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RESEARCH

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Recycled Pavements Using Foamed Asphalt in Minnesota

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16. Abstract (Limit: 200 words)

Foamed asphalt was discovered in Iowa by Csanyi in 1956, and has become a useful road rehabilitation tool when used in conjunction with cold in-place recycle (CIR) and full-depth reclamation (FDR) processes. The advance of pavement recycling and foaming technology has made foamed asphalt a common rehabilitation technique in many parts of the world including Europe, Asia, Africa, Canada, and parts of the United States. Iowa has used the technique extensively and has developed specifications for the construction of foamed asphalt FDR and CIR stabilized roadways. The intention of this research project, Investigation 873, is to develop FDR and CIR foamed asphalt specifications and report data and information that will assist engineers in Minnesota with successfully implementing foamed asphalt recycling techniques.

There are already several foamed asphalt CIR projects in Minnesota that have been completed on low volume roads. The roadways were rehabilitated in Fillmore and Olmsted Counties from 2004 to 2008, and are performing quite well to date. The Minnesota Department of Transportation (Mn/DOT) has taken Falling Weight Deflectometer (FWD) and core data from these projects in order to examine the in-situ properties of the stabilized pavement layer, as well as the material properties of the foamed asphalt itself. The FWD data analysis reveals that the recycled pavement layer develops a relatively uniform strength despite the high variability inherent in most low-volume roads. Core data indicates that the foamed asphalt forms a cohesive matrix when mixed with the fines from the reclaimed material, which does not disintegrate when cored. Overall PG grade of the recycled layer changed significantly from the original mix in some cases, but not in others. The cause of this is unknown, however, differences in the procedures used and materials present at the different projects may help explain this. It is recommended that FWD, ground penetrating radar (GPR), and core analysis be performed before and after foamed asphalt projects to more accurately define these differences.

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Recycled Pavements Using Foamed Asphalt in Minnesota

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Executive Summary

Foamed asphalt is not a new concept with respect to pavement rehabilitation and stabilization. Many countries in the world use the process as a tool to help maintain the integrity of their transportation infrastructure. Some states in the US have already used foamed asphalt with success. However, general information about the successful use of foamed asphalt CIR/FDR stabilization is not widely known or available for Minnesota applications. The goal of this project, Investigation 873, is to gather and record information regarding best practices, construction techniques, mix design, specifications, and performance of foamed asphalt recycled pavement. This information was then used to develop a design guideline and specification for the use of foamed asphalt in Minnesota, which is included with this report.

To date, Fillmore and Olmsted counties in Minnesota have both used foamed asphalt CIR on projects constructed from 2004 to 2008. The projects are wearing relatively well, although they are not old enough to yet determine their overall lifetime performance. Heuristically, the return of the cracks has been relatively slow and the spacing between cracks has increased. It would be very useful to continue to track the performance of these roads as the years progress to fully quantify the performance of these projects.

Monitoring the Olmsted and Fillmore County projects consisted of FWD testing and roadway cores. FWD tests were taken after the construction of the foamed asphalt roadways. Back- and forward-calculations were performed on the deflection data obtained by the FWD. A three-layer pavement model provided the greatest correlation between the back- and forward-calculations. Part of this may be due to the HMA overlay acting as one with the foamed asphalt layer. Another reason for this may be due to the nature of forward-calculation, as it does not account for additional layers in the pavement system besides the bituminous material, base, and subgrade. In any case, the moduli derived from the back- and forward-calculations showed a significant level of uniformity along the profile of the various roads studied. Beyond this uniformity, it also seems that the foamed asphalt CIR layer provides adequate structural strength. Future research projects should consider taking FWD data prior to the construction of the projects to compare with the after-construction data.

Cores taken from the projects in Fillmore and Olmsted counties show that the foamed asphalt layer remains a cohesive unit and does not crumble after coring. Furthermore, lab analysis shows that overall binder grade may or may not change significantly after the addition of foamed asphalt. The binder grade of the original mix did not change significantly for the Fillmore County projects, whereas the binder grade did change significantly for the Olmsted County projects. This may be caused by construction technique or conditions at the construction site. Close observation of the construction of future foamed asphalt projects may give hints as to the origin of these differences in the overall binder grade. Furthermore, additional study of the foamed asphalt projects in Fillmore and Olmsted Counties will reveal whether or not this difference in binder grade affects overall roadway performance.

Mix design is another factor that may play a strong role in roadway performance and life. Mix design may be most critical for FDR pavement operations with foamed asphalt because of inherent variations in base thickness. Overestimation of base thickness based on data from

coring may allow the reclamation machine to mix additional subgrade material in with the pavement materials. This increase in minus 200 material might require the adjustment of the foamed asphalt injection rate. If an adjustment is not made, the mixture of AC and recycled pavement may be too lean and may leave the stabilized layer more susceptible to water saturation and/or lower strengths. Mn/DOT has decided to require a mix design for all foamed asphalt stabilized FDR projects for this reason. However, Mn/DOT will not require a mix design for foamed asphalt CIR operations because of the greater level of homogeneity of the pavement section above the base. Since a CIR project leaves 1-2 inches of pavement, there is less likelihood that base materials would become part of the mixture. The CIR foamed asphalt projects in Fillmore and Olmsted counties did not use a mix design, and the projects have performed quite well to date. It remains unknown whether a mix design would have improved the performance witnessed thus far.

Further study of the projects constructed in Minnesota will add to the knowledge base regarding constructability and performance. In addition, it would be beneficial to take some data and measurements before a project is constructed, so that it may be compared to data taken after completion of the project. This is particularly true of FWD data because the moduli derived from the deflection data are not absolute, and may differ depending on the backcalculation technique or software used. As such, the change in the roadway's modulus values after rehabilitation is of greater interest than the absolute moduli themselves. Crack survey data taken before construction would also be useful to identify how soon the majority of reflective cracking returns, and to what extent and severity.

Certainly, the success of foamed asphalt elsewhere helped determine the overall direction of this research, with the goal of providing local engineers with the information necessary to design and construct a foamed asphalt reclamation project. It is hoped that engineers will gain confidence in foamed asphalt reclamation through continued monitoring of such newly constructed projects as well as through monitoring the projects referenced in this report.

Chapter 1
Introduction

Foamed Asphalt was first developed in Iowa as a method to stabilize soil (Csanyi, 1956). In the decades since the inception of foamed asphalt, pavement recycling technology advanced to the point where it could be commonly used for roadway rehabilitation. It was not long before the foamed asphalt concept was combined with recycled pavement stabilization as a common-use technique. Subsequent increases in crude prices in the 1970's caused foamed asphalt to gain popularity for use in base and reclaimed pavement stabilization as recycling and foaming technology continued to improve. Since the 1970's the use of foamed asphalt for stabilizing base and reclaimed materials has once again increased in popularity with increases in crude oil prices, and increased environmental and energy concerns. The price of asphaltic concrete (AC) increased by nearly a factor of 2, from $275/ton in April 2006 to $545/ton by early July 2008. By the first week in August 2008, the price of AC had further increased to $700/ton corresponding to an increase of 2.5 times the price recorded in April 2006 (Geib, 2008). Since raw materials are becoming more expensive, it is becoming more important to find ways to reuse the materials already in-place in the roadway. The use of in-place materials saves energy because the materials are processed in-situ, which greatly reduces the trucking required to haul away old pavement materials as waste. Subsequent addition of foamed asphalt to the reclaimed bituminous pavement enhances its strength and moisture resistance.

