Large-Scale Laboratory Testing of Geosynthetics in Roadway Applications Project Annual Update

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&

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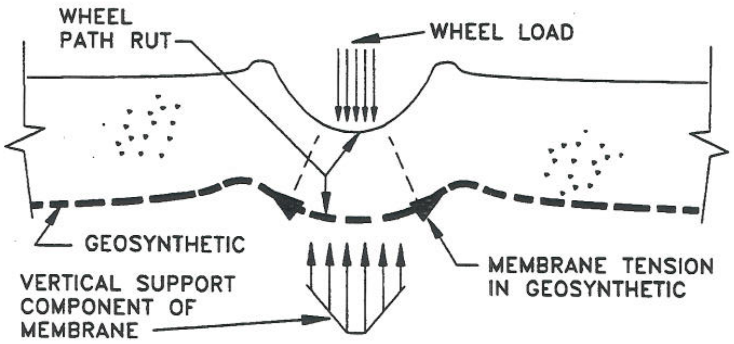
MDT Presentation: April 12, 2021

Background of Project

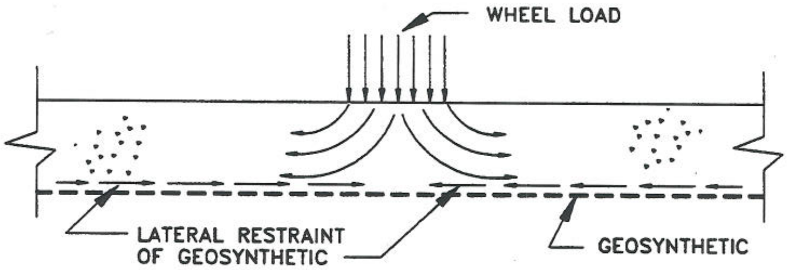
- MDT routinely uses woven and non-woven geotextiles in paved roads for stabilization and separation

Stabilization (Construction Expedient)

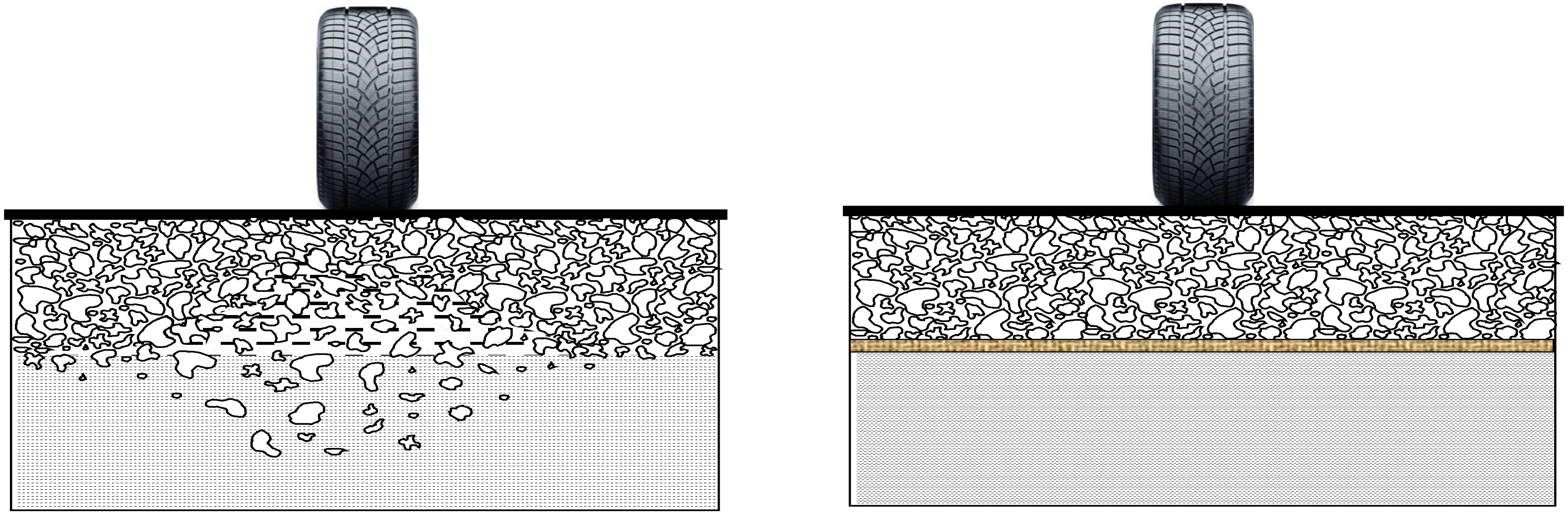
1) Softer subgrade



2) Firmer Subgrade



Separation



Objective of Project

- Once the road is constructed, do these same geotextiles offer structural benefit to the operational paved road?
- Do they allow a greater amount of traffic to be applied with all other variables being equal?

Project Approach

- Construct indoor test sections matching typical MT rural highway conditions and traffic

TRI Accelerated Pavement Tester

History

- Research idea, late 2015
- Draft proposal early 2016
- Proposal put on-hold due to insufficient funding
- New proposal late 2017
- Project start date: February 2018
- First loading June 2019
- Reconstruction and second loading October 2019, completed January 2020.

Tasks

- Task 1: Literature review (completed 7/31/2018)
- Task 2: Test section planning and design (completed 1/30/2019)
- Task 3: Test section construction and trafficking (completed 1/15/2020)
- Task 4: Analysis and synthesis of results
- Task 5: Reporting

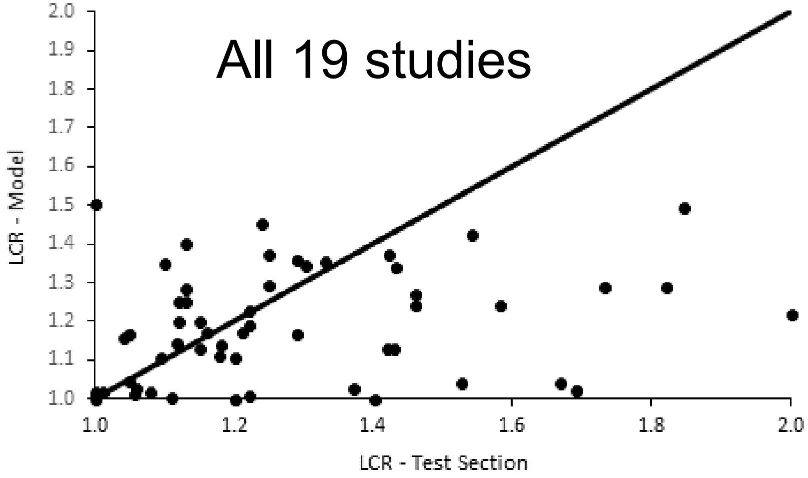
Task 1: Literature Review

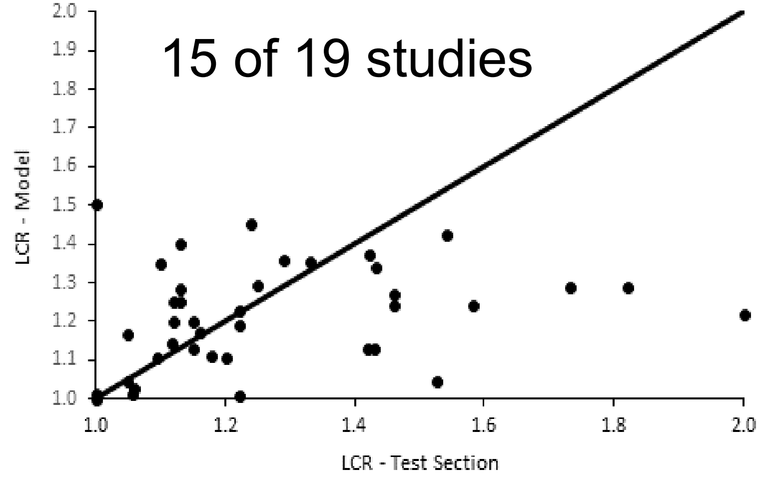
- Organization
  - Updated review of test section projects
  - Summary of variables impacting observed benefit
  - Review of design methods
  - Assessment of suitability of spreadsheet model

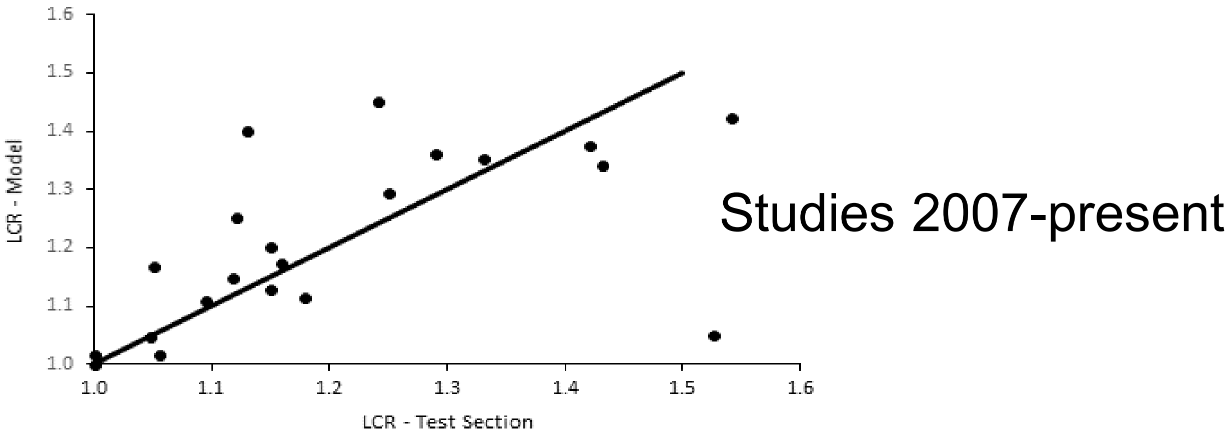
Task 1: Literature Review

- Findings
  - Previously established trends of decreasing benefit with increasing subgrade strength and increasing pavement structural number still hold
  - CBR > 8, no benefit
  - SN > 4, no benefit
  - Placement position: important but still inconclusive

