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Evaluation of Pavement Rehabilitation Strategies on Route 165 and Prediction Performance

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EVALUATION OF PAVEMENT REHABILITATION STRATEGIES ON ROUTE 165
AND PREDICTION PERFORMANCE

BY

KATHLEEN WILSON

A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF THE
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IN
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DOCTOR OF PHILOSOPHY DISSERTATION

OF

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2016
ABSTRACT

Many roads in Rhode Island are coming to their intended design life and are now considered in poor condition. Significant number of roads with severe deterioration is being rehabilitated through full depth reclamations (FDR) with various additives. FDR can rejuvenate subbase and pavement structures. Route 165 in Exeter, Rhode Island, was selected as a test road with four different treatments and a control. The road had severe pavement distresses such as alligator cracking, pot holes, shoving and raveling and was not a candidate for a resurfacing. The road had a FDR in 2013 which included a control section, three test sections with additives which consisted of calcium chloride, asphalt emulsion, and Portland cement, and a geo-grid section. Triaxial testing was performed on the subbase materials and subgrade soils before and after the FDR treatments to determine the resilient modulus. The results of the material testing were used to predict the performance of each of the test sections by using AASHTOWare Pavement ME Design software.

The 200 mm (8.0 in.) rehabilitated base/subbase layer was covered with 62.5 mm (2.5 in.) Hot Mix Asphalt (HMA) with Warm Mix Asphalt (WMA) additive base and 50 mm (2 in.) surface. The maximum sizes of base and surface aggregate were 19 mm (3/4 in.) and 12.5 mm (1/2 in.), respectively. Properties of HMA mixtures with WMA additives including dynamic modulus were determined as input parameters and for further analysis.

Of the five test sections, it was predicted that the pavement with the FDR layer stabilized with Portland cement would perform the best overall. Next is calcium chloride followed by the control (no additive), geo-grid and asphalt emulsion.

A condition survey was conducted in 2015 winter, but there was no surface distresses found on any of the five test sections. A plan for long term performance evaluation has been developed, and an optimal strategy has been recommended, i.e., predicting performances before rehabilitating any broken roads.
ACKNOWLEDGEMENTS

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A research project entitled “Evaluation of Pavement Rehabilitation Strategies on Route 165 and Prediction of Performance” was submitted for funding to the Rhode Island Department of Transportation (RIDOT) by the Department of Civil & Environmental Engineering at the University of Rhode Island (URI) in April, 2003. A Research and Technology Development Cooperative Agreement was subsequently entered into by the RIDOT and the URI for conducting research involving the field performance of five tests sections on Route 165, Exeter, RI.

Introductory works, which preceded the start of the project, involved preparing a scope of work and project cost as well as sampling of Route 165 materials by another research grant from URI. Purchasing of a computer program from AASHTO was done in November, 2015. I am indebted to Messrs. Colin Franco and Michael Sock of Research and Technology Development Section, and Mr. Michael Byrne of Material Section of RIDOT.
# TABLE OF CONTENTS

ABSTRACT ........................................................................................................ ii

ACKNOWLEDGEMENTS ................................................................................. iii

TABLE OF CONTENTS ................................................................................... iv

LIST OF TABLES ............................................................................................. vi

LIST OF FIGURES ........................................................................................... viii

1. INTRODUCTION ....................................................................................... 1

   1.1 Objectives of Study ................................................................. 2

   1.2 Significance of Study .................................................... 4

2. Rehabilitation of Route 165 ................................................................. 7

   2.1 History ................................................................. 7

   2.2 Pre-Construction Material Testing ................................. 8

   2.3 Methodologies and/or Procedures .................................. 8

3. Performance Prediction of Rehabilitated Asphalt Pavement with
   AASHTOWare Pavement ME Design Software .......... 26

   3.1 Resilient Modulus of Subgrade Soils ............................... 27

   3.2 Resilient Modulus of Existing Subbase ....................... 27

   3.3 Resilient Modulus of Full Depth Reclamation (FDR) of
       New Base/Subbase ....................................................... 28
3.4 Determination of Physical Properties of Asphalt
   Base and Surface Layers ........................................ 29
3.5 Traffic Spectrum Obtained from Weigh-in Motion
   (WIM) Data .......................................................... 30
3.6 Climate Data ...................................................... 31
3.7 Prediction of Performance with AASHTOWare Pavement
   ME Design Software ............................................... 31
   3.7.1 Prediction of Performance for Control Test Section
          (Cold FDR) ...................................................... 35
   3.7.2 Prediction of Performance for the Calcium Chloride Section .. 35
   3.7.3 Prediction of Performance for Portland Cement
          Concrete Section ............................................... 36
   3.7.4 Prediction of Performance for Geo-Grid Section .............. 36
   3.7.5 Prediction of Performance for Asphalt Emulsion Section ...... 37
   3.7.6 Summary .......................................................... 37

4. Evaluation of Performance of Rehabilitated Asphalt Pavement .............. 55
4.1 Surface Distresses and Field Condition Survey .......................... 55
   4.1.1 Permanent Deformation and Rutting .......................... 56
   4.1.2 Fatigue Cracking .......................................... 56
   4.1.3 Thermal Cracking .......................................... 56
4.2 Serviceability and Roughness .......................................... 56
   4.2.1 International Roughness Index .................................. 56
4.3 Structural Capacity and Deflection .................................... 57
4.4 Analysis of Ground Penetrating Radar (GPR) ............................ 59
4.5 Comparative Analysis between Performance Prediction and Evaluation ...... 60
   4.5.1 Control Test Section ........................................ 61
   4.5.2 Calcium Chloride Section ................................... 61
   4.5.3 Portland Cement Section .................................... 62
4.5.4 Asphalt Emulsion Section ....................................... 62
4.5.5 Geogrid Section .................................................. 63

4.6 Selection of Best Alternatives Based on Short-Term Evaluation .......... 63
4.6.1 Forecasting Future Performance through Tieing with Pavement Structural Health Index (PSHI) ................. 63
4.6.2 Optimal Strategies for Rehabilitation .............................. 64

4.7 Guidelines for Long-term Evaluation and Optimal Rehabilitation Design Strategies ............................................................. 64

5. Conclusions and Recommendations ........................................ 76
5.1 Findings ........................................................................ 76
5.2 Recommendations .......................................................... 79
5.3 Conclusions .................................................................... 80

6. BIBLIOGRAPHY .................................................................. 81

7. Appendix A. MED Reports .................................................. 83

8. Appendix B. Asphalt Properties ............................................. 142
9. Appendix C. Monthly Traffic Reports ....................................... 146
10. Appendix D. Windshield Surveys and dTIMS Report ................. 160
11. Appendix E. Construction IRI ................................................ 171
12. Appendix F. FWD Reports .................................................. 174
13. Appendix G. Ground Penetrating Radar Report ...................... 192
14. Appendix H. RIDOT Full Depth Reclamations Specifications ....... 194
15. Appendix Modified MED Reports ........................................ 205
## LIST OF TABLES

2.1 Soil Survey for Rhode Island .......................................................... 12
2.2 Nuclear Guage Readings for Route 165 .............................................. 13
2.3 Locations of Test Section .............................................................. 14
2.4 Summary of Physical Properties of Selected Subgrade Soils from the Route 165 Site .............................................................. 15
2.5 Summary of Physical Properties of Selected 1980s RAP blends from the Route 165 Site .............................................................. 16
2.6 Summary of Physical Properties of Selected FDR RAP/virgin Aggregate from Rte 165 Site .............................................................. 17
2.7 Cardi 12.5 mm mix – RI 165 ............................................................. 18
2.8 Cardi 12.5 mm mix – RI 165 ............................................................. 19
3.1 Materials Testing for Route 165 ....................................................... 39
3.2 Resilient Moduli of Sampled 1980s RAP/Virgin Blends Route 165 Site .............................................................. 40
3.3 Summary of Resilient Moduli for Selected FDR with and Without Additives .............................................................. 41
3.4 Summary of Basic Properties of the FDR Blends ................................. 42
3.5 Physical Properties of Class 19 HMA Base Layer ............................... 43
3.6 Creep Compliance of both Mixtures with Respect to Creep Time ............ 44
3.7 Monthly Traffic Counts from December 2014- Nov 2015 ...................... 45
3.8 Control (Cold Recycled) Distress Prediction Summary for 20 Years .......... 46
3.9 Calcium Chloride Section Data Results for 20 Years ............................ 47
3.10 Portland Cement Section Prediction Summary for 20 Years .................. 48
3.11 Asphalt Emulsion Section Distress Prediction Summary ....................... 49
3.12 Geo-Grid Section Distress Prediction Summary ................................ 50
3.13 Comparison of Performance Predictions ......................................... 51
4.1 Comparison of Performance Predictions on MED IRI and Contractor’s Run
4.2 Comparison Between Subbase and URI Lab Results vs Hogg Method FWD Results
4.3 Comparison of Years to Predicted Threshold Distress
4.4 Control Section (Cold Recycled) Pavement Performance
4.5 Calcium Chloride Pavement Performance
4.6 Portland Cement Runs to Increase Pavement Performance
4.7 Asphalt Emulsion Pavement Performance
4.8 Geo-grid Pavement Performance
4.9 Comparison of Years of Predicted Threshold Distress and Cost
4.10 Cost Comparison for Thicker Class 19 Base Course
### LIST OF FIGURES

| Figure | Description                                                                 | Page |
|--------|-----------------------------------------------------------------------------|------|
| 1-5    | Locus Map                                                                    | 6    |
| 2.1    | Cross Section of Route 165 after Rehabilitation in 1986                     | 20   |
| 2.2    | Cross Section of Route 165 with Control Test Section                        | 21   |
| 2.3    | Cross Section of Route 165 with Calcium Chloride Section                    | 22   |
| 2.4    | Cross Section of Route 165 with Emulsion Section                            | 23   |
| 2.5    | Cross Section of Route 165 with Portland Cement Section                     | 24   |
| 2.6    | Cross Section of Route 165 with Geo-Grid Section                            | 25   |
| 3.1    | Grain Size Distribution for all 1980 RAP/Virgin Blend Samples               | 52   |
| 3.2    | Grain Size Distribution for all FDR Samples                                 | 53   |
| 3.3    | Vehicle Classification According to FHWA                                    | 54   |
Chapter 1

INTRODUCTION

It has been estimated that the amount of miles of truck traffic on our highways will be increasing and surpassing all other modes of freight shipments in the near future. Tractor trailers and heavy vehicles account for a majority of the damage done to highways (Lee and Peckham et al. 1990). The states, especially Rhode Island, are having a hard time keeping up with and paying for maintenance and rehabilitation (M&R). This means there will be more wear done to our highways than ever before, and the states will have to do more M&R with less funding. To meet upcoming highway demand, the Rhode Island Department of Transportation (RIDOT) has been testing alternative subbase material strategies such as full depth reclamations (FDR) and has been expanding their use.

RIDOT wants to build a better road, to have less physical maintenance and to control costs. The final product according to RIDOT is a high performance road. Reclaiming a roadway can fulfill RIDOTs wants by increasing the stiffness of the subbase and increase the pavement life.

Achieving higher performance at a 30% to 50% cost savings can be realized with a full reclamation according to pavement recycling systems. Reclaimed materials are retained and reused on site, consequently reducing trucking costs for new materials.

- Lifecycle cost savings: lower maintenance
- Environmental: recycles in-place material
- Uses value of existing pavement
• In-depth: eliminates cracking patterns
• Minimizes costly import/export
• Structural upgrade to base: R-Value, strength
• Shorter construction time, less disruption

(http://www.pavementrecycling.com).

In the 1980, RIDOT had a program to reclaim pavements throughout the state. In 2013, Route 165 was slated to re-reclaimed. An idea was formed to use four different strategies and a control (Figure 1.1). The objectives of this project are: to test the existing subbase materials before and after full depth reclamation, to predict the performance of different subbase strategies and to evaluate the short-term and long-term performance over time.

1.1 Objective of Study

Route 165 is a unique candidate for research because it is seven miles long without many intersections, the subgrade layer has a high water table and there is severe frost action in winter. The objectives of the present research project are as follows:

1. Predict the performance of five test sections on Route 165 which include the following subtasks:

   * Collect and/or determine environmental inputs including temperature, moisture and Freeze-Thaw etc.

   * Work with a URI research team to collect and/or determine basic properties and resilient modulus of the existing subbase materials of Route 165.
* Collect and/or determine properties of reclaimed base/subbase materials on the five test sections on Route 165.

* Collect and/or determine properties of two and a half inches of Class 19 warm mix asphalt (WMA) (19 mm Superpave) asphalt base (through working with RIDOT Material Section and Villanova University, Pennsylvania) on Route 165.

* Collect and/or determine properties of two inch Class 12.5 WMA (12.5 mm superpave) asphalt surface (through working with RIDOT Material section and Villanova University, Pennsylvania) on Route 165.

* Collect Weigh-In-Motion (WIM) data from the RIDOT Traffic Research Section for initial two-way average annual daily truck traffic (AADTT), percent trucks in design Lane, percent trucks in design lane, percent trucks in design directions, and operational speed on Route 165.

* Predict performance including rutting, fatigue cracking, thermal cracking and roughness in terms of International Roughness Index (IRI) using AASHTOWare Pavement ME Design (MED).

2. Perform a visual condition survey on Route 165.

3. Secure falling weight deflectometer (FWD) testing data from RIDOT on Route 165 after construction.

* Analyze data including deflection basin.
4. Collect profilometer test data from RIDOT to evaluate the smoothness after construction.

5. Evaluate distresses, if any, and determine which layer has weakness.

6. Evaluate the five different strategies and recommend the best one for future RIDOT rehabilitation projects from the Route 165 project. The five strategies are a control, calcium chloride, asphalt emulsion, Portland Cement, and geo-grid. RIDOT has used calcium chloride and cold recycled mix but not Portland cement no asphalt emulsion. Geo-grid has been used in the state for drainage problem areas.

7. Provide an optimal design and strategies for future RIDOT rehabilitation projects.
   * Assist future testing and evaluation after the 2016 summer.
   
   The outcome of this research project will provide a guideline for future maintenance and rehabilitation (M&R) projects.