Foamed asphalt has been used in many parts of the world such as South Africa, Australia, Canada, Europe, and Asia. Some states in the US have already developed foamed asphalt specifications, and have used them to construct pavement stabilization projects with success. In Minnesota, Fillmore and Olmsted Counties have also tried foamed asphalt cold in-place recycling (CIR) with success. However, there is very little performance data from these projects for potential designers to draw on. Furthermore, Minnesota does not have a foamed asphalt specification or design guide for designers to reference. Investigation 873 is intended to develop a specification and design guide, and document the projects constructed in Minnesota to begin a record of pertinent data regarding the performance of foamed asphalt stabilized base.

The Work Plan for INV 873 includes 7 tasks, which are discussed in this report:

1) Background
   Assemble background information and identify techniques and technology for using foamed asphalt efficiently and effectively for reclamation projects in Minnesota.
2) Meetings
   Interview experts of foamed asphalt technology. Determine the primary factors affecting successful construction of foamed asphalt reclamation projects.
3) Local Road Authority Survey
   Perform a survey of foamed asphalt projects constructed in Minnesota and include in the final report.
4) Develop a General Design Guideline/Specification

Develop a general design guideline and/or specification that will assist state, County, City, and Township designers utilize foamed asphalt for full depth reclamation (FDR) and cold in-place recycle (CIR) projects.

5) Performance Monitoring
   Performance monitoring and analysis, including cores and FWD tests, on the foamed asphalt projects identified in Task 3.
6) Draft Final Report
7) Final Report

Chapter 2
Minnesota Historical Perspective

2.1 Overview

Tasks 1-3 of Investigation 873 are somewhat similar in overall direction, in that they focus on gathering existing data, information, and knowledge regarding the use of foamed asphalt in Minnesota. A literature search produced general information regarding application and design of foamed asphalt stabilized bituminous pavements. Limited information is available about these types of pavements in Minnesota to date. In addition to the literature search, a compact summary report of foamed asphalt construction procedures, mix design principles, laboratory testing information and strength data, conveys information regarding foamed asphalt as it pertains to pavements in Minnesota (Appendix A). Finally, a survey of the foamed asphalt projects constructed in Minnesota was conducted to identify and log the location, construction year, and history of the pavement prior to reclamation. This survey is included as an appendix in the summary report in Appendix A.

2.2 Literature Search

The literary references shown below contain information about the various facets of foamed asphalt pavement recycling. This reference list is not all inclusive; rather, it is based on certain topics identified as most critical for successful completion of foamed asphalt reclamation. These topics were determined through meetings with experts and review of reports from past construction projects using foamed asphalt. These topics include, but are not limited to, mix design, subgrade soils, material properties of foamed asphalt, early life-cycle performance, project selection and general site conditions, and existing pavement structure and condition.

1. **Lee, Hosin, Ph.D., P.E., and YongJoo Kim (2003),** *Development of a Mix Design Process for Cold In-Place Rehabilitation Using Foamed Asphalt*. Final Report for TR-474 Phase I, Iowa Highway Research Board, University of Iowa.

2. **Lane, Becca, and Tom Kazmierowski (2005)**, *Implementation of Cold In-Place Recycling with Expanded Asphalt Technology in Canada*. Transportation Research Record, Vol. 1905/2005, pp 17-24. http://trb.metapress.com/content/4418366321164n11/fulltext.pdf Accessed 6/27/2007.

   CIR with foamed asphalt results in a fairly smooth, hard, uniform surface suitable for temporary traffic, and provided an excellent platform for HMA paving operations. It is also a more cost- and time-efficient method of using recycled materials than CIR with other emulsion methods. CIR with foamed asphalt provides a pavement structures that performs at least as well as conventional CIR techniques for the short term. Furthermore, curing times are reduced to the order of 3 days as opposed to 14 days for the standard CIR techniques. This lessens inconvenience to the traveling public and expedites construction activities.

3. **Mallick, Rajib, and Yamini V. Nanagiri, Rick Bradbury, Brian Marquis, Dale Peabody and Mike Marshall (2005)**, report submitted to TRB Committee A2B04 (Committee on Pavement Rehabilitation (AFD70)) for publication as a Transportation Research Circular: *Use of Foamed Asphalt in the Recycling of Pavements*.

   Foamed asphalt increases the shear strength and reduces the moisture susceptibility of granular materials. The strength characteristics of foamed asphalt materials approach those of cemented materials. Additionally, foamed asphalt requires less binder and water than other types of cold mixing due to the increased surface area of the foamed asphalt binder. Foamed asphalt can be compacted immediately, saving construction times. Environmental side effects are reduced with foamed asphalt because of low risk of runoff during stock piling; and reduction of volatile evaporation because curing does not require such evaporation.

4. **Loizos, Dr. Anreas, et. al. (2006)**, *Early Life Performance of Cold-In Place Pavement Recycling Using the Foamed Asphalt Technique*, Department of Transportation Planning and Engineering : Laboratory of Highway Engineering, National Technical University of Athens (NTUA), Athens, Greece.

   FWD testing is a useful tool for indicating early life (< 2 years) performance of CIR using foamed asphalt. FWD deflections and back calculated stiffness values both indicate a trend of increasing stabilization of the pavement structure over the first 6 months of pavement life. Back calculated FWD stiffness values routinely exceeded the values obtained from the laboratory tests on cores. There is continuing research regarding the difference in modulus of FWD tests versus lab tests, and which value is the "true" modulus value of the material. However, the FWD back calculated values exceeded the design stiffness values after six months of traffic use.

2.3 Survey and Results

The survey conducted for this report involved contacting City and County entities responsible for transportation infrastructure within their jurisdiction. The survey results are included at the end of the summary report in Appendix A. Just two Minnesota Counties responded as having used foamed asphalt as a method for road rehabilitation. Of these two Counties (Fillmore and Olmsted) both had used foamed asphalt with CIR methods, but have not yet used foamed asphalt with FDR.

Fillmore County foamed asphalt projects are concentrated on two particular roads, CSAH 5 and CSAH 8. CSAH 5 was rehabilitated in two segments in 2005 and 2006 due to extensive cracking and distress. CSAH 8 was rehabilitated in three segments during the 2005, 2006, and 2008 construction seasons for similar reasons. The road segments range in length from 6 to 7.2 km (**3.8 to 4.5 miles**). The roads have all performed very well to date, and the amount and severity of reflective cracking has been minimal.

Olmsted County foamed asphalt projects are located on three roads: CSAH 1, CSAH 10, and CSAH 24, and were constructed during 2004 and 2005. The road segments range in length from

2.1 to 5.3 km (**1.3 to 3.3 miles**), and consist of a 100 mm (**4 inch**) foamed asphalt layer using PG 52-34 binder, and two 38 mm (**1.5 inch**) layers of HMA using PG 58-34 binder.

