Effects of Volumetric and Mechanistic Test Variability on Predicted Performance of Asphalt Pavements Using the MEPDG

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INTRODUCTION

- Transition from empirical design to mechanistic-empirical design procedures
  - Requires material inputs
    - Evaluate the effect of the variability of inputs on predicted performance
    - Establish confidence in performance predictions
- Deviation from either material or construction specifications often lead to premature pavement distresses or even failure

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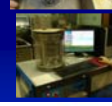
INTRODUCTION

- MEPDG features the prediction of pavement performance
  - Rutting
  - Cracking
  - Smoothness
- The design guide software
  - Four Modules
    - Project Summary,
    - Traffic,
    - Environmental/Climate, and
    - Pavement Structure
      - Material Characterization



http://www.fhwa.dot.gov/pavement/concrete/images/medpg.gif

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INTRODUCTION

- MEPDG: Material input module
  - Based on hierarchal structure
    - Level 1 - measured mechanistic properties
    - Level 2 - predicted mechanistic values
    - Level 3 - national default values
  - Volumetric/Mechanistic
    - Laboratory testing
      - Variability

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INTRODUCTION

- Adequate QA practices
  - Ensure HMA properties conform to specifications
  - Avoid premature failure of HMA
- How does the variability effect predicted pavement performance?
- The NCHRP Project 9-48, "Field versus Laboratory Volumetrics and Mechanical Properties,"
  - initiated to quantify sources and causes of variability in the measurements of volumetric and mechanical properties of dense-graded asphalt mixtures

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OBJECTIVE

- Evaluate the effects of variability of volumetric and mechanistic properties on predicted performance
  - asphalt pavements using the MEPDG.

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- Collected volumetric and mechanistic properties
  - Survey
  - 13 state DOTs and FHWA Trailer
  - To quantify variability

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- Volumetric Properties
  - Asphalt Content
  - Air Voids, VMA, VFA
  - Gmb, Gmm
  - Field Density
- Mechanistic Properties
  - Dynamic Modulus, Phase angle
  - Flow Number
  - Indirect Tensile Strength
- Three Pavement Structures
  - Low Traffic
  - Medium Traffic
  - High Traffic

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- Effect of volumetric variability on predicted mechanistic properties of asphalt mixtures using the
  - Fonseca-Witczak predictive model was quantified
  - Monte Carlo simulation.
- Effects of mechanistic variability on the design outcomes were evaluated using the MEPDG.

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Quantification of Variability in HMA Design Inputs

- Two main types of statistical analyses were conducted in order to quantify the magnitude of the variability of volumetric and mechanistic properties:
  - (1) statistical analysis of the individual data sets
    - From the 13 DOTs and FHWA
  - (2) a meta-analysis of the combined data sets
    - national average of variability
  - Interim Report
    - NCHRP Project 9-48

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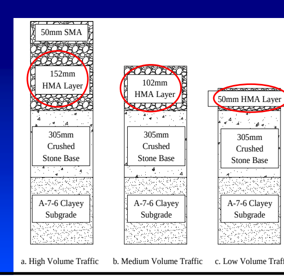
Pavement Performance Prediction

- The MEPDG software was used to predict the performance of three typical Louisiana pavement structures for three traffic levels
  - Low
  - Medium
  - High
- Varying HMA Layer



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MEPDG Design Inputs

- New flexible pavement
  - service life of 20 years
- Pavement failure limits
  - LADOTD criteria

Distress	Traffic Level (AADTT)		
	High (14,554)	Medium (1,992)	Low (816)
IRI (mm/km)	1973 (125in/mile)	3175 200(in/mile)	3969 (250in/mile)
Rut Depth (mm)	9.6 (3/8in)	14.2 (9/16in)	14.2 (9/16in)

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MEPDG Traffic Inputs

- LADOTD provided values for multiple traffic classifications
  - average annual daily traffic (AADT),
  - truck factors, and
  - vehicle class distribution
- Default values developed from LTPP data for hourly distribution and growth factor were used.