1.2 Significance of Study

Chapter two discusses the construction methodologies and/or procedures performed on Route 165. It was important to keep the different test strategies as uniform as possible to have a comparison study. The special job specifications for the contractor were written to keep the depth of reclamation constant. Chapter three provides the results of the different subbase strategy tests such as sieve analysis, resilient modulus, and densities. Collection and compilation of the WIM station data on average annual daily truck traffic (AADTT), WMA mixes, material properties of the subbase and subgrade, and climate data. Performance comparisons and ranking between the different MED strategies. Chapter four consists of surface distresses and field condition surveys, forward
calculations of FWD deflections, serviceability and roughness, comparative analysis between prediction and evaluation of the test strategies, best alternatives base on short term evaluations and optimal strategies. Chapter 5 provides the conclusion and recommendations of this research and guidelines for long-term evaluation and optimal rehabilitation design.
Chapter 2
Rehabilitation of Rhode Island Route 165

2.1 History

Route 165 was last reconstructed in 1986. The roadway was reclaimed to a depth of 125 mm (5 in.) and mixed with calcium chloride. The pavement thickness, after resurfacing, was 37.5 mm (1-1/2 in.) of bituminous surface course and 62.5 mm (2-1/2 in.) of bituminous modified binder course over a 125 mm (5 in.) cold recycled base layer mixed with a ratio of 1:2 bituminous pavement/gravel and 200 mm (8 in.) of existing gravel subbase layer (Figure 2.1).

A geotechnical engineering exploration and analysis was conducted at the request of RIDOT by V.A. Nacci and Associates, Consulting Soil, and Foundation Engineers on September 25, 1987. It may be noted that, Route 165 was originally built on soft deposits (swamp). Depending on the nature of the soft deposit, “construction” dealt with this in one of two ways: one was by removal of the unsuitable material and the other was by “floating the embankment on the soft soil, often with considerable settlement” (Nacci et al., 1987).

Eleven test borings were completed for the reconstruction, which found embankments consisting of sand, some gravel, silt, fibrous organic deposits (peat), and organic silt. Other test borings indicated that Route 165 was built on glacial till and stratified kame deposits. There were pockets in the granite bedrock near the surface, which contributed to a high water table. An exploration and analysis found an additional seven areas of swamp deposits.

Table 2.1 shows the various soil types and properties, and American Association of State and Highway Transportation Officials (AASHTO) classifications of the soil ranges from A-1 to A-4 (USDOA 1981). Soils within Route 165 has a low shrink-swell potential but has a potential for frost action. Route 165 is not comprised of any clay materials, therefore the plasticity index is zero. Areas of Route 165 that contain Adrian, Walpole, and Ridgebury have severe wetness, low strength, and severe frost action.
The RIDOT, throughout the years, has performed both material and pavement testing on this roadway primarily through RIDOT maintenance programs. Skid tests measuring pavement smoothness were performed in 2003, 2006, and 2010 (see Appendix H). The results show that in 2003, Route 165 had skid numbers between 52 and 58. In 2010, the skid number ranged from 50 to 56 while the 2006 data showed values between 43 to 49. Overall, Route 165 has shown a noticeable decrease in pavement smoothness and rideability.

2.2 Pre-Construction Material Testing

In 2012, the RIDOT Material Section, in conjunction with the URI Department of Civil and Environmental Engineering, performed testing on the unbound materials from five sample areas within Route 165. The areas where field samples were taken are in the general vicinity of the poorer numbers of skid tests. Twelve field samples were taken between November 27, 2012 and December 6, 2012. Nuclear gauge readings were taken at the sample areas at the same time to measure in-situ dry density, wet density, water contents, and percent moisture. Stationing, utility pole numbers, and planned treatment areas were recorded to insure future samples were taken in the same locations (Table 2.2). The 2012 samples were taken to URI for resilient modulus testing, and the results from RIDOT/URITC Project Number 000154 were used as parameters to run the AASHTOWare ME pavement program (Bradshaw et al. 2015).

2.3 Methodologies and/or Procedures

A test road, i.e., Route 165 in Exeter was rehabilitated and used to predict and evaluate the performance of different strategies. Four test sections used the full depth eight-inch FDR base/subcase, and three of them were stabilized with calcium chloride, asphalt emulsion, and Portland cement. The fifth test section was reconstructed with geo-grid and six inches of filter stone sandwiched between the layers. The control section was reclaimed in a similar method as the rest of the reclaimed test sections and no additives was used. All four test and one control section were
paved with two and a half inch thick Class 19 HMA base and two inches Class 12.5 HMA surface.

As previously mentioned, Route 165 is approximately seven miles long consisting of seven hills and valleys. The reclaimed test sections were given at least one hill and valley. The geo-grid section has only a small section for this research project and each test section has a different segment length and area of construction (see Table 2.3).

Based on the RIDOT Job Specifications, each of the reclaimed test sections and the geo-grid section were designed to conform to the same material gradation with 95% to 100% passing a three inch sieve and 2% to 15% passing a number 200 sieve to achieve a comparable performance between the test sections. The contractor had to comply with not having any stone, rock, cobble, or asphalt material being more than four inches in width or length. Cross sections of each test section are shown in Figures 2.2 through 2.6.

Equipment used consisted of: reclaimer, vibratory sheepfoot rollers and motorized graders. Compaction was in accordance with AASHTO T180, Method D to a uniform density of no less than 95% of maximum and pavement operations took place during acceptable temperature ranges. However, a sudden downpour during Portland cement placement and washed all the material away. The Portland cement section was then regraded and new Portland cement applied.

Full depth reclamation (FDR) with calcium chloride consisted of using a calcium chloride (CaCl₂) solution. This procedure used AASHTO M 144 specifications for calcium chloride with a solution being at 35% +/- 1%, alkali chloride 2% maximum as NaCl, and magnesium at 0.1% maximum as MgCl. From the RIDOT’s Specification 406.9901: A calcium pressure distributor was used to distribute the CaCl₂ solution at a rate of 0.1 to 2 gallons per square yard with a spray bar length of up to 20 feet. The distributor shall be equipped with a digital volumetric accumulator meter capable of measuring gallons applied and distance traveled. The volume and measuring device
shall be equipped with a power unit for the pump so that the application is by pressure, not gravity. The spray nozzles and pressure system shall provide a sufficient and uniform fan-shaped spray of material throughout the entire length of the spray bar at all times while operating, and shall be adjustable laterally and vertically. The spray shall completely cover the roadway surface receiving the treatment (RIDOT SPC 406.9901).

Full depth reclamation with bituminous stabilizer consisted of using an asphalt emulsion of grade MS-2 or HFMS-2. This procedure used AASHTO M.03.03.4 144 specifications for asphalt emulsion. From the RIDOT’s Specification 406.9903: The asphalt emulsion distributor shall be capable of applying asphalt emulsion in measured quantities at any rate from 0.1 to 1.5 gallons per square yard of roadway surface, at any length of spray bar up to 12 feet. It shall be capable of maintaining the application rate to a tolerance of \(\pm 0.03 \text{ gals/\text{yd}^2}\) regardless of change in grade, width or direction of the road. It shall be equipped with a thermometer for the emulsion and a digital volumetric accumulator meter capable of measuring gallons applied and distance traveled. The volume and measuring device shall be equipped with a power unit for the pump so that application is by pressure, not gravity. The spray nozzles and pressure system shall provide a sufficient and uniform fan-shaped spray of material throughout the entire length of the spray bar at all times while operating, and shall be adjustable both laterally and vertically. The spray shall completely and uniformly cover the roadway surface receiving the treatment (RIDOT SPC 406.9901).

Based on RIDOT’s Specification 406.9904, Portland cement was spread by distributing a measured amount of cement in front of the reclaimer. The spreader uniformly blended cement and existing materials to the specified percentage +/- three pounds /square yard (across the roadway. The Contractor was required to provide a method for verifying that the correct amount of cement was being applied. Additionally, the cement spreader was
equipped with a tractor-trailer utilizing “a Drop behind system” which was pressure controlled. Each day the operator would calibrate the drop to make sure the correct application was being applied. The trailer was filled four to five times daily with bulk delivery trucks. Three pounds per square yard comes out to be four percent Portland cement mix.

A section of geo-grid mechanically stabilized layer was placed as another test section for a comparison. Distributors of the Tensar International Corporation Technologies were highly interested in demonstrating their product and made claims to its durability and strength. RIDOT decided to use geo-grid along with the reclaimed sections to have a complete test road. The Tensar product was used in an area of the road that has a high seasonal water table.

The physical properties of each 2013 test sections were determined at URI and are shown in Tables 2.4 through 2.6. Physical properties of selected subgrade soils from Route 165 site sample locations are presented in Table 2.4 (Bradshaw et al. 2015). Physical properties of selected 1980s RAP blends from Route 165 site is presented in Table 2.5. (Bradshaw et al. 2015). Physical properties of selected FDR RAP blends of Route 165 site is presented in Table 2.6. (Bradshaw et al. 2015).

The rehabilitated eight inch base/subbase were covered with two and a half (2.5) inches of Class 19 WMA base and two inches of Class 12.5 WMA surface layer as shown in Figures 2.2 to 2.6. A summary of some of the volumetric data for the Class 12.5 WMA surface materials is shown in Tables 2.7 and 2.8.
| Location | Flooding Frequency | High Water Table FT | High Water Table Months | Potential Freeze Action | Depth In | Permeability | Shrink-Swell Potential | AASHTO Classification | Liquid Limit | Plasticity Index | USDA Texture | Local Roads and Streets |
|----------|--------------------|---------------------|------------------------|-------------------------|----------|--------------|-----------------------|-----------------------|--------------|----------------|--------------|-------------------------|
| Adiron   | As                 | Frequent            | 0-1.0                  | Nov-Mar                 | High     | 20-95        | 8-20                  | Low                   | A-2,A-3,A-1 | NP            | Sand, Fine Loam      | Severe: Weather, floods, low strength |
| Bridghampton  | Bsb,BsD*             | None                | >6                     | High                    | 8-41     | 6-2.5       | Low                   | A-2                   | NP           |                 | Gravelly sandy Loam, sandy Loam | Severe: Frost Action |
| Canton   | Ck,Ck,Ck               | None                | >6                     | Low                     | 22-80    | 6.0-30      | Low                   | A-2,A-4               | 0<19         | NP            | Fine Gravelly Loam, Sandy Loam | Moderate: Block |
| Carisle  | Cb                 | Frequent            | 0-1.0                  | Sep-Oct                 | High     | 0-85        | 2-4.0                 | PT                    |              |               | Sand, Loam        | Moderate: Low strength, weather, floods |
| Ethel    | EB                 | None                | >6                     | Moderate                | 25-60    | <20        | Low                   | A-1                   | NP           |                | Very Gravelly sand, Gravelly Sand | Moderate: Frost Action |
| Hendley  | HbA,Hc              | None                | >6                     | Low                     | 17-40    | >20        | Low                   | A-1                   | <10          | NP            | Restricted Gravelly Loamy, Fine Sand to very Gravelly Loamy, Gravelly Clays | Slight, Moderate: Block |
| Mermac   | Mm,A,MmB            | None                | >6                     | Low                     | 28-60    | 8-20       | Low                   | A-1                   | NP           |                | Restricted Sand to very Gravelly Loamy | Slight |
| Ridgbury | Rf                 | None                | 0-1.6                  | Nov-Mar                 | High     | 20-60       | <4.2                  | Low                   | A-2,A-4      | NP            | Sandy Loam, Gravelly Loam | Severe: Large stones, weather |
| Scarnor  | Rb                 | Rare                | 0-1.6                  | Nov-Jul                 | High     | 18-60       | >6                   | Low                   | A-1,A-3      | NP            | Loamy Sand, Sand, Sandy Loam | Severe: Weather, floods |
| Selden   | SSA, SSA, SSA, SSA, SSA | None       | 1.5-3.5               | Nov-Ayr                 | Moderate  | 17-50       | >6                   | Low                   | A-2,A-4      | NP            | Fine Sandy Loam, Gravelly Loamy | Moderate: Frost Action |
| Weecks   | Wa                 | None                | 0-1.5                  | Nov-Ayr                 | High     | 18-60       | >6                   | Low                   | A-1,A-3,A-3 | NP            | Fine Sandy Loam, Sandy Loam, Gravelly Loam | Severe: Weather, floods |

(Soil Survey of Rhode Island, United States Department of Agriculture, Soil Conservation Service in Cooperation with RI Agricultural Experiment Station, 1981)
| Sample ID | Station | Offset | Direction | Utility Pole | Date Sampled | Nuclear Gauge Readings |
|-----------|---------|--------|-----------|--------------|--------------|-----------------------|
|           |         |        |           |              |              | Dry Density | Wet Density | Water, lbs | Moisture % |
| 1 CaCl    | 39+25 +/-| Center of Travel Lane | Westbound | Pole 304 | 11/27/2012 | 126.0 | 132.7 | 5.6 | 4.4 |
|           |         |        |           |              |              | 122.3 | 129.2 | 5.3 | 4.3 |
| 2 PC      | 135+60 +/-| Center of Travel Lane | Eastbound | Pole 381 | 11/27/2012 | 125.8 | 129.8 | 3.9 | 3.1 |
|           |         |        |           |              |              | 125.1 | 128.8 | 3.7 | 3.0 |
| 3 PC      | 162+70 +/-| Center of Travel Lane | Eastbound | Pole 400 | 11/29/2012 | 129.8 | 135.1 | 5.2 | 4.0 |
|           |         |        |           |              |              | 129.4 | 134.5 | 5.1 | 3.9 |
| 4 PC      | 204+84 +/-| Center of Travel Lane | Westbound | Pole 428 | 11/29/2012 | 139.6 | 141.3 | 4.2 | 3.0 |
|           |         |        |           |              |              | 135.7 | 139.9 | 4.2 | 3.1 |
| 5 Blt     | 327+85 +/-| Center of Travel Lane | Westbound | Pole 518 | 11/29/2012 | 144.5 | 149.8 | 5.2 | 3.6 |
|           |         |        |           |              |              | 144.3 | 149.3 | 5.0 | 3.5 |
| 6 PC      | 250+10 +/-| Center of Travel Lane | Eastbound | Pole 488 | 11/29/2012 | 132.6 | 137.8 | 5.2 | 3.9 |
|           |         |        |           |              |              | 131.6 | 136.8 | 5.1 | 3.9 |
| 7 CaCl    | 95+29 +/-| Center of Travel Lane | Westbound | Pole 347 | 12/4/2012 | 126.7 | 133.1 | 6.3 | 5.0 |
|           |         |        |           |              |              | 127.5 | 133.4 | 6.3 | 4.9 |
| 8 Geo     | 285+00 +/-| Center of Travel Lane | Westbound | Pole 489 | 12/4/2012 | 130.4 | 135.7 | 5.2 | 4.0 |
|           |         |        |           |              |              | 130.8 | 136.2 | 5.4 | 4.1 |
| 9 Blt     | 340+00 +/-| Center of Travel Lane | Eastbound | Pole 528 | 12/4/2012 | 125.0 | 131.0 | 6.0 | 4.8 |
|           |         |        |           |              |              | 125.3 | 131.0 | 5.7 | 4.5 |
| 10 Geo    | 309+84 +/-| Center of Travel Lane | Eastbound | Pole 505 | 12/4/2012 | 129.7 | 134.6 | 4.9 | 3.8 |
|           |         |        |           |              |              | 129.9 | 134.6 | 4.7 | 3.6 |
| 11 Recy   | 117+21 +/-| Center of Travel Lane | Eastbound | Pole 369 | 12/5/2012 | 131.0 | 136.7 | 5.7 | 4.3 |
|           |         |        |           |              |              | 131.8 | 137.4 | 6.5 | 4.1 |
| 12 CaCl   | 92+54 +/-| Center of Travel Lane | Eastbound | Pole 321 | 12/5/2012 | 123.5 | 128.9 | 5.3 | 4.3 |
|           |         |        |           |              |              | 129.6 | 134.8 | 5.2 | 4.0 |