Chapter 3
Development of a General Design Guideline/Specification

3.1 General Design Guideline/Specification

The overall objective of this task is to develop a finished specification for foamed asphalt applications in Minnesota. However, a complete specification will require more research and observation of actual construction to identify important points to include, and address potential issues or difficulties. Although the current product is very close to a final specification, it can be used as a general design guideline in the interim (Appendix B). Once finished it may be used as a stand-alone specification. However, it may be beneficial to eventually incorporate the foamed asphalt FDR and CIR specifications developed here into two separate specifications covering full-depth reclamation (FDR) and cold in-place recycling (CIR). These general specifications for FDR and CIR would cover unbound (FDR), emulsion, and foamed asphalt applications; and would provide unified specifications for each construction technique. Iowa DOT's current FDR and CIR specifications are structured in this way.

Critical examinations of FDR and CIR specifications from the Iowa Department of Transportation, Nevada Department of Transportation, and Ontario Ministry of Transportation provided the framework for constructing the Mn/DOT guideline/specification. Several points of interest required additional attention to optimize foam CIR operations to Minnesota conditions. These points include:

1) Gradation
2) Binder grade
3) Mineral stabilizing agents
4) Mix design considerations

The gradation requirements differ between the FDR and CIR specifications in the size of the largest sieve (38 mm (**1.5 inches**) for FDR, and 32 mm (**1.25 inches**) for CIR). The reason for this is that, in the past, concern was raised over the quality of recycled asphalt pavement (RAP) gradation from a single-unit CIR machine. Mn/DOT now requires a multiple unit CIR train for all projects involving CIR. The other main reason for differing gradation requirements between FDR and CIR is the fact that a typical CIR layer is thinner than a typical FDR layer, thus requiring a smaller nominal maximum aggregate size in order to avoid aggregate sizes that might approach that of the thickness of the CIR layer. Similarly, Mn/DOT requires a minimum paving lift thickness based on maximum nominal aggregate size for hot-mix paving as well (Mn/DOT specification 2360.1-B). Tables 3.1 and 3.2 show the FDR and CIR gradation requirements for the RAP material.

Table 3.1 FDR Gradation Requirement

FDR Gradation Requirement	
Sieve Size	Percent Passing
37.5 mm (1.5”)	98-100%
25 mm (1.0”)	90-100%
75 μm (#200)	7-15%

Table 3.2 CIR Gradation Requirement

CIR Gradation Requirement	
Sieve Size	Percent Passing
31.5 mm (1.25”)	98-100%
25 mm (1.0”)	90-100%
75 μm (#200)	7-15%

Mn/DOT requires that PG 52-34 asphalt be used for foamed asphalt CIR. PG 52-34 binder has been used successfully on foamed asphalt CIR projects in Fillmore and Olmsted Counties in Minnesota, and has therefore been chosen as the best option until further examination of other potential PG binder alternatives. This binder seems ideal because it is relatively soft and should create a more workable mixture when mixed with the older oxidized pavement materials. Using such a binder should have the effect of producing a more stable, workable composite material from the old paving mix, which may have been subject to varying degrees of oxidation, thus making it more brittle.

Mineral additives are often used to improve the strength characteristics of the foamed asphalt RAP material, meet gradation requirements, or both. Mn/DOT requires that mineral additives meet the following requirements:

1) Portland cement shall meet ASTM Type I.
2) Fly ash shall come from an approved source.
3) Hydrated lime shall meet the requirements of Mn/DOT 3106.
4) Limestone fines shall come from limestone crushing operations.

The primary benefit of using mineral additives such as Portland cement, fly ash, and hydrated lime is that they can significantly improve the overall strength characteristics of the foamed asphalt RAP layer. As much as 1.5% (by weight of RAP) of these additives may be added without significantly affecting the fatigue resistance of the stabilized layer, while simultaneously improving the recycled layer’s strength retention when saturated with water. Limestone fines provide benefit by helping the RAP mixture meet the optimal 7-15% by weight gradation range, and can be used in conjunction with the Portland cement, fly ash, and hydrated lime.

Mineral additive may be placed on top of the pavement, and mixed with the reclaimed pavement concurrently with injection of the foamed asphalt. Alternatively, it may be placed on the pulverized pavement after an initial pass of the reclaimer, and subsequently mixed and injected with foamed asphalt on the second pass of the reclaimer. However, new pavement reclamation equipment technology has incorporated the ability to add the mineral additives as a powder or slurry on the fly, eliminating the need for placing the mineral additives before or after reclamation.

It is critical that enough fines are present in the reclaimed material in order for the foamed asphalt to properly coat the RAP. This is why addition of fines, ideally via mix design, is an important step in construction of a foamed asphalt stabilized pavement layer.

The approach to the issue of a mix design was, initially, to require one for every foamed asphalt job. However, since CIR foamed asphalt jobs in Minnesota have been relatively successful without a mix design, it has been left at the option of the engineer to make that decision. The reason for this is due to the nature of materials used in a CIR project. A typical CIR project will leave at least 1 or 2 inches of bituminous pavement in place, and does not incorporate base materials into the reclaimed layer that may introduce a higher level of material variability. Since the RAP is then relatively uniform, large adjustments in foamed asphalt content are not necessary. This allows the project engineer to start with a foamed asphalt rate of 2%, and then adjust higher or lower as necessary. This is in fact how the projects in both Fillmore and Olmsted Counties were constructed. Iowa DOT does not require a mix design for CIR foamed asphalt as well, and have been successful in constructing CIR foamed asphalt pavements for many years now. 1.8% foamed asphalt content is typical for Iowa DOT CIR projects, however, it is generally better to have a little too much foamed asphalt as opposed to too little (Heitzman, 2008), on the order of 2-3%. Despite not being a requirement, a mix design is still recommended to optimize the strength and longevity of the pavement.

The Mn/DOT guidelines require a mix design for FDR foamed asphalt because base thickness can vary significantly enough such that subgrade material may become part of the reclaim mixture. This means that a greater amount of minus #200 material may become present in the mixture. The ability of the foamed asphalt to form a cohesive matrix may be greatly reduced if the foamed asphalt content is not adjusted to meet the change in minus #200 material. Texas DOT may have experienced failure due to these types of effects (Chen, 2006). The results of the forensic investigation for U.S. 82 in Texas indicated that inconsistent construction of the foamed asphalt stabilized layer most likely lead to the early deterioration of the roadway; and that increased attention to site conditions and/or a carefully performed mix design may have helped avoid the pavement failure.

To perform a mix design, samples may be obtained by coring the pavement, or by digging test pits in the pavement sections. Test pits are often preferred because they offer a more representative sample of the pavement in question, and also provide a greater quantity of material for use in the laboratory mix design process. The air dried bituminous portion of the sample may be frozen and subsequently broken up in a jaw crusher. Once the pavement sample has been prepared into representative proportions, a foamed asphalt mix design “table” is necessary to complete a proper mix design. Wirtgen and Soter both manufacture foamed asphalt mix design tables, at a price of around $35,000 to $40,000 (Heitzman, 2008). Greater detail regarding the foamed asphalt mix design process can be found in the summary report in Appendix A.