Task 1: Spreadsheet Model







Task 2: Test Section Planning and Design – Test Facility

Dual wheels, 9000 lb, 90 psi

Task 2: Materials

- HMA
  - Extensive testing work to match MDT materials

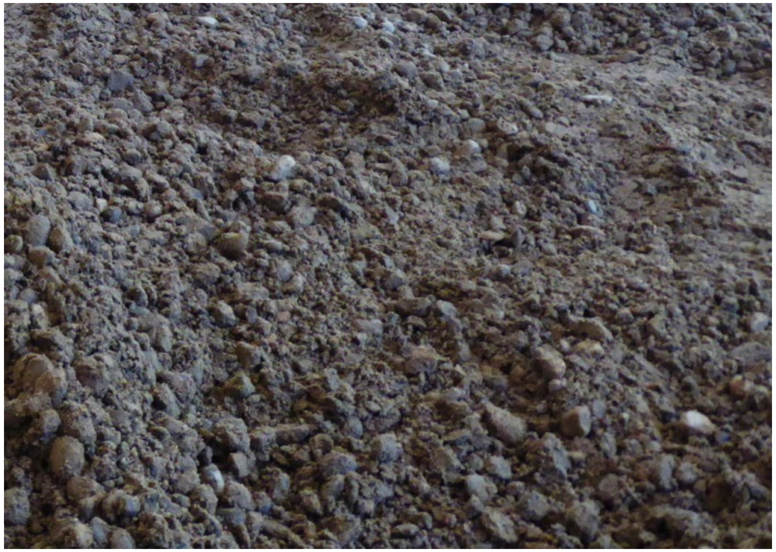
Property	Surface C
PG Grade	64-22
Asphalt content (%)	5.55
Rice specific gravity (G_{mm})	2.45
Bulk specific gravity (G_{mb})	2.34
Air void content (%)	4.35
VMA	16.9

Task 2: Materials

- Base Aggregate
  - Brewer Pit, Forsyth, MT: SP, A-1-a

Property	
Specific gravity of fine mat'ls	2.653
Specific gravity of course mat'ls	2.631
Fractured face content (1+)	65%
% passing #200 sieve	4.6%
Maximum dry unit weight‡	136.9 pcf
Optimum moisture content‡	7.7%
CBR @ 95% Modified Proctor dry unit weight	100%
R-value at 2.07 MPa (300 psi) exudation pressure	72.5
L.A. Abrasion loss	18%
Micro-Deval loss	5.5%

‡ determined using Modified Proctor method (ASTM D1557)



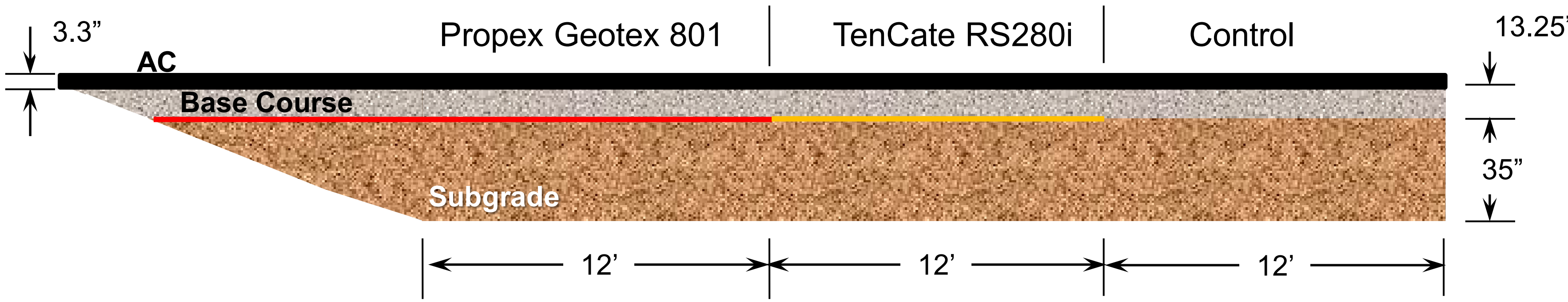
Task 2: Materials

- Subgrade
  - Manufactured clay, CL, A-6

Property	
Liquid Limit	40%
Plastic Limit	25%
Plasticity Index	15%
% passing #200 sieve	75.5%
Maximum dry unit weight†	102 lb/ft^3
Optimum moisture content†	18.6%
Maximum dry unit weight‡	112 lb/ft^3
Optimum moisture content‡	17.0%
R-value at 2.07 MPa (300 psi) exudation pressure	23.5

† determined using Standard Proctor method (ASTM D698)
‡ determined using Modified Proctor method (ASTM D1557)

Task 3: Test Section Construction and Trafficking



Test Sections:
- Control (no geosynthetic)
- TenCate RS280i – woven textile
- Propex Geotex 801 – non-woven textile

Predicted response:

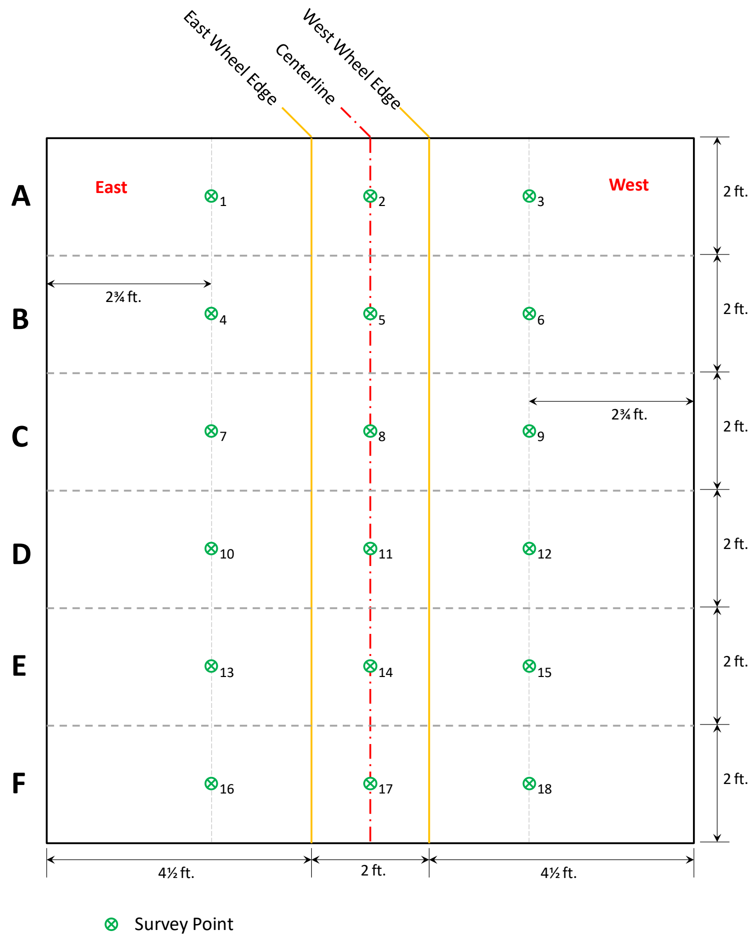
320k cycles to failure
900k cycles to failure
450k cycles to failure

Construction QC Testing Plan

- Elevation and thickness – surveys
- In-situ shear strength (subgrade) – vane shear
- In-situ moisture content – oven
- Dynamic stiffness – LWD
- Strength – CBR and/or DCP
- Density – sand cone and/or nuclear density

