PERFORMANCE PREDICTION OF PAVEMENT REHABILITATING STRATIGIES

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A Rhode Island Highway, Route 165 in Exeter was rehabilitated in 2013 with five different strategies i.e., Control (without additive), Calcium Chloride, Asphalt Emulsion, Portland cement and Geogrid. The base/subbase layer was prepared by Full Depth Reclamation (FDR) method. The goal of the project was to predict the performance of pavement under different rehabilitation strategies and to select the best reclamation technique. The AASHTOWare Pavement ME Design software was used to predict performance. It requires four different categories of inputs, i.e., General information, Traffic input, Climatic input, and Material properties. General information includes pavement type and history. Traffic input data was provided by Rhode Island Department of Transportation (RIDOT) from Weighing in Motion (WIM) instrument embedded in pavement for this research study. The AASHTOWare Pavement ME design has an extensive number of weather stations embedded in its software for ease of use and implementation. Providence station in Rhode Island was selected for the present research study. Material properties required extensive testing which includes resilient modulus, dynamic modulus, creep compliance, thermal conductivity, poison's ratio and volumetric properties. Resilient moduli of subgrade soils, existing subbase layer, and reclaimed subbase/base layer with and without additives were determined at University of Rhode Island (URI). Dynamic modulus test was conducted at University of New Hampshire (UNH). Volumetric properties were determined by the RIDOT Material Section. Default values of the software were used for creep compliance, thermal conductivity and poison's ratio. It was observed from the outputs that asphalt concrete top down fatigue cracking happened on all strategies whereas the one with asphalt emulsion only passed for thermal cracking and permanent deformation in asphalt layer. It was also observed that the strategy with Portland cement performed the best whereas the one with asphalt emulsion did the worst, i.e., it would last for only 5 years. In summary, it was predicted that the reclaimed strategies in order of best performance were: Portland cement, calcium chloride, control, geo-grid and asphalt emulsion.

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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, 1990). Every 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 State agencies 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 M&R strategies, e.g., using subbase materials with reclaimed asphalt pavement (RAP), and has been expanding their use.

Reclaiming a roadway can increase the stiffness of the subbase and increase the pavement life. Savings of 25-50% have been realized over a full depth reclamation (FDR) according to the LA County Department of Public Works. Reclaimed materials are retained and reused on site, consequently reducing trucking costs for new materials.

In the 1980's, RIDOT had a program to reclaim pavements throughout the state. Route 165 was one of the roads and was programmed to be re-reclaimed using four different strategies and a control in 2013 (Figure 1).

Figure 1 A view of Route 165 before Rehabilitation in 2013.

The objectives of this project are: to test the existing subbase materials before and after reclamation, to predict the performance of strategies with different FDR subbase and to evaluate the short-term and long-term performance over time.

Route 165 is a unique candidate for research because the subgrade layer has a high water table and severe frost action. The objectives of the research project were:

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 hot mix asphalt (19 mm super pave) asphalt base (through working with RIDOT Material Section) on Route 165.
   - Collect and/or determine properties of two inch Class 12.5 HMA (12.5 mm super pave) asphalt surface (through working with RJDOT Material section) on Route 165.
   - Collect Weigh in Motion (WIM) data from RIDOT research center section for traffic volume, truck classification and truck weights on Route 165.
   - Collect and/or determine climate data.
   - Predict performance including rutting, fatigue cracking, thermal cracking and roughness in terms of International Roughness Index (IRI) using AASHTOWare Pavement ME Design (MED).
2. Evaluate distresses, if any, and determine which layer has weakness.
3. Evaluate the five different strategies and recommend the best one for future RIDOT rehabilitation projects from the Route 165 project.
4. Provide an optimal design and strategies for future RIDOT rehabilitation projects

The outcome of this research project would be providing a guideline for future maintenance and rehabilitation (M&R) projects, since RIDOT mainly maintains and/or rehabilitate existing pavements.

Background History:

Route 165 was last reconstructed in 1986. The roadway was reclaimed to a depth of five inches (5 in.) and mixed with calcium chloride. The pavement thickness, after resurfacing, was one and a half inches (1-1/2 in.) of bituminous surface course and two and a half inches (2-1/2 in.) of bituminous modified type binder course over a five inch (5 in.) cold recycled base layer mixed with a ratio of 1:2 bituminous pavement/gravel and eight inches (8 in.) of existing gravel subbase layer (Figure 2)

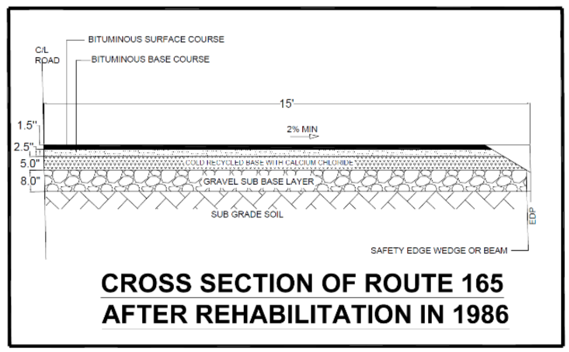

Figure 2 Cross Section of Route 165 after Rehabilitation in 1986

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, original 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. The soil within

Route 165 has a low shrink-swell potential but has a potential for frost action. Plasticity index is not present. Therefore, the soil is not comprised of any clay material. Areas of Route 165 that contain Adrian, Walpole, and Ridge bury have severe wetness, low strength, and severe frost action.

