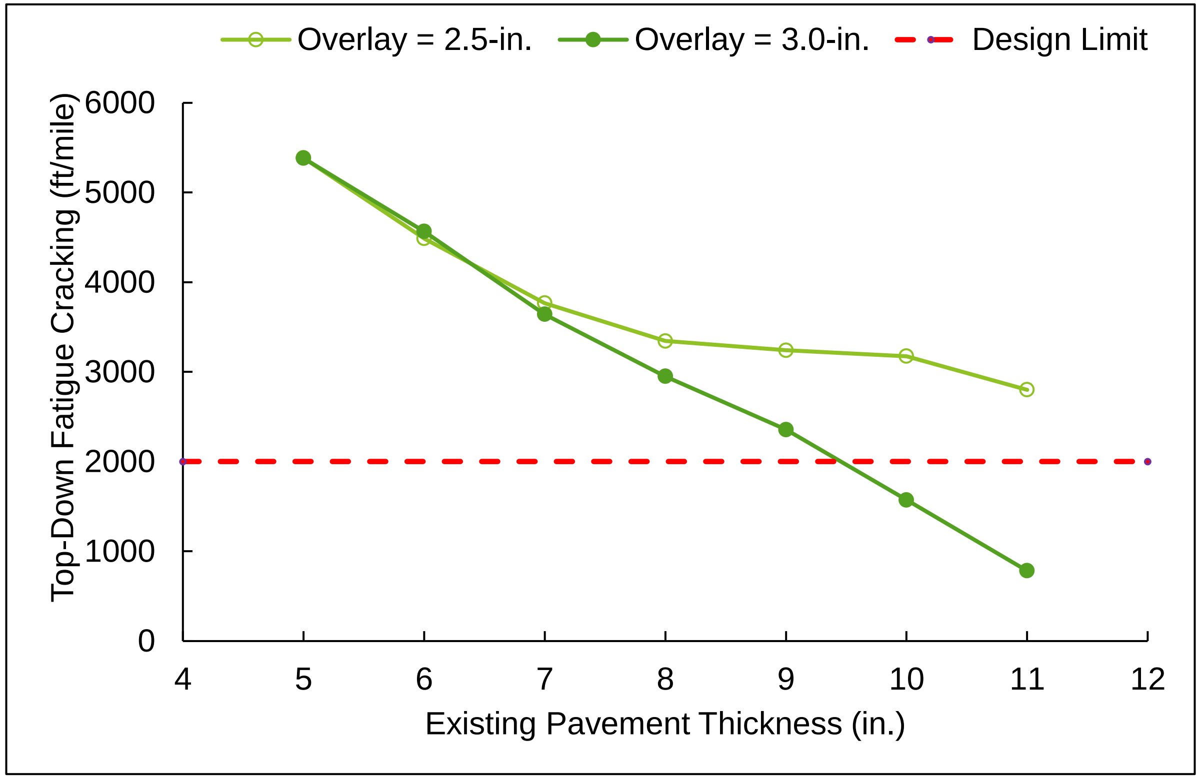
Effect of Pavement Stiffness on Distresses

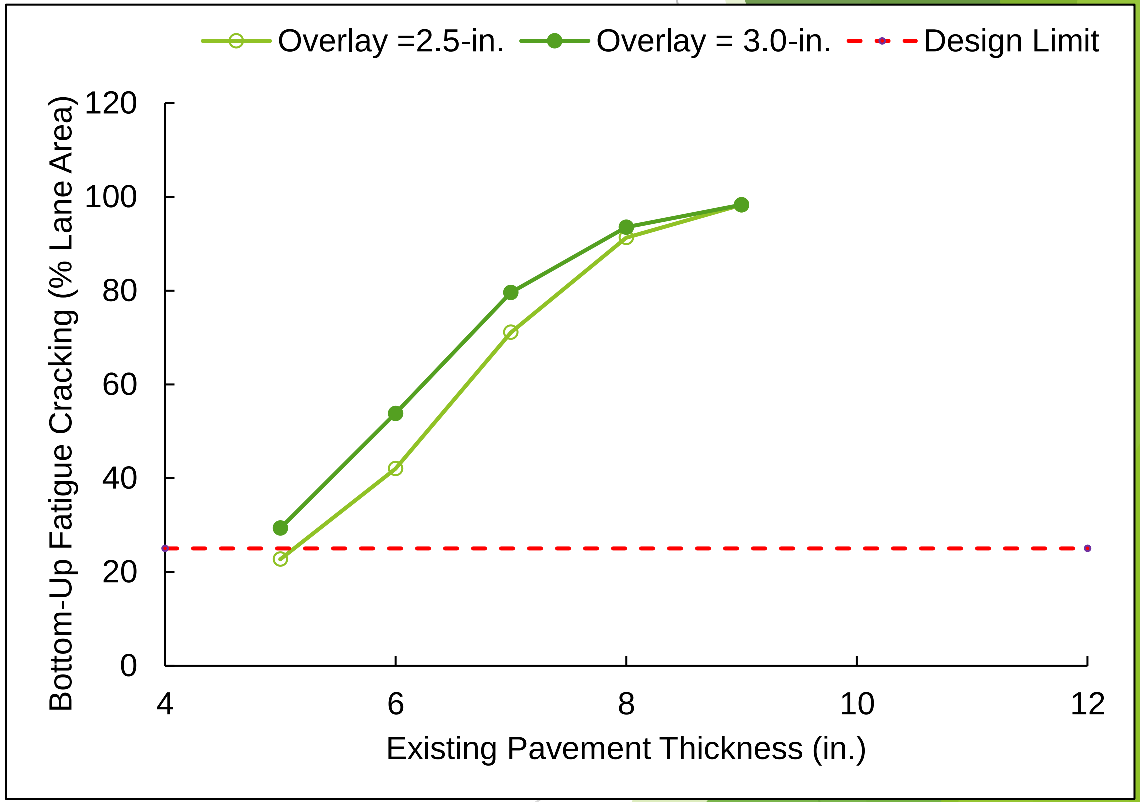




Oklahoma Example 2: US 412(Asphalt Overlay Design)

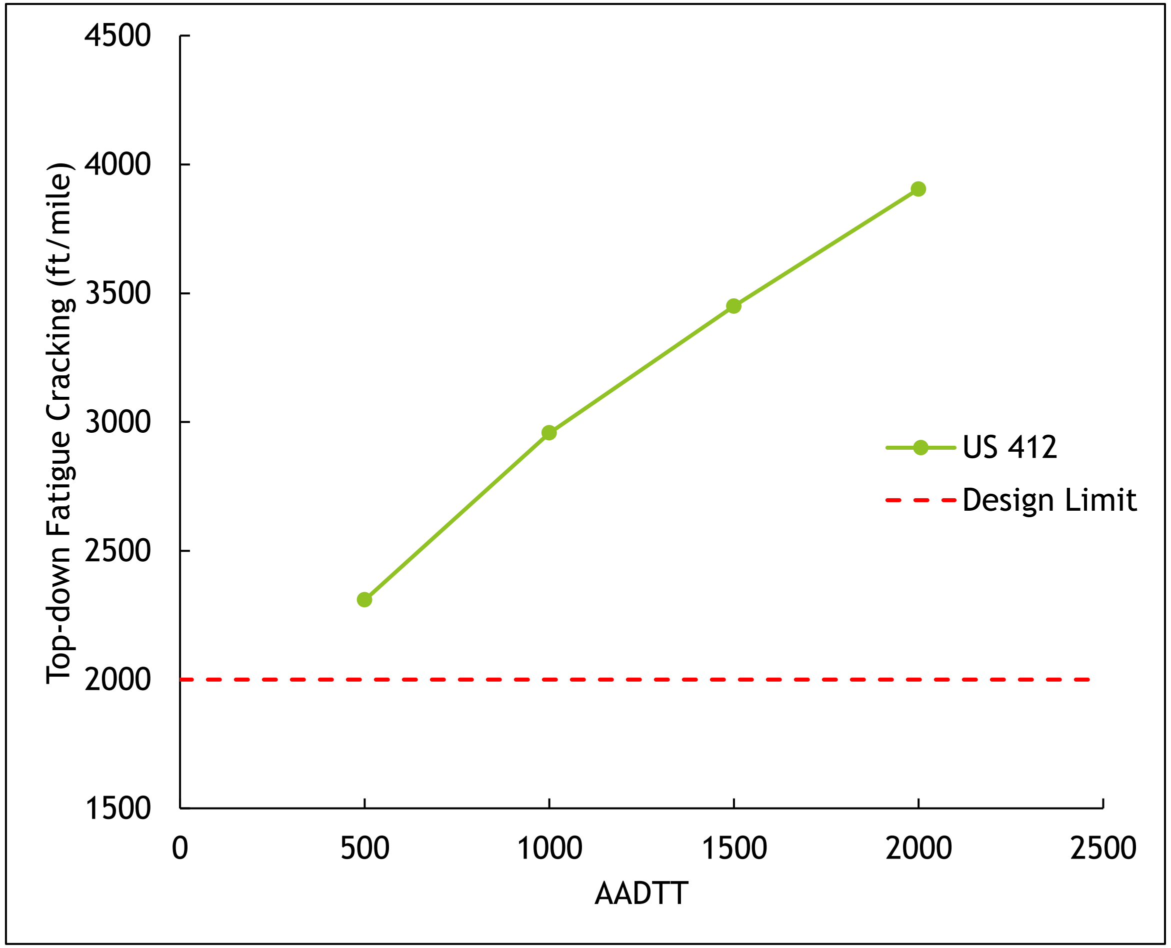
Effect of Pavement Thickness on Distresses