Construction Surveys

18 points per layer per test section

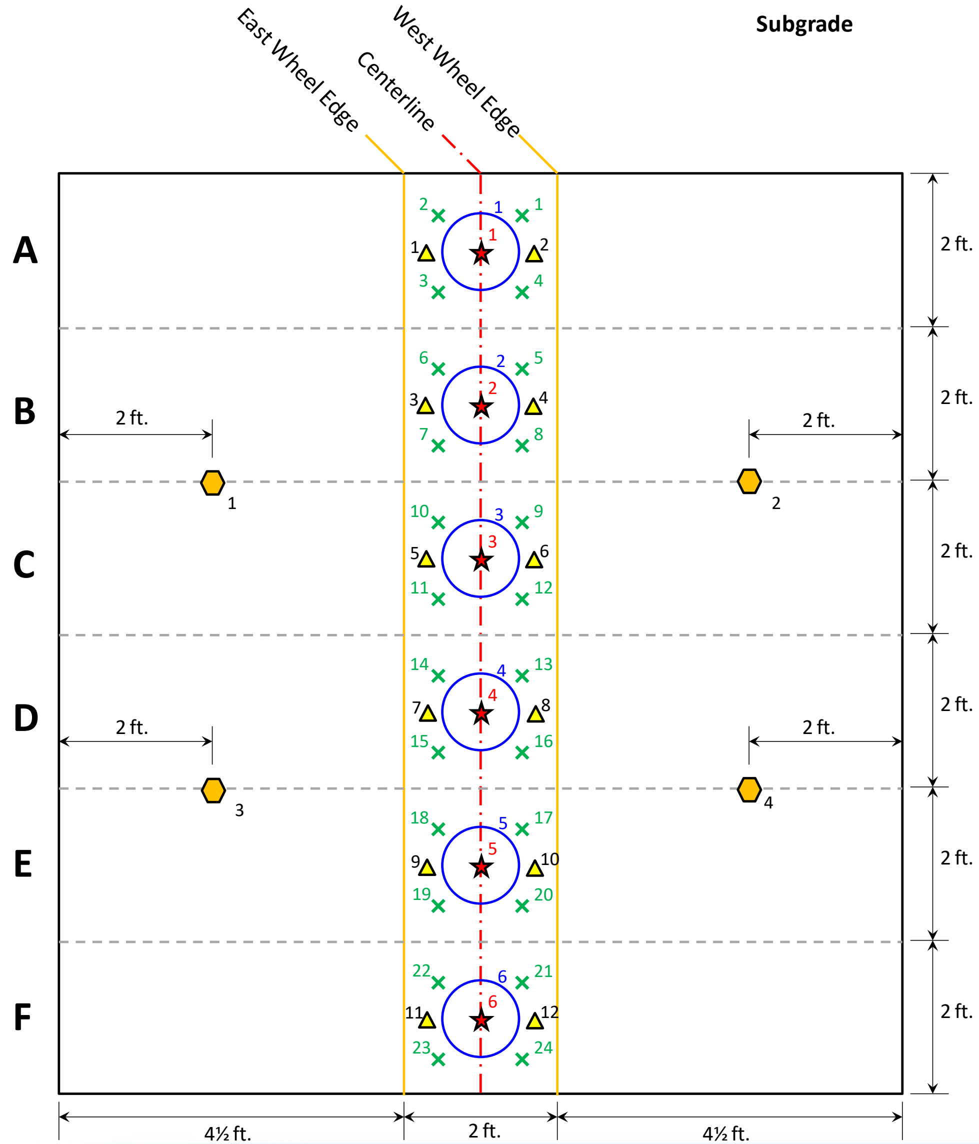


Measurements in Each Test Section

Subgrade

Measurement Type	Layer	Measurements per Layer
In-situ shear strength (vane)	All	24
Moisture content	All	12
Bearing strength (CBR)	All	2
Dynamic stiffness (LWD)	4, 5, 6	6
Strength (DCP)	Final	6
Unit weight (sand cone)	Final	4

Subgrade Measurements



Measurement Type

- Vane Shear – all layers
- Moisture Content – all layers
- Lightweight Deflectometer – final 3 layers
- Dynamic Cone Penetrometer – final layer only
- Sand Cone Density – final layer only

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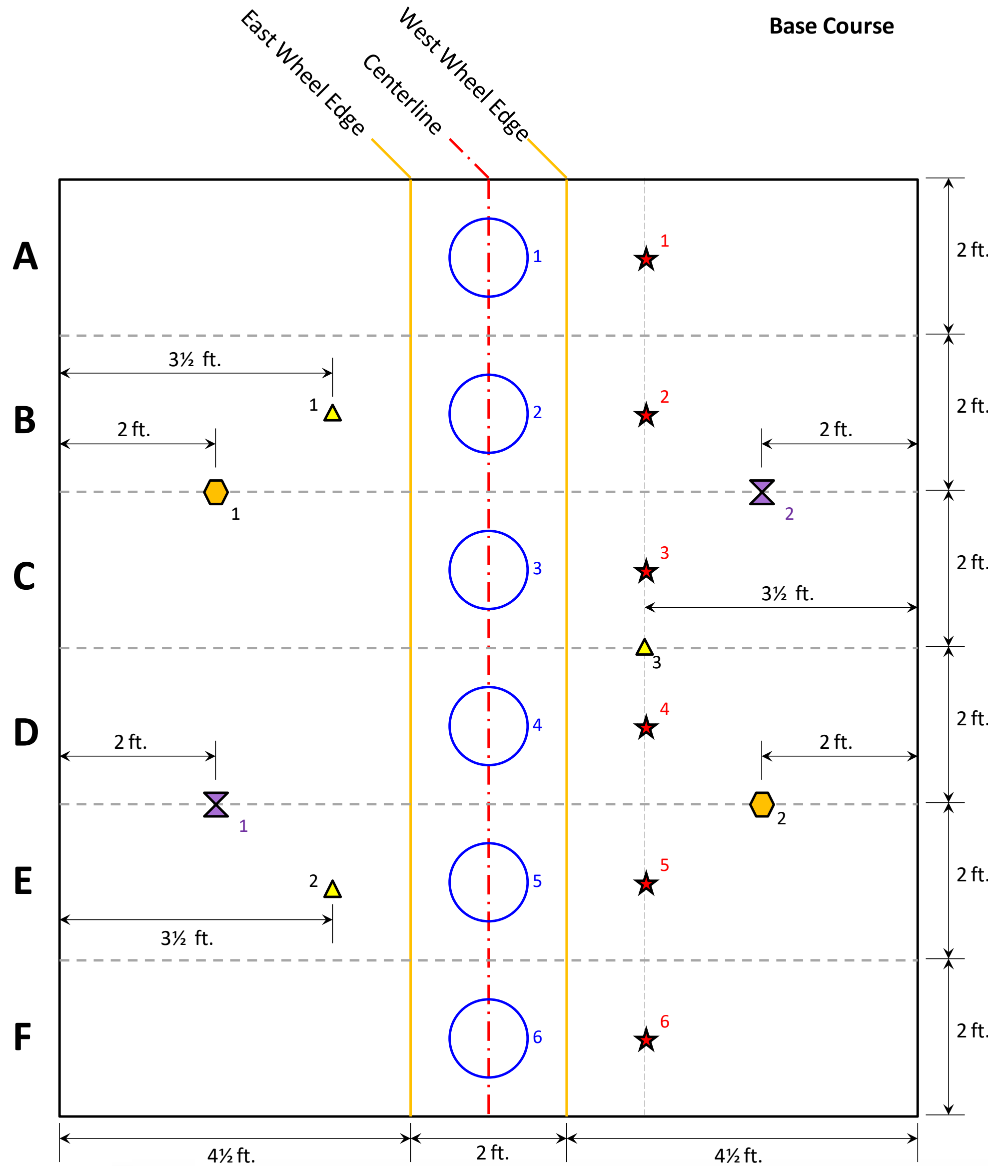
Measurements in Each Test Section

Base Course

Measurement Type	Layer	Measurements per Layer
Moisture content	All	3
Dynamic stiffness (LWD)	All	6
Strength (DCP)	Final	6
Unit weight (sand cone)	Final	2
Unit weight (nuclear densometer)	Final	2-4

Base Course Measurements



Measurement Type

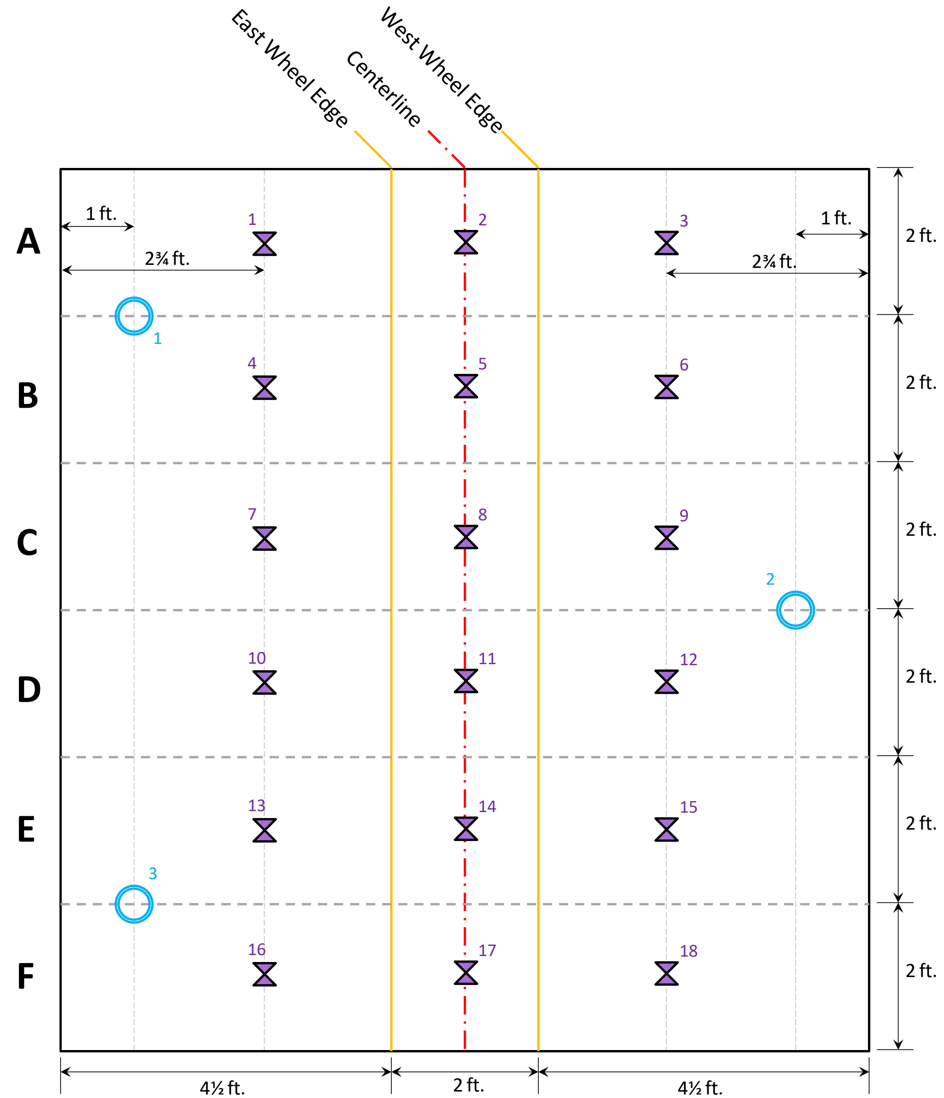
- Moisture Content – all layers
- Lightweight Deflectometer – all layers
- Dynamic Cone Penetrometer – final layer only
- Nuclear Densometer – final layer only
- Sand Cone Density – final layer only