(RIDOT Material Section 2013)
Table 2.3 Locations of Test Sections

| Test Section         | Station       | Square yards | Elevations | Locations | Utility Pole Locations | Segment Length in feet |
|----------------------|---------------|--------------|------------|-----------|------------------------|------------------------|
| Control Section      | 48+50 to 75+00 | 9,000        | 303        | 67+25     | 369                    | 2,650                  |
| Calcium Chloride     | 0+00 to BK 44+82 to 48+50 | 31,000      | 396        | 39+25     | 304                    | 9,332                  |
| Portland Cement      | 75+00 to 232+00 | 52,335      | 144        | 117+88    | 400                    | 15,700                 |
| Bituminous Stabilizer| 267+00 to 333+00 | 22,000      | 397        | 282+00    | 518                    | 6,600                  |
| Geo Grid             | 232+00 to 267+00 | 12,500      | 367        | 258+60    | 506                    | 3,500                  |
Table 2.4 Summary of Physical Properties of Selected Subgrade Soils from Route 165 Site

| Location of Sample Number | Max Dry Density kN/m³ | Max Dry Density (lbs/ft³) | Optimum Water Content (%) | Specimen Dry Density kN/m³ | Specimen Dry Density (lbs/ft³) | Specimen Water Content (%) | Specimen Relative Water Content (%) |
|--------------------------|-----------------------|---------------------------|---------------------------|---------------------------|-------------------------------|---------------------------|-----------------------------------|
| 7 Control                | 21.1                  | 134.3                     | 5.2                       | 19.8                      | 126.1                         | 5.3                       | 94.0                              |
| 11a Control              | 21.1                  | 134.3                     | 3.9                       | 20                        | 127.3                         | 3.6                       | 95.0                              |
| 11b Control              | 21.1                  | 134.3                     | 3.9                       | 20                        | 127.3                         | 3.7                       | 95.0                              |
| 12a CaCl₂                | 21.5                  | 136.9                     | 4.0                       | 20.2                      | 128.6                         | 4.0                       | 94.0                              |
| 12b CaCl₂                | 21.5                  | 136.9                     | 4.0                       | 20.2                      | 128.6                         | 3.5                       | 94.0                              |
| 2 Portland Cement        | 21.6                  | 137.5                     | 3.8                       | 20.4                      | 129.9                         | 4.0                       | 94.0                              |

Bradshaw et al., 2015
Table 2.5 Summary of Physical Properties of Selected 1980s RAP Blends from Route 165 Site

| Location of Sample Number | Rap Content (%) | Max Dry Density kN/m$^3$ | Max Dry Density (lbs/ft$^3$) | Optimum Water Content (%) | Specimen Dry Density kN/m$^3$ | Specimen Dry Density (lbs/ft$^3$) | Specimen Water Content (%) | Specimen Relative Water Content (%) |
|---------------------------|-----------------|--------------------------|-----------------------------|---------------------------|-----------------------------|-------------------------------|---------------------------|----------------------------------|
| 11 Control                | 20              | 21.3                     | 135.6                       | 4.7                       | 20.6                        | 131.1                         | 3.3                       | 97.0                             |
| 12 CaCl$_2$               | 40              | 21                       | 133.7                       | 4.4                       | 19.9                        | 126.7                         | 4.6                       | 95.0                             |
| 9 Asphalt Emulsion       | 26              | 20.9                     | 133.1                       | 5.4                       | 20                          | 127.3                         | 5.0                       | 96.0                             |
| 4a Portland Cement       | 25              | 21                       | 133.7                       | 3.6                       | 19                          | 121.0                         | 3.5                       | 91.0                             |
| 4b Portland Cement       | 25              | 21                       | 133.7                       | 3.6                       | 20                          | 127.3                         | 3.4                       | 95.0                             |
| 6 Portland Cement        | 15              | 21                       | 133.7                       | 3.7                       | 20.4                        | 129.9                         | 3.5                       | 97.0                             |
| 8a Geo-Grid              | 25              | 21.5                     | 136.9                       | 3.2                       | 20.1                        | 128.0                         | 2.5                       | 93.0                             |
| 8b Geo-Grid              | 25              | 21.5                     | 136.9                       | 3.2                       | 20.6                        | 131.1                         | 3.3                       | 96.0                             |
| 8c Geo-Grid              | 25              | 21.5                     | 136.9                       | 3.2                       | 19.6                        | 124.8                         | 8.5                       | 91.0                             |
| 8d Geo-Grid              | 25              | 21.5                     | 136.9                       | 3.2                       | 20.5                        | 130.5                         | 3.4                       | 95.0                             |

Bradshaw et al., 2015
Table 2.6 Summary of Physical Properties of Selected FDR RAP/Virgin Aggregate Blends from Route 165 Site

| Location of Sample Number | Max Dry Density kN/m³ | Max Dry Density (lbs/ft³) | Optimum Water Content (%) | Specimen Dry Density kN/m³ | Specimen Dry Density (lbs/ft³) | Specimen Water Content (%) | Specimen Relative Water Content (%) |
|---------------------------|-----------------------|----------------------------|---------------------------|----------------------------|-------------------------------|-----------------------------|-----------------------------------|
| 7A Control                | 21.2                  | 135.0                      | 3.9                       | 20.4                       | 129.9                         | 3.6                         | 96.0                              |
| 7b Control                | 21.2                  | 135.0                      | 3.9                       | 20.4                       | 129.9                         | 3.6                         | 96.0                              |
| 1 CaCl₂ (24 hours)        | 21.2                  | 135.0                      | 3.4                       | 20.6                       | 131.1                         | 3.4 (3.3)                   | 97.0                              |
| 5 Asphalt Emulsion (5 Days) | 20.5                | 130.5                      | 4.0                       | 19.8                       | 126.1                         | 4 (3.7)                     | 97.0                              |
| 4a Portland Cement (4 Hours) | 20.7                | 131.8                      | 3.4                       | 20.0                       | 127.3                         | 3.3 (2.3)                   | 97.0                              |
| 4b Portland Cement (7 Days) | 20.7                | 131.8                      | 3.4                       | 20.0                       | 127.3                         | 3.4 (.77)                   | 97.0                              |

Bradshaw et al 2015

Notes: 1. The curing time is given in parenthesis.
   2. The water content of the specimen after curing is given in parenthesis.
   3. Maximum dry density and specimen dry density values have been corrected for oversize particles and represent field values.
| Mixture Description | Sample No | Gmm | Gsb | Gmb | % Air Void |
|---------------------|-----------|-----|-----|-----|------------|
| 5.2AC-3.0AV         | 1         | 2.452 | 2.630 | 2.386 | 2.7        |
|                     | 2         |       |      | 2.373 | 3.2        |
|                     | 3         |       |      | 2.385 | 2.7        |
|                     | 1         | 2.452 | 2.630 | 2.292 | 6.5        |
|                     | 2         |       |      | 2.289 | 6.6        |
|                     | 3         |       |      | 2.291 | 6.6        |
| 5.2AC-9.0AV         | 1         | 2.452 | 2.630 | 2.244 | 8.5        |
|                     | 2         |       |      | 2.240 | 8.6        |
|                     | 3         |       |      | 2.241 | 8.6        |
| 5.6AC-5.0AV         | 1         | 2.438 | 2.630 | 2.318 | 4.9        |
|                     | 2         |       |      | 2.325 | 4.6        |
|                     | 3         |       |      | 2.311 | 5.2        |
| 5.6AC-7.0AV         | 1         | 2.458 | 2.630 | 2.280 | 7.3        |
|                     | 2         |       |      | 2.267 | 7.0        |
|                     | 3         |       |      | 2.269 | 6.9        |
| 5.6AC-9.0AV         | 1         | 2.438 | 2.630 | 2.221 | 8.9        |
|                     | 2         |       |      | 2.212 | 9.3        |
|                     | 3         |       |      | 2.221 | 8.9        |
| 6.1AC-4.0AV         | 1         | 2.420 | 2.630 | 2.315 | 4.3        |
|                     | 2         |       |      | 2.314 | 4.4        |
|                     | 3         |       |      | 2.311 | 4.5        |
| 6.1AC-7.0AV         | 1         | 2.420 | 2.630 | 2.246 | 7.2        |
|                     | 2         |       |      | 2.239 | 7.5        |
|                     | 3         |       |      | 2.245 | 7.2        |
| 6.1AC-9.0AV         | 1         | 2.420 | 2.630 | 2.195 | 9.3        |
|                     | 2         |       |      | 2.191 | 9.5        |
|                     | 3         |       |      | 2.287 | 8.8        |
Table 2.8 Cardi 12.5 mm Mix – RI -165

Binder Grade
PG-64-28S polymer modified with Resiltherm, Wm Mt Asphalt

| Binder Content | Low  | Optimum | High |
|----------------|------|---------|------|
|                | 9.5  | 5.6     | 4.1  |

Effective Binder Content

| Low  | 4.997 |
| Optimum | 3.394 |
| High | 2.879 |

Layer Property, Base - RI 165

Old pavement structure
1.3% bituminous surface course
1.5% bituminous base course
12% gravel borrow

New pavement structure
2.2% Modified class 13.5 LIMA
2.2% base HI-FRM
2% Resiltherm

| Gradation | Source | Cardi O' Beam % | Cardi 30' Beam % | Cardi 30' Beam % | Ji 30' Beam % | Ji 30' Beam % | Ji 30' Beam % | Overall Target Coverage |
|-----------|--------|----------------|-----------------|-----------------|---------------|---------------|---------------|--------------------------|
|           | 1.25   | 2.00           | 0.00            | 0.00            | 0.00          | 0.00          | 0.00          | 0.00                     |
|           | 1.50   | 2.00           | 0.00            | 0.00            | 0.00          | 0.00          | 0.00          | 0.00                     |
|           | 1.75   | 2.00           | 0.00            | 0.00            | 0.00          | 0.00          | 0.00          | 0.00                     |
|           | 2.00   | 2.00           | 0.00            | 0.00            | 0.00          | 0.00          | 0.00          | 0.00                     |
|           | 2.25   | 2.00           | 0.00            | 0.00            | 0.00          | 0.00          | 0.00          | 0.00                     |
|           | 2.50   | 2.00           | 0.00            | 0.00            | 0.00          | 0.00          | 0.00          | 0.00                     |
|           | 2.75   | 2.00           | 0.00            | 0.00            | 0.00          | 0.00          | 0.00          | 0.00                     |
|           | 3.00   | 2.00           | 0.00            | 0.00            | 0.00          | 0.00          | 0.00          | 0.00                     |
|           | 3.25   | 2.00           | 0.00            | 0.00            | 0.00          | 0.00          | 0.00          | 0.00                     |
|           | 3.50   | 2.00           | 0.00            | 0.00            | 0.00          | 0.00          | 0.00          | 0.00                     |
|           | 3.75   | 2.00           | 0.00            | 0.00            | 0.00          | 0.00          | 0.00          | 0.00                     |
|           | 4.00   | 2.00           | 0.00            | 0.00            | 0.00          | 0.00          | 0.00          | 0.00                     |

19
CROSS SECTION OF ROUTE 165
AFTER REHABILITATION IN 1986

Figure 2.1 Cross Section of Route 165 after Rehabilitation in 1986
CROSS SECTION OF ROUTE 165
FOR CONTROL TEST SECTION

Figure 2.2 Cross Section of Route 165 with Control Test Section
CROSS SECTION OF ROUTE 165 FOR CALCIUM CHLORIDE SECTION

Figure 2.3 Cross Section of Route 165 with Calcium Chloride Section
CROSS SECTION OF ROUTE 165 FOR PORTLAND CEMENT SECTION

Figure 2.4 Cross Section of Route 165 with Portland cement Section
CROSS SECTION OF ROUTE 165 FOR EMULSION SECTION

Figure 2.5 Cross Section of Route 165 with Emulsion Section
CROSS SECTION OF ROUTE 165 FOR GEO GRID SECTION

Figure 2.6 Cross Section of Route 165 with Geo Grid Section
Chapter 3
Performance Prediction of Rehabilitated Asphalt Pavement
with AASHTOWare Pavement ME Design Software

Previously, Rhode Island used the 1993 American Association of State Highway and Transportation Officials (AASHTO) Guide for Design of Pavement Structures to design the pavement thickness and subbase layers. The guide used graphs to calculate traffic equivalency values, freeze-thaw factors, and resilient modulus to find a design structural number.

The new updated method uses truck traffic, climate data, WMA mixture and subbase material properties for a mechanistic empirical design (Refer to Appendix A). There are three hierarchical levels in AASHTOWare Pavement ME Design (MED):

Level 1. Uses laboratory i.e. resilient modulus, HMA mixture properties that is project specific or a library of test materials results.

Level 2. Input values are estimated for correlations and regression equations

Level 3. Input parameters are estimated or global defaults are used. (AASHTO et al., 2015)

There are several WMA properties that are needed to be inputted into the Pavement ME program to perform a Level 1 design. The RIDOT performs fifteen AASHTO and ASTM testing on its materials and warm mix asphalt as shown in Table 3-1 for all its construction projects. These tests are the MED inputs that are needed to predict
longitudinal cracking, alligator cracking, transverse cracking, rutting or other permanent deformation, IRI, and reflection cracking over a selected design life.

3.1 Resilient Modulus of Subgrade Soils

As discussed in Chapter 2, subbase and subgrade soil samples were collected during construction for testing. According to the results of a sieve analysis on the material, the subbase consisted of gravelly sand or A-1-b AASHTO classification which is consistent with the material shown for that location in the 1981 Soil Survey of Rhode Island; this soil was also found under a previous URI study (Lee et al. 2003). The URI study reported resilient modulus (Mr), which is deviator stress over recoverable strain, values for Rhode Island subgrade soils ranged from 7,506 psi to 9,304 psi (Lee et al. 2003) and an Idaho study for comparison shows the same types of gravel material ranged from 8,000 psi to 19,000 psi (Hardcastle et al. 1993).

3.2 Resilient Modulus of Existing Subbase.

Before the Full Depth Reclamation (FDR), four inches of asphalt pavement were removed from the roadbed for ten test sections located throughout the length of the road. Approximately twelve inches of existing subbase layer including five inches of previously recycled material were collected. It should be noted, the collected samples were mix with seven inches of the existing gravel borrow and the five inches of previously reclaimed material was not tested separately. Resilient moduli of the ten subbase test sections were
determined by using triaxial chamber apparatus according to AASHTO T 307-99 procedure. Resilient moduli values are presented in Table 3.2.