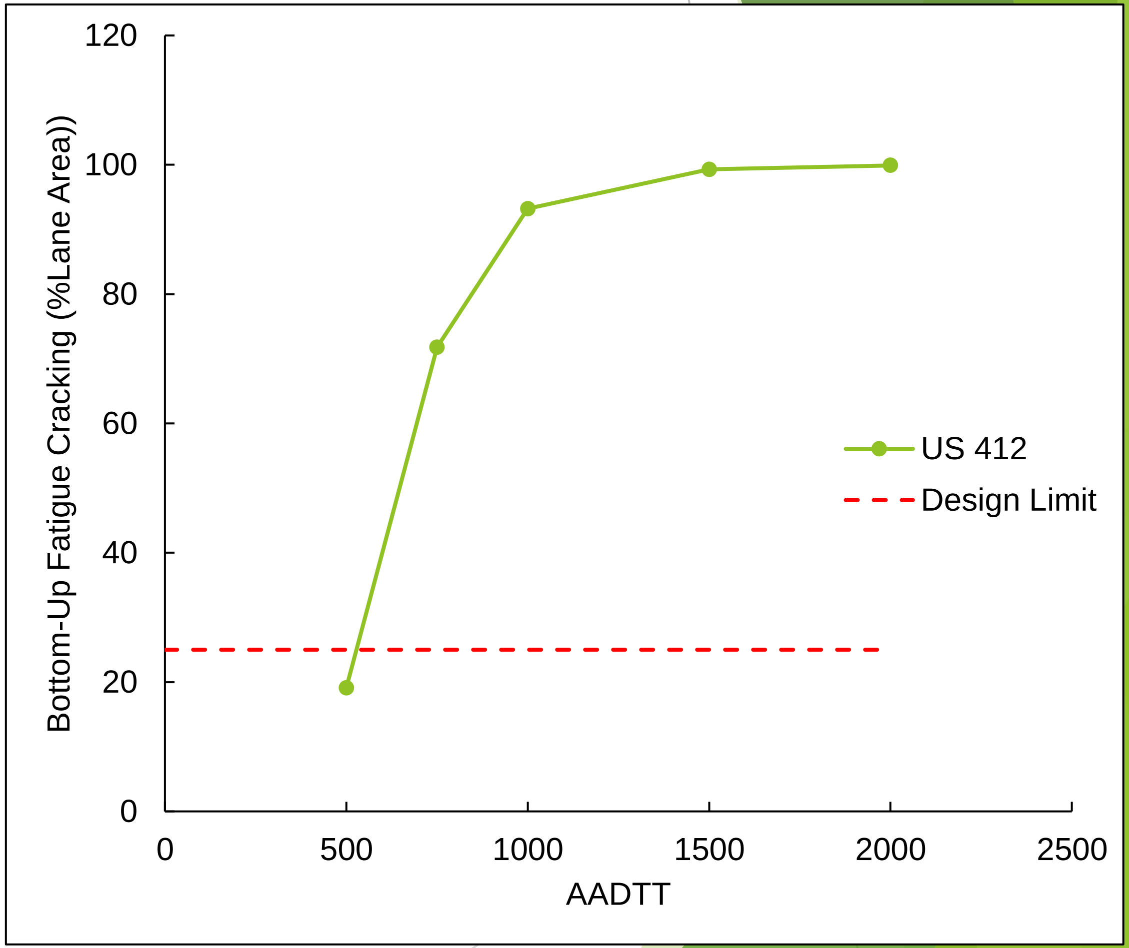




Oklahoma Example 2: US 412(Asphalt Overlay Design)

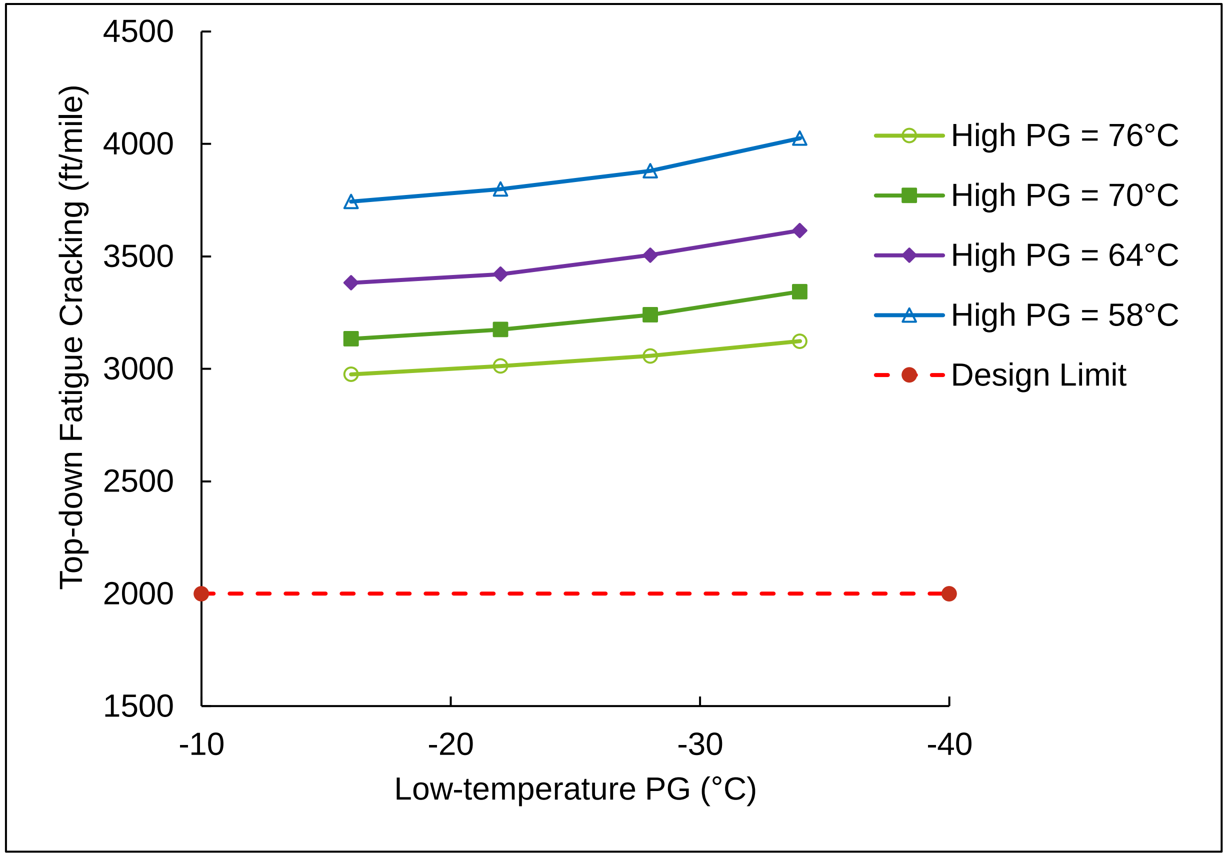
Effect of Traffic Level on Distresses

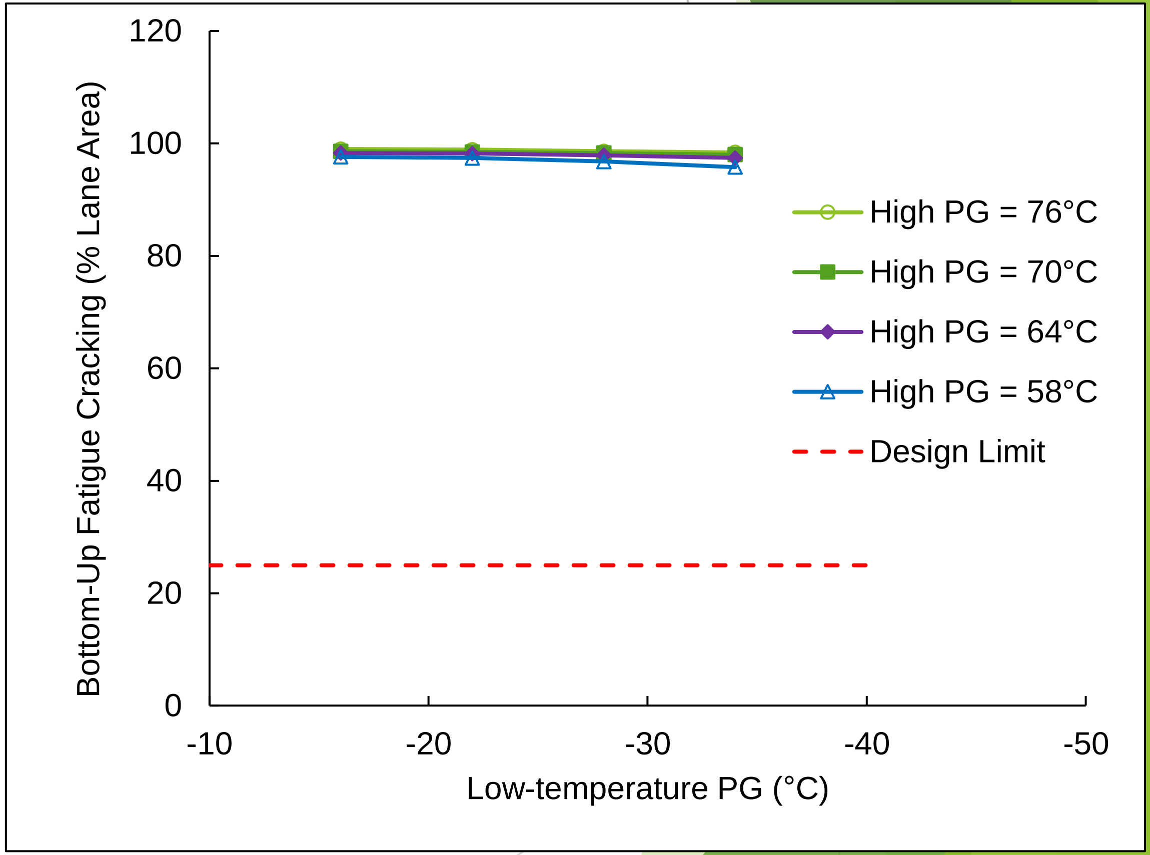




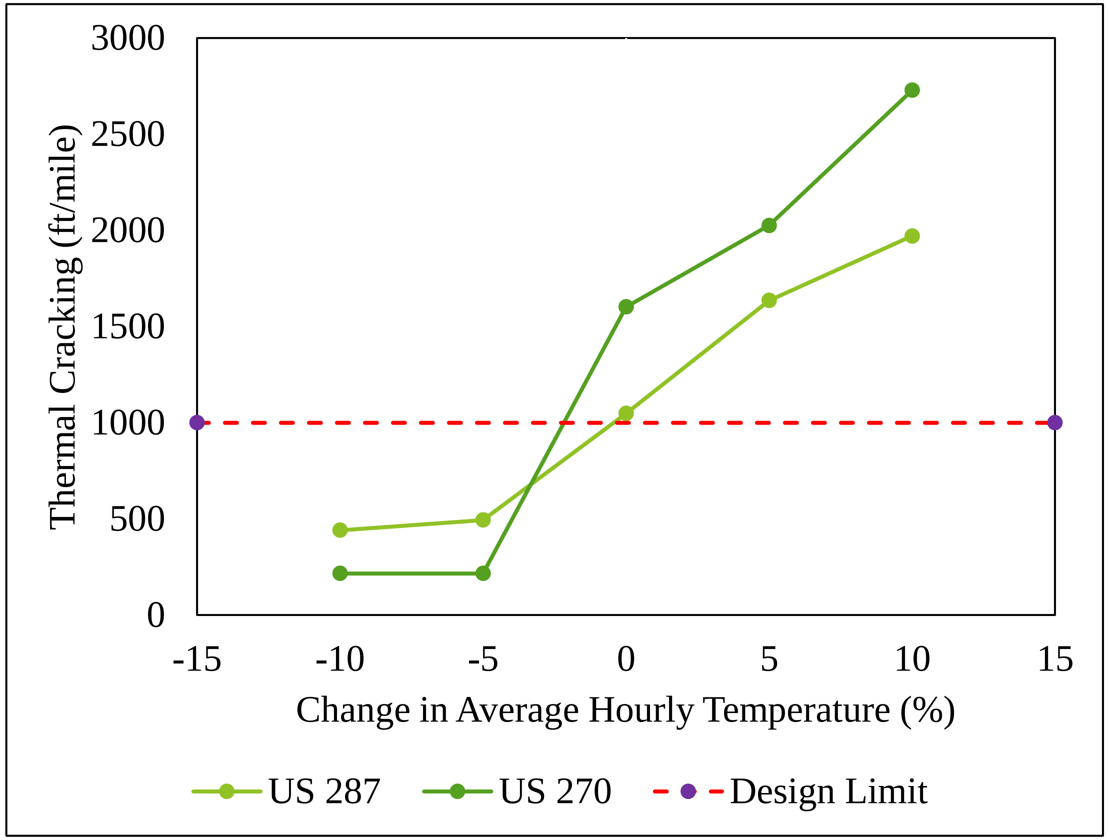
Oklahoma Example 2: US 412(Asphalt Overlay Design)