Asphalt Measurements

Measurement Type

Nuclear Densometer

6 in. Asphalt Core



Subgrade Construction

- Mix subgrade to target moisture content
- Compact small area using jumping jack
- Test vane shear strength, and adjust if necessary
- Install in pit
- Track in place with skid-steer
- Compact with drum compactor
- Conduct in-situ material testing
- Cover to minimize changes over time

Mixing Subgrade

Subgrade Prior to Compaction

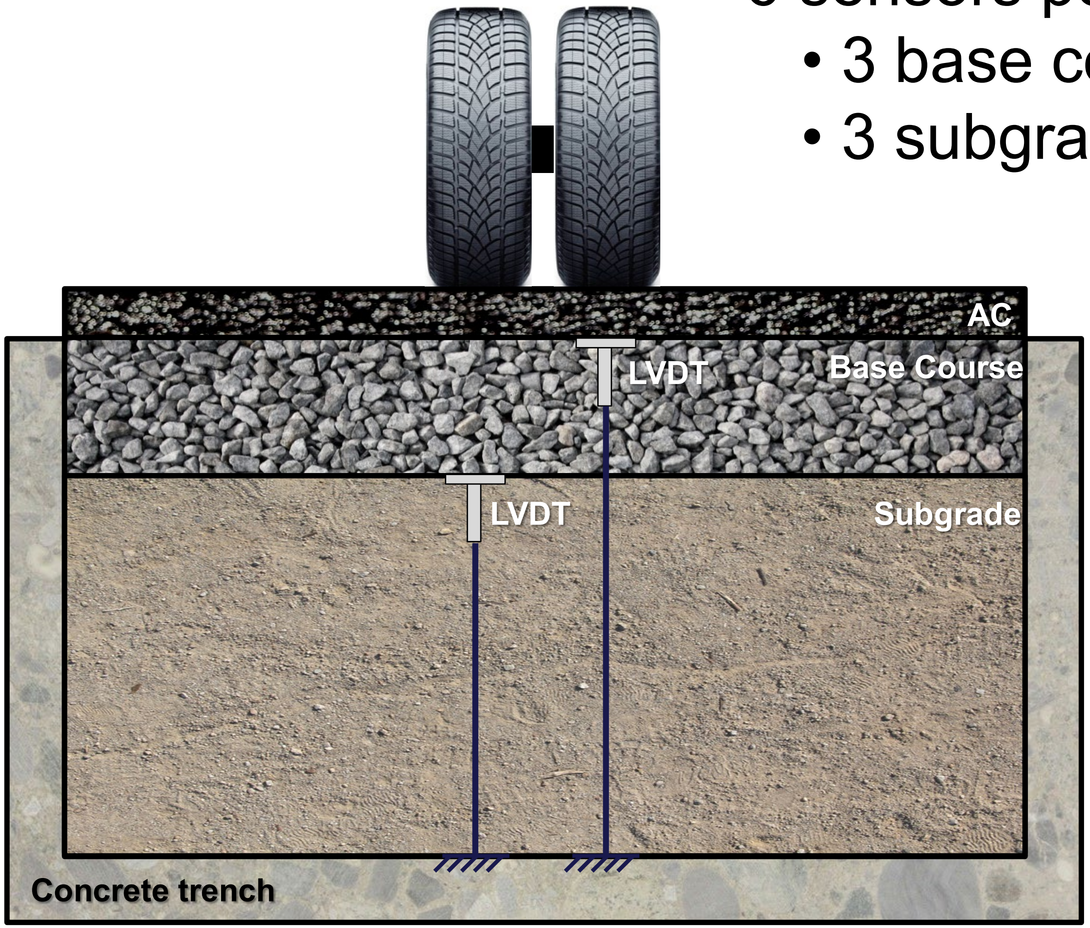
Compacting Subgrade

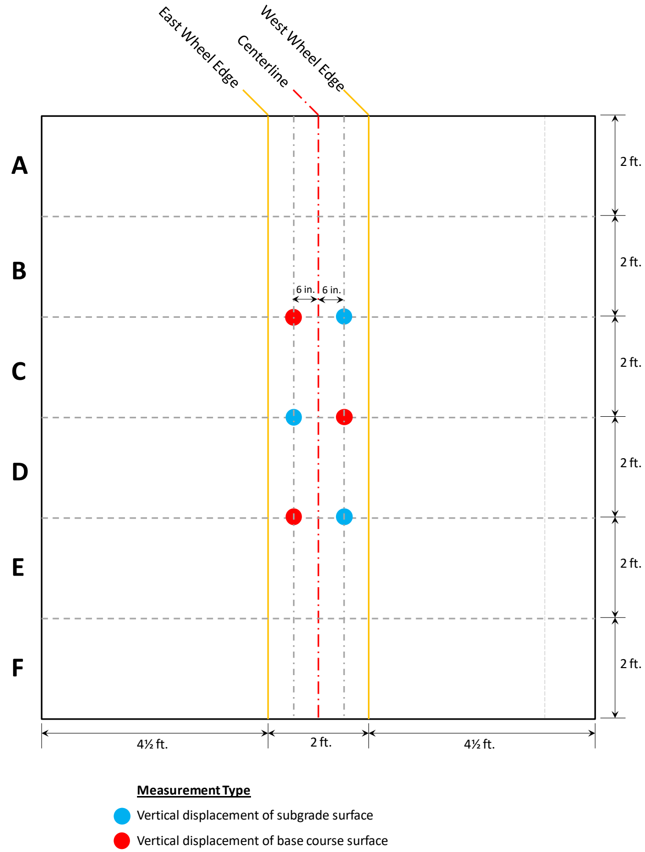
Leveling Final Subgrade Surface

Final Subgrade Surface

Instrumentation Layout

- 6 sensors per test section
  - 3 base course
  - 3 subgrade





Installing LVDT Anchor

Installing LVDT

Installing Geosynthetics

Installing Geosynthetics

Base Course Construction

<u>Procedure</u>:
- Mix to OMC
- Two layers ~ 6 in. thick
- Screed level
- Compact

Installing Base

Screeded Base

Compaction

Final Surface

Density taken on surface met specification of 1st construction

Asphalt Paving

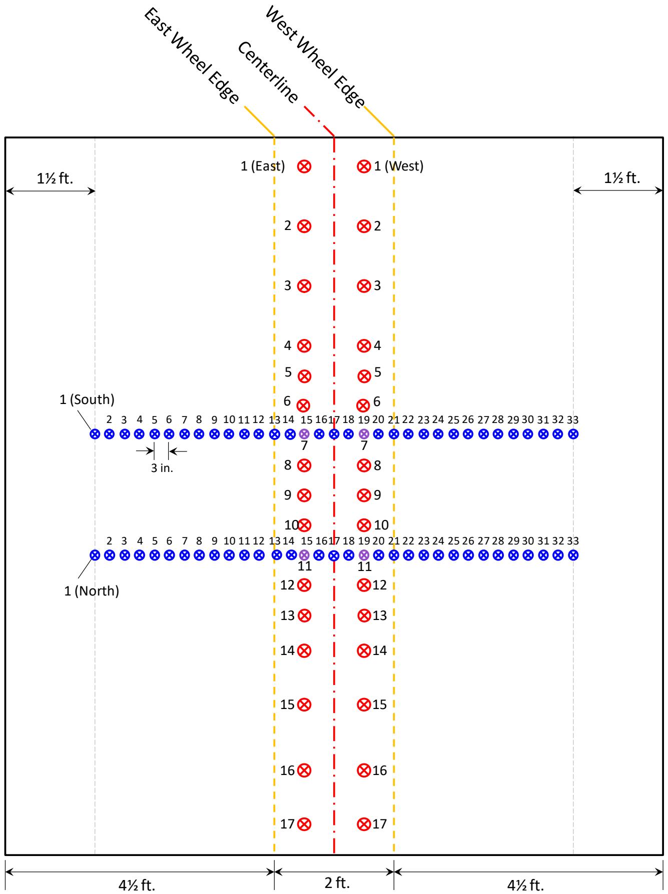
- Single lift
- Target thickness = 3.0 in.
- +/- 0.15 in. tolerance
- Target density = 92%
- Nuclear density testing
  18 meas./test section

Final Surface

Accelerated Trafficking

- ~10 passes per min.
- 9,000 lb.
- Dual wheel assembly
- 90 psi tire pressure
- Localized climate control