The laboratory resilient moduli values varied from 17,000 psi to 74,000 psi. Subsequent material testing of the ten samples for the percent RAP content using AASHTO T 308, are shown in Table 2.5. For the 1980 old recycled mixture, the subbase samples have an asphalt content between fifteen and forty percent with most of the samples having a pavement content of twenty-five percent.

A grain size distribution, AASHTO T 27, Figure 3.2 sieve analysis shows the samples as relatively uniform (Bradshaw, et al., 2015). The samples show that the contractor performed a good job of reclaiming.

3.3 Resilient Modulus of New Full Depth Reclamation (FDR) of New Base/Subbase

In construction, four inches of old asphalt surface and base layers were reclaimed into four inches of previously reclaimed subbase, and a new eight-inch homogeneous FDR base/subbase layer was formed. Samples were taken, before the new construction FDR base/subbase layer were mixed with the three different strategies, to URI for testing. Before triaxial testing, four samples were mixed with additives in the lab according to RIDOT specifications for Route 165. Out of the six samples two control FDR samples were tested without additives, one sample was mixed with CaCl₂, one sample was mixed with asphalt
emulsion, and two samples were mixed with Portland cement. For the Portland cement samples, one was cured for 4 hours and the other 7 days before testing.

The resilient moduli of FDR base/subbase layer were determined by using AASHTO T307-99, and results are shown in Table 3.3 (Bradshaw et al., 2015).

Six samples for the percent asphalt (RAP) content, maximum dry unit weight, optimum moisture content and Dry unit weight shown in Table 3.4 and a grain size distribution, Figure 3.3, show the samples as relatively uniform (Bradshaw et al., 2015).

3.4 Determination of Physical Properties of Asphalt Base and Surface Layers

The Route 165 project used two and one half inches of Class 19 WMA for the base layer and two inches of Class 12.5 WMA for the surface layer. Mechanical properties of WMA including Dynamic modulus, ($E_{HMA}, E^*$) for the surface and base layers were acquired from Villanova University and Cardi Corporation’s WMA testing, and are shown in Appendix B. An example of the physical Properties of Class 19 WMA base layer is shown in Table 3.5, and are used as input parameters for MED software.

Creep compliance was acquired from a URI study, and used as an input parameter for the MED software (Lee et al., 2014). The creep compliance results are used according
to the MEPDG for new pavement only. Those values are shown in Table 3.6. Creep compliance is a test for thermal low temperature cracking.

3.5 Traffic Spectrum Obtained from Weigh-in-Motion (WIM) Data

All truck traffic data inputted into the MED software came from a WIM station on Route 165, and was obtained from RIDOT Research Section. Data included average annual daily traffic (AADT) which is broken down into vehicle classification, monthly adjustment factors, hourly adjustment factors, daily vehicle counts and percent trucks in design direction. The average annual daily truck traffic (AADTT) is calculated for Class 4 to Class 13 vehicles. FHWA Vehicle Classifications according to their class are shown in Figure 3.3. The AADTT from December, 2014 to November, 2015 is 150. The percent trucks in design direction was calculated at 51/49. Heavy trucks is cumulatively calculated as 295,762 truck vehicles over ten years and 627,848 truck vehicles in the highest design direction. These values are calculated by calculating the number of trucks per year and adding each year together for ten or twenty years with a 1.3% increase in truck traffic and multiplying that number by .51 (the design direction).

Monthly traffic counts from December 2014 to November 2015 are broken down into truck traffic counts and percent vehicles for each class are shown in Table 3.7. Monthly traffic reports and percent trucks in design direction are shown in Appendix C.
3.6 Climate Data

Climate is an important parameter in the MED and has to be downloaded from (hcd) files from the website www.me-design.com. The download from the website comprises of climate data for all 50 states of United States from 1997 to 2005. (AASHTO is in the process of updating their files to current climate data this spring). The closest active weather station to Route 165 is at TF Green Airport, Warwick. The downloaded climate data includes monthly temperature, precipitation, sunshine, air temperature, maximum frost and wind speed. Summaries of the climate data are shown on pages six and seven of the MED output reports. Shown in Appendix A.

MED uses the climate data for transverse cracks (non-load cracks), enhanced integrated climate model (EICM) calculates the WMA temperatures on an hourly basis and MED uses those hourly temperatures to estimate the WMA properties (creep compliance and indirect tensile strength) to calculate the tensile stress throughout the WMA surface (AASHTO et al., 2015).

3.7 Prediction of Performance with AASHTOWare Pavement ME Design Software

In the present study, the five test sections were run using the MED. There are six design parameters needed and have been explained in Sections 3.1 through 3.6.

- Resilient Modulus
  Lab values from URI
• HMA properties for Class 12.5 WMA and Class 19 WMA
  Creep compliance
  Effective binder content
  Air voids
  Asphalt Dynamic modulus
  Asphalt Binder

• Traffic
  AADTT
  Vehicle classification
  Percent trucks in Design lane

• Climate
  Green Airport, Warwick

• Projected pavement design life
  Estimated

• Pavement layer make up
  Ground penetrating radar
Performance distress prediction outputs will include:

- AC bottom-up fatigue cracking (% lane area)
- AC top-down fatigue cracking (ACTDFC) (ft/mile)
- AC thermal cracking (ft/mile)
- Permanent deformation - AC only (in)
- Permanent deformation - total pavement (in)
- Terminal IRI (in/mile)

Distress or performance indicators terms for asphalt pavements are important to recognize and accurately identify them in the field.

AC bottom-up fatigue cracking (alligator cracking) is caused by repeated wheel loads and on pavements has an alligator pattern. They originate from the bottom of an asphalt layer and travel up to the surface. Bottom up cracking show up as multiple short, longitudinal or transverse cracks in the wheel path.

AC top-down fatigue cracking (top down cracking) is also caused by repeated wheel loads but the cracking is parallel to the pavement centerline. Longitudinal cracks originate from the top and go down. Raveling and/or rack deterioration can occur along the edges of these cracks. These cracks do not look like alligator cracks.
AC thermal cracking are non-wheel load cracking due to low temperatures or thermal cycling.

Permanent deformation - AC only (reflection transverse cracking) is a non-wheel load cracking induced by reflection from transverse joint or crack in underlying pavement.

Permanent deformation is a surface depression in the wheel path resulting from plastic or permanent deformation in each layer. The rut depth is representative of the maximum vertical difference in elevation between the transverse profile on the HMA surface and a wire-line across the lane width. MED also computes the rut depths within the HMA, unbound aggregate layers and foundation. (AASHTO et al., 2015).

Terminal IRI’s functional adequacy is quantified by pavement smoothness for both flexible and rigid pavements. Rough roads lead to user discomfort but higher vehicle costs.

From Table 3.3, shows five confining stresses of 21 kPa, 35kPa, 69 kPa, 103 kPa, and 138 kPa. Each confining stress has three deviator stresses and three Mr values. The mean Mr values for the four test sections for the 35 kPa confining stress are used in this study. The 35 kPA was selected because the 21 kPA appears too low. In the future when the pavement is measured in the field and downloaded from dTIMS for the five distresses, a determination can be made for which confining stress is the best fit. The MED can be
rerun with a higher confining pressure and the predictions re-evaluated. This method is how
the MED will be calibrated for future projects.

3.7.1 Prediction of Performance for Control Test Section (Cold Recycled)

The control test section on Route 165 was reclaimed to a depth of eight inches and
did not receive any additives. After the FDR, as shown in Figure 2.2, a one inch of old 1980
recycled blend with the old CaCl₂ subbase material was assumed left and is represented in
the MED.

Table 3.8 shows the MED output from using the Mr from laboratory testing. There
is one predicted design output failure for AC top-down fatigue cracking (longitudinal
cracking). The target and predicted values are from the MED control URI generated report
page 1. Shown in Appendix A.

3.7.2 Prediction of Performance for the Calcium Chloride Section

The calcium chloride section was full depth recycled and mixed with CaCl₂ to a
depth of eight inches on Route 165. After the FDR, as shown in Figure 2.3, a one inch of
old recycled blend with CaCl₂ is assumed left and is represented in the MED.
Table 3.9 shows the MED output from using the Mr from laboratory tests. There is one predicted design output failure for AC top-down fatigue cracking (longitudinal cracking). The target and predicted values are from the MED Calcium chloride URI generated report page 1. Shown in Appendix A.

3.7.3 Prediction of Performance for Portland Cement Section

The Portland cement section was full depth recycled to a depth of eight inches with the cement mixed throughout. A one inch of old recycled blend mixed with CaCl\textsubscript{2} is assumed left and is represented in the MED, Figure 2.4.

There were two Portland cement samples tested for this project. Sample 4a was mixed with Portland cement (PC) and tested after four hours, while sample 4b was mixed with PC and tested after 7 days. The Portland cement section on Route 165 was micro cracked after four hours and traffic was allowed on the newly compacted surface. Since micro cracking prevents the PC to gain any more stiffness, sample 4a is used in this study.

The MED was run with the layer thicknesses and Mr as shown below in Table 3.11. There are no predicted output failures. The target and predicted values are from the MED Portland Cement URI generated report page 1. Shown in Appendix A.

3.7.4 Prediction of Performance for Asphalt Emulsion Section

The asphalt emulsion section was full depth recycled to a depth of eight inches with only the first three inches mixed with emulsion as shown in Figure 2.5.
The MED was run with the layer thicknesses and Mr as shown below in Table 3.10. There is one predicted design output failure for AC top-down fatigue cracking (longitudinal cracking).

3.7.5 Prediction of Performance for Geo-Grid Section

The Tensar geo-grid section used full depth recycled material to a depth of ten inches and did not receive any additives. To install the geo-grid, sixteen inches of subbase were removed from the road after FDR and stockpiled. The geo-grid was installed on top of the subgrade and six inches of filter stone were placed on the geo-grid. Another geo grid layer was placed over the filter stone and ten inches of FDR were placed and compacted, Figure 2.6. For this test, the control material for sample 7b Mr mean values for confining stress of 35 kPa were used from Table 3.3.

The MED was run with the layer thicknesses and Mr as shown below in Table 3.12. There is one predicted design output failure for AC top-down fatigue cracking (longitudinal cracking).

3.7.6 Summary

The comparison between the control and the other four test sections are shown below in Table 3.13. The most prevalent distress, in the four test sections, is in the asphalt layer. AC top down fatigue cracking (longitudinal cracking) for the control, CaCl₂, asphalt
emulsion and geo-grid predicted cracking will be greater than the estimated twenty year target of two thousand feet per mile. The Portland cement section is the only test section that did not have any predicted distresses for twenty years. The higher the AC top down cracking, the earlier the threshold distress is noted. The years to predicted threshold distress comes from the third table on page thirteen of each of the test sections MED reports. Shown in Appendix A.

Having AC top down fatigue cracking (longitudinal cracking) means the pavement layer of four and half inches in not thick enough for the actual truck traffic loading. Either the Class 12.5 WMA or the Class 19 WMA layer should have been thicker. Since the cost of the Class 19 WMA was thirty dollars less than the Class 12.5 WMA, using the Class 19WMA will save on cost.

The test sections in order of best performance are: Portland cement, CaCl₂, control, geo-grid and asphalt emulsion with the smallest amount of cracking and highest predicted threshold distresses in years. All the test sections predict that there will not be any permanent deformation in the subbase or AC layer, or AC bottom up fatigue cracking (alligator cracking). The higher resilient moduli, the better the results for less distresses.
Table 3.1 Material Testing for Route 165

| AASHTO | T 88 | Particle Size Analysis of Soils | URI |
|---------|------|--------------------------------|-----|
| T 265  |      | Laboratory Determination of Moisture Content of Soils | URI |
| T 307  |      | Determining of Resilient modulus of Soils and Aggregate Materials | URI |
| ASTM   | D2487| Classification of Soils for Engineering Purposes | URI |

**Laboratory Unbound Materials**

**Asphalt Binder**

| AASHTO | T 315 | Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer (DSR) | RIDOT Materials Section |
|---------|------|------------------------------------------------------------------------------------------------|------------------------|
| T 316  |      | Determination of Asphalt Binder Using Rotational Viscometer | RIDOT Materials Section |

**Hot Mix Asphalt**

| AASHTO | T 27 | Sieve Analysis of Fine and Course Aggregates | RIDOT Materials Section |
|---------|------|-----------------------------------------------|------------------------|
| T 84  |      | Specific Gravity and Absorption of Fine Aggregates | RIDOT Materials Section |
| T 85  |      | Specific Gravity and Absorption of Course Aggregates | RIDOT Materials Section |
| T 166 |      | Bulk Specific Gravity of Compacted Hot Mix Asphalt (HMA) Using Saturated Surface Dry | RIDOT Materials Section |
| T 209 |      | Theoretical Maximum Specific Gravity (GMM) and Density of Hot Mix Asphalt Paving Mixtures | RIDOT Materials Section |
| T 308 |      | Determining the Asphalt Binder Content of Hot Mix Asphalt (HMA) by the Ignition Method | RIDOT Materials Section |
| T 312 |      | Preparing and Determining the Density of Asphalt Mixture Specimens by Means of the Superpave Gyratory Compactor | RIDOT Materials Section |
| T 342 |      | Determining Dynamic Modulus of Hot Mix Asphalt In Situ Deflection Measurements (FWD) | RIDOT Materials Section |

**Material Specification**

| M 320 | Performance-Graded Asphalt Binder | Villanova University |
| M 323 | Superpave Volumetric Mix Design | Villanova University |