Chapter 4
Performance Monitoring

4.1 Falling Weight Deflectometer Data

A Dynatest 8000 Series Falling Weight Deflectometer (FWD) was used to gather data from the County Roads in Minnesota that were constructed using foamed asphalt. CSAH 1, CSAH 10, and CSAH 24 in Olmsted County were tested; and CSAH 5 and CSAH 8 in Fillmore County were tested. The Olmsted County sections were each constructed entirely in one construction season, while the Fillmore County roads were constructed in 2 and 3 segments in as many construction seasons. See the end of Appendix A for a general summary regarding the construction of these roadways.

FWD data was gathered between the wheel paths of the up-station lane direction for each roadway in the study. The FWD tests were taken at an approximate spacing of 0.08 km (**0.05 mile**). All the roadways included in this study were tested on July 17 and 18, 2008. FWD data was not taken prior to construction of the foamed asphalt stabilized layer, so the data presented in this study represents only the after-construction state of the pavement.

The FWD sensor array consists of sensors placed at 0, 203, 305, 457, 610, 762, 914, 1219, 1524, and 1829 mm (**0, 8, 12, 18, 24, 30, 36, 48, 60, and 72 inches**) from the center of the load plate. The data from the furthest three sensors at 1219, 1524, and 1829 mm were not included in the back-calculation analysis due to non-linear subgrade soils and rigid bottom effects of, at times, relatively shallow bedrock. The loading pattern consists of a total of seven drops; three drops at 40 kN (**9 kips**), two drops at 53 kN (**12 kips**), and two drops at 67 kN (**15 kips**). The drops at 53 kN and 67 kN (**12 kips and 15 kips**) were used to back-calculate layer modulus values.

Forward calculated moduli presented in this paper were calculated using the methods and spreadsheets developed for FHWA Publication FHWA-HRT-05-152, and are provided for comparison to the back calculated moduli. Forward calculated modulus values are used as a the back calculated values by helping to validate the model that the back calculations are based on.

4.2 FWD Deflections and Moduli

The foamed asphalt stabilized pavement showed no overt data trends differentiating it from any other pavement structure of similar thickness. Modulus values calculated from the deflection data were relatively consistent with the LTPP forward calculations. The larger modulus variations within a road's profile are likely due to varying pavement section thicknesses, varying subgrade materials, and undulating bedrock depth. However, the forward- and back-calculated moduli were quite consistent between the various roads surveyed despite these variations (see Appendix C). The software program ELMOD was used to determine the layer moduli by using a 3 layer model. A 3 layer model was chosen so that the LTPP forward-calculation methods could take into account the presence of the foamed asphalt reclaimed layer. The three layers consist of the combined thicknesses of the HMA overlay and foamed asphalt layer, the combined thicknesses of the old mix and base materials, and the thickness of the subgrade. The 50-75 mm (**2-3 inch**) HMA overlay was combined with the 100-150 mm (**4-6 inch**) foamed asphalt layer;

with the underlying 50-175 mm (**2-7 inch**) of old mix combined with a 150-200 mm (**6-8 inch**) base layer. The thickness of the third layer, the subgrade, was determined by the ELMOD software as it iterated to minimize the difference between the calculated and measured basins.

ELMOD contains a subroutine (BELLS) to calibrate the moduli to a standard temperature with knowledge of air & pavement temperature at the time of the test, and the previous day's average air temperature. The LTPP forward-calculation procedure also contains the BELLS algorithm, and those moduli were calibrated similarly as such. Furthermore, the back- and forward-calculated were screened using the LTPP criteria from FHWA Publication FHWA-HRT-05-152. See Table 4.2 for the definition of these criteria. The majority of the calculation comparisons fell into the acceptable category, with a moderate few falling into the marginal category, and virtually none categorized as questionable or unacceptable. The fact that almost no forward- and back-calculation ratios were categorized as questionable or unacceptable helped to confirm the validity of using a 3-layer model for the back-calculations. Furthermore, the positive results from the LTPP screening process also confirms that combining the HMA and foamed asphalt as one layer, and old bituminous mix and base materials as another layer, is a viable structural model. Refer to Appendix C to view the FWD moduli along the roadway profile for both forward- and back-calculated methods.

Table 4.1 LTPP Screening Criteria and Codes

Description of the Correspondence Between Forward-Calculated and Back-Calculated Modulus Values	Correspondence Codes	Ratio of Forward-Calculated and Back-Calculated Modulus Values
Acceptable	0	2/3 < Ratio $\leq$ 1.5
Marginal	1	0.5 < Ratio* $\leq$ 2
Questionable	2	1/3 < Ratio** $\leq$ 3
Unacceptable	3	Ratio $\leq$ 1/3, or Ratio > 3

* and not code 0
** and not codes 1 or 0

4.3 Roadway Cores

Cores were taken from the Olmsted and Fillmore County roadways in June 2008 to confirm layer thicknesses for the HMA, foamed asphalt layer, and old bituminous mix. Core sampling was not extended through the base material as the base materials were likely to have high spatial variation due to the construction processes and techniques used when the roads were built in the late 1950's and early 1960's. In general, 150-200 mm (**6-8 inches**) of base material was assumed for forward- and back-calculations of all roadways included in this study, based on thicknesses reported by the County Highway Departments. Figure 4.1 shows the pavement layer thicknesses as measured from the cores.