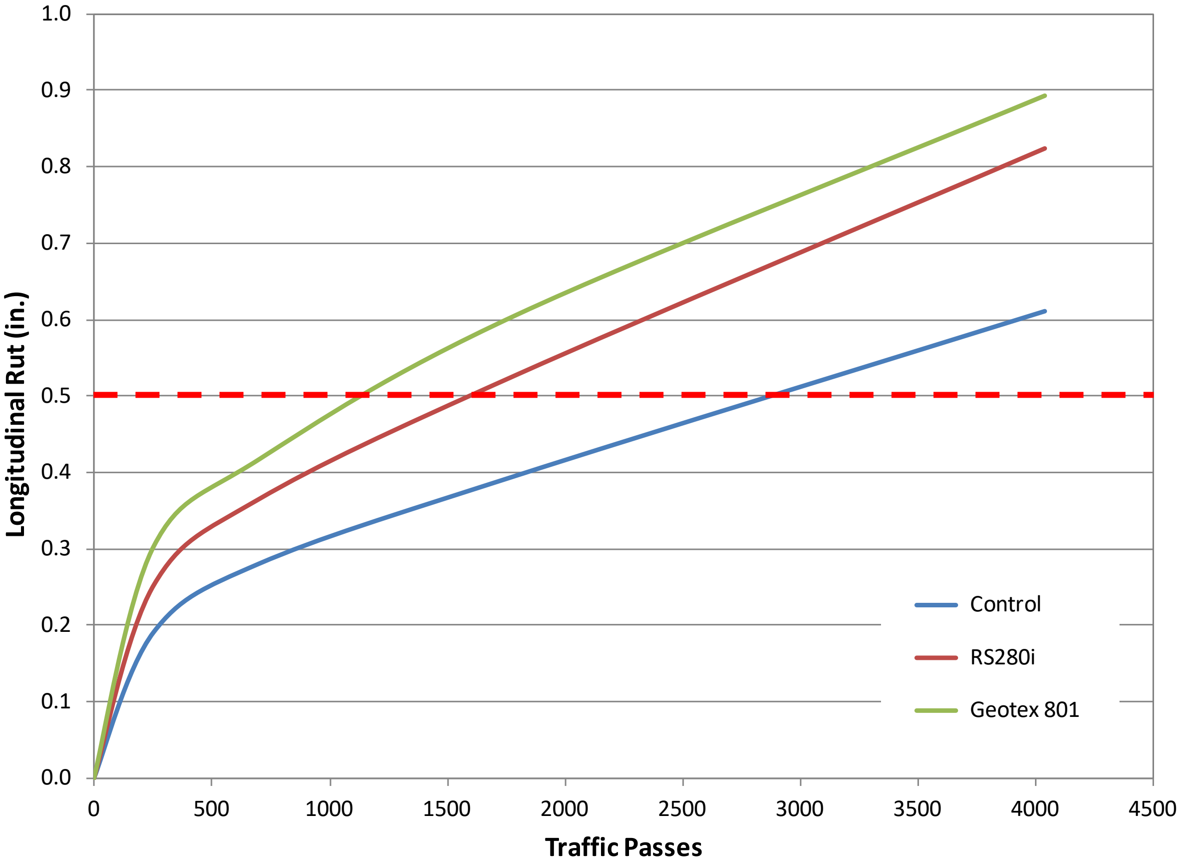
Surface Rut Measurements



Measurements in each test section:

- 34 measurements of longitudinal rut (17 per tire track)
- 2 transverse profiles

Longitudinal Rut Response



Primary observations:
- Rapid rut accumulation
- Control performed best

Why Large Strains in Base Course?

- Base compacted at optimum moisture content
- Was not part of QC plan to measure density of first layer
- First layer was too wet and did not get compacted properly
- Reluctance to distort subgrade surface with compaction equipment

Reconstruction

- Remove asphalt
- Remove base course
- Remove instrumentation
- Remove geosynthetics
- Re-level subgrade surface (removed ~1 in.)
- Rebuild base and asphalt layers

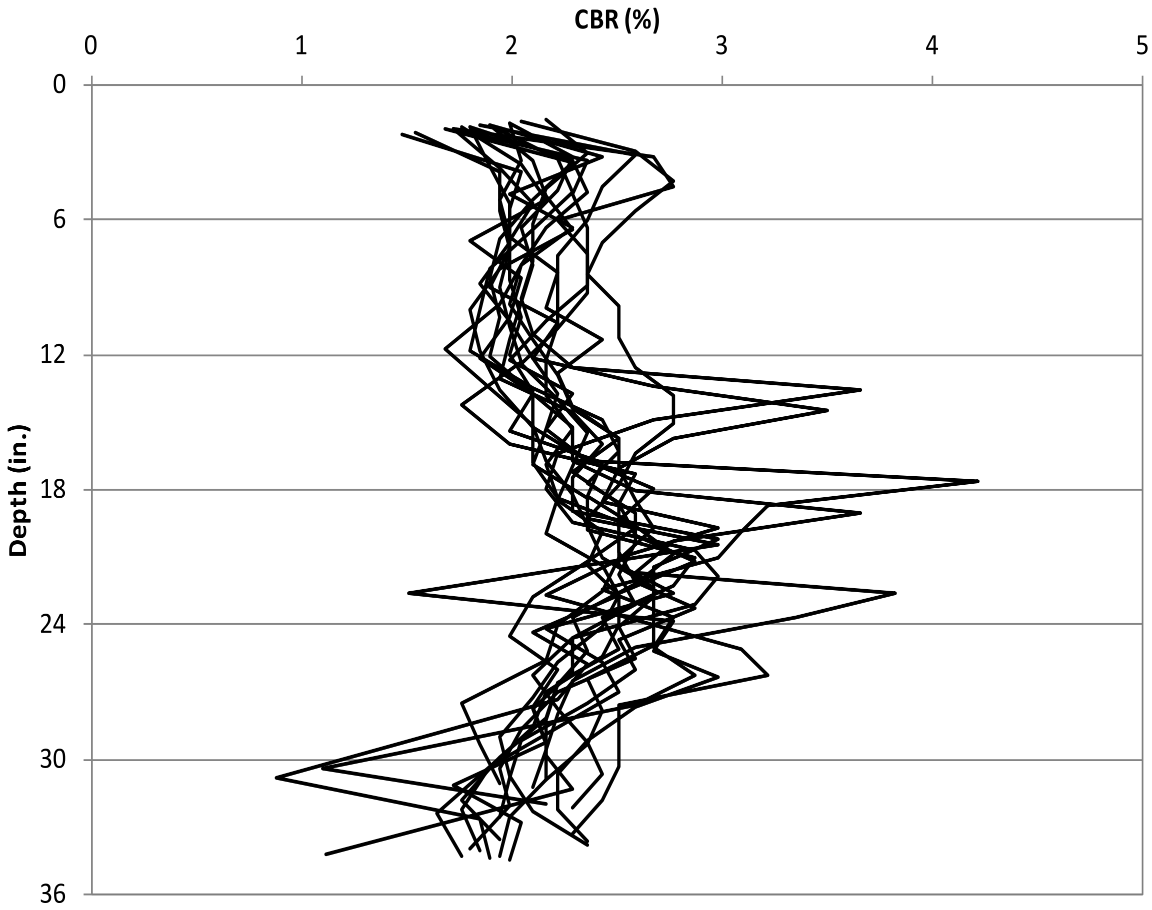
Subgrade Moisture Content

- 72 measurements per test section
- Average values
  - Test Section 1 = 27.7%
  - Test Section 2 = 27.7%
  - Test Section 3 = 27.7%
- Range of layer averages: 25.8 – 28.7 %

Subgrade Vane Shear

- 144 measurements per test section
- Average values
  - Test Section 1 = 107.4 kPa
  - Test Section 2 = 104.3 kPa
  - Test Section 3 = 105.1 kPa

Subgrade Dynamic Cone Penetrometer



- Avg. per test section
  - Sect. 1 = 2.27
  - Sect. 2 = 2.27
  - Sect. 3 = 2.24

Base Dry Unit Weight

Layer†	Average Unit Weight (lb/ft³) and Percent Compaction		
	Test Section 1	Test Section 2	Test Section 3
3 (nuclear)	137.5 (100.6%)	136.9 (100.1%)	137.7 (100.7%)
3 (sand cone)	137.7 (100.7%)	138.7 (101.5%)	137.5 (100.6%)
2	137.7 (100.7%)	137.9 (100.9%)	136.5 (99.9%)
1	136.0 (99.5%)	135.5 (99.1%)	137.4 (100.5%)

† Layer 1 is the bottom base layer, and Layer 3 is the top layer.

Base Dynamic Stiffness (LWD)

Layer†	Average Dynamic Stiffness (MN/m^2)		
	Test Section 1	Test Section 2	Test Section 3
3	123.63	115.54	122.42
2	24.25	19.63	23.77
1	19.40	15.98	17.85

† Layer 1 is the bottom base layer, and Layer 3 is the top layer.