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Climate

- Climatic data were obtained from the MEPDG climate database for the city of Baton Rouge, Louisiana
- The water table depth (2.1m) was calculated via the relationship based on surface elevations in the Gulf Coast regions in the United States *(14)*

Water Table Altitude = Land-surface altitude * 0.8978

- The land-surface elevation was determined from the MEPDG climatic database

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HMA Dynamic Modulus

- Variation of predictive E* based on variability of material input
  - Variability based on 13 state DOTs data
  - Monte Carlo simulation

$$\log E^* = 3.750063 + 0.02932\rho_{200} - 0.001767(\rho_{200})^2 - 0.002841\rho_4 - 0.058097V_a - 0.802208\left(\frac{V_{beff}}{V_{beff}+V_a}\right) + \frac{3.871977 - 0.0021\rho_4 + 0.003958\rho_{38} - 0.000017(\rho_{38})^2 + 0.005470\rho_{34}}{1+e^{(-0.603313-0.313351\log(f)-0.393532\log(\eta))}}$$

- Input:
  - Binder Viscosity
  - Binder Content
  - Air Voids
  - Gradation
- Laboratory measured
  - AASHTO TP 79
  - FHWA
  - University of Arkansas
  - MnRoad

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Base and Subgrade Properties

- Resilient Modulus values for crushed limestone base and clayey subgrade were collected determined from literature *(15)*
- These values were kept constant for each pavement structure.

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DISCUSSION OF RESULTS

Individual States Analyses

- Collect Data
  - 13 States and FHWA Trailer provided data sets.
- Each data set: Determine variability
  - volumetric and mechanistic properties
    - Standard deviation and coefficient of variation
- "National Average Variability"
  - computed
- Example - Oklahoma DOT
  - OK site manager
  - Volumetric and Gradation data: 2,163 Mixtures
    - Air Void,
    - Voids in the Mineral Aggregate,
    - Mixture Bulk Specific Gravity (Gmb),
    - Asphalt Content, and
    - Aggregate Gradation

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Oklahoma DOT Analysis

- Levels of Variability in Oklahoma DOT Volumetric Properties

Property	Variability (St. Dev.)	CV (%)	Number of Mixtures
Air Voids (SSD), %	0.38	10.3	2001
Asphalt Content, %	0.20	4.4	935
VMA, %	0.38	2.9	1796
G_{mb}	0.008	0.3	2004
Passing 19.0 mm (3/4")	1.75	1.6	322
Passing 12.5 mm (1/2")	2.04	2.3	831
Passing 9.5 mm (3/8")	2.43	3	1001
Passing 4.75 mm (No. 4)	2.72	4.6	1002
Passing 2.36 mm (No. 8)	2.17	5.3	1002
Passing 1.18 mm (No. 16)	1.7	5.7	1002
Passing 0.6 mm (No. 30)	1.43	6.2	1002
Passing 0.3 mm (No. 50)	1.18	7.4	1002
Passing 0.15 mm (No. 100)	0.83	9.2	1002
Passing 0.075 mm (No. 200)	0.49	9.6	1002

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Average Variability of Volumetric Properties

- Average of Volumetric Variability Determined from 13 states data sets

Property	Sample Type	Range of St. Dev.	Average St. Dev.
Asphalt Content, %	PL	0.17 – 0.24	0.21
Air Voids, %	PL	0.36 – 0.99	0.62
VMA, %	PL	0.37 – 0.65	0.54
VFA, %	PL	3.40 – 5.16	4.28
G_{mb}	PL	0.008 – 0.018	0.013
G_{mb}	PF	0.016 – 0.025	0.021
G_{mm}	PL	0.005 – 0.012	0.009
Field Density, %	PF	0.74 – 1.49	1.12

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Average Variability of Volumetric Properties