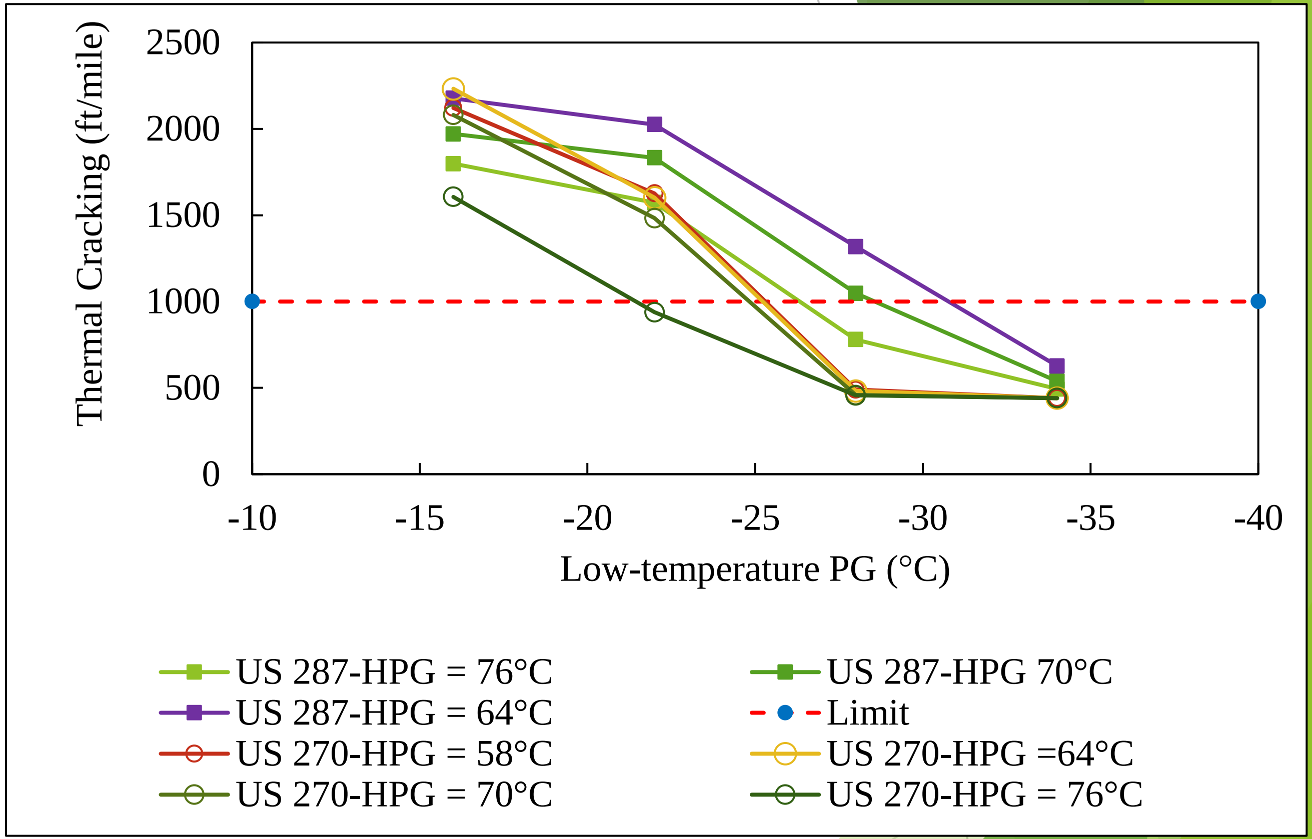
Effect of Binder PG on Distresses





Effect of Hourly Temperature and Binder PG Thermal Cracking





LUNCH TIME!

Workshop Schedule

Day 1

Morning Session
- ME Design Methodology, Software, and Process

Afternoon Session
- Discuss Design Outputs and Adequacy of Design
- New Asphalt/Concrete Design

Day 2

Morning Session
- Asphalt/Concrete Overlay Design
- Oklahoma Project Examples

Afternoon Session
- Classroom Exercises (Asphalt/Concrete/Overlay Design)

Day 3

Morning Session
- Calibration/Sensitivity Analysis/Backcalculation
- Q&A, Reviewing Topics

CLASSROOM EXERCISE #1
New Asphalt Pavement Design

- Roadway: 88^{th} Avenue (West of Rosemary Street)
- Location: Commerce City, Colorado
- Classification (CDOT): Minor Arterial
- Number of Lanes: 4 (2 in each direction)
- Base/Pavement Construction: April 2022
- Traffic Opening: May 2022

CLASSROOM EXERCISE #1

New Asphalt Pavement Design

Distress Type	Value
Initial IRI (in/mile)	61
Terminal IRI (in/mile)	200
Pavement Deformation – total pavement (in)	0.80
AC Bottom-Up Fatigue Cracking (% lane area)	25.00
AC Thermal Cracking (ft/mile)	1500.00
AC Top-Down Fatigue Cracking (% lane area)	25.00
Permanent Deformation – AC Only (in)	0.65

Traffic Parameter	Value
Initial two-way AADTT	2,745
Compound Growth Rate	1.41%
Vehicle Cluster	CDOT Cluster 3
Percent of Trucks in Design Direction	50.0%
Percent of Trucks in Design Lane	90.0%
Operational Speed	60 mph

Reliability: 90%
Subgrade: Silty, Clayey Sand
R-Value: 17 (M_r = 7,501 psi)

Top Lift: SX(100)PG76-28
Bottom Lift: S(100)PG64-22

https://www.morganpavement.com/blog/how-much-does-asphalt-pavement-cost/


TIME FOR A
BREAK

CLASSROOM EXERCISE #2
New Concrete Pavement Design

- Roadway: S. Santa Fe Dr.
- Location: Englewood, Colorado
- Classification (CDOT): Principal Arterial
- Number of Lanes: 6 (3 in each direction)
- Base/Pavement Construction: September 2022
- Traffic Opening: October 2022

CLASSROOM EXERCISE #2

New Concrete Pavement Design

Distress Type	Value
Initial IRI (in/mile)	78
Terminal IRI (in/mile)	200
JPCP Transverse Cracking (% slabs)	7.0
Mean Joint Faulting (in)	0.14

Joint Design	Value
Joint Spacing (ft)	15
Dowel Diameter (in)	1.50
Slab Width (ft)	12.0

Traffic Parameter	Value
Initial two-way AADTT	5,959
Compound Growth Rate	1.00%
Vehicle Cluster	CDOT Cluster 3
Percent of Trucks in Design Direction	50.0%
Percent of Trucks in Design Lane	60.0%
Operational Speed	55 mph

Reliability: 90%
Subgrade: Silty, Clayey Sand (A-6)
R-Value: 20 (M_r = 7,844 psi)

https://www.concreteconstruction.net/how-to/construction/concrete-paving-colorado-style_o

Day 1

Morning Session

- ME Design Methodology, Software, and Process

Afternoon Session

- Discuss Design Outputs and Adequacy of Design
- New Asphalt/Concrete Design

Day 2

Morning Session

- Asphalt/Concrete Overlay Design
- Oklahoma Project Examples

Afternoon Session

- Classroom Exercises (Asphalt/Concrete/Overlay Design)

Day 3

Morning Session

- Calibration/Sensitivity Analysis/Backcalculation
- Q&A, Reviewing Topics

End of Day 2 Session


WELCOME TO
DAY 3
Discover the Excellence
Of M-E Pavement Design.

Workshop Schedule

Day 1

Morning Session

- ME Design Methodology, Software, and Process

Afternoon Session

- Discuss Design Outputs and Adequacy of Design
- New Asphalt/Concrete Design

Day 2

Morning Session

- Asphalt/Concrete Overlay Design
- Oklahoma Project Examples

Afternoon Session

- Classroom Exercises (Asphalt/Concrete/Overlay Design)

Day 3

Morning Session

- Calibration/Sensitivity Analysis/Backcalculation
- Q&A, Reviewing Topics

M-E Pavement Design Calibration/Sensitivity/Backcalculation

Dr. Nur Hossain, PhD, PE

Mechanistic Input Parameters and Model Calibration for Design and Performance Evaluation of Flexible Pavements in Oklahoma

Literature Review

Authors	State	Research Area
Haider et al. (2011)	Michigan	- Developed Level 1 and Level 2 traffic input parameters
Romanoschi et al. (2011)	New York	- Developed Level 1 traffic input parameters
Ishak et al. (2010)	Louisiana	- Developed Level 1 traffic input parameters
Smith and Diefenderfer (2010)	Virginia	- Developed Level 1 traffic input parameters
Li et al. (2009)	Washington	- Developed Level 1 traffic input parameters - Calibrated the rutting models
Tran and Hall (2007)	Arkansas	- Developed Level 1 traffic input parameters
Tarefder et al. (2013)	New Mexico	- Calibrated the distress models using Level 3 data
Hall et al. (2011)	Arkansas	- Calibrated the rutting models using Level 3 data
Hoegh et al. (2010)	Minnesota	- Calibrated the rutting models using Level 2 & Level 3 data
Banerjee et al. (2009)	Texas	- Calibrated the rutting models using Level 2 & Level 3 data
Muthadi and Kim (2008)	North Carolina	- Calibrated the rutting models using Level 2 & Level 3 data

Gaps in Existing Literature

- Some developed Level 1 traffic inputs, but not Level 1 materials inputs.
- Traffic inputs developed for a month or a year at most, not for an extended period of time (say 3 to 4 years).
- Calibration performed using Level 3 inputs, not Level 1.
- Many could not calibrate models using layer-wise data, because forensic study was not available.

Research Questions

- Is it important to develop Level 1 input parameters?
- Which input parameters are most sensitive?
- Is calibration of the MEPDG distress models required?
- How different pavement layers contribute to rutting?