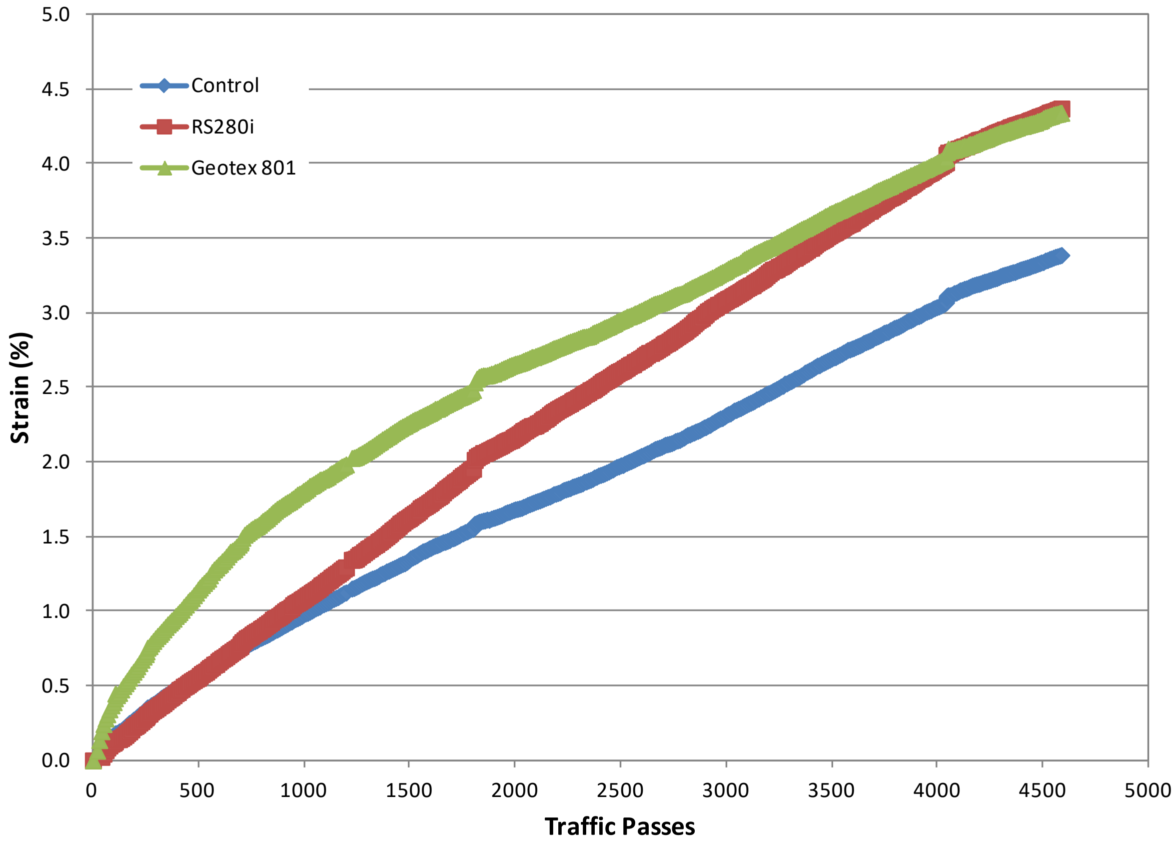
Base Construction Comparisons

Parameter	Phase I	Phase II
Thickness (in.)	13.4	13.3
Moisture content by layer* (%)	7.9 / 5.5	6.5 / 6.6 / 6.0
Dyn. Stiffness by layer* (MN/m^2)	5.8 / 23.1	17.7 / 22.6 / 120.5
CBR from DCP (%)	17.7	73.4
Density by layer* (pcf)	138.8 (final layer only)	136.3 / 137.4 / 138.0

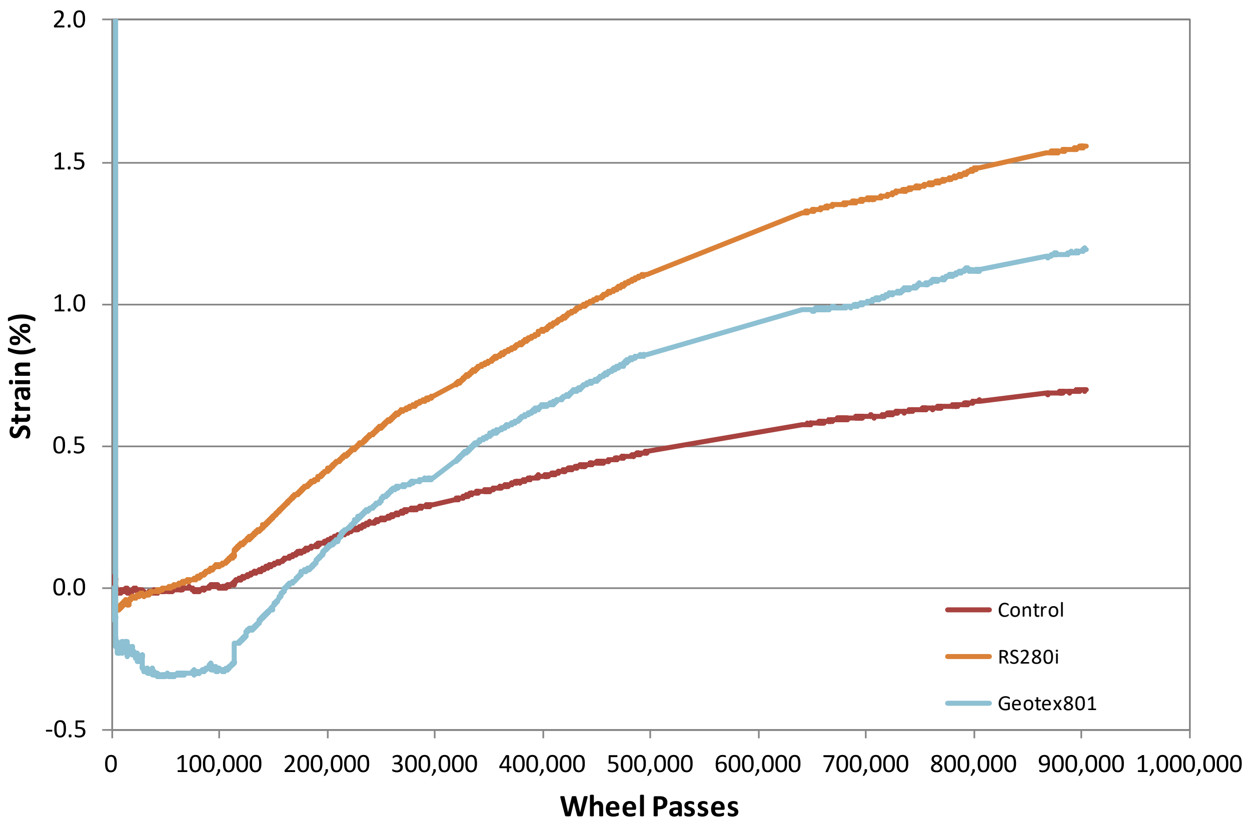
*Earlier numbers are associated with lower layers