- Average of Aggregate Gradation Variability Determined from 13 states data sets

Sieve Size	Sample Type	Range of St. Dev.	Average St. Dev.
25.0 mm (1")	PL	0.68 – 2.66	1.67
19.0 mm (3/4")	PL	0.82 – 2.59	1.71
12.5 mm (1/2")	PL	0.89 – 3.54	2.22
9.5 mm (3/8")	PL	1.61 – 3.75	2.68
4.75 mm (No. 4)	PL	1.87 – 3.48	2.68
2.36 mm (No. 8)	PL	1.75 – 2.73	2.24
1.18 mm (No. 16)	PL	1.56 – 2.05	1.81
0.600 mm (No. 30)	PL	1.37 – 1.89	1.63
0.300 mm (No. 50)	PL	1.07 – 1.28	1.18
0.150 mm (No. 100)	PL	0.64 – 0.99	0.82
0.075 mm (No. 200)	PL	0.34 – 0.84	0.59

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Average Variability of Mechanistic Properties

- Average of Mechanistic Variability Determined from 13 states data sets and FHWA Trailer

Properties	CV (%) Range		Average CV (%)	Number of Mixtures
	Min	Max		
Dynamic Modulus	10.0	23.8	13.9	58
Phase angle	3.9	15.4	7.1	58
Flow Number	37.3	52.1	45.2	89
Indirect Tensile Strength	11.9	15.4	13.7	9

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Variability of Dynamic Modulus

- %CV = 13.9%
  - Measured from laboratory tests
    - FHWA
    - Univ of Arkansas
    - MnRoad
- %CV = 8.1%,
  - Based on Monte Carlo simulation of 10,000 repetitions
    - 13 DOTs

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Effect of Variability on Predicted Pavement Performance

- MEPDG Software was used
- Three levels of Dynamic Modulus
  - Mean, Mean ± 10%, Mean ± 20%
- Measured effects of predicted pavement distresses
  - Rutting
  - Fatigue Cracking
  - Smoothness

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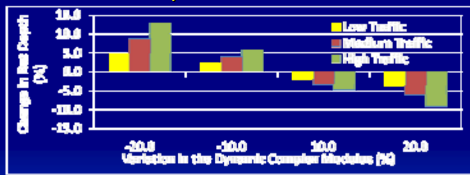

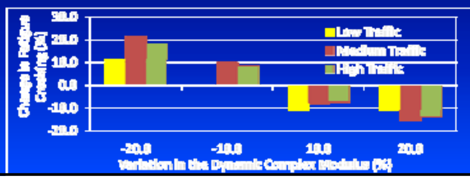

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Effects of Variability on Pavement Structural Design

- Reduced E* → Decreases design life

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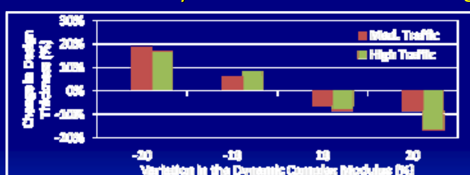
Effects of Variability on Pavement Structural Design



- Reduced E* → requires increased design thickness (HMA only)

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SUMMARY and CONCLUSIONS

- Variation of E* was determined
  - Predictive equation
  - Laboratory test results
- Average CV in E* was 8.1%
  - calculated from the Fonseca-Witczak model
- Average CV in E* was 13.9%
  - Laboratory test data
- Variability in volumetric properties will not affect the accuracy of the design when
  - Level 2
  - Fonseca-Witczak Model

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- Predicted pavement distresses from MEPDG indicated
  - Variability level in the E* ≤ 10% → predicted level of performance of ≤ 10%
  - Variability level in the E* up to 20% → design life of the pavement structures by up to 42%
  - Variability level in the E* up to 20% → design HMA thickness up to 19%.
- Predicted top-down cracking damage over the pavement service life was minimal
  - predicted top-down cracking was not greatly influenced by the variability E*

THANK YOU