In 2012, the RIDOT, in conjunction with the URI Department of Civil and Environmental Engineering, performed testing unbound layer materials from five sample areas within Route 165. 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. The 2012 samples were taken to URI for resilient modulus testing, and the resilient modulus results from URITC Project Number 000154 research project are being used as parameters for the AASHTOWare ME pavement program (Bradshaw et al. 2015).

Methodologies and/or Procedures:

A test road, i.e., Route 165 was rehabilitated in Exeter and used to predict and evaluate the performance of different strategies in 2013. Four test sections used the full depth eight-inch FDR base/subbase and three sections were stabilized with Portland cement, calcium chloride, and asphalt emulsion. The fourth test section was reconstructed with geo-grid and six inches of filter stone sandwiched between the layers. All four tests and one control section were paved with two and a half inch thick Class 19 HMA and two inches Class 12.5 HMA. Based on the RIDOT Job Specifications, each of the reclaimed test sections and the geogrid 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 control test section are shown in Figures 3.

Equipment used consists of: reclaimer, vibratory sheep foot 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 operation took place during acceptable temperature ranges

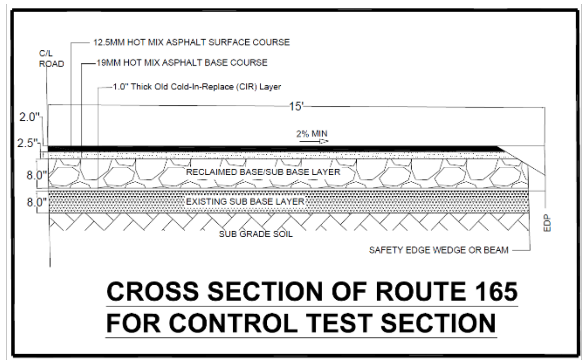

Figure 3 Cross Section of Control Test Section on Route 165

However, a sudden downpour occurred during Portland cement placement and washed all the material away. The Portland cement section was then regraded and new Portland cement. Route 165 is approximately seven miles long with seven hills and valleys. The reclaimed test sections contained 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.

Full depth reclamation with calcium chloride consisted of using a calcium chloride ($CaCl_2$) solution. This procedure used AASHTO M 144 specifications for calcium chloride with a solution being at 35% +/- 1%, alkali chloride 2% maximum as $NaCl_2$, and magnesium at 0.1 % maximum as $MgCl_2$. From the RIDOT's Specification.

Full depth reclamation with bituminous stabilizer consisted of using an asphalt emulsion of grade MS-2 or HFMS-2. This procedure used was AASHTO M.03.03.4 144 specifications for asphalt emulsion.

Based on RIDOT specifications 406.9903, 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.

The control section was reclaimed in a similar method as the rest of the reclaimed test section and no additives were used.

A section of geo-grid mechanically stabilized layer was placed as another test section for a comparison. Distributors of the Tenser 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 Tenser product was used in an area of the road that has a high seasonal water table.

Analysis:

Previously, Rhode Island used the 1993 AASHTO Guide for Design of Pavement Structures to design the HMA 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, HMA mixture and subbase material properties for a mechanistic empirical design. There are three hierarchical levels in AASHTOWare Pavement ME Design (MED).

1. Level 1. Uses laboratory results i.e. Resilient modulus, HMA mixture properties that are project specific or a library of test materials results. (AASHTO 2015).
2. Level 2. Input values are estimated for correlations and regression equations. (AASHTO 2015).
3. Level 3. Input parameters are estimated or global defaults are used. (AASHTO 2015).

There are several HMA properties that are inputs into the Pavement ME program to perform a Level 1 design. The RIDOT performs nineteen AASHTO and ASTM tests on its materials and hot mix asphalt 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.

Resilient Modulus of Subgrade Soils s were collected under a URI study (Bradshaw et al 2015) during construction for testing. The URI study reported Mr Values for Rhode Island subgrade soils ranged from 7,506 psi to 9,304 psi (Lee et al. 2003).

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 mixed with seven inches of the existing gravel borrow and the five inches of previously reclaimed material. 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. The laboratory resilient moduli values varied from 17,000 psi to 74,000 psi.

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 layers were mixed with the three different strategies and taken 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 samples were mixed with Portland cement, one sample with $CaCl_2$, and one with asphalt emulsion. The two control FDR samples were tested without additives. The resilient moduli of FDR base/subbase layer were determined by using AASHTO T307-99.