Max. dry unit weight = 136.9 pcf
OMC = 7.7%

Avg Strain in Base 1st Construction

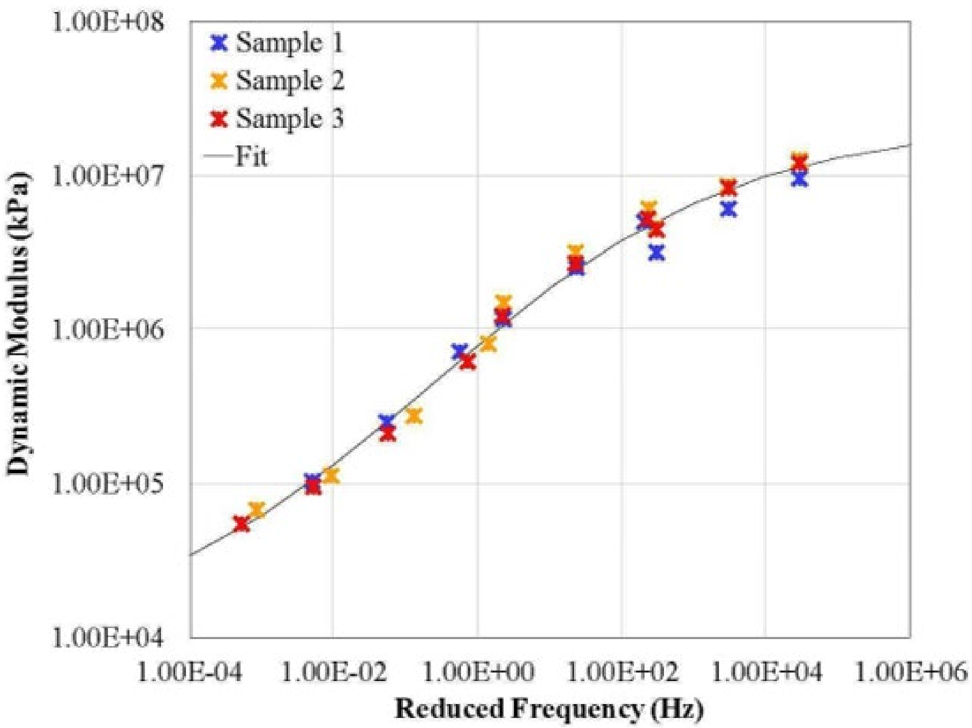


Avg Base Course Strain, 2nd Construction

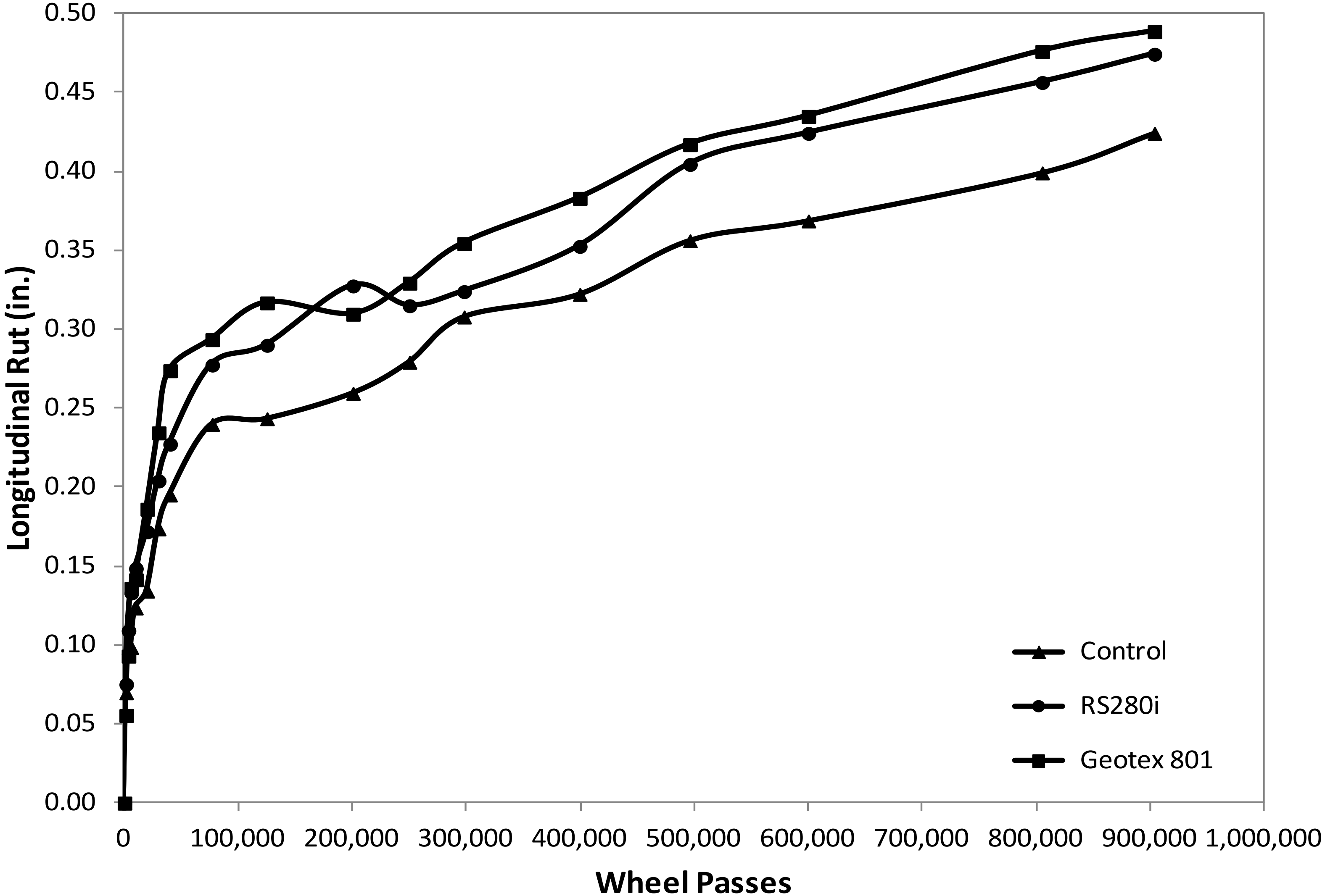


HMA

Nuclear Density	Average Density and Percent Compaction		
	Test Section 1	Test Section 2	Test Section 3
Density (lb/ft^3)	137.8	139.4	140.8
Percent Compaction (%)	90.1	91.2	92.1



Rutting Results



Post-Trafficking Forensic Analysis

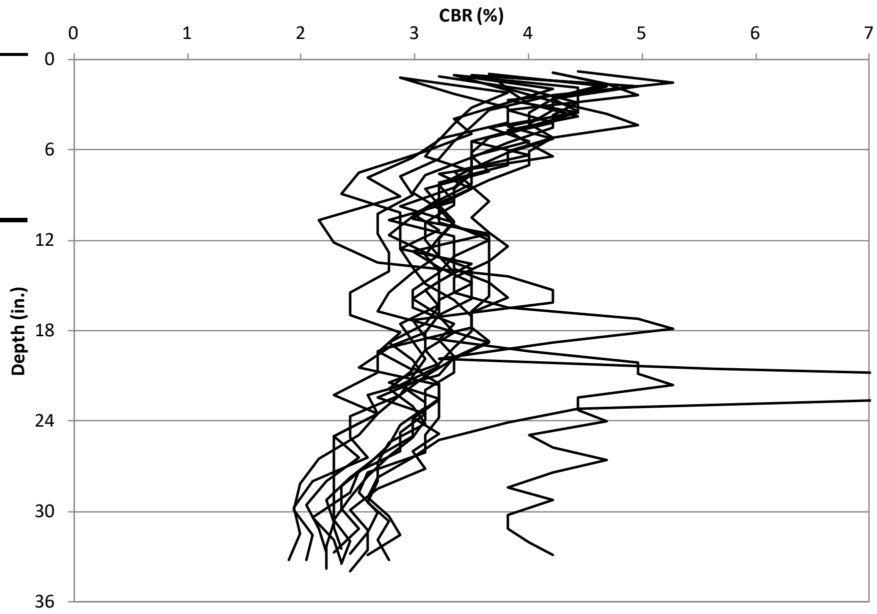
HMA Density

Location	Density (lb/ft^3)			
	Test Section 1	Test Section 2	Test Section 3	Average
Prisms Inside Wheel Path	142.7	143.5	142.8 143.6	143.1
Prisms Outside Wheel Path	139.6	142.3	141.7	141.2
Cores Outside Wheel Path	141.6	144.2	142.9	142.9
Average	141.3	143.3	142.8	142.4

Post-Trafficking Forensic Analysis

Subgrade Moisture and DCP

Measurement Depth	Average Moisture Content (%)		
	Control	RS280i	Geotex 801
Surface	25.0	25.3	24.4
1 in. below	25.5	25.7	25.2
2 in. below	26.3	26.2	25.5



Task 4: Analysis and Synthesis of Results

- Evaluation of representative subgrade strength
  - Complicated by: elapsed time from placement, set-up (thixotropy), moisture loss, base and HMA reconstruction
  - Original placement: w = 28 %, Vane = 100 kPa, CBR estimate = 2.5 %
  - Measurements taken during 2nd construction and forensic work suggest best CBR estimate = 3.5 %

Comparison of Results to Literature

- Saghebfar et al. (2016): RS280i, thicker section, stronger subgrade (CBR=5), TBR=1.38.

Comparison of Results GMA WPII (Berg et al., 2000)

Roadway Design Conditions		Geosynthetic Type					
Subgrade	Base/Subbase Thickness [1] (mm)	Geotextile		Geogrid [2]		GG-GT Composite	
		Nonwoven	Woven	Extruded	Knitted or Woven	Open-graded Base [3]	Well Graded Base
Low (CBR < 3) (M_R <30 MPa)	150 - 300	❹	●	●	❏	●	⑤
	> 300	❹	❹	◗	◗	◗	⑤
Firm to Very Stiff (3 ≤ CBR ≤ 8) (30 ≤ M_R ≤ 80)	150 - 300	⑥	◗	●	❏	●	⑤
	> 300	⑥	⑥	◗[7]	❏	❏	⑤
Firmer (CBR > 8) (M_R >80 MPa)	150 - 300	❍	❍	◗	❏	❏	⑤
	> 300	❍	❍	❍	❍	❍	⑤

Key: ● — usually applicable ◗ — applicable for some (various) conditions
❍ — usually not applicable ❏ — insufficient information at this time ⑤ — see note

Notes:
1. Total base or subbase thickness with geosynthetic reinforcement. Reinforcement may be placed at bottom of base or subbase, or within base for thicker (usually > 300 mm) thicknesses. Thicknesses less than 150 mm not recommended for construction over soft subgrade. Placement of less than 150 mm over a geosynthetic not recommended.
2. For open-graded base or thin bases over wet, fine-grained subgrades, a separation geotextile should be considered with geogrid reinforcement.
3. Potential assumes base placed directly on subgrade. A subbase also may provide filtration.

❹ Reinforcement usually applicable, but typically addressed as a subgrade stabilization application.

⑤ Geotextile component of composite likely is not required for filtration with a well graded base course; therefore, composite reinforcement usually not applicable.

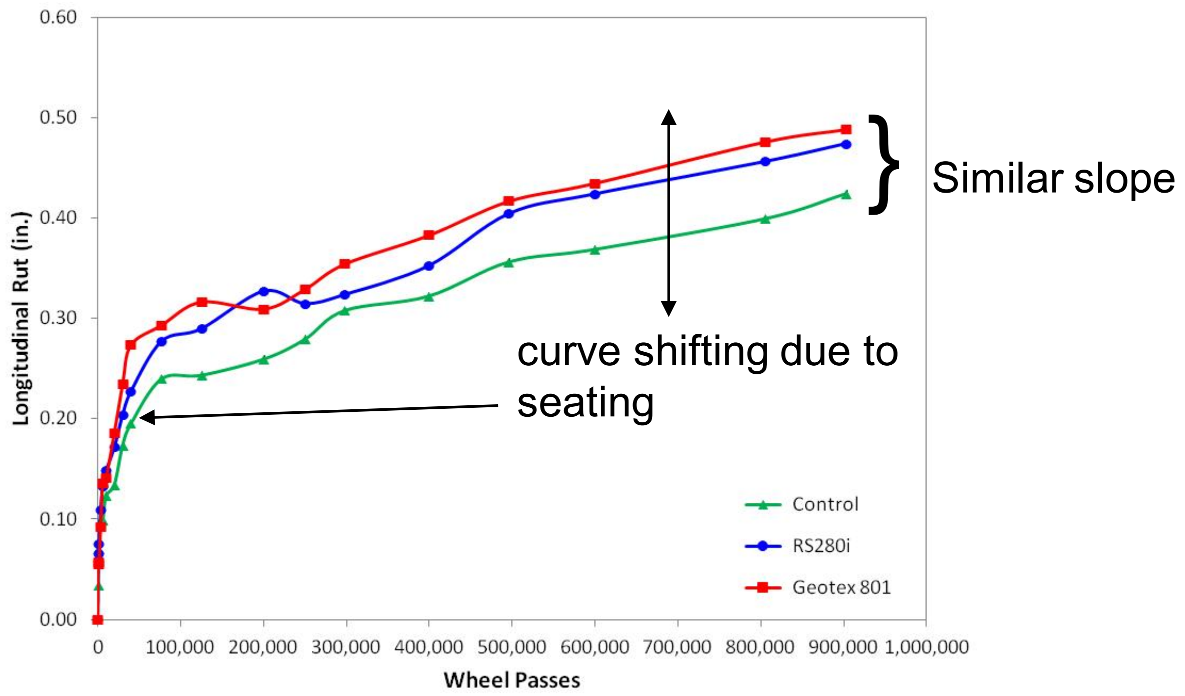
⑥ Separation and filtration application; reinforcement usually not applicable.

7. Usually applicable when placed up in the base course aggregate. Usually not applicable when placed at the bottom of the base course aggregate.

- Firm subgrade, base > 300 mm, reinforcement usually not applicable.
- Low strength subgrade, base > 300 mm, reinforcement usually applicable.