**Standard Practices and Terminology**

| R 37 | Application of Ground Penetrating Road Radar (GPR) to Highways | RIDOT Material Section |
| R 43 | Quantifying Roughness of Pavement | Vendor |
Table 3.2 Resilient Moduli of Sampled 1980s RAP/Virgin Blends from Route 165 Site

| Sample | Resilient Modulus MPa (KoA) |
|--------|------------------------------|
| 4a     | 124 (17.9) 141 (20.4) 154 (22.3) 170 (24.6) 191 (27.7) 201 (29.1) 251 (36.6) 272 (39.4) 286 (38.8) 290 (39.4) 215 (41.5) 235 (41.9) 266 (46.9) 305 (49.0) |
| 4b     | 123 (17.8) 141 (20.4) 161 (23.3) 170 (25.0) 191 (30.0) 207 (32.6) 225 (38.5) 266 (44.2) 305 (45.8) 316 (42.0) 318 (42.0) 338 (46.8) 368 (49.0) 379 (53.5) |
| 5 (Cement) | 120 (17.4) 132 (19.1) 145 (21.0) 162 (23.6) 182 (26.3) 213 (29.9) 244 (33.3) 269 (38.5) 295 (41.7) 325 (42.0) 331 (43.1) 344 (47.1) 373 (51.4) |
| 6 (Cement) | 121 (17.4) 137 (19.1) 153 (21.0) 176 (23.6) 198 (26.3) 212 (29.9) 230 (33.3) 251 (38.5) 270 (41.7) 301 (42.0) 317 (43.1) 371 (48.8) 407 (54.0) |
| 8a     | 130 (17.4) 154 (19.8) 168 (22.1) 188 (25.5) 209 (28.7) 221 (30.7) 272 (39.1) 299 (43.6) 316 (45.3) 316 (45.9) 352 (48.7) 381 (55.2) 387 (56.1) 403 (65.5) |
| 8b     | 139 (18.0) 154 (19.8) 168 (22.1) 188 (25.5) 209 (28.7) 221 (30.7) 272 (39.1) 299 (43.6) 316 (45.3) 316 (45.9) 352 (48.7) 381 (55.2) 387 (56.1) 403 (65.5) |
| (Geogrid) | 20.1 (20.3) 22.3 (24.3) 25.3 (27.2) 30.3 (30.3) 32.0 (30.4) 30.3 (30.4) 35.2 (35.3) 40.8 (35.3) 43.3 (39.2) 45.9 (42.7) 49.5 (45.0) 50.7 (50.7) 55.3 (58.5) 59.8 (58.9) |
| 9c     | 148 (23.4) 168 (24.3) 189 (27.4) 214 (31.0) 243 (38.4) 265 (48.9) 342 (58.2) 398 (58.7) 450 (55.2) 493 (56.6) 562 (60.0) 642 (64.2) 643 (74.0) 643 (74.0) |
| (Geogrid) | 58.0 (23.4) 67.4 (24.3) 86.4 (27.4) 107.0 (31.0) 128.1 (38.4) 150.8 (48.9) 218.3 (58.2) 270.2 (58.7) 326.3 (55.2) 382.1 (56.6) 440.8 (60.0) 493.4 (64.2) 643.0 (74.0) |
| 9d     | 158 (23.4) 175 (24.3) 194 (27.4) 226 (31.0) 252 (38.4) 267 (48.9) 355 (58.2) 398 (58.7) 450 (55.2) 507 (56.6) 562 (60.0) 642 (64.2) 643 (74.0) 643 (74.0) |
| (Geogrid) | 58.0 (23.4) 67.4 (24.3) 86.4 (27.4) 107.0 (31.0) 128.1 (38.4) 150.8 (48.9) 218.3 (58.2) 270.2 (58.7) 326.3 (55.2) 382.1 (56.6) 440.8 (60.0) 493.4 (64.2) 643.0 (74.0) |
| 9     | 122 (23.4) 135 (24.3) 149 (27.4) 167 (31.0) 184 (38.4) 201 (48.9) 287 (58.2) 333 (58.7) 392 (55.2) 440 (56.6) 507 (60.0) 562 (64.2) 642 (74.0) 72.2 (72.2) |
| (Emulsion) | 17.8 (19.5) 21.6 (24.3) 24.2 (28.4) 29.9 (35.0) 38.1 (39.0) 45.0 (40.0) 41.5 (41.5) 45.0 (45.0) 50.0 (50.0) 55.0 (55.0) 60.0 (60.0) 65.0 (65.0) 70.0 (70.0) |
| 11     | 142 (23.4) 164 (24.3) 181 (27.4) 197 (31.0) 222 (38.4) 245 (48.9) 326 (58.2) 370 (58.7) 426 (55.2) 480 (56.6) 532 (60.0) 585 (64.2) 642 (74.0) 643 (74.0) |
| (Cement) | 21.3 (23.4) 23.4 (24.3) 25.5 (27.4) 31.1 (31.0) 36.1 (36.1) 41.0 (41.0) 46.1 (46.1) 51.3 (51.3) 56.3 (56.3) 61.3 (61.3) 66.3 (66.3) 71.3 (71.3) 76.3 (76.3) 81.4 (81.4) |
| 0 (KPa) | 21 22 21 35 35 35 69 69 69 103 103 103 138 138 138 |
| 0 (MPa) | 21 22 21 35 35 35 69 69 69 103 103 103 138 138 138 |
| 0 (MPa) | 21 22 21 35 35 35 69 69 69 103 103 103 138 138 138 |
| t10 (KPa) | 10 20 29 16 32 49 49 49 65 97 97 97 49 65 130 |

(Bradshaw et al., 2015)

Bradshaw et al 2015)

\(\sigma_3 = \text{confining stress}\)

\(\sigma_d = \text{deviator (cyclic) stress} = \sigma_1 - \sigma_3\)

\(\sigma_0 = \text{bulk stress} = (\sigma_1 + \sigma_2 + \sigma_3)\)

\(\tau_{oct} = \text{octahedral shear stress} = 2^{1/3} \cdot 3 \sigma_d\)
Table 3.3. Summary of resilient moduli of selected FDR with and without additives.

| Sample | Resilient Modulus (MPa) |
|--------|-------------------------|
|        | Cyclic (15%) | Cyclic (5%) | Cyclic (5%) | Cyclic (5%) |
| 1      | 225 (17%)     | 236 (16%)   | 247 (15%)   | 261 (14%)   |
|        | 306 (19%)     | 319 (20%)   | 365 (21%)   | 365 (21%)   |
|        | 201 (15%)     | 201 (15%)   | 210 (14%)   | 210 (14%)   |
|        | 201 (15%)     | 201 (15%)   | 210 (14%)   | 210 (14%)   |
|        | 315 (21%)     | 315 (21%)   | 315 (21%)   | 315 (21%)   |
|        | 488 (32%)     | 488 (32%)   | 488 (32%)   | 488 (32%)   |
| 4p     | 386 (27%)     | 386 (27%)   | 386 (27%)   | 386 (27%)   |
|        | 307 (21%)     | 307 (21%)   | 307 (21%)   | 307 (21%)   |
|        | 315 (21%)     | 315 (21%)   | 315 (21%)   | 315 (21%)   |
|        | 427 (28%)     | 427 (28%)   | 427 (28%)   | 427 (28%)   |

(Bradshaw et al., 2015)

\( \sigma_1 = \text{confining stress} \)

\( \sigma_d = \text{deviator (cyclic) stress} = \sigma_1 - \sigma_3 \)

\( \sigma = \text{bulk stress} = (\sigma_1 + \sigma_2 + \sigma_3) \)

\( \tau_{oct} = \text{octahedral shear stress} = 2^{5/3} \sigma_d \)
Table 3.4 Summary of Basic Properties of the FDR Blends

| Sample          | RAP Content (%) | Max. Dry Unit Weight (kN/m³) | Optimum Moisture Content (%) | Dry Unit Weight (kN/m³) |
|-----------------|-----------------|------------------------------|------------------------------|------------------------|
| FDR-NoTreat     | 63              | 21.2                         | 3.9                          | 20.4                   |
| FDR-NoTreat-R   | 63              | 21.2                         | 3.9                          | 20.4                   |
| FDR-CaCl2-24hr  | 71              | 21.2                         | 3.4                          | 20.6                   |
| FDR-Emuls-5D    | 57              | 20.5                         | 4.0                          | 19.8                   |
| FDR-PC-4hr      | 61              | 20.7                         | 3.4                          | 20.0                   |
| FDR-PC-7D       | 61              | 20.7                         | 3.4                          | 20.0                   |

(Bradshaw et al., 2015)
Table 3.5 Physical Properties of Class 19 HMA Base Layer

| Binder Grade | Effective Binder Content | PG 64-28V polymer modified with Evotherm, Warm Mix Asphalt |
|--------------|--------------------------|----------------------------------------------------------|
| Binder Content | Low | 5.9 |
|               | Optimum | 6.3 |
|               | High | 6.8 |
|               | Low | 5.519 |
|               | Optimum | 5.921 |
|               | High | 6.423 |

(RIDOT Material Section 2014)
Table 3.6 Creep Compliance of both Mixtures with Respect to Creep Time

| Creep time t (s) | -20 °C HMA | -20 °C CIR | -10 °C HMA | -10 °C CIR | 0 °C HMA | 0 °C CIR |
|------------------|------------|------------|------------|------------|----------|----------|
| 0                | 8.97389E-08 | 9.41206E-07 | 4.13707E-07 | 8.54305E-07 | 5.21493E-07 | 2.55396E-06 |
| 1                | 9.63726E-08 | 9.69910E-07 | 4.57243E-07 | 9.22395E-07 | 6.20040E-07 | 2.73292E-06 |
| 2                | 1.02322E-07 | 1.00329E-06 | 4.91514E-07 | 9.63768E-07 | 7.80792E-07 | 2.88960E-06 |
| 5                | 1.18060E-07 | 1.07410E-06 | 5.55092E-07 | 1.04849E-06 | 8.78080E-07 | 3.13043E-06 |
| 10               | 1.36596E-07 | 1.15122E-06 | 6.26694E-07 | 1.13398E-06 | 1.08040E-06 | 3.39047E-06 |
| 20               | 1.66465E-07 | 1.25065E-06 | 7.29301E-07 | 1.24203E-06 | 1.35649E-06 | 3.73268E-06 |
| 50               | 1.99800E-07 | 1.46296E-06 | 9.41902E-07 | 1.44683E-06 | 1.54403E-06 | 4.35663E-06 |
| 100              | 2.15918E-07 | 1.70172E-06 | 1.19198E-06 | 1.67104E-06 | 2.56138E-06 | 5.00597E-06 |

(Lee et al., 2014)
### Table 3.7 Monthly Traffic Counts from Dec 2014-Nov 2015

| Vehicle Class | 4    | 5    | 6    | 7    | 8    | 9    | 10   | 11   | 12   | 13   | Total |
|---------------|------|------|------|------|------|------|------|------|------|------|-------|
| Dec-14        | 28   | 1333 | 298  | 93   | 202  | 1625 | 13   | 1    | 12   | 0    | 3605  |
| Jan           | 17   | 1168 | 298  | 84   | 139  | 1301 | 4    | 1    | 84   | 0    | 3096  |
| Feb           | 19   | 1466 | 371  | 103  | 155  | 1495 | 2    | 2    | 38   | 0    | 3651  |
| Mar           | 22   | 1389 | 229  | 22   | 245  | 1966 | 11   | 1    | 49   | 3    | 3937  |
| Apr           | 38   | 1691 | 250  | 46   | 261  | 2136 | 13   | 0    | 30   | 1    | 4466  |
| May           | 41   | 2116 | 335  | 140  | 261  | 2015 | 12   | 4    | 41   | 1    | 4966  |
| June          | 64   | 2109 | 319  | 105  | 339  | 2180 | 25   | 5    | 65   | 1    | 5212  |
| July          | 37   | 2432 | 387  | 106  | 407  | 2115 | 20   | 1    | 56   | 2    | 5563  |
| Aug           | 43   | 2523 | 452  | 214  | 466  | 2064 | 16   | 6    | 45   | 1    | 5830  |
| Sept          | 34   | 2408 | 285  | 63   | 353  | 2234 | 20   | 0    | 78   | 0    | 5475  |
| Oct           | 24   | 1899 | 395  | 145  | 418  | 2144 | 7    | 2    | 64   | 0    | 5098  |
| 15-Nov        | 36   | 1296 | 296  | 119  | 281  | 1781 | 23   | 0    | 66   | 2    | 3900  |
| Total         | 407  | 21835| 3921 | 1247 | 3535 | 23065| 176  | 34   | 640  | 24   | 54884 |

**Vehicle Class Distribution**

| Distribution | 0.74% | 39.81% | 7.14% | 2.27% | 6.44% | 42.05% | 0.31% | 0.05% | 1.16% | 0.03% | 100% |

(RIDOT Research Section, Dec 2014–Nov 2015)
Table 3.8 Control Section (Cold Recycled) Distress Prediction Summary Using a Twenty Year Design Life

### Design Inputs

| Layer Type                        | Thickness | Laboratory           | Mr (psi) |
|-----------------------------------|-----------|-----------------------|----------|
| Flexible                          | 2         |                       |          |
| Flexible                          | 2.5       |                       |          |
| Cold recycled (FDR RAP)           | 8         | Bradshaw et al., 2015 | 37,655   |
| Non-stabilized (1980 Virgin RAP)  | 1         | Bradshaw et al., 2015 | 30,650   |
| Non-stabilized (Ex. gravel borrow)| 8         | Lee et al., 2003      | 13,620   |
| Subgrade                          | Semi-infinite |                   | 9304     |

### Design Outputs

| Distress                                    | Target   | Predicted   | Criterion Satisfied |
|---------------------------------------------|----------|-------------|---------------------|
| AC bottom-up fatigue cracking (% lane area) | 25.00    | 8.28        | Pass                |
| AC top-down fatigue cracking (ft/mile)      | 2,000.00 | 2,800.40    | Fail               |
| AC thermal cracking (ft/mile)               | 1,000.00 | 84.34       | Pass                |
| Permanent deformation - total pavement (in)  | 0.75     | 0.52        | Pass                |
| AC only permanent deformation (in)          | 0.25     | 0.07        | Pass                |
| Terminal IRI (in/mile)                      | 172.00   | 147.61      | Pass                |
Table 3.9 Calcium chloride (CaCl2) Section Prediction Summary Using a Twenty Year Design Life

### Design Inputs

| Layer Type                          | Thickness | Laboratory         | Mr (psi)   |
|-------------------------------------|-----------|---------------------|------------|
| Flexible                            | 2.00      |                     |            |
| Flexible                            | 2.50      |                     |            |
| Cold recycled (FDR RAP)             | 8.00      | Bradshaw et al., 2015 | 43,890    |
| Non-stabilized (1980 Virgin RAP)    | 1.00      | Bradshaw et al., 2015 | 31,510    |
| Non-stabilized (Ex. gravel borrow)  | 8.00      | Lee et al., 2003    | 13,620     |
| Subgrade                            | Semi-infinite |                     | 9,304      |

### Design Outputs

| Distress                                           | Target | Predicted     | Criterion Satisfied |
|----------------------------------------------------|--------|---------------|---------------------|
| AC bottom-up fatigue cracking (% lane area)        | 25.00  | 5.63          | Pass                |
| AC top-down fatigue cracking (ft/mile)             | 2,000.00 | 2,585.29     | Fail                |
| AC thermal cracking (ft/mile)                      | 1,000.00 | 84.84       | Pass                |
| Permanent deformation - total pavement (in)        | 0.75   | 0.51          | Pass                |
| Permanent deformation - AC only (in)               | 0.25   | 0.07          | Pass                |
| Terminal IRI (in/mile)                             | 172.00 | 147.20        | Pass                |
Table 3.10 Portland Cement Section Distress Prediction Summary using a Twenty Year Design Life