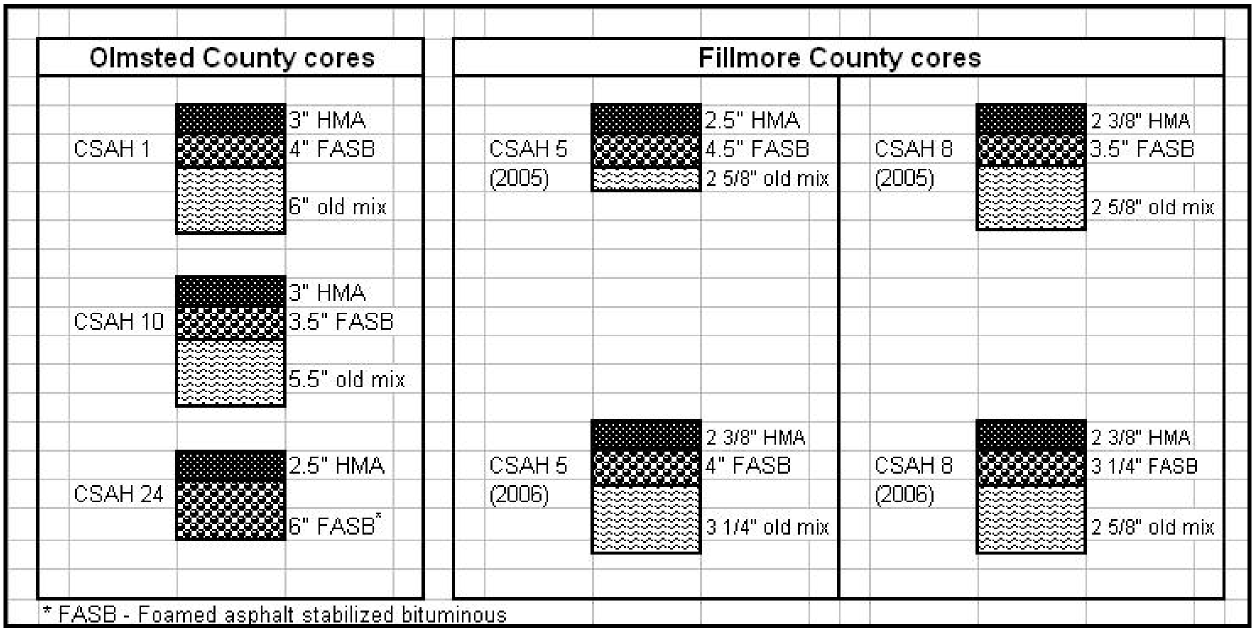

Figure 4.1 Pavement Thicknesses from Core Data

In addition to pavement thickness, the cores were analyzed in the laboratory to determine the grade of the old binder, and the grade of the composite binder created from the addition of the foamed asphalt. Percent content of asphalt, percent contribution to final binder grade (foamed asphalt binder versus old bituminous binder) was also determined by lab analysis of the cores. The added percent of foamed asphalt was deduced by analyzing the asphalt content of the old bituminous pavement and subtracting that value from the asphalt percent content of the foamed asphalt layer. The results of these lab tests are shown in Table 4.3.

Table 4.2 Lab Analysis of Foamed Asphalt Cores

Sample ID	*Overall AC %*	*DSR Grade*	*BBR Grade*	*% Foam AC Added*	*Contribution to final binder*	
					% new AC	*% RAP*
CSAH 8 - Layer 2	7.09	73.8	-20.4			
CSAH 8 - Layer 3	4.14	73.5	-20.1	2.95	41.6%	58.4%
CSAH 5 - Layer 2	6.95	70.5	-26.6			
CSAH 5 - Layer 3	4.72	69.4	-25.6	2.23	32.1%	67.9%
CSAH 10 - Layer 2	6.94	64.8	-32.1			
CSAH 10 - Layer 3	3.79	75.3	-19.4	3.15	45.4%	54.6%
CSAH 1 - Layer 2	7.23	65.5	-30.8			
CSAH 1 - Layer 3	4.78	71.3	-24.3	2.45	33.9%	66.1%
CSAH 24 - Layer 2	6.69	65.2	-27.9			

In Table 4.3, “layer 2” represents the foamed asphalt layer of the respective CSAH. Items labeled “layer 3” represents the old mix layer of the respective CSAH. The main trend of note is that the percent new AC versus percent RAP is most similar for CSAH 1 and CSAH 5; and CSAH 10 and CSAH 8. Each pair also has a similar percent foam AC added. The main difference is that each CSAH in the CSAH pairs is from a different County. Furthermore, the first CSAH pair (CSAH 1 and CSAH 5) exhibit very little difference in the PG grading of the foamed layer and the old mix layer. The second CSAH pair (CSAH 10 and CSAH 8) show a significant difference between the PG grading of the foamed layer and the old mix layer. It is theorized that differences in construction and recycling conditions may have lead to this difference, although this remains unknown for certain. It would be beneficial for future research to be able to observe and record the foamed asphalt construction operations closely, with regard to this type of binder analysis.

Chapter 5
Conclusion

The concept of using foamed asphalt as a technique to stabilize FDR and CIR materials has been around for several decades and in fact is used in many parts of the world already. Iowa, Nevada, California, Illinois, Wisconsin, Colorado, and Louisiana have tried foamed asphalt road reclamation techniques, to name a few. Two Counties in Minnesota have tried foamed asphalt CIR methods to rehabilitate some of their low volume roads. Overall the projects have been a success, by both providing a smooth, durable platform for placing a surface treatment, and by effectively increasing the time it takes for reflective cracking to appear. It is recommended that monitoring and data collection continue throughout the life of these pavements in order to properly examine lifetime performance.

Initial data collection included post-construction FWD testing and cores taken from the roads. The cores showed that the foamed asphalt portion remained intact after coring and appeared very similar to the HMA layers upon visual inspection. The pavement layer thicknesses measured from the cores were used to perform forward- and back-calculations on the FWD data. Since back-calculation is highly sensitive to layer thicknesses less than 4 inches, it was necessary to combine several of the layers in order to determine a meaningful modulus. Furthermore, the LTPP forward-calculation methods are based on a three layer pavement system. Thus, a three layer pavement system was chosen in order to utilize the LTPP method for checking the back-calculated moduli. The three layer model that minimized the difference between the forward- and back-calculated moduli consisted of:

1) The top lifts of HMA combined with the foamed asphalt layer,
2) The underlying old HMA combined with the base layer,
3) The subgrade.

The fact that the best correlation between the ELMOD back-calculations and the LTPP forward-calculations was achieved by combining the HMA and foamed asphalt layers, does not necessarily indicate that the properties of the foamed asphalt layer are similar to that of the HMA. Structural evaluation of the foamed asphalt layer is best left to a more comprehensive study with a larger set of roads, in order to ensure statistical meaning and identify outliers. Future research projects should also consider taking FWD data prior to the construction of the projects in order to compare with the after-construction data.

In addition to providing pavement layer thickness data, the cores taken from Fillmore and Olmsted Counties were sent to the Mn/DOT Materials Lab for extraction and gradation testing. Lab analysis shows that overall binder grade may or may not change significantly after the addition of foamed asphalt (see Table 4.3). The binder grade of the original mix did not change significantly for the Fillmore County projects, whereas the binder grade did change significantly for the Olmsted County projects. This effect occurred despite all roadways in the study starting at similar asphalt grades in the old bituminous (the reclaimed layer), and undergoing injection of nearly the same proportion of foamed PG 52-34. The major aspect that differed significantly between the roadways, besides the change in PG grade of the foamed layer, is the percent rap contained in the foamed layer. Since the various layers of the pavement vary significantly in thickness from the base, to the initial HMA layer(s), to the subsequent overlay(s), differences in the PG grade of the individual layers may be contributing to the differences in PG grade of the foamed layer. Continued study of the foamed asphalt projects in Fillmore and Olmsted Counties will reveal whether or not this difference in binder grade affects overall roadway performance.

Mix design is another factor that may play a strong role in roadway performance and life. Mix design may be most critical for FDR pavement operations with foamed asphalt because of inherent variations in base thickness. Overestimation of base thickness based on data from coring may cause the reclamation machine to unintentionally mix additional subgrade material in with the pavement materials. This increase in minus 200 material might require adjustment of the foamed asphalt injection rate. If an adjustment is not made, the mixture of AC and recycled pavement may be too lean and may leave the stabilized layer more susceptible to water saturation and/or lower strengths. Mn/DOT requires a mix design (see Appendix B) for all FDR foamed asphalt stabilized projects for this reason. However, Mn/DOT does not require a mix design for foamed asphalt CIR operations because of the greater level of homogeneity of the pavement section above the base. Since a CIR project leaves 1-2 inches of pavement, there is less likelihood that base materials would become part of the mixture. The CIR foamed asphalt projects in Fillmore and Olmsted counties did not use a mix design, and the projects have performed quite well to date. It remains unknown whether a mix design would have improved the performance witnessed thus far.