Methods & Approach

Phase 1

- Collect Traffic Data
- Collect Performance Data
- Perform Lab Tests:
  - Dynamic Modulus
  - Dynamic Shear Rheometer
  - Resilient Modulus

Phase 2

- Analyze Traffic Data
- Develop Level 1 Traffic and Material Inputs for MEPDG
- Compare Level 1 & 3 Inputs
- Analyze Sensitivity

Phase 3

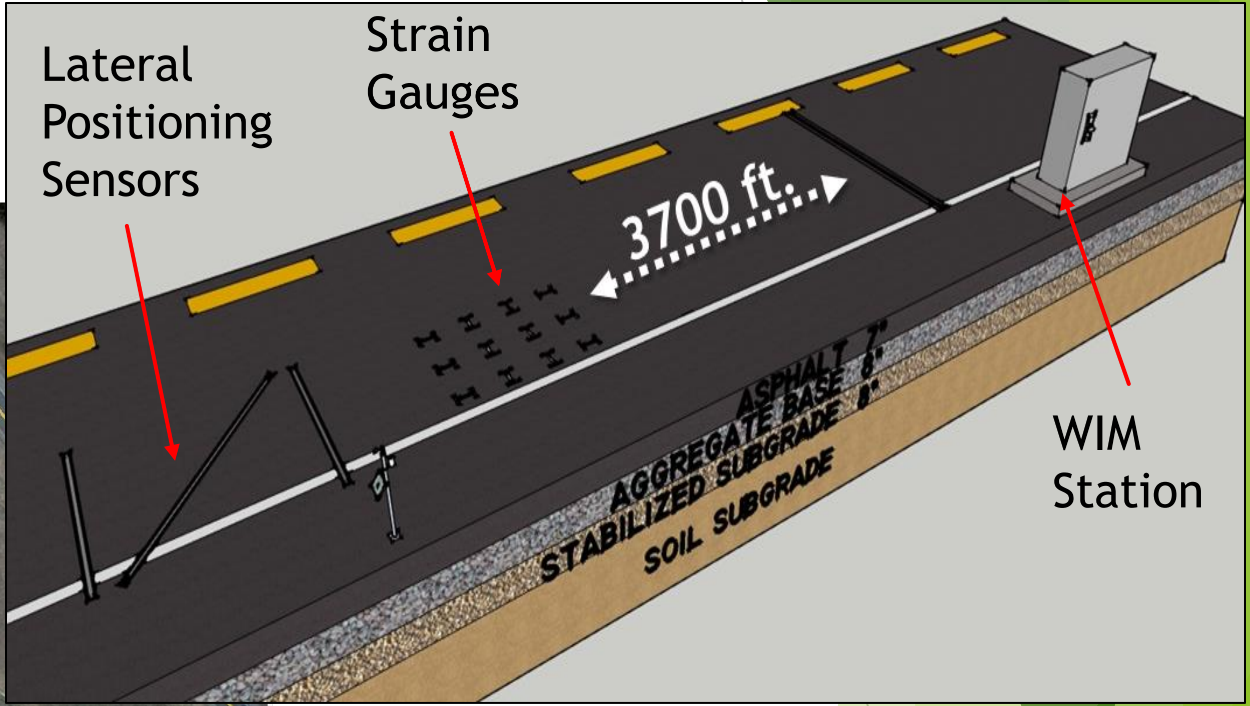
- Find out Rut Contribution of Different Layers

Phase 4

- Calibrate MEPDG Rut Models

Field Tests

- Construction & Instrumentation of the Test Section



Field Tests

- Measurement of Pavement Distresses on the Test Section
  a) Three types of distresses: rutting, fatigue cracking and IRI
  b) Measurement conducted every 3 months for 6 years

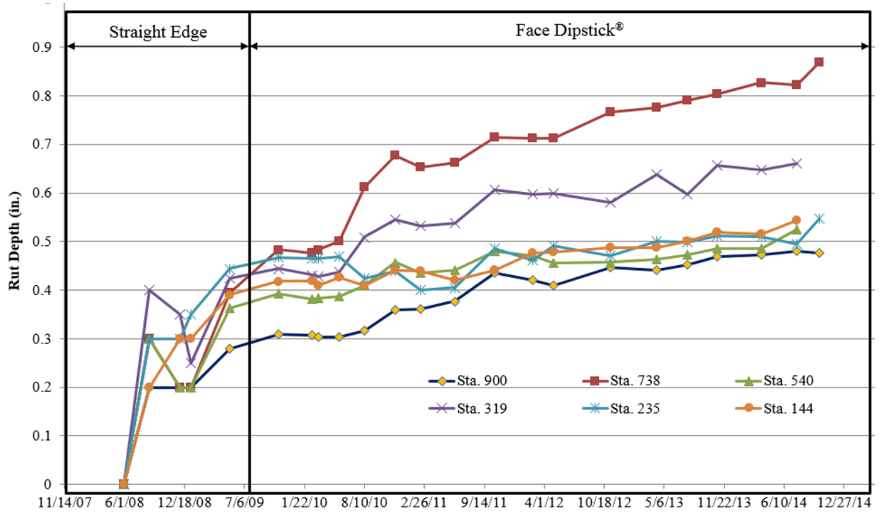
Rut Measurement

IRI Measurement

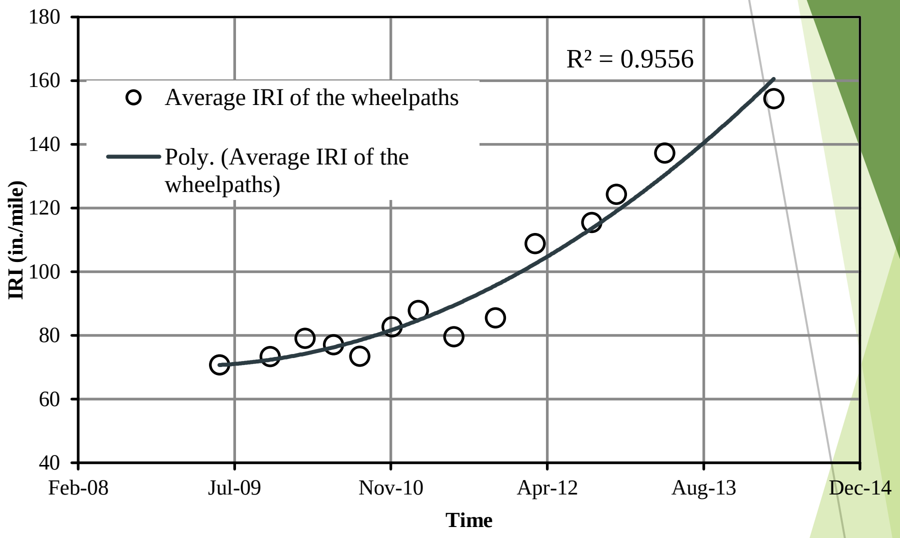
Crack Mapping

Field Tests

- Measured Pavement Distresses on the Test Section



Rut Measurement



IRI Measurement

Crack Mapping

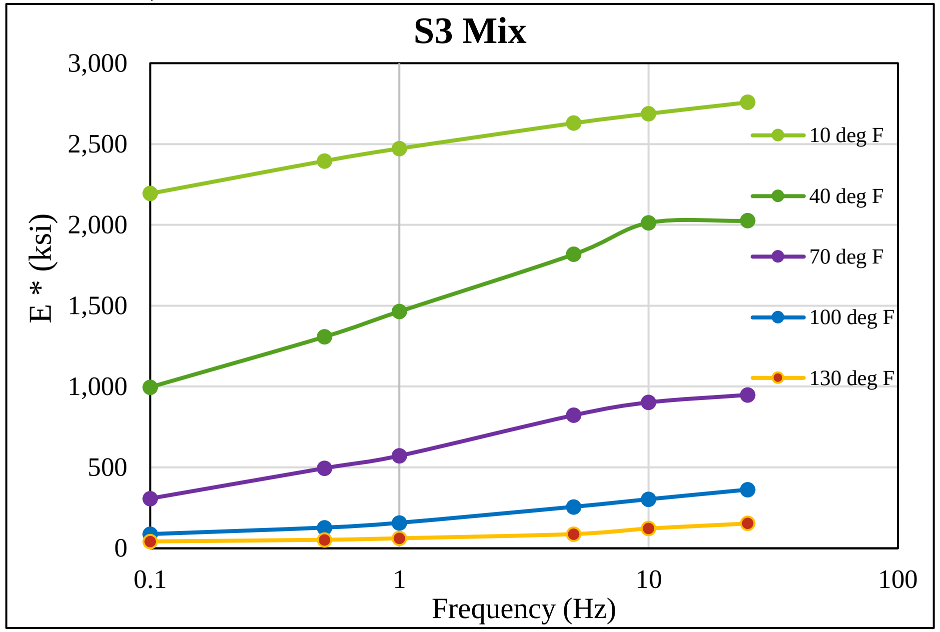
Development of MEPDG Inputs

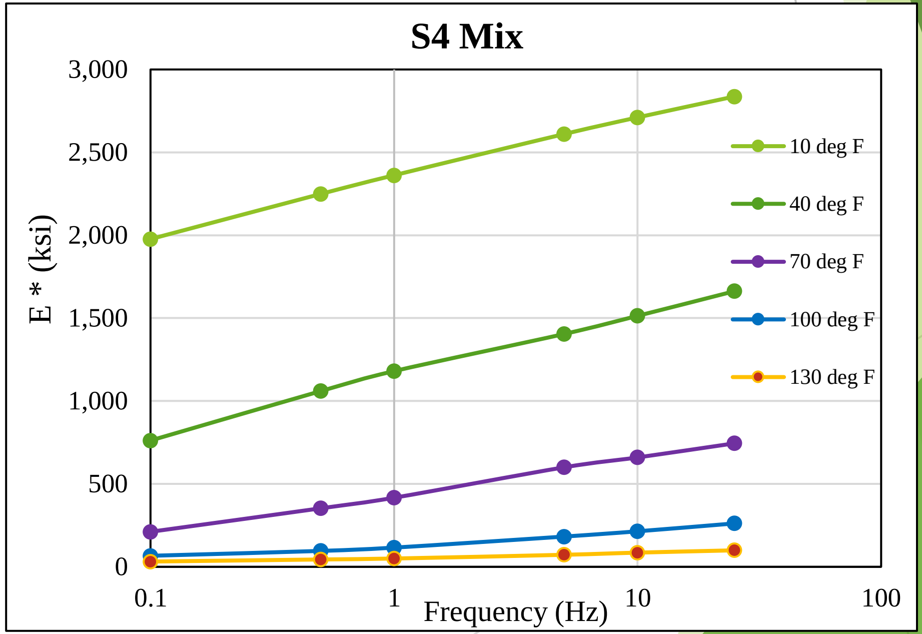
- **Materials**

  Asphalt Mix

  - Dynamic Modulus tests performed on loose asphalt mixes.

  - Target air voids from extracted cores (8±0.5% for S3, 9±0.5% for S4)





Development of MEPDG Inputs

- **Materials**

  Asphalt Binder

  - Dynamic Shear Rheometer (DSR) tests on PG 64-22 binder.