### Design Inputs

| Layer Type                      | Thickness | Laboratory         | Mr (psi)  |
|---------------------------------|-----------|---------------------|-----------|
| Flexible                        | 2.00      |                     |           |
| Flexible                        | 2.50      |                     |           |
| Cold recycled (FDR RAP)         | 8.00      | Bradshaw et al., 2015 | 70,240.00 |
| Non-stabilized (1980 Virgin RAP)| 1.00      | Bradshaw et al., 2015 | 27,170.00 |
| Non-stabilized (Ex. gravel borrow) | 8.00   | Lee et al., 2003    | 13,620.00 |
| Subgrade                        | Semi-infinite | Lee et al., 2003 | 9,304.00 |

### Design outputs

| Distress                           | Target | Predicted | Criterion Satisfied |
|------------------------------------|--------|-----------|---------------------|
| AC bottom-up fatigue cracking (% lane area) | 25.00  | 2.19      | Pass                |
| AC top-down fatigue cracking (ft/mile)    | 2,000.00 | 1,782.67  | Pass                |
| AC thermal cracking (ft/mile)           | 1,000.00 | 84.84     | Pass                |
| Permanent deformation - total pavement (in) | 0.75   | 0.49      | Pass                |
| Permanent deformation - AC only (in)     | 0.25   | 0.07      | Pass                |
| Terminal IRI (in/mile)                | 172.00 | 145.42    | Pass                |
### Table 3.11 Asphalt Emulsion Prediction Summary Using a Twenty Year Design Life

#### Design Inputs

| Layer Type                        | Thickness | Laboratory        | Mr (psi) |
|-----------------------------------|-----------|-------------------|----------|
| Flexible                          | 2         |                   |          |
| Flexible                          | 2.5       |                   |          |
| Cold recycled (FDR RAP)           | 3         | Bradshaw et al., 2015 | 31,420   |
| Cold recycled (FDR RAP)           | 5         | Bradshaw et al., 2015 | 26,440   |
| Non-stabilized (Ex. gravel borrow)| 8         | Lee et al., 2003  | 13,620   |
| Subgrade                          | Semi-infinite | Lee et al., 2003  | 9304     |

#### Design Outputs

| Distress                          | Target | Predicted | Criterion Satisfied |
|-----------------------------------|--------|-----------|---------------------|
| AC bottom-up fatigue cracking (% lane area) | 25     | 17.38     | Pass                |
| AC top-down fatigue cracking (ft/mile)  | 2000   | 3502.66   | Fail                |
| AC thermal cracking (ft/mile)        | 1000   | 84.84     | Pass                |
| Permanent deformation - total pavement (in) | 0.75   | 0.54      | Pass                |
| Permanent deformation - AC only (in) | 0.25   | 0.07      | Pass                |
| Terminal IRI (in/mile)             | 172    | 149.55    | Pass                |
Table 3.12 Geo-Grid Prediction Summary Using a Twenty Year Design Life

### Design Inputs

| Layer Type                  | Thickness | Laboratory          | Mr (psi)  |
|-----------------------------|-----------|---------------------|-----------|
| Flexible                    | 2         |                     |           |
| Flexible                    | 2.5       |                     |           |
| Cold recycled (FDR RAP)     | 10        | Bradshaw et al., 2015 | 30,040    |
| Cold recycled (FDR RAP)     | 5         | Bradshaw et al., 2015 | 13,620    |
| Subgrade                    | Semi-infinite | Lee et al., 2003   | 9304      |

### Design Outputs

| Distress                               | Target | Predicted | Criterion Satisfied |
|----------------------------------------|--------|-----------|---------------------|
| AC bottom-up fatigue cracking (% lane area) | 25     | 16.66     | Pass                |
| AC top-down fatigue cracking (ft/mile)  | 2000   | 3,367.31  | Fail                |
| AC thermal cracking (ft/mile)           | 1000   | 84.84     | Pass                |
| Permanent deformation - total pavement (in) | 0.75   | 0.51      | Pass                |
| Permanent deformation - AC only (in)    | 0.25   | 0.07      | Pass                |
| Terminal IRI (in/mile)                  | 172    | 148.35    | Pass                |
Table 3.13 Comparison of Performance Predictions

| Design Outputs                                      | Control | CaCl2   | Asphalt Emulsion | Portland Cement | Geo-Grid |
|-----------------------------------------------------|---------|---------|-------------------|------------------|----------|
| AC bottom-up fatigue cracking (% lane area)         | Target  | Predicted | Predicted | Predicted | Predicted | Predicted |
| AC top-down fatigue cracking (ACTDFC) (ft/mile)     | 2,000.00 | 2,800.40 | 2,585.29 | 3,502.66 | 1,782.67 | 3,367.31 |
| AC thermal cracking (ft/mile)                       | 1,000.00 | 84.34   | 84.34   | 84.84   | 84.34   | 84.34   |
| Permanent deformation - AC only (in)                | 0.25    | 0.07    | 0.07    | 0.07    | 0.07    | 0.07    |
| Permanent deformation - total pavement (in)         | 0.75    | 0.52    | 0.51    | 0.54    | 0.49    | 0.51    |
| Terminal IRI (in/mile)                              | 172.00  | 147.61  | 147.20  | 149.55  | 145.42  | 148.35  |
| Years to predicted threshold distress ACTDFC (Years)| 8       | 10      | 4.0     | 25      | 5       |
Figure 3.1 Grain Size Distribution for all 1980 RAP/Virgin Blend Samples

(Bradshaw et al., 2015)
Figure 3.2 Grain Size Distribution for all FWD Samples

(Bradshaw et al., 2015)
Figure 3.3 Vehicle Classification according to FHWA

| FHWA Vehicle Classifications |
|--------------------------------|
| 1. Motorcycle                  | 5. Single Unit 3-Axle Truck  |
| 3 axes; 2 or 3 tires           | 5. Single Unit 3-Axle Trucks |
| 2. Passenger Cars              | 6. Single Unit 4 or More-Axle Trucks |
| 7 axles, car type 1 or 2 axle ratio | 4 or more axles, single unit |
| 3. Pickup, Panel, Van          | 7. Single Unit 4 or More-Axle Trucks |
| 3 axles, car type 1 or 2 axle ratio | 4 or more axles, single unit |
| 4. Bus                         | 8. Single Unit 5 or More-Axle Trucks |
| 2 or 3 axles, full length      | 9. Single Unit 5 or More-Axle Trucks |
| 5. Single Unit 5 or More-Axle Trucks | 6 or more axles, single trailer |
| 6. Single Unit 6 or More-Axle Trucks | 10. Single Unit 6 or More-Axle Trucks |
| 9 axles, single trailer        | 10. Multi-Trailer 3- or 4-Axle Trucks |
| 11. Multi-Trailer 6 or More-Axle Trucks | 8 or more axles, multiple trailers |
| 6 or more axles, multiple trailers | 12. Multi-Trailer 7 or More-Axle Trucks |
| 7 or more axles, multiple trailers |

Http://onlinemanuals.txdot.gov/txdotmanuals/tri/images/FHWA_Classification_Chart_Final.png
4.1 Surface Distresses and Field Condition Survey

On December 21, 2015, pavement windshield surveys were conducted on Route 165 by both URI Graduate students and Professor K. Wayne Lee and the results of these surveys are shown in Appendix D. Five pavement sections (10 feet wide x 100 feet in length) were selected near utility poles, previous FWD testing sites, and permanent land markers, for ease of identification.

The pavement sections did not show any low, moderate or severe pavement distresses such as rutting or cracking but there were signs of minor raveling of the pavement. No major defects were expected since the pavement was recently placed in the summer of 2014. As a result, these December field surveys would become the base line for continuous monitoring of this road by URI students.

In addition to conducting the windshield surveys, the Rhode Island Department of Transportation has on-going contracts with vendors whose responsibilities include measuring the IRI, rutting and cracking using vehicles equipped with computers, cameras, and lasers. Information is down-loaded into a Deighton’s Total Infrastructure Management System (dTIMS) management database in the form of photographs, pavement defect data, and locations. DTIMS functions include three types of scoring: (1) a cross tab transformation to rate distresses and severity levels; (2) expression and formula transformations to place a deduct value from sample areas and calculate a pavement condition index (PCI), respectively; and structured table outputs with column and rows.
4.1.1 Permanent Deformation and Rutting

No deformation or rutting to report.

4.1.2 Fatigue Cracking

No fatigue cracking to report.

4.1.3 Thermal Cracking

No thermal cracking to report.

4.2 Serviceability and Roughness

4.2.1 International Roughness Index

MED predicts terminal International Roughness Index (IRI) or smoothness in inches per mile. Using parameters which are input into the program, the target, predicted, and reliability models are calculated and are shown on page one of the MED reports. The targeted value of 172 inch/miles is considered the upper limit found acceptable by AASHTOWare, IRI values under 95 inch/mile are ranked as acceptable. Table 4.1 shows both the results of the individual test pavement reports from MED and the final IRI which were done by the RIDOT Material Section for bonus/penalty performance. Page 12 of each of the MED reports (Refer to Appendix A) show that the starting IRI is between 70 and 95
inch/mile. The contractor’s final IRI, shown in Appendix E, came in as low as 58 inch/mile to 88 inch/mile for the west bound lane, as available. All of the test sections passed and the MED predicts the IRI will not reach the upper 172 inch/mile limit for approximately twenty years. The contractor received a bonus for his IRI results.

Currently, RIDOT performs regular IRI tests on its roadways to monitor pavement performance over time. Based on pavement performance and distress type, Page 12 of the MED Analysis Output Charts show the IRI values increasing over time. Thus, based on these distresses and calculated MED IRI, it seems feasible that RIDOT would be able to compare their field generated values to the predicted charts in order to track performance of the MED.

4.3 Structural Capacity and Deflection

In an effort to predict roadway deflection, the RIDOT recently utilized its recently refurbished Kuab Falling Weight Deflectometer (FWD) on Route 165 which, incidentally, was one of the first roads it was used on. FWD results can be used to determine in situ resilient moduli of both the subgrade and subbase by back and forward calculations. RIDOT has been using FWD on their roads for years but, unfortunately, was neither able to internally interpret the results nor perform back calculations successfully. Until now, an unexpected discovery was made on interpreting the FWD deflections through the Long Term Pavement Performance Hogg Method (Refer to Appendix F).
The results of the resilient moduli from both Figures 3.3 and the Hogg Method shown in Table 4.2 show promise but warrant further evaluation. It is assumed that the better Mr values from the Hogg Method are due to the calibrated sensors and computer upgrades.

The Hogg Method uses a Long Term Pavement Performance (LTPP) Excel spreadsheet to calculate moduli which can then be used to predict pavement performance. Deflection data, corresponding back-calculated moduli, or other deflection-based parameters strongly relate to pavement performance, and the premise of mechanistic-empirical design methods is to control stresses and strains as a response to traffic.” (LTPP, 2006). The Hogg Method is based on the work of J. Boussinesq, 1885, whose equations estimate vertical soil stresses:

\[
\theta_z = \frac{Q(3z^3)}{2\pi (R^2 + z^2)^{3/2}}
\]

\(Q = \) point load

\(z = \) depth from ground surface to the place where \(\theta_z\) is desired

\(R = \) horizontal distance from point load to the place where \(\theta_z\) is desired.

There are cautions, however, with the use of the Hogg Method which state that the forward-calculated modulus data is not intended to replace back-calculated or any other form of modulus of elasticity measurements. The question becomes how realistic are the estimates for pavement evaluation and/or design? There are four approaches to evaluate
and determine in situ stiffness, and distresses (LTPP, 2006) and they are (1) the triaxial tests, (2) AASHTOPavement ME design, (3) dTIMS and the (4) Hogg Method. The dTIMS results can be compared to the predictions of the MED which in turn can be used back calculate the Mr. The Mr values can then be verified by laboratory testing and the Hogg Method. Any previously reclaimed roadway which had been reclaimed can be de-constructed, if you will, to verify all parameters.

4.4 Analysis of Ground Penetrating Radar (GPR)

Ground penetrating Radar (GPR) was performed on Route 165 in June, 2015 after the final surface course was placed. The original, existing pavement thickness for each test section varied from 4.13 inches to 4.55 inches. The average core thickness for the Class 12.5 WMA pavement was 2.29 inches and the average pavement thickness for the 19mm pavement was 2.81 inches. The GPR was used to confirm that the roadway was being constructed according to RIDOT specifications. In areas where the pavement thickness varied between 4.13 and 4.21 inches, the west-bound geo-grid test, Portland cement, and recycled sections need to be monitored for possible premature cracking because of the relatively small pavement thickness. (Pavement thickness is an input parameter within both the Hogg Method and MED). (Refer to Appendix G)
4.5 Comparative Analysis between Performance Prediction and Evaluation

After the MED reports for the five test sections were run, the MED output showed AC top down fatigue cracking (longitudinal cracking) as the only output distress in four of the five test sections (Table 4.3). The predicted distress was over the target or threshold value. The target value represents the amount of distress that would trigger some type of major rehabilitation activity (AASHTO, 2015). According to the MED report, using the asphalt emulsion and Portland cement test sections, for example, it would take five years to reach the two thousand feet per mile for AC top down cracking for the asphalt emulsion but twenty years for Portland cement. AC top down cracking is due to the pavement layer being too thin and a low Mr. In the test sections as shown in Table 4.4 to Table 4.7, extra pavement thickness, cost analysis, and years to failure, MED inputs were re-run to see what would cause the predicted AC top down cracking to go below the two thousand target threshold.

Thus, based on the aforementioned, we know that it will take a number of years before the threshold distress can be predicted for the five test sections i.e control, CaCl₂, asphalt emulsion, Portland cement, and geo-grid. We do know that year number eight is the “unofficial” time where pavements start showing distress and will most likely need to receive some form of maintenance treatment e.g crack sealing; chip seal. That said, the asphalt emulsion and geo-grid test sections are predicted to need treatment in four and five years in this study, with predicted AC top down cracking of 3,502 ft/mile and 3,367 ft/mile.
It was surprising to see how high the AC top down fatigue cracking number in the asphalt emulsion test section because the material has been successfully used as an FDR additive in many states.

4.5.1 Control Test Section

According to Table 4.4, the control section was predicted to reach a threshold distress in AC top down cracking in eight years. If the pavement thickness had been increased by one inch, all of the predicted values would have been below the target thresholds for twenty years. The down side to this would have been the approximately $526,000 in additional costs for 8,552 tons of asphalt pavement. The yearly cost for eight years is $332,676 and $159,368 for twenty years. The total cost with the extra asphalt pavement, the control test section ranks two out of five.