Certainly, the success of foamed asphalt elsewhere helped determine the overall direction of this research, with the goal of providing local engineers with the information necessary to design and construct a foamed asphalt reclamation project. It is hoped that engineers will gain confidence in foamed asphalt reclamation through continued monitoring of such newly constructed projects; as well as monitoring of the projects referenced in this report.

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Appendix A

Summary Report on Foamed Asphalt Road Rehabilitation

Road Rehabilitation Using Foamed Asphalt

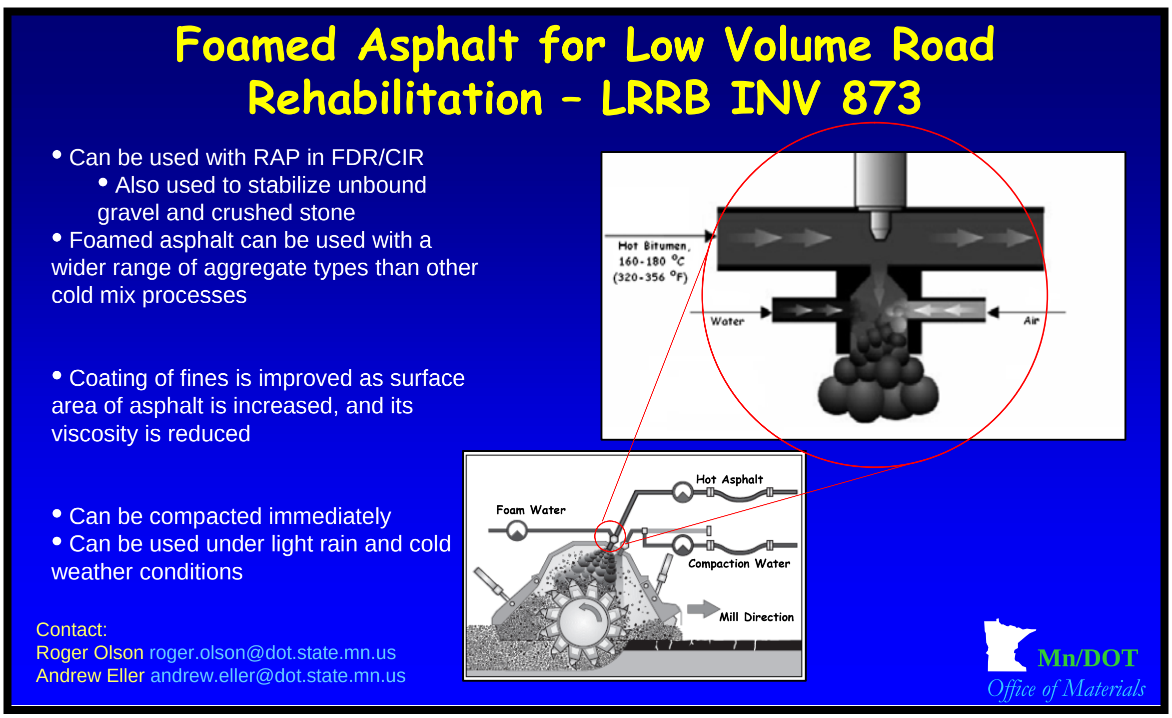
2008 M&RR

Author: Roger Olson
Andrew Eller

March 2008

INTRODUCTION

During the Arab Oil Embargo of 1973, the price of crude oil quadrupled to $12 per barrel. The price of asphalt, the bottom of the crude oil barrel, also increased significantly during this time and the cost of highway construction and rehabilitation rose dramatically. Contractors and equipment manufacturers quickly recognized that recycling reclaimed asphalt pavement (RAP) could provide many benefits and opportunities in the road construction and rehabilitation realm. Milling machines were developed, hot mix asphalt plants were modified to allow the addition of RAP to mixes, and soil stabilization equipment was redesigned to reclaim existing pavements in-place.



Technological improvements of the early asphalt pavement recycling methods and equipment have made the process more feasible as a rehabilitation method. New hot and cold mix plants and several types of powerful in-place recycling equipment are now available; and performance based testing and mix design methods have improved greatly. The high price of asphalt, the need to conserve energy, the reduced availability of high quality aggregates and the dwindling supply of landfill space provided the incentive for these advances. However, the major factor in the rapid growth of recycling was the excellent performance of recycled pavements.

APPLICATION

Until the mid-90's, almost all asphalt cold recycling had been done with emulsions. In recent years one of the fastest growing "new" recycling technologies is the use of foamed or expanded asphalt (which was actually discovered in the 1950's in the USA). Foamed asphalt is produced when a small quantity of cold water is introduced into hot asphalt. As the asphalt foams due to the expansion of the water to steam, its volume increases 10 to 30 times and its viscosity is greatly reduced, enabling it to be dispersed in and mixed with cold, moist aggregates and RAP. The renewed interest in foamed asphalt technology has largely been due to the development of laboratory and field equipment that allows foamed asphalt to be produced safely under precisely controlled conditions. Precise control of the foamed asphalt process is necessary due to the nature of reclamation itself, as well as the behavior of the foamed asphalt. The foamed asphalt must be of a certain temperature and mixed in the correct proportion to water. Furthermore, the gradation of the reclaimed material must meet certain ranges in order for the foamed asphalt to become a sound pavement layer (See **Figure 1**).

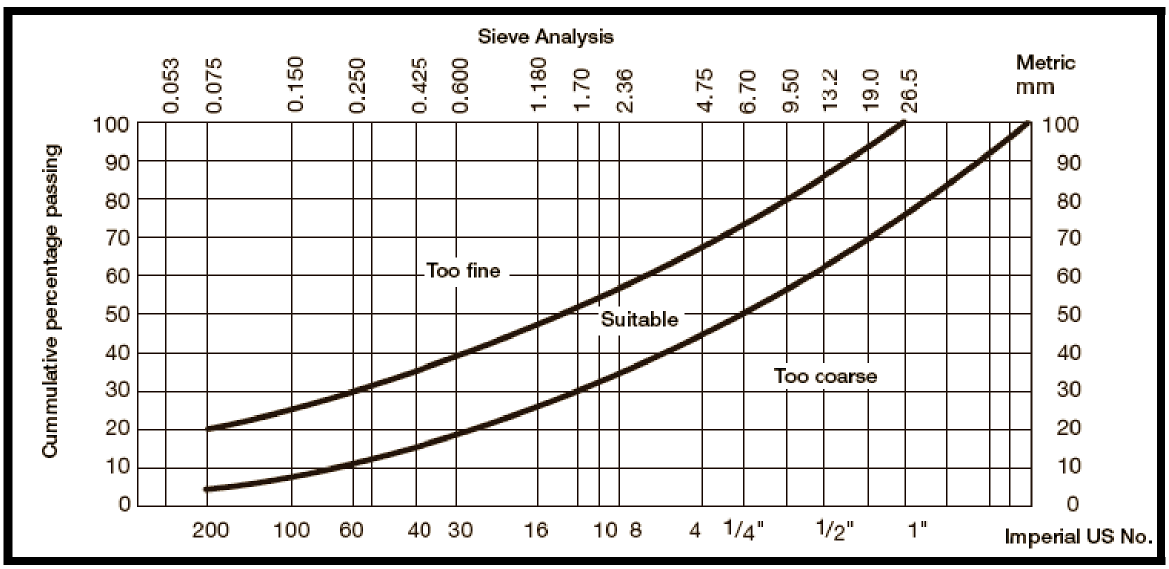


Figure 1. Range of acceptable gradations for optimal performance.