Temperature (°F)	Angular Frequency = 10 rad/sec	
	G* (Pa)	δ (°)
142	6153	77
147	3930	18
153	2713	79

Development of MEPDG Inputs

- **Materials**

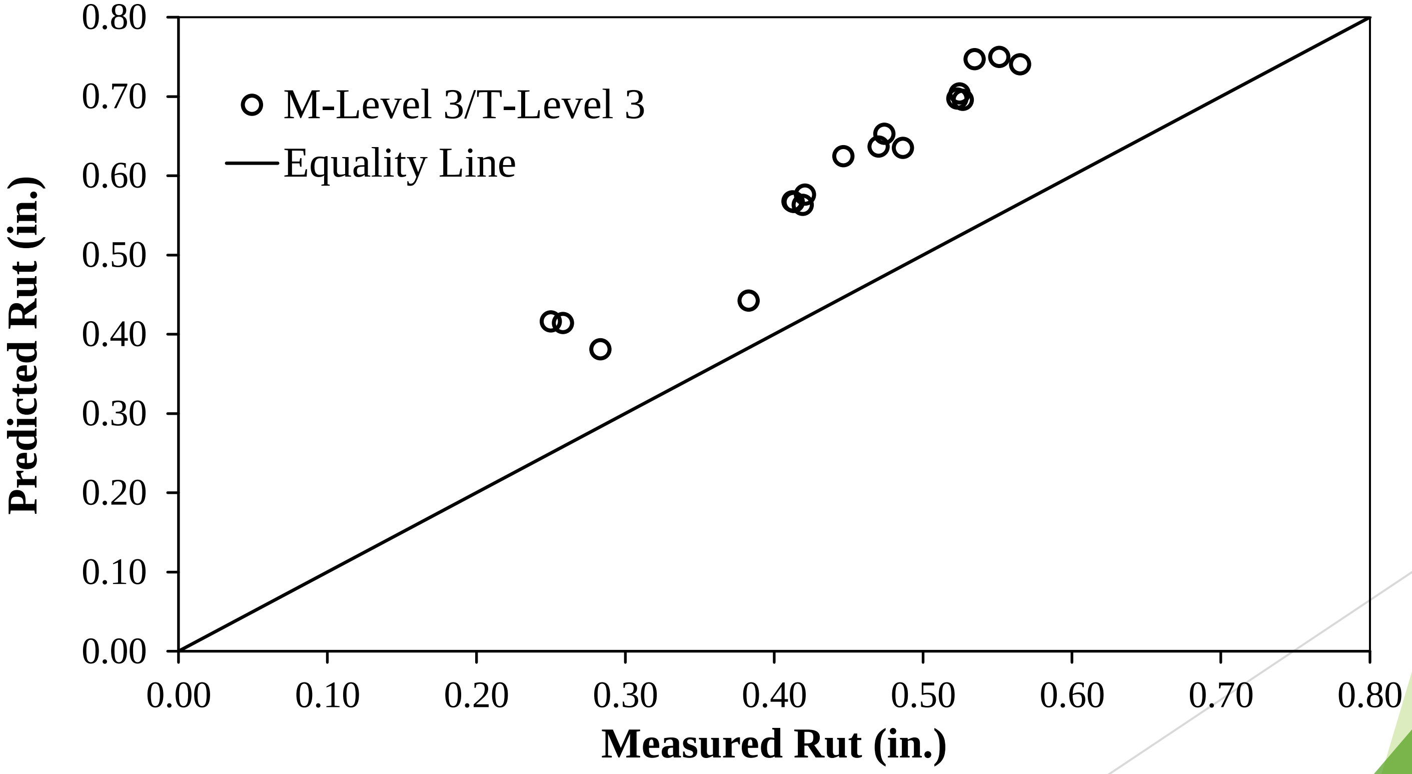
  Aggregate Base, Stabilized & Natural Subgrades

  - Resilient Modulus tests on aggregate base, stabilized subgrade and natural subgrade layers.

Layer	Resilient Modulus (psi)
Aggregate Base	30,000
Stabilized Subgrade	57,466
Natural Subgrade	12,327

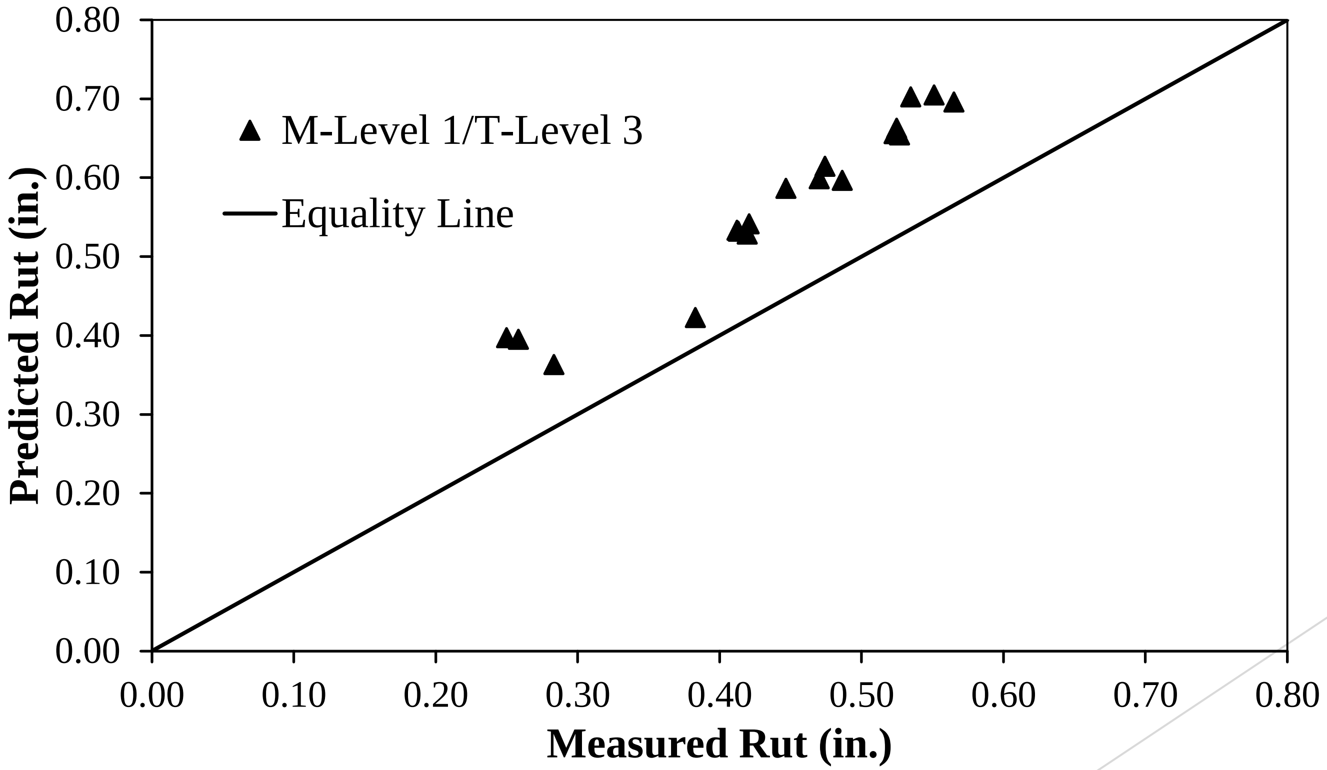
Sensitivity of Input Parameters

- Rut Prediction using Level 3 Inputs (Traffic & Materials)
  - p-value = 0.0001 < 0.05
  - Error ranges from 15% to 66%, Average 37%.



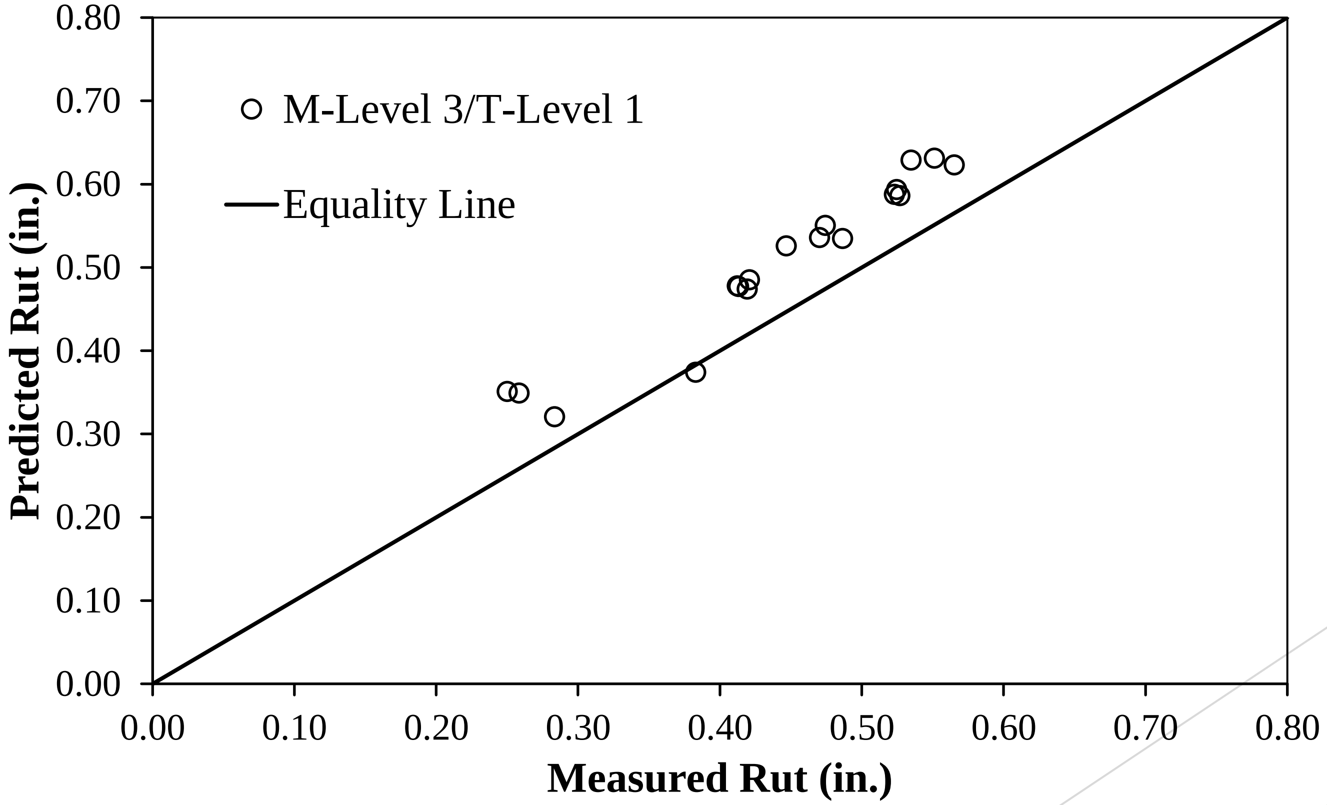
Sensitivity of Input Parameters

- Rut Prediction using Level 1 Materials, Level 3 Traffic Inputs
  - p-value = 0.001 < 0.05.
  - Error ranges from 10% to 59%, Average 30%.