The Route 165 project used two and one half inches of Class 19 HMA for the base layer and two inches of Class 12.5 HMA for the surface layer. Mechanical properties of HMA including Dynamic modulus, (E_{hma}, E^*) for the surface and base layers were acquired from Villanova University. Cardi Corporation's HMA testing.

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 for new pavement only and is a test for evaluating thermal cracking.

All truck traffic data inputted into the MED software came from a WIM station on Route 165, and was obtained from RIDOT's Traffic Research Section. Data included average annual daily traffic (AADT) which is broken down into vehicle classification, monthly adjustment factors, hourly adjustment factors and daily vehicle counts. 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 4. The AADT from December, 2014 to November, 2015 is 150.

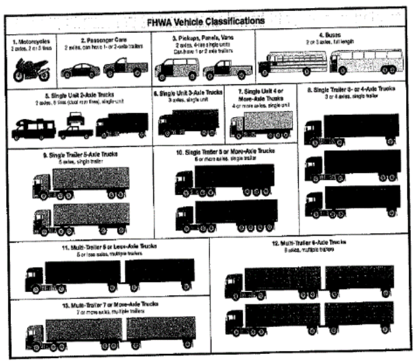

Figure 4: FHWA Vehicle Classification

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 files from the website is comprised 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 depth and wind speed. The MED uses the climate data for transverse cracks (non-load cracks), an enhanced integrated climate model (EICM) calculates the HMA temperatures on an hourly basis and the MED uses those hourly temperatures to estimate the HMA properties (creep compliance and indirect tensile strength) to calculate the tensile stress throughout the HMA surface (AASHTO 2015).

Performance distress prediction outputs includes:

1. Terminal IRI (in/mile)
2. Permanent deformation
3. AC Bottom-up fatigue cracking
4. AC Top-down fatigue cracking
5. AC Thermal cracking
6. Permanent deformation- AC only

The comparison of outputs obtained from AASHTOWare ME design software between the control and the other four test sections is shown in Table 3.13. The most prevalent distress, in the four test sections, is in AC top down fatigue cracking (longitudinal cracking) for the control, CaCl2, asphalt emulsion and geo-grid. The Portland cement section is the only test section that did not have any predicted distresses. The higher the resilient moduli is, the better results for less distress

Table 1: Comparison of performance prediction of five test sections of Route 165

Design Outputs		Control	Calcium Chloride	Emulsion	Cemet	Geo-grid
Distress	Target	Predicted	Predicted	Predicted	Predicted	Predicted
Permanent deformation	0.75	0.5	0.5	0.5	0.43	0.45
AC bottom-up fatigue cracking	25	2.3	2	8.3	1.7	2.5
AC top-down fatigue cracking (ACTDFC)	2000	2492.7	2086.5	3155.6	1448.9	2637.2
Permanent deformation-AC only	0.25	0.05	0.05	0.07	0.05	0.04
AC thermal cracking	1000	84.3	84.3	84.3	84.3	84.3
Terminal IRI (in/mile)	172	144.7	144	145.3	142.7	144
Years to predict threshold distress ACTDFC (Years)		11	18	5	29	9

Having AC top down fatigue cracking (longitudinal cracking) means the pavement layer of four and one half inches is not thick enough for this road. Either the Class 12.5 HMA or the Class 19 HMA should have been thicker. The test sections in order of best performance are: Portland cement, $CaCl_2$, control, geogrid 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.

Conclusions and Recommendations

Conclusions:

There were several findings from the investigation about the performance of the five test sections.

1. Of the five test sections, Portland cement performed the best overall in having less distresses. Next is calcium chloride, followed by cold recycled (control), geo-grid, and asphalt emulsion.
2. Resilient modulus testing ranked three test sections: Portland cement, calcium chloride, and asphalt emulsion.
3. Portland cement, calcium chloride, control, and geo-grid test sections are predicted not to have any distresses for at least nine years.
4. None of the test sections are predicted to have AC bottom up fatigue, thermal AC cracking, or permanent deformations.
5. Portland cement is an excellent additive, but the curing time can be a problem on narrow roads where detours are not possible.
6. The higher the resilient modulus value, the less pavement thickness is needed.

Recommendations:

There are several recommendations which can be considered by RIDOT. They are listed below.

1. Perform resilient modulus tests on subbase material on future FDRs. Any subbase resilient modulus that is less than 25,000 psi should be modified to increase its stiffness.
2. In design, using two or more strategies is not a bad thing. Geo-grid is a better at dealing with a high water table or poor drainage than calcium chloride or plain cold recycling.
3. Portland cement is an additive to use if there is heavy truck traffic and the pavement is wide enough.
4. Since asphalt emulsion did not perform well, it should be investigated further whether it can be used on another State road.
5. Earlier versions of the MEPDG were cumbersome and slow. Although, collecting all the input data took long time, typically two weeks, the new software finishes a run in less than five minutes. Thus, MED should have its lease extended.

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