Olmstead and Fillmore Counties in Minnesota have implemented foamed asphalt recycling technology with success, and the roadways continue to perform well through the present. Fillmore County uses foamed asphalt recycling exclusively, and has not performed an HMA overlay in several years. In October 2007, Minnesota Department of Transportation (Mn/DOT) representatives took a field trip to several roads in Fillmore County constructed using foamed asphalt. Many of the roads were 5 years old, or more, and exhibited little to no cracking, rutting, or other distress. Olmstead County has experienced a similar level of success as Fillmore County; with roadways built around the same time period. It is the aim of this study to examine the necessary components that lead to successful completion of foamed asphalt stabilized roads. Furthermore, the ultimate goal is to develop a guidance or specification that will assist City, County, and State officials when considering or implementing a foamed asphalt job in Minnesota. (See **Appendix A** for a list of foamed asphalt projects completed in Minnesota).

BENEFITS

Foamed asphalt was discovered in 1956 by Iowa State University Professor Ladis Csanyi. Professor Csanyi produced foamed asphalt by introducing steam into hot bituminous asphalt. Some time later, Mobil Oil Co. improved on the technique by adding atomized water to the hot bitumen. This is the method currently used to produce foamed asphalt, however, it did not come in to common use until the early 1990's due to patenting and other factors. Prior to the 1990's, recycling techniques were being explored in countries such as the USA, Australia, and South Africa; as well as several European Countries. Laboratory testing of foamed asphalt material had progressed over the years as well. This provided an environment that was ripe for the implementation of foamed asphalt on a larger scale. As a result, equipment manufacturers began to improve the safety and efficacy of the foaming systems in order to provide services for the increasing demand for recycled pavements and foamed asphalt materials.

The benefits of using foamed asphalt recycled pavement rehabilitation are many, two of which are arguably the most prominent in the current political and economic climate. Those two benefits are the relative environmental friendliness of using foamed asphalt with RAP versus hot mix, and its economic feasibility i.e. equivalent pavement strengths can be constructed using foamed asphalt with RAP, for an upfront cost similar to other bituminous construction methods. Some other benefits that foamed asphalt with RAP provides are:

- Foamed asphalt can be used with 5-20% fines
- Increased shear strength and resistance to flexural fatigue
- Reduction of moisture susceptibility
- Can be compacted immediately after injection of foamed asphalt and sufficient mixing
- May be stockpiled without binder runoff or leaching, remains workable for a relatively long time
- Foamed asphalt can be used under some adverse weather conditions (light rain or cold weather)
- No evaporated volatiles as with HMA and cutback emulsions
- Reduction in transportation costs, foamed asphalt requires less binder and water than other types of cold mixing

LABORATORY AND MIX DESIGN PROCEDURES

In order to select and characterize the optimum foaming properties of an asphalt binder, the expansion ratio and half life of the foamed asphalt must be quantified. The expansion ratio of foamed asphalt is defined as the ratio of the maximum volume attained by the foamed asphalt material, divided by the original volume of the binder. The half-life is defined as the amount of time it takes for the foamed asphalt to lose 50% of the maximum volume attained during the initial foaming process. Expansion ratio is an indicator of how well the foamed asphalt will coat the paving materials, while half-life is an indicator of the foam's overall stability (See **Figure 2**). In **Figure 2**, the expansion ratio is 24, and the half-life is 20 seconds.

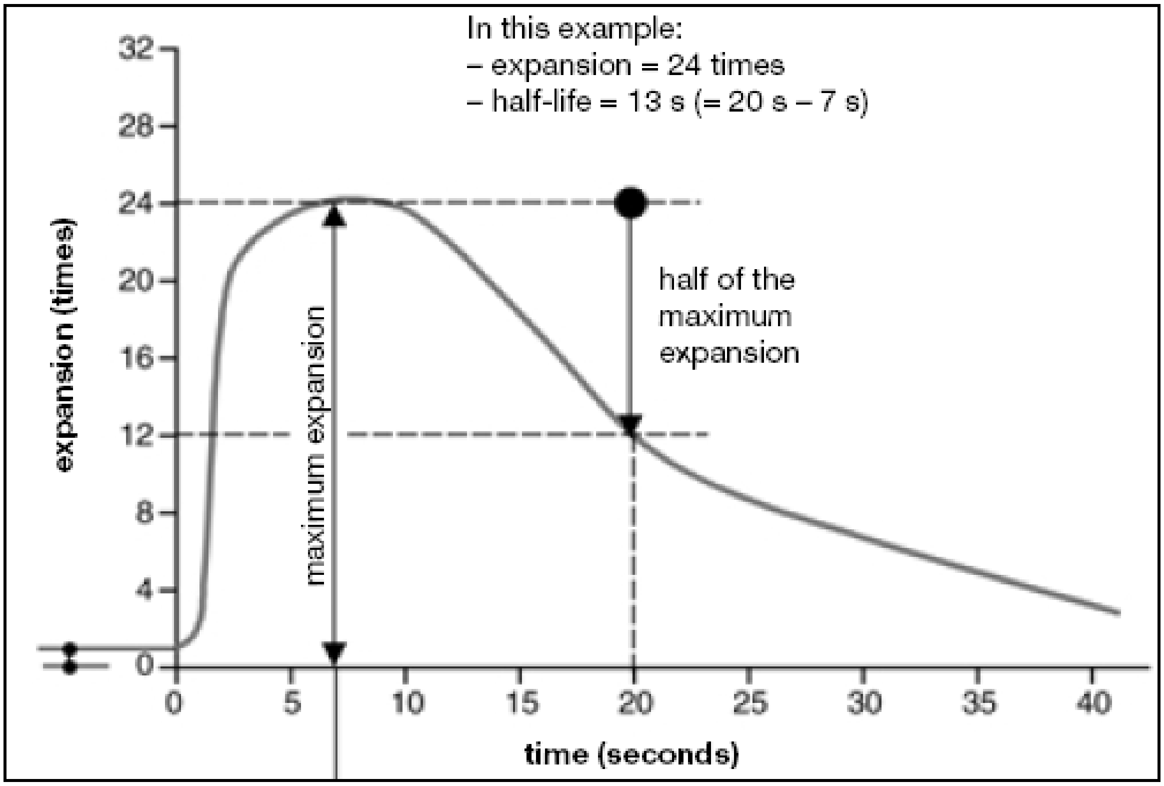


Figure 2. Graph showing Expansion Ratio and Half-Life concepts.