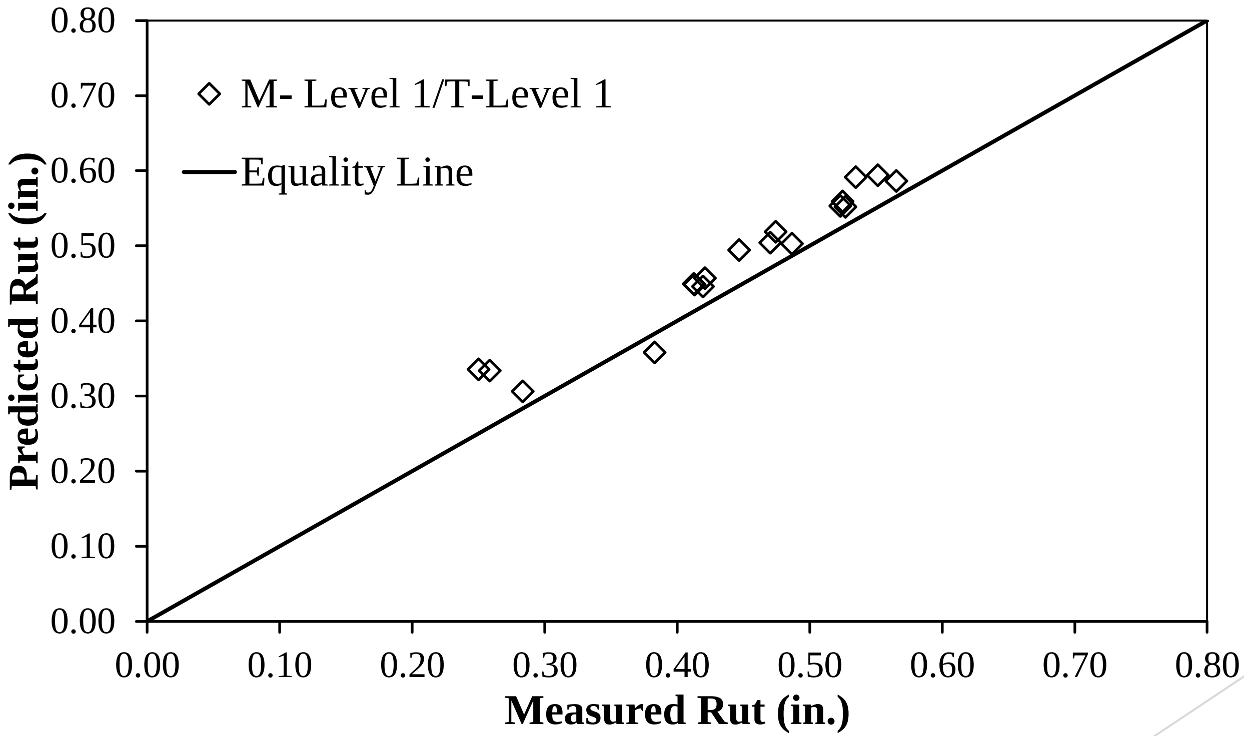
Sensitivity of Input Parameters

- Rut Prediction using Level 3 Materials, Level 1 Traffic Inputs
  - p-value = 0.03 < 0.05.
  - Error ranges from 2% to 41%, Average 16%.



Sensitivity of Input Parameters

- Rut Prediction using Level 1 Materials, Level 1 Traffic Inputs
  - p-value = 0.045 < 0.05.
  - Error ranges from 2% to 30%, Average 10%.



Traffic more sensitive than materials

Sensitivity of Traffic Input Parameters

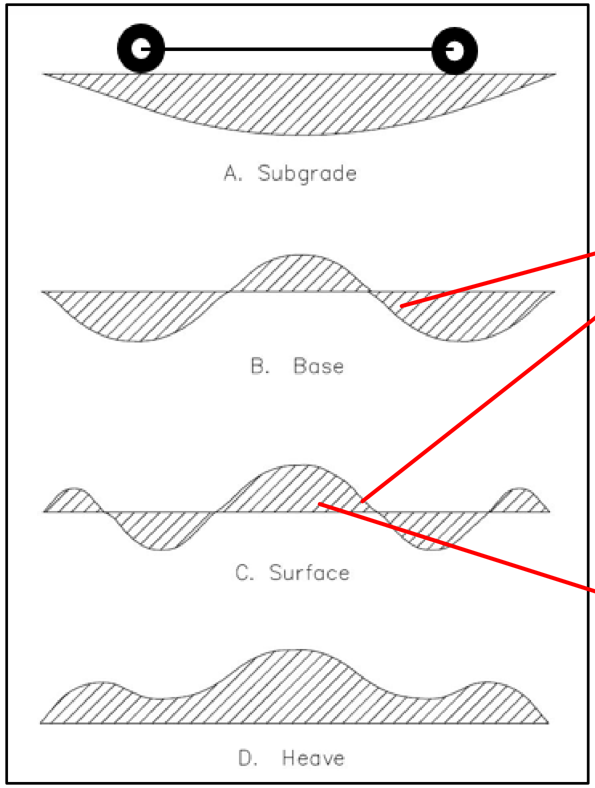
- Rut Prediction using Different Combinations of Traffic Inputs

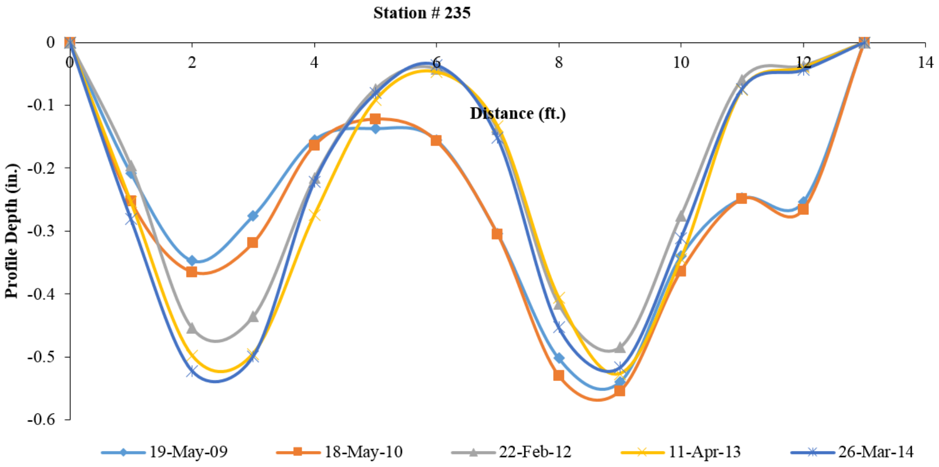
Combination #	Combination Type	Difference between Measured and Predicted Rut				
		Average	Minimum	Maximum	SSE	p-value
1	Level 1 ALS, Level 3 MAF & VCD	16%	2%	41%	0.081	0.04 < 0.05
2	Level 1 VCD, Level 3 ALS & MAF	24%	6%	52%	0.189	0.005 < 0.05
3	Level 1 MAF, Level 3 ALS & VCD	29%	10%	58%	0.284	0.001 < 0.05

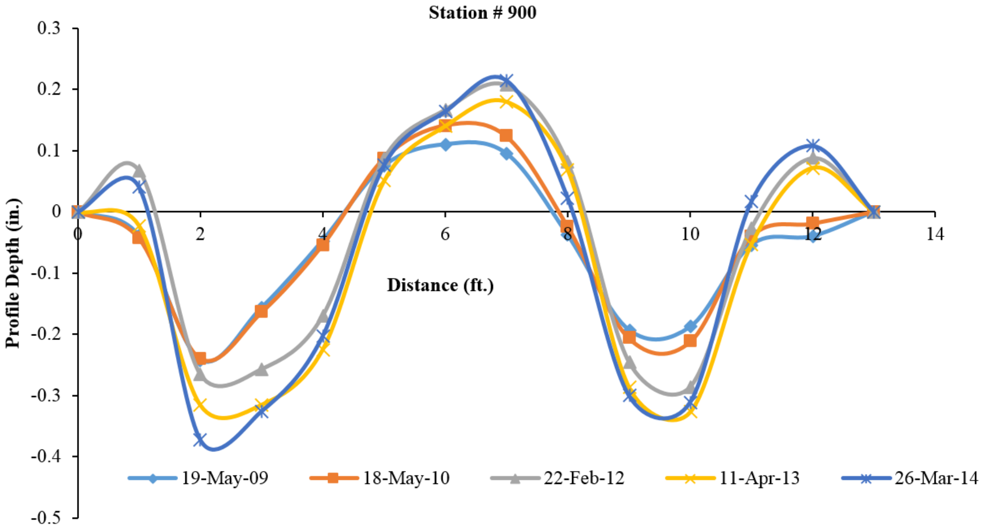
ALS is the most sensitive traffic input

Forensic Study

- Comparison of Rut Profiles (NCHRP vs Field)