4.5.2 Calcium Chloride Section

The CaCl\textsubscript{2} section is predicted to reach a threshold of 2,585 linear feet of AC top down fatigue cracking (longitudinal cracking) in ten years see Table 4.5. If the pavement thickness had been increased by one inch, all of the predicted values would have been below the target thresholds for twenty years. The down side to this would have been the approximately $526,000 in additional costs for 8,552 tons of asphalt pavement. The yearly
cost for ten years is $364,715 and $208,655 for twenty years. The total cost with the extra pavement, the calcium chloride section ranks four out of five.

4.5.3 Portland Cement Section

In Table 4.6, the Portland cement section, which had the highest Mr of any of the other sections, should not show any distress until roughly year thirty and it is in the terminal IRI (in/mile). In spite of this, the cement was not allowed to fully cure for seven days and thus micro-cracked after four hours. From Table 3.5, the Mr would have been 126,000 psi (mean of the Mr for the 35 kPa confining stress) if traffic had not been allowed on the travel lane. Both the width of the road and the traffic volumes prevented one lane from being closed for the seven days since a detour was not feasible. The cost for twenty-five years would be $158,206. The total cost with the extra pavement, the Portland cement section ranks first out of five.

4.5.4 Asphalt Emulsion Section

According to Table 4.7, the asphalt emulsion section was predicted to reach a threshold distress in AC top down cracking in four years. If the pavement thickness had been increased by one and a half inch, all of the predicted values would have been below the target thresholds. The down side to this would be the increased cost of 12,828 tons of asphalt needed to reach the additional thickness. The $788,000 is a high price to pay for fifteen additional service years. But the cost for four years would be $742,351 and $187,916 for twenty years. The total cost with the extra pavement, the calcium chloride section ranks three out of five.
4.5.5 Geogrid Section

According to Table 4.8, the geo-grid section was predicted to reach a threshold distress in AC top down cracking in five years. If the pavement thickness had been increased by one and a half inch, all of the predicted values would be below the target thresholds and the pavement would not see any predicted cracking for twenty years. The down side would be the increased cost of $788,000.00 for 12,828 tons of asphalt pavement. The up side, however, would be an increase in fifteen additional service years. The yearly cost for ten years is $1,326,543 and $357,933 for twenty years. The total cost with the extra pavement, the geo-grid section ranks five out of five.

4.6 Selection of Best Alternatives Based on Short-Term Evaluation

4.6.1 Forecasting Future Performance through Tie-ins with Pavement Structural Health Index (PSHI)

MED can fit within the states’ preservation system by using performance indicators that dTIMS does not. For instance, dTIMS catalogues IRI, rutting, cracking and deformation through yearly field surveys, while MED uses AADTT, resilient modulus, pavement layer make-up, HMA properties, and climate to predict the same pavement distresses over time. DTIMS surveys the surface course and MED predicts the subsurface conditions. Thus, MED predictions can be adjusted accordingly.
4.6.2 Optimal Strategies for Rehabilitation

One finding of the MED, is determining the right combination of subbase Mr to pavement thickness. MED makes it very easy to run multiple models for worst and best case scenarios. Resurfacings and reclamations should have Mr values checked before construction to find if an additive would benefit the subbase stiffness. Monitoring pavement PSHI can catch a road before it deteriorates too far, but the subbase Mr should be evaluated before treatment is determined. For example, too many times RIDOT has milled two inches and put back two inches of pavement on a road only to have the pavement break up in a short amount of time. The MED reported output shows how longitudinal cracking can be a sign of too thin of a pavement thickness.

4.7 Guidelines for Long-Term Evaluation and Optimal Rehabilitation Design Strategies

A material database consisting of resilient moduli, pavement core data and sieve analysis needs to be created for easy reference for Design Engineers. The RIDOT has years of collected data but unfortunately no “on-line” database. URI, on the other hand, has already done extensive resilient moduli testing with seasonal variations on subbase and subgrade materials and needs to incorporate these results into the state’s database. The results of the testing should be included in one main database along with any new testing done. (Lee et al., 2001)

LTPP currently has a Microsoft Excel Program that uses falling weight deflectometer (FWD) deflections to predict resilient moduli of the asphalt layers, subbase and subgrade materials. The program, however, requires pavement and subbase thicknesses
as input parameters which a GPR can provide. FWD testing is already being performed on state highways and this information should be appropriately documented and compiled into a database.

The Materials Sections has equipment that performs tests that the Design Engineer needs to incorporate into their designs. A list of capabilities of this equipment should be shared.

RIDOT’s Pavement Committee, currently made up of personnel from the Materials, Design, and Construction Sections, oversees all pavement designs on both reconstruction and resurfacing projects. Usually the only information available/discussed during the meetings include sieve analysis data, pavement cores, and traffic AADT. It is a mistake not to have subbase Mr and MED reports at that meeting.
### Table 4.1  Comparison of Performance Predictions for IRI

| Distress, Terminal IRI (in/mile) | Control | CaCl2 | Asphalt Emulsion | Portland Cement | Geo-grid |
|----------------------------------|---------|-------|------------------|-----------------|----------|
| Target                           | 172.00  | 144.78| 143.93           | 145.39          | 142.65   |
| Predicted                        | Predicted | Predicted | Predicted | Predicted | Predicted |
| Average Final rideability Results Rte 165 - WB (in/mi) Left/right lane. Initial IRI = 63 | 58.4/46.9 | 44/40.43 | 65.8/88.9 | 64.3/52.9 | 63.7/56.7 |

Values from the RIDOT Material Section
| Material Type | Sample | Lab results* Range in psi | Confining Stress 21 kPa to 138 kPa | Average lab Results psi | Hogg Model Range in psi | Average Hogg Method Mr - psi |
|---------------|--------|---------------------------|-------------------------------------|-------------------------|-------------------------|-----------------------------|
| Cold Recycled | 7a     | 25,961 - 58,015           | 41,988                              | 33,961-62,284           | 51,942                  |
| Cold Recycled | 7b     | 34,809 - 83,831           | 59,320                              | 33,961-62,284           | 51,942                  |
| CaCl 1        | 1      | 36,549 - 82,381           | 59,465                              | 47,749-62,608           | 53,598                  |
| Cement 4 hour | 4a     | 55,984 - 107,037          | 81,510                              | 40,940-58,273           | 50,486                  |
| Cement 7 day  | 4b     | 76,579 - 275,281          | 175,930                             | 40,940-58,273           | 50,486                  |
| Asphalt Emulsion | 5     | 25,816 - 53,808          | 39,812                              | 36,596-47,076           | 41,959                  |
| Geo-Grid      | Not Tested | 23,164 - 40,997         | 34,414                              |                         |                         |

* Bradshaw, Costa, Giampa, Genovesi, and Hernberg, 2015
| Distress                                      | Target  | Control | CaCl₂  | Asphalt Emulsion | Portland Cement | Geo-Grid |
|----------------------------------------------|---------|---------|--------|------------------|-----------------|----------|
| AC bottom-up fatigue cracking (% lane area)  | 25.00   | 8.28    | 5.63   | 17.38            | 2.85            | 16.66    |
| AC top-down fatigue cracking (ACTDFC) (ft/mile) | 2,000.00 | 2,800.40 | 2,585.29 | 3,502.66       | 1,782.67       | 3,367.31 |
| AC thermal cracking (ft/mile)                | 1,000.00 | 84.34   | 84.34  | 84.84            | 84.34           | 84.34    |
| Permanent deformation - AC only (in)         | 0.25    | 0.07    | 0.07   | 0.07             | 0.07            | 0.07     |
| Permanent deformation - total pavement (in)  | 0.75    | 0.52    | 0.51   | 0.54             | 0.49            | 0.51     |
| Terminal IRI (in/mile)                       | 172.00  | 147.61  | 147.20 | 149.55           | 145.42          | 148.35   |
| Years to predicted threshold distress ACTDFC (Years) | 8       | 10      | 4      | 25               | 5               |          |
### Table 4.4 Control Section (Cold Recycled) - Pavement Performance

| Design Outputs | 2.5” Class 19 WMA Base | Additional 1” of Class 19 WMA Base (3.5”) |
|----------------|------------------------|----------------------------------------|
|                | Distress               | Target | Predicted | Predicted |
| AC bottom-up fatigue cracking (% lane area) | 25.00 | 8.28 | 2.01 |
| AC top-down fatigue cracking (ft/mile) | 2,000.00 | 2,800.40 | 1,840.61 |
| AC thermal cracking (ft/mile) | 1,000.00 | 84.34 | 84.34 |
| Permanent deformation - total pavement (in) | 0.75 | 0.52 | 0.47 |
| AC only permanent deformation (in) | 0.25 | 0.07 | 0.07 |
| Terminal IRI (in/mile) | 172.00 | 147.61 | 144.71 |
| 1” Additional tons of asphalt for 7 miles | 0 | 4,276.00 |
| Class 19 WMA @ $61.50/ton cost | 0 | $262,974.00 |
| Years to predicted threshold distress ACTDFC (Years) | 8 | 20 |
| Additional years of Service | 0 | 12 |

### Cost Analysis per Year for the Control Section (Cold Recycled) (2.5”)

| Unit cost | Item | Quantity | Amount |
|-----------|------|----------|--------|
| $92.50    | 2”   | Class 12 WMA * | 21,380 | $1,238,303 |
| $61.50    | 2.5” | Class 19 WMA | 20,135 | $1,238,303 |
| $1.50     | 8”   | Subbase | 123,200 | $184,800 |
|           |      | Total | $2,661,405 |
|           |      | 8 year Life cycle cost / year | $332,676 |

### Cost Analysis per Year for the Control Section (Cold Recycled) (3.5”)

| Unit cost | Pavement Thickness | Item | Quantity | Unit | Amount |
|-----------|--------------------|------|----------|------|--------|
| $92.50    | 2”                 | Class 12 WMA * | 20,135 | Ton | $1,238,303 |
| $61.50    | 3.5”               | Class 19 WMA | 28,687 | Ton | $1,764,251 |
| $1.50     | 8”                 | Subbase | 123,200 | SY | $184,800 |
|           |                    | Total | $3,187,353 |
|           |                    | 20 year Life cycle cost / year | $159,368 |

* WMA quantity had extra tons for berm and paved waterways.
Figure 4.5 Calcium Chloride Pavement Performance

| Design Outputs                  | 2.5” Class 19 WMA Base | Additional 1” of Class 19 WMA Base (3.5”) |
|--------------------------------|------------------------|------------------------------------------|
| **Distress**                    | **Target**             | **Predicted**                            | **Predicted** |
| AC bottom-up fatigue cracking (% lane area) | 25.00                  | 5.63                                     | 1.94          |
| AC top-down fatigue cracking (ft/mile) | 2,000.00               | **2,585.29**                             | 1,635.07      |
| AC thermal cracking (ft/mile)    | 1,000.00               | 84.84                                   | 84.84         |
| Permanent deformation - total pavement (in) | 0.75                   | 0.51                                     | 0.47          |
| Permanent deformation - AC only (in) | 0.25                   | 0.07                                     | 0.07          |
| Terminal IRI (in/mile)           | 172.00                 | 147.20                                   | 144.47        |
| Years to predicted threshold distress ACTDFC (years) | 10.00                   | 20.00                                    |
| 1” Additional tons of asphalt for 7 miles | 0.00                  | 8,552.00                                 |
| Class 19 WMA @ $61.50/ton        | 0                      | $525,948.00                              |
| Additional years of service      | 0                      | 10                                       |

Cost Analysis per Year for Calcium Chloride (2.5”)

| Unit cost | Pavement Thickness | Item           | Quantity | Unit | Amount         |
|-----------|--------------------|----------------|----------|------|----------------|
| $92.50    | 2”                 | Class 12 WMA * | 21,380   | Ton  | $1,977,650.00  |
| $61.50    | 2.5”               | Class 19 WMA   | 20,135   | Ton  | $1,238,302.50  |
| $3.50     | 8”                 | Subbase        | 123,200  | SY   | $431,200.00    |
|           |                    | **Total**      |          |      | **$3,647,152.50** |

**10 year Life cycle cost / Year**

$364,715.25

Cost Analysis per Year for Calcium Chloride (3.5”)

| Unit cost | Pavement Thickness | Item            | Quantity | Unit | Amount         |
|-----------|--------------------|-----------------|----------|------|----------------|
| $92.50    | 2”                 | Class 12 WMA *  | 21,380   | Ton  | $1,977,650.00  |
| $61.50    | 3.5”               | Class 19 WMA    | 28,687   | Ton  | $1,764,250.50  |
| $3.50     | 8”                 | Subbase         | 123,200  | SY   | $431,200.00    |
|           |                    | **Total**       |          |      | **$4,173,100.50** |

**20 year Life Cycle Cost / Year**

$208,655.03

* WMA quantity had extra tons for berm and paved waterways.
Figure 4.6 Portland Cement Pavement Performance for 25 years

| Design Outputs | 2.5” Class 19 WMA Base |
|----------------|-------------------------|
| **Distress**   | **Target** | **Predicted** |
| AC bottom-up fatigue cracking (% lane area) | 25.00 | 2.80 |
| AC top-down fatigue cracking (ft/mile) | 2,000.00 | 1,990.66 |
| AC thermal cracking (ft/mile) | 1,000.00 | 84.84 |
| Permanent deformation - total pavement (in) | 0.75 | 0.51 |
| Permanent deformation - AC only (in) | 0.25 | 0.08 |
| Terminal IRI (in/mile) | 172.00 | 160.78 |
| Years to predicted threshold distress ACTDFC (years) | 25.00 |
| Additional tons of asphalt | 0.00 |
| Additional cost per ton $61.50 | 0 |
| Additional years of service past 20 years | 5 |

| Cost Analysis | Cost Analysis per Year for the Portland Cement (2.5”) |
|---------------|-------------------------------------------------------|
| **Unit cost** | **Pavement Thickness** | **Item** | **Quantity** | **Unit** | **Amount** |
| $92.50       | 2”          | Class 12 WMA * | 21,380    | Ton     | $1,977,650.00 |
| $61.50       | 2.5”        | Class 19 WMA   | 20,135    | Ton     | $1,238,302.50 |
| $6.00        | 8”          | Subbase        | 123,200   | SY      | $739,200.00   |
| **Total**    |             |                |           |         | $3,955,152.50 |
| **25 year Life cycle cost / Year** | $158,206.10 |