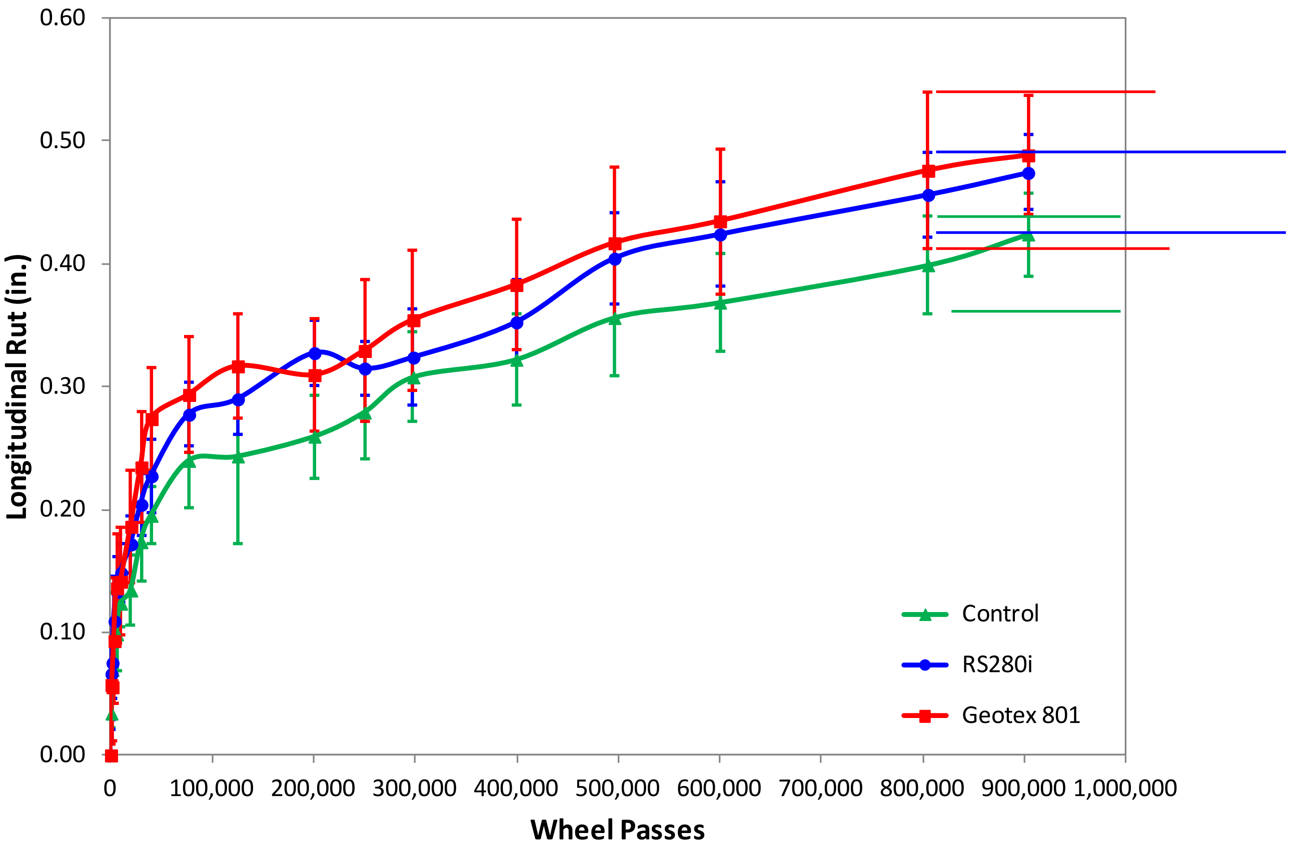
Analysis of Rutting Results
Arguments for Sections Performing Similarly

I. Initial seating or shakedown



Analysis of Rutting Results
Arguments for Sections Performing Similarly

II. Average +/- one standard deviation of measurement points



Analysis of Rutting Results
Arguments for Sections Performing Similarly

III. Reliability/Probability Theory

- Variability of constructed properties leads to a possibility that underperformance of the two geotextile sections is due to poorer properties.
- Greater variability of properties results in a greater possibility (probability) for this explanation.
- Formally addressed by using the variability of constructed properties to evaluate the probability that the traffic carried by the two geotextile sections equaled or exceeded that of the control.

Probability Theory

- Duncan (2000). “Factors of Safety and Reliability in Geotechnical Engineering”
- Steps
  - Identify properties of most importance
    - HMA and base layer thickness
    - Subgrade vane shear strength
    - Subgrade in-field CBR strength
    - Subgrade dynamic stiffness
    - Subgrade DCP
    - Base course dynamic stiffness
    - Base course DCP
    - HMA dynamic modulus
  - Determine average values and standard deviation of each property for each test section

Probability Theory

- Steps (continued)
  - Use subgrade properties to determine average value and standard deviation of subgrade resilient modulus

Test Section	Resilient Modulus (psi)		Subgrade Average CBR
	Average	Standard Deviation	
1	5540	455	3.69
2	5233	350	3.49
3	4985	271	3.32

Probability Theory

- Steps (continued)
  – Use base course properties to determine average values and standard deviation of base layer structural coefficient, a_2

Test Section	a_2	
	Average	Standard Deviation
1	0.140	0.013
2	0.135	0.008
3	0.140	0.009

Probability Theory

- Steps (continued)
  - Determine average values and standard deviation of HMA and base course layers

Test Section	Thickness (in)	
	Average	Standard Deviation
1	3.39	0.16
2	3.40	0.13
3	3.31	0.19

Test Section	Thickness (in)	
	Average	Standard Deviation
1	13.44	0.14
2	13.18	0.19
3	13.26	0.22

Probability Theory

- Steps (continued)
  - Use average property values along with AASHTO (1992) pavement design equation to calculate (predict) ESAL's for each test section (ESAL-P). ESAL-O gives ESAL's observed in test sections at rut depth = 0.4 inch, selected to match ESAP-P for control.

Parameter	Test Section 1	Test Section 2	Test Section 3
Reliability	85%	85%	85%
Z_R	-0.46	-0.46	-0.46
S_o	0.45	0.45	0.45
ΔPSI	1.7	1.7	1.7
M_R (psi)	5540	5233	4985
a_1	0.41	0.41	0.41
D_1 (in)	3.39	3.40	3.31
a_2	0.140	0.135	0.140
D_2 (in)	13.44	13.18	13.26
SN	3.27	3.24	3.21
ESAL-P	8.05E+05	6.64E+05	5.66E+05
ESAL-O	8.05E+05	4.73E+05	4.34E+05

Probability Theory

- Intermediate conclusion: Use of average properties and AASHTO equation predicts geotextile sections *should have* carried less traffic, but not by the extent observed.

Probability Theory

- Steps (continued)
  - Vary each parameter by + and – one standard deviation and calculate ESAL ($ESAL_1^+$, $ESAL_1^-$)
  - Determine ESAL standard deviation, coefficient of variation, reliability and probability for each test section

Test Section	σ_{ESAL}	*COV* (%)	*P* (%)
1	3.21 E 05	39.9	-
2	1.78 E 05	29.6	12.5
3	1.71 E 05	30.3	8.8

- Interpretation
  - Variability of test section constructed properties leads to a 12.5 % chance that the traffic carried by test section 2 would equal or exceed that of the control. 8.8 % chance for test section 3.

Probability Theory

- Conclusion
  - Low levels of probability imply that variation of constructed properties does not account for the control section outperforming the geotextile sections.
  - Shows excellent consistency of constructed properties between the sections.
  - Eliminates this as an explanation.
  - Erodes support for “data-scatter” explanation.
  - Leaves “seating or shakedown” as the most likely explanation.

Evaluation of Spreadsheet Model

Parameter	Test Section 2	Test Section 3	Test Section 3
D_1 (in)	3.40	3.31	3.31
a_1	0.41	0.41	0.41
D_2 (in)	13.18	13.26	13.26
a_2	0.135	0.140	0.140
Subgrade CBR	3.5	3.3	3.3
$G_{SM\text{-}2\%}$ (kN/m)	775	26	440
G_{MR}	0.897	0.827	0.827
Reduction factor for interface shear	0.690	0.970	0.780
Reduction factor for Poisson's Ratio	checked	unchecked	checked
Reduction factor for shear modulus	checked	unchecked	checked

Average Properties

Measured from wide-width tensile tests

Need to be unchecked to produce TBR=1

Increased to this value when reduction factor boxes are checked

Spreadsheet Model

- Reasonable parameters used to show no benefit when CBR = 3.3 to 3.5
- When CBR=2.5, TBR = 1.35 and 1.19 for test sections 2 and 3, respectively.

Geotextile Costs and Benefits

- Table of typical costs

District	Subgrade Excavation/Fill ($/yd^3)	Base Course ($/yd^3)	HMA ($/ton)	RS280i ($/yd^2)	Geotex 801 ($/yd^2)
1	6.50	25.00	73.05	3.00	1.50
2	7.00	25.00	76.05	3.00	1.50
3	7.50	30.00	79.05	3.00	1.50
4	7.50	37.00	81.05	3.00	1.50
5	7.00	30.00	81.05	3.00	1.50

Geotextile Costs and Benefits

- Benefits:
  - Modest amount of reinforcement when subgrade CBR = 2.5
  - Geotextiles offer insurance against more rapid pavement deterioration during seasonally weak periods requiring fewer rehabilitation treatments
  - Separation and filtration:
    - Maintain integrity of base course layer.
    - Reduce amount of rehabilitation needed at scheduled periods.
    - Provides confidence in rehabilitation decision making.
    - Avoids worse case of having to replace base layer during a scheduled rehabilitation

Conclusion

- For section thickness examined and subgrade CBR = 3.5, no structural benefit
- For subgrade CBR = 2.5, modest structural benefit
- Test section results support spreadsheet model
- Model results and GMA WPII are in agreement
- Model should be used to assess upcoming projects where reinforcement might be beneficial
- Model improvements could include replacement of check boxes with property values

Implementation Plan