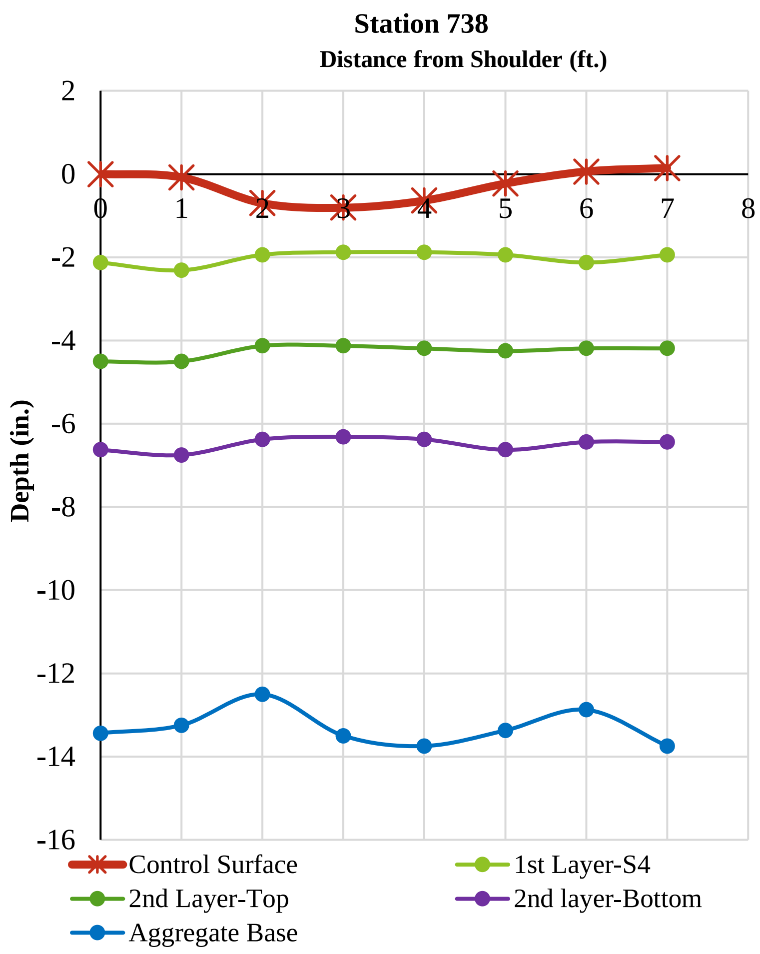


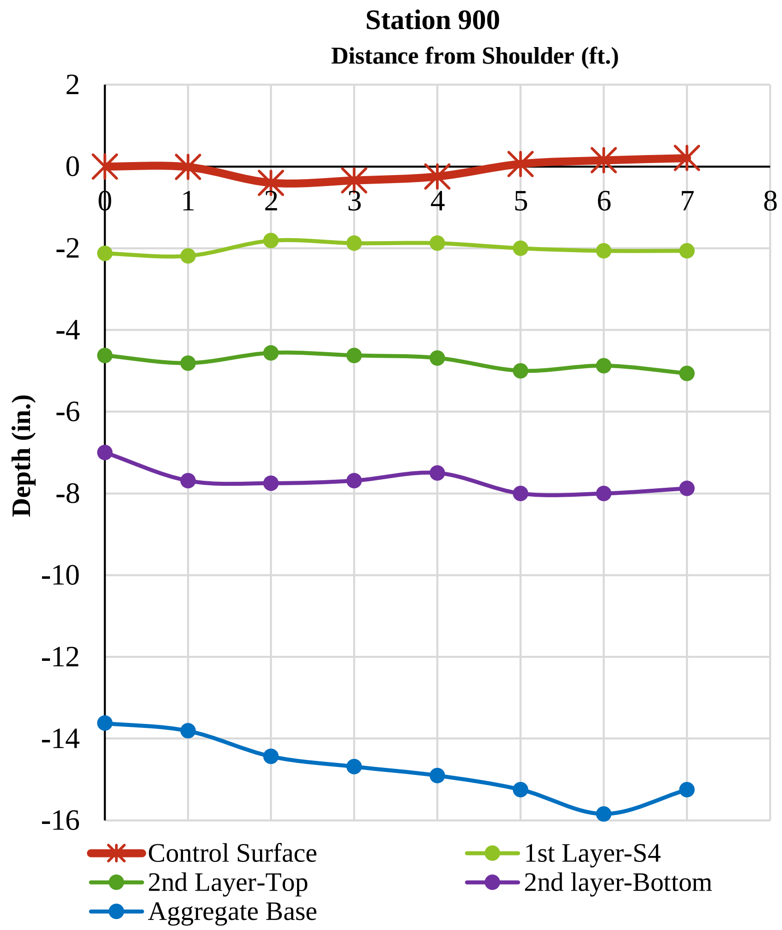
Forensic Study

- Trenching Study

Forensic Study

- Rut Distribution in Different Layers





Local Calibration of Local MEPDG Rut Models

- Rut Models in the MEPDG
  - Rut Depth for Asphalt Layers

$$\frac{\varepsilon_p}{\varepsilon_r} = K_z \beta_{r1} 10^{k_{r1}} T^{\beta_{r2} k_{r2}} N^{\beta_{r3} k_{r3}}$$

  - Rut Depth for Base and Subgrade Layers

$$\delta_a = \beta_{s1} k_1 \varepsilon_v h \left(\frac{\varepsilon_0}{\varepsilon_r}\right) \left| e^{-\left[\frac{\rho}{N}\right]^{\beta}} \right|$$

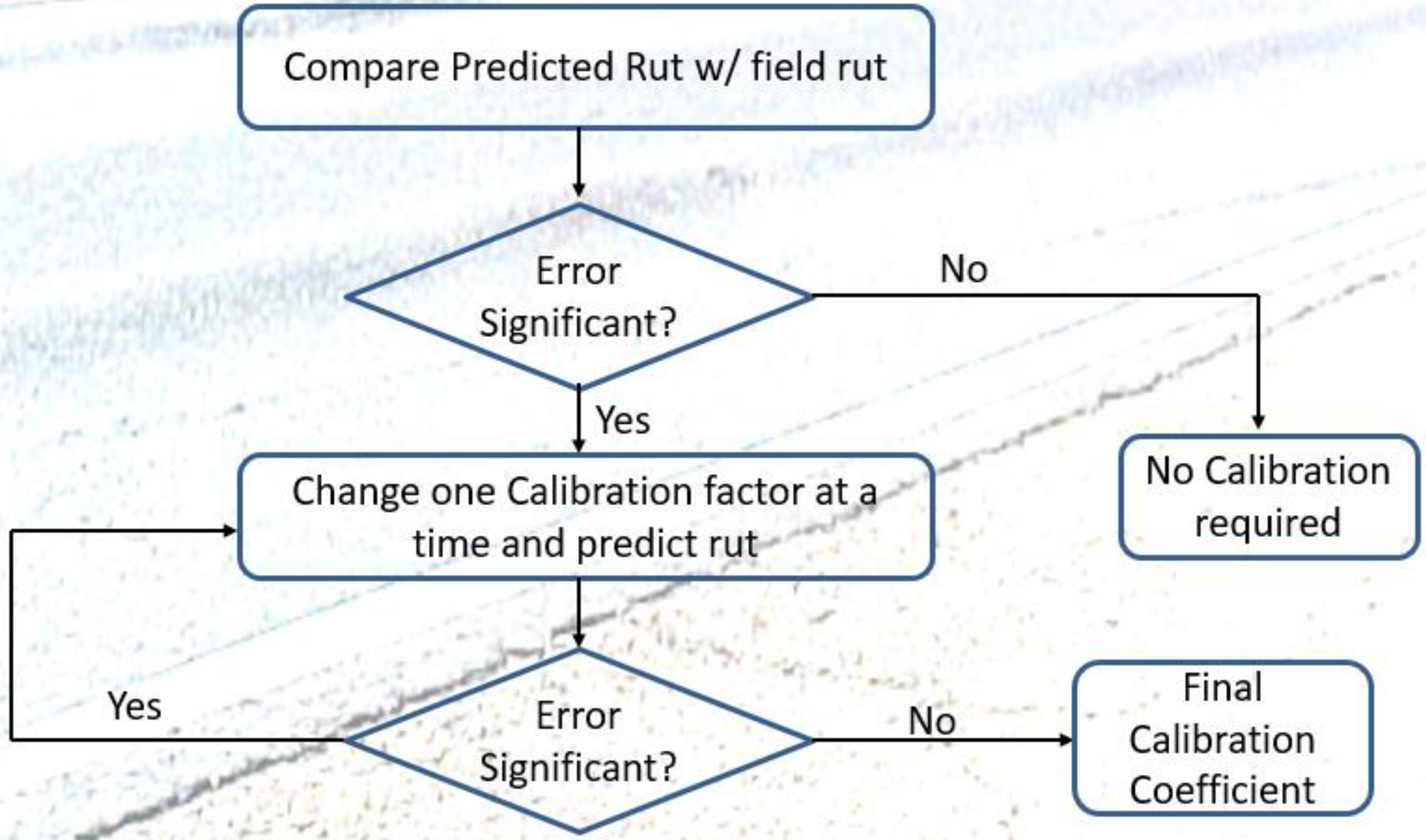
  - Total Rut Depth

$$RD = h_{AC} \varepsilon_r K_z \beta_{r1} 10^{k_{r1}} T^{\beta_{r2} k_{r2}} N^{\beta_{r3} k_{r3}} +$$

$$\beta_{GB} k_{GB} \varepsilon_v h_{GB} \left(\frac{\varepsilon_0}{\varepsilon_r}\right) \left| e^{-\left[\frac{\rho}{N}\right]^{\beta}} \right| + \beta_{SG} k_{SG} \varepsilon_v h_{SG} \left(\frac{\varepsilon_0}{\varepsilon_r}\right) \left| e^{-\left[\frac{\rho}{N}\right]^{\beta}} \right|$$

Local Calibration of Local MEPDG Rut Models

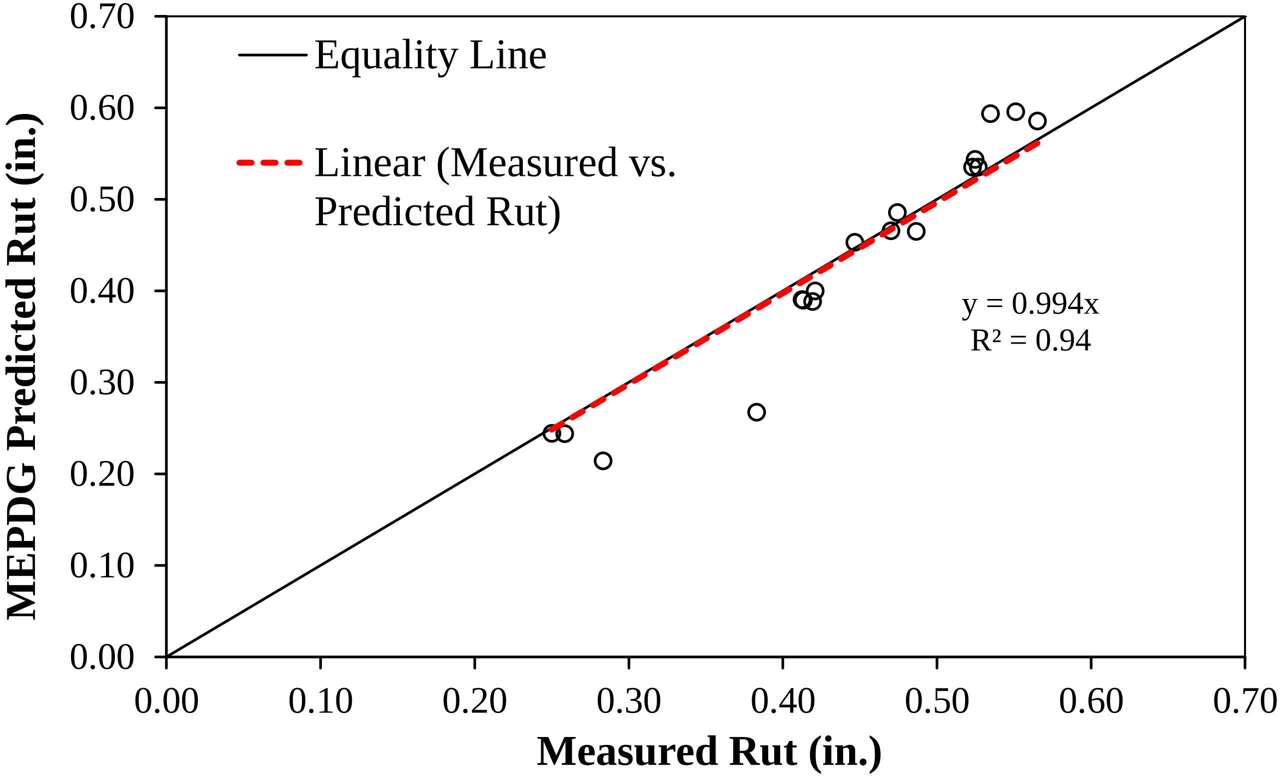
- Local Calibration Methodology



Local Calibration of Local MEPDG Rut Models

- Final Calibration Factors:

  β_{r1} = 1.25, β_{r2} = 1, β_{r3} = 1.05, β_{GB} = 0.05 and β_{SG} = 0.05.



p-value = 0.83 > 0.05

Conclusions

- MEPDG over-predicted rut (more than 30%) using Level 3 inputs. Error reduced to 10% by using the Level 1 inputs.
- Significant differences observed between the Level 1 and Level 3 traffic inputs. Level 3 MAF is 1.0, whereas, Level 1 MAFs for Class 9 varies from 0.57 to 1.18. Frequency of the peak values of Level 1 ALS is much higher than the default values for Class 9 vehicles (approximately 4 to 12%).
- Traffic more sensitive than materials.
- ALS is the most sensitive traffic input, followed by VCD and MAF.
- Rut was contributed mostly by the HMA layers, more specifically, the surface (S4) layer.