* WMA quantity had extra tons for berm and paved waterways.
Table 4.7 Asphalt Emulsion Pavement Performance

| Design Outputs                                                                 | 2.5" Class 19 WMA Base | Additional 1.5" of Class 19 WMA Base (4") |
|--------------------------------------------------------------------------------|-------------------------|--------------------------------------------|
| Distress                                                                       | Target                  | Predicted       | Predicted       |
| AC bottom-up fatigue cracking (% lane area)                                    | 25.00                   | 17.38          | 1.95            |
| AC top-down fatigue cracking (ft/mile)                                         | 2,000.00                | 3502.66        | 1,744.64        |
| AC thermal cracking (ft/mile)                                                  | 1,000.00                | 84.84          | 84.84           |
| Permanent deformation - total pavement (in)                                    | 0.75                    | 0.54           | 0.46            |
| Permanent deformation - AC only (in)                                           | 0.25                    | 0.07           | 0.07            |
| Terminal IRI (in/mile)                                                         | 172.00                  | 149.55         | 144.38          |
| Years to predicted threshold distress ACTDFC (years)                           | 4.00                    | 20.00          |                 |
| 1.5 " Additional tons of asphalt for 7 miles                                   | 0.00                    |                | 12,828.00       |
| Class 19 WMA @ $61.50/ton cost                                                 | 0.00                    |                | $788,922.00     |
| Additional years of service                                                    | 0.00                    |                | 16              |

Cost Analysis per Year for the Asphalt Emulsion (2.5")

| Unit cost | Pavement Thickness | Item          | Quantity | Unit  | Amount          |
|-----------|--------------------|---------------|----------|-------|-----------------|
| $92.50    | 2"                 | Class 12 WMA *| 21,380   | Ton   | $1,238,302.50   |
| $61.50    | 2.5"               | Class 19 WMA  | 20,135   | Ton   | $1,238,302.50   |
| $4.00     | 8"                 | Subbase       | 123,200  | SY    | $492,800.00     |

Total $2,969,405.00

4 year Life cycle cost / Year $742,351.25

Cost Analysis per Year for the Asphalt Emulsion (4")

| Unit cost | Pavement Thickness | Item          | Quantity | Unit  | Amount          |
|-----------|--------------------|---------------|----------|-------|-----------------|
| $92.50    | 2"                 | Class 12 WMA *| 21,380   | Ton   | $1,238,302.50   |
| $61.50    | 4"                 | Class 19 WMA  | 32,963   | Ton   | $2,027,224.50   |
| $4.00     | 8"                 | Subbase       | 123,200  | SY    | $492,800.00     |

Total $3,758,327.00

20 year Life Cycle Cost /Year $187,916.35

* WMA quantity had extra tons for berm and paved waterways.
Table 4.8 Geo-Grid Pavement Performance for 20 years

Design Outputs

| Distress                                         | Target | 2.5” Class 19 WMA Base | 1.5” of Class 19 WMA Base (4”) |
|--------------------------------------------------|--------|-------------------------|-------------------------------|
| AC bottom-up fatigue cracking (% lane area)      | 25.00  | 16.66                   | 1.94                          |
| AC top-down fatigue cracking (ft/mile)           | 2,000.0| 3,367.31                | 1,734.15                      |
| AC thermal cracking (ft/mile)                    | 1,000.0| 84.84                   | 84.34                         |
| Permanent deformation - total pavement (in)      | 0.75   | 0.51                    | 0.45                          |
| Permanent deformation - AC only (in)             | 0.25   | 0.07                    | 0.07                          |
| Terminal IRI (in/mile)                           | 172.00 | 148.35                  | 143.69                        |
| Years to predicted threshold distress ACTDFC (years) | 5.00 | 20.00                   |                               |
| 1.5 ” Additional tons of asphalt 7 miles         | 0.00   | 12,828.00               |                               |
| Class 19 WMA @ $61.50/ton cost                   | 0      | $788,922.00             |                               |
| Additional years of service                      | 0      | 15                      |                               |

Cost Analysis per Year for the Geo-Grid Section (2.5”)

| Unit cost | Pavement Thickness | Item                     | Quantity | Unit  | Amount       |
|-----------|--------------------|--------------------------|----------|-------|--------------|
| $92.50    | 2”                 | Class 12 WMA *           | 21,380   | Ton   | $1,238,302.50|
| $61.50    | 2.5”               | Class 19 WMA             | 20,135   | Ton   | $1,238,302.50|
| $1.50     | 10”                | Cold recycled (FDR RAP)  | 32,963   | SY    | $49,444.50   |
| $15.00    | Geo-grid Layer     | 246,400                  |          | SY    | $3,696,000.00|
| $20.00    | 6”                 | Filter stone             | 20,533   | CY    | $410,666.67  |
|           | Total              |                          |          |       | $6,632,716.17|

5 year Life Cycle Cost / Year $1,326,543.23

Cost Analysis per Year for the Geo-Grid Section (4”)

| Unit cost | Pavement Thickness | Item                     | Quantity | Unit  | Amount       |
|-----------|--------------------|--------------------------|----------|-------|--------------|
| $92.50    | 2”                 | Class 12 WMA *           | 21,380   | Ton   | $1,238,302.50|
| $61.50    | 4”                 | Class 19 WMA             | 28,687   | Ton   | $1,764,250.50|
| $1.50     | 10”                | Cold recycled (FDR RAP)  | 32,963   | SY    | $49,444.50   |
| $15.00    | Geo-grid Layer     | 246,400                  |          | SY    | $3,696,000.00|
| $20.00    | 6”                 | Filter Stone             | 20,533   | CY    | $410,666.67  |
|           | Total              |                          |          |       | $7,158,664.17|

20 year Life Cycle Cost / Year $357,933.21

* WMA quantity had extra tons for berm and paved waterways.
Table 4.9  Comparison of Years of Predicted Threshold Distress and Cost

| Distress                                    | Target | Predicted | Predicted | Predicted | Predicted | Predicted |
|---------------------------------------------|--------|-----------|-----------|-----------|-----------|-----------|
| Class 10 WMA as built                       |        | 2.5"      | 2.5"      | 2.5"      | 2.5"      | 2.5"      |
| AC bottom-up fatigue cracking (% lane area) | 25.00  | 8.28      | 5.63      | 17.38     | 2.85      | 16.66     |
| AC top-down fatigue cracking (ACTDFC (ft/mile)) | 2,000.00 | 2,800.40 | 2,585.29 | 3,502.66 | 1,782.67 | 3,367.31 |
| AC thermal cracking (ft/mile)               | 1,000.00 | 84.34     | 84.34     | 84.84     | 84.34     | 84.34     |
| Permanent deformation - AC only (in)        | 0.25   | 0.07      | 0.07      | 0.07      | 0.07      | 0.07      |
| Permanent deformation - total pavement (in) | 0.75   | 0.52      | 0.51      | 0.54      | 0.49      | 0.51      |
| Terminal IRI (in/mile)                      | 172.00 | 147.61    | 147.20    | 149.55    | 146.42    | 148.35    |
| Years to predicted threshold distress - ACTDFC (Years) | 8      | 10        | 4         | 25        | 5         |
| Cost of pavement structure (Class 12.5, Class 19, subbase) | $2,661,405 | $3,647,153 | $2,969,405 | $3,955,153 | $6,632,716 |
| Cost of pavement structure/ACTDFC per year for 7 miles | $332,676  | $364,715 | $742,351 | $158,206 | $1,326,543 |
Table 4.10  Cost Comparison for Thicker Class 19 Base Course

| Design Outputs                                      | Control | CaCl2 | Asphalt Emulsion | Portland Cement | Geo-Grid |
|-----------------------------------------------------|---------|-------|------------------|-----------------|----------|
| Distress                                             | Target  | Predicted | Predicted | Predicted | Predicted | Predicted |
| Class 19 WMA revised thickness                       | 3.5"    | 3.5"   | 4"              | 2.5"           | 4"       |
| AC bottom-up fatigue cracking (% lane area)          | 25.00   | 2.01   | 1.94            | 1.95           | 2.85     | 1.95     |
| AC top-down fatigue cracking (ACTDFC) (ft/mile)      | 2,000.00| 1,840.61| 1,635.07       | 1,744.64       | 1,782.67 | 1,744.64 |
| AC thermal cracking (ft/mile)                        | 1,000.00| 84.34  | 84.84           | 84.84          | 84.84    | 84.84    |
| Permanent deformation - AC only (in)                 | 0.25    | 0.47   | 0.47            | 0.46           | 0.07     | 0.46     |
| Permanent deformation - total pavement (in)          | 0.75    | 0.07   | 0.07            | 0.07           | 0.49     | 0.07     |
| Terminal IRI (in/mile)                               | 172.00  | 144.71 | 144.47          | 144.38         | 145.42   | 144.38   |
| Years to predicted threshold distress ACTDFC (Years) | 20      | 20     | 20              | 25             | 20       |
| Cost of pavement structure (Class 12.5, Class 19, subbase) | $3,187,353 | $4,173,101 | $3,758,327    | $3,955,153    | $7,158,664 |
| Cost of pavement structure/ACTDFC per year for 7 miles| $159,368 | $208,655 | $187,916       | $158,206       | $357,933  |
Chapter 5

Conclusions and Recommendations

5.1 Findings

Five test sections with FDR and various additives were established on Rt. 165 in Exeter, RI to study the performance of the road with the help of the Rhode Island Department of Transportation (RIDOT). This study included research, laboratory triaxial testing of subbase materials and subgrade soils, rehabilitation performance predictions by AASHTOWare Pavement ME Design software, and a condition survey to come up with long term performance monitoring and optimum pavement rehabilitation strategies.

There were several findings while investigating the performance of the five test sections.

**Pavement Distress and Cost**

Of the five test sections, the section with Portland cement performed the best overall in having the least amount of distresses and the longest predicted service life; next is calcium chloride, followed by cold recycled (control), geo-grid, and asphalt emulsion. Table 4.8 shows the comparison of years of predicted threshold distress and cost for AC top down fatigue cracking (ACTDFC) in feet per mile. The AC top-down fatigue cracking and predicted years were
obtained from the AASHTOWare Pavement ME design software using the lab tested resilient moduli. According to the prediction models, in Table 4.8, the Portland cement section was the only section that doesn’t fail in the ACTDFC. In addition, is predicted to last over twenty-five years. The other test sections are predicted to reach the ACTDFC between five and ten years. The costs of the pavement structure for all the sections were between 2.6 million to 6.6 million dollars. The asphalt emulsion and geo-grid sections are not cost effective since they are predicted to reach threshold distress in a very short amount of time.

**Permanent Deformations, AC Bottom Up, Fatigue Cracking and Thermal Cracking**

None of the test sections are predicted to have permanent deformation, AC bottom up fatigue, or thermal AC cracking for over a twenty year period as shown in Table 4.3. Terminal IRI is predicted to be sixteen percent below the target goal for twenty years. Other distresses such as permanent deformation in the asphalt layer and AC bottom up fatigue cracking are predicted not to be present for twenty years. As discussed, AC top down fatigue cracking fails in all of the test sections except for Portland cement.

**Portland Cement Section**

It appears that Portland cement is an excellent additive, but the curing time can be a problem on narrow roads like Route 165 where detours are not possible. Detours drive up the costs for the project because of the additional traffic control and the delays to the traveling public. Portland cement should be considered for future projects only where a detour is feasible. Route 165 has
150 heavy trucks per day, and would benefit greatly from a more durable pavement like Portland cement. However this roadway could not support a detour therefore used alternating traffic was used for construction.

**Resilient Modulus**

The various test sections had different lab calculated resilient moduli. The higher the Mr value used, the less AC top down fatigue cracking. When comparing Tables 3.2 and 4.3, the pavement layers and reclamation depths are held constant. The only real change is the resilient modulus and the only distress that failed is the AC top down fatigue cracking. Portland cement has the highest Mr values and the predicted cracking is not expected to exceed the threshold for 25 years.

**Condition Survey**

Condition surveys from the dTIMS database can be used to verify the MED predictions of the five test sections. For this project, a windshield survey was completed after construction in 2015 and an automated survey for download into dTIMS. RIDOT will track the pavement performance for years to determine the best performance section.

**Pavement Performance**

Table 4.9 compares the predicted threshold distress and cost over twenty years for thicker Class 19.0 WMA base courses comparing the five test sections. The control, calcium chloride, asphalt emulsion and geo-grid test sections would be able to pass all distress targets over twenty years by increasing the thickness of the Class 19 WMA by one inch to one and a half inches. Table 4.9 provides material costs and the total cost per year for all the test sections. Table 4.8
compares the cost/year of each test section on Route 165. The order from least expensive to most expensive section is Portland cement, calcium chloride, control, asphalt emulsion, and geo-grid. Compare that to Table 4.9 for costs associated with the ideal pavement thickness and the order changes slightly as follows: Portland cement, control, calcium chloride, asphalt emulsion and geo-grid.

5.2 Recommendations

There are several recommendations that will be presented to RIDOT on how to increase pavement performance. They are:

1. Perform triaxial tests and FWD testing on subbase material on future FDR projects in the planning stage of design. Any subbase material which has less than 25,000 psi of resilient modulus should be modified with an additive to increase its stiffness. The number of triaxial tests and FWDs can be determined by how distressed the pavement is. The poorer the pavement condition, the more testing should be done to determine the cause of failure.

2. MED and PHSI have great potential to predict and monitor future performance of FDR roads. Thus, RIDOT may consider using both tools for the design of new reclaimated pavement structures.

3. The Hogg Method should be investigated to see if its results can be used as MED input data. The Excel program can be modified and calibrated to lab results to better fit the state’s subbase material. Triaxial tests can also be used to verify the Hogg Method results.

4. It is recommended that Portland cement should be used as an additive if there is heavy truck traffic and the pavement is wide enough to support detours or lane closures for at least the seven day recommended curing time without traffic loads.

5. Asphalt emulsion could be investigated further on another state road. Increasing the depth of the layer that contains emulsion from three inches to five or six inches could improve
performance, but it will increase the cost. We could analyze our predictions against the condition survey data from dTIMS to see how close the predictions were to the MED.

6. RIDOT leases the MED program from AASHTO on a yearly basis and should be renewed. Earlier versions of the MED were slow, but new software provides not only important prediction information but also runs in less than five minutes. The information that can be derived from MED can be highly useful if dTIMS, GPR, triaxial tests and/or FWDs are used in conjunction with the MED.

7. Collecting the data for the MED inputs took two weeks for all the test sections. All the information to do a Level 1 analysis is available but it is scattered throughout the RIDOT Departments. A library of pavement material, subbase resilient moduli, AADTT, cores, and GPR can improve collection time and prevent unnecessary extra testing.

8. If the RIDOT’s falling weight deflectometer and ground penetrating radar are to be used to determine the pavement stiffness and pavement thickness, these machines need to be calibrated on a regular basis and receive scheduled maintenance.

5.3 Conclusions

Overall, the Portland cement test section has the highest predicted performance, but is difficult to construct due to curing time and traffic detours on Route 165. Calcium chloride and the control sections were least expensive, but needed to have a thick base course which would increase cost. Geo-grid is typically used in poor drainage areas with high water tables on highways and has a high cost. Asphalt emulsions can work if either the asphalt emulsion is mixed to a deeper depth or an additional inch and a half of base course is used.

It should be interesting to see in the coming years how well the MED predictions for the test sections compare with the future distresses.
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