Conclusions

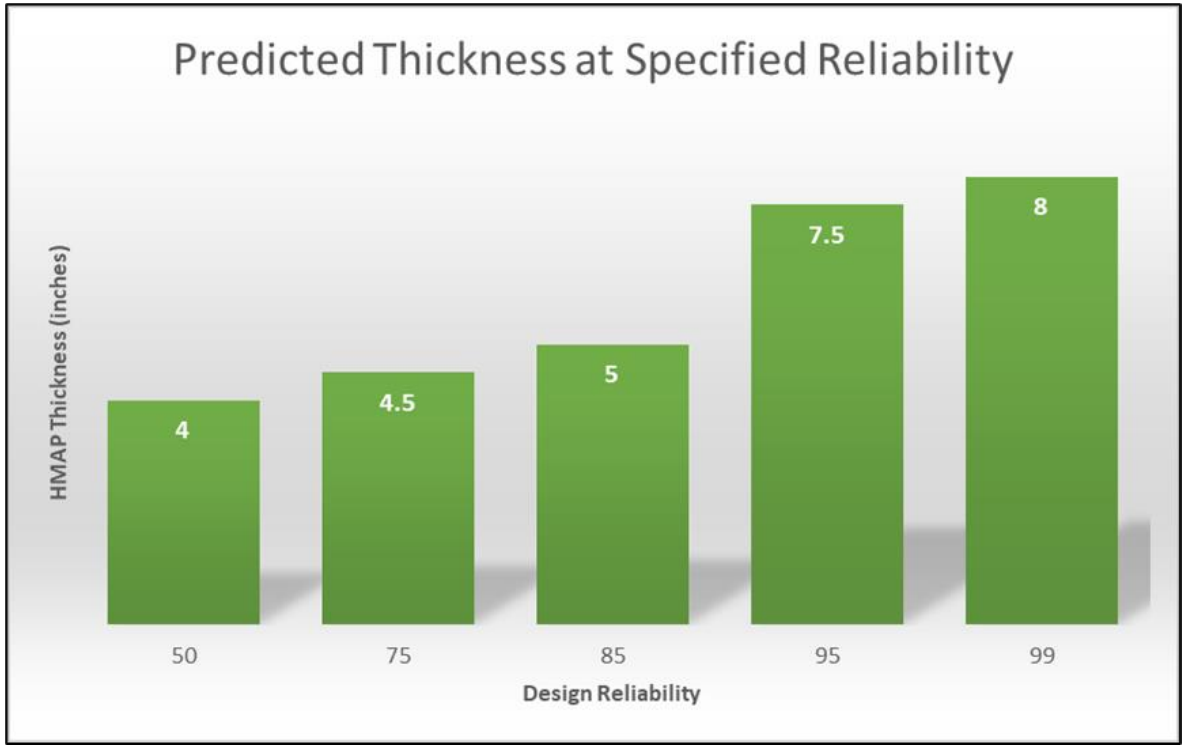
- The stabilized subgrade layer and the HMA layer with RAP (S3 layer) were effective in containing rut to within the top HMA layer.
- Final calibration factors for the rut models were β_{r1} = 1.25, β_{r2} = 1, β_{r3} = 1.05, β_{GB} = 0.05 and β_{SG} = 0.05.
- Minimal cracking (less than 1%) and significant rutting (0.868 in.) were observed on the test section.
- Rut accumulated mostly in summer months. Rate rate of rutting in the first summers months was much higher than the second summer months.

Recommendations

- Since, this was the first and only instrumented test section in Oklahoma to observe the field performances, the results could not be validated on other sites. ODOT should validate the calibration for other locations in near future.
- Local calibrations of fatigue models should be performed for Oklahoma conditions.
- ODOT should develop Level 1 traffic input parameters from the active WIM stations throughout the state, and Level 1 materials input parameters for commonly used materials in Oklahoma.

Distress Type	Achieved Reliability (%) (with National/Default Calibration Factors)	Target Reliability (%)	Achieved Reliability (%) (with CDOT Calibration Factors)
Terminal IRI (in/mile)	99.85	90	96.37
Permanent Deformation – total pavement (in)	91.75	90	97.43
AC bottom-up fatigue cracking (% lane area)	100.00	90	90.96
AC thermal cracking (ft/mile)	100.00	90	99.69
AC top-down fatigue cracking (ft/mile)	100.00	90	100.00
Permanent deformation – AC only (in)	100.00	90	99.02
Pavement Thickness Required to Achieve a Passing Design using the Calibration Factors	11 inches 6 inches base	-	7.5 inches 6 inches base

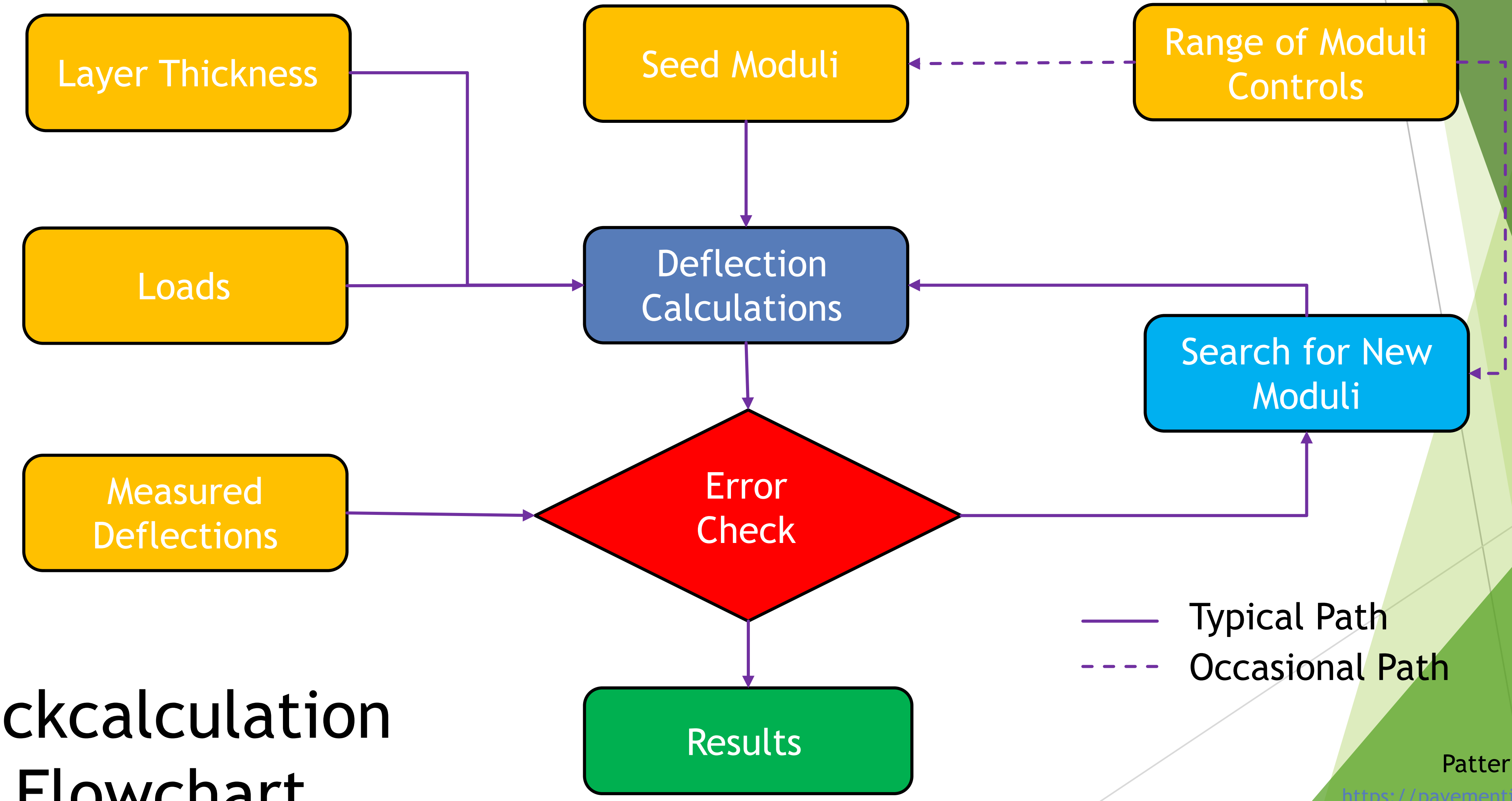
Design Reliability Effect on Pavement Thickness



Backcalculation

- “Backcalculation” is a standalone software program that can be used for mechanistic evaluation of pavement surface for rehabilitation design by analyzing raw deflection data from three FWD pavement deflection devices (e.g. Dynatest, JILS, and KUAB).
- The tool provides three major functions: pre-processing deflection data (project segmentation), backcalculation, and post-processing of results to generate inputs for rehabilitation design.
- Using the data from FWD devises, the software backcalculates the in-situ elastic layer moduli for flexible and rigid pavements and generating inputs for performing rehabilitation design.
- It can also be used to perform loss of support analysis and load transfer efficiency (LTE) calculations.
- The tool uses the EVERCALC® algorithm for the iterative process. The typical measure of convergence is typically Root Mean Square Error (RMSE). An adequate range for RMSE is 1% to 2%. Can be used to estimate the k-value of a soil.
- It takes a measured surface deflection and attempts to match it (with some error) with a calculated surface deflection generated from an identical pavement structure assuming a similar modulus/layer stiffness. The assumed layer modulus in the calculated model are adjusted until they produce a surface deflection that closely matches the measured one.

Backcalculation Flowchart



Patterned after Lytton, 1989

https://pavementinteractive.org/reference-desk/design/structural-design/backcalculation/

Oklahoma Statistics

- It costs approximately $100,000 to construct 1 in. thick asphalt layer per lane mile of typical interstate pavements in Oklahoma (ODOT Price History from July 1, 2015 to December 31, 2015).
- Typical thicknesses of asphalt layers in interstate pavements in Oklahoma range from 9 to 12 inches (Hossain et al., 2014).
- According to a majority of DOTs in the U.S., without accurate input data and calibration coefficients, pavements are typically overdesigned by approximately 25% (Hall et al., 2011).
- Therefore, for asphalt layers alone, approximately $225,000 to $300,000 could be saved per lane mile of interstate pavements.

Looking Ahead…

- M-E Design is a dynamic process…
  - There is ongoing research and development
- The world is changing…
  - Population growth
  - Climate
  - Pavement materials

Questions?

References

- CDOT, *M-E Pavement Design Manual*, 2021, Colorado Department of Transportation, Denver, CO, 2021.
- Backcalculation. *Pavement Interactive*. https://pavementinteractive.org/reference-desk/design/structural-design/backcalculation/ Date Accessed: July 20, 2021.

THANK YOU!