Selection of Asphalt Temperature and Percent Water

The expansion ratio and half-life of an asphalt binder depends on the chemical constituents of the asphalt, its temperature, and the amount of water used for foaming. The expansion ratio and half-life are inversely related in that, for a given temperature, the expansion ratio increases with increasing amounts of added water, while the half-life decreases with increasing amounts of added water. The optimum amount of added water can be determined from laboratory testing by first identifying expansion ratios and half-lives for discrete sets of temperatures and water contents. The results are then plotted against water percent content on the x-axis (See **Figure 3**). The optimum amount of added water typically ranges from 1 to 4 percent, and varies depending on the asphalt used. The optimum amount of injected water (at a corresponding asphalt type and temperature) should be chosen by using the graph to cross reference water content with a corresponding expansion ratio greater than 10 and half-life greater than 12 seconds. The optimum asphalt temperature is chosen in a similar fashion.

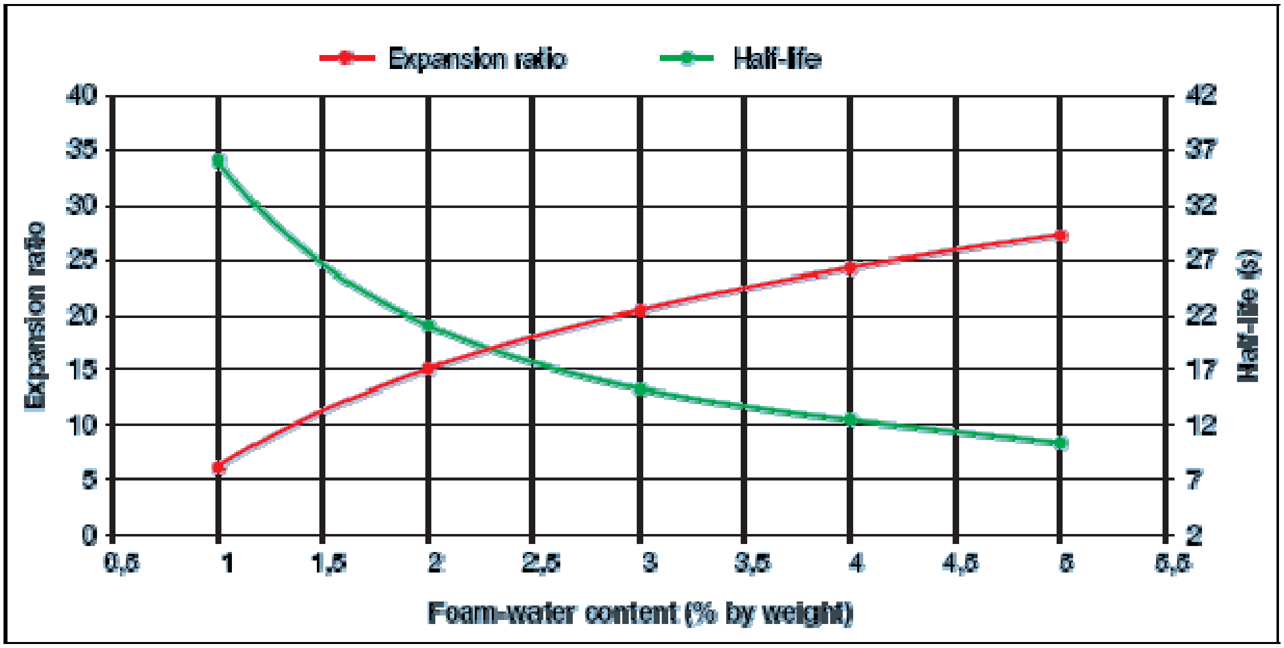


Figure 3. Isothermal curves for Half-Life and Expansion Ratio

Selection of Optimum Asphalt Content – Mix Design

The first step in the mix design process is to determine the gradation of the materials to be recycled, as well as the asphalt content of a representative sample of the RAP materials. The optimum water content and maximum dry density of the representative sample are determined by AASHTO T180 (standard moisture-density relationship). If gradations reveal that the recycled material does not contain the required 5-20% fines necessary for proper binding of the foamed asphalt, as much as 2% (by total weight) Portland cement may be added to provide cementitious bonding, as well as retained tensile strength. Addition of more than 2% portland cement is not recommended in order to avoid cracking. In the case of full depth reclamation (FDR), lime may be added if the Plasticity Index (PI) of the reclaimed granular material is 10 or greater. It is important to note that lime or cement should be added and mixed thoroughly with the reclaimed materials before injection of the asphalt. The timing of the additives and subsequent compaction processes performed in the field should closely parallel the procedures performed in the laboratory in order to be sure that the aggregate material will provide sufficient strength in combination with the use of a particular asphalt source.

The samples of aggregate types present in the reclaimed materials are then tested with a range of foamed asphalt percentages to see how they react together. The typical aggregate types and ranges of foamed asphalt are:

- Milled material/filler material: 1-5% asphalt by mass
- Crushed stone/sand mix: 2-6% asphalt by mass
- Sandy material: 3-7% asphalt by mass

Each material type is combined with the specified amount of foamed asphalt and compacted, cured (with a Marshall compactor), measured for bulk density, and tested for indirect tensile strength (ITS) in both wet and dry conditions. The optimum asphalt content is determined from a plot of ITS versus foamed asphalt content. The optimum asphalt content is generally selected as the value that gives the maximum wet ITS.

Strength of Foamed Asphalt in Pavement

The strength of a foamed asphalt pavement layer has been shown to provide adequate structural resistance to failure in many projects around the world, as well as several projects in Minnesota. Adequate strength is derived from foamed asphalt through proper mix design and laboratory procedures, careful investigation of field conditions, and analysis of any adverse conditions existing at the site. Due to in-situ variations in pavement layers and subgrade materials, it is imperative that field samples are representative of the materials across the site so that the material properties and their reaction to additives can be quantified and accounted for during the mix design process. Laboratory procedures should closely mimic the procedures used in the field during application of foamed asphalt techniques. This will help reduce uncertainty inherent in dealing with in-situ variations in pavement, base, and subgrade layers.

Structural layer coefficients for foamed asphalt can range from 0.13 to 0.35 per inch (M_r of 100 to 360 ksi) for a corresponding asphalt content range of 4.5 to 2.5 percent (See **Figure 4**). Furthermore, studies performed by Maine DOT using a Portable Seismic Property Analyzer (PSPA) on some of their foamed asphalt projects found a range of 131 to 595 ksi. Texas DOT determined modulus values from DCP, Falling Weight Deflectometer (FWD), and PSPA on portions of foamed asphalt base layers that were exhibiting alligator cracking and rutting in the pavement surface. These tests gave modulus ranges of 20 to 80 ksi (DCP), and 100 to 1200 ksi (Young's Modulus, SPA)[1].

[1] Note: The ratio between DCP, SPA, PSPA, or FWD is not a direct 1:1 correlation. Values are cited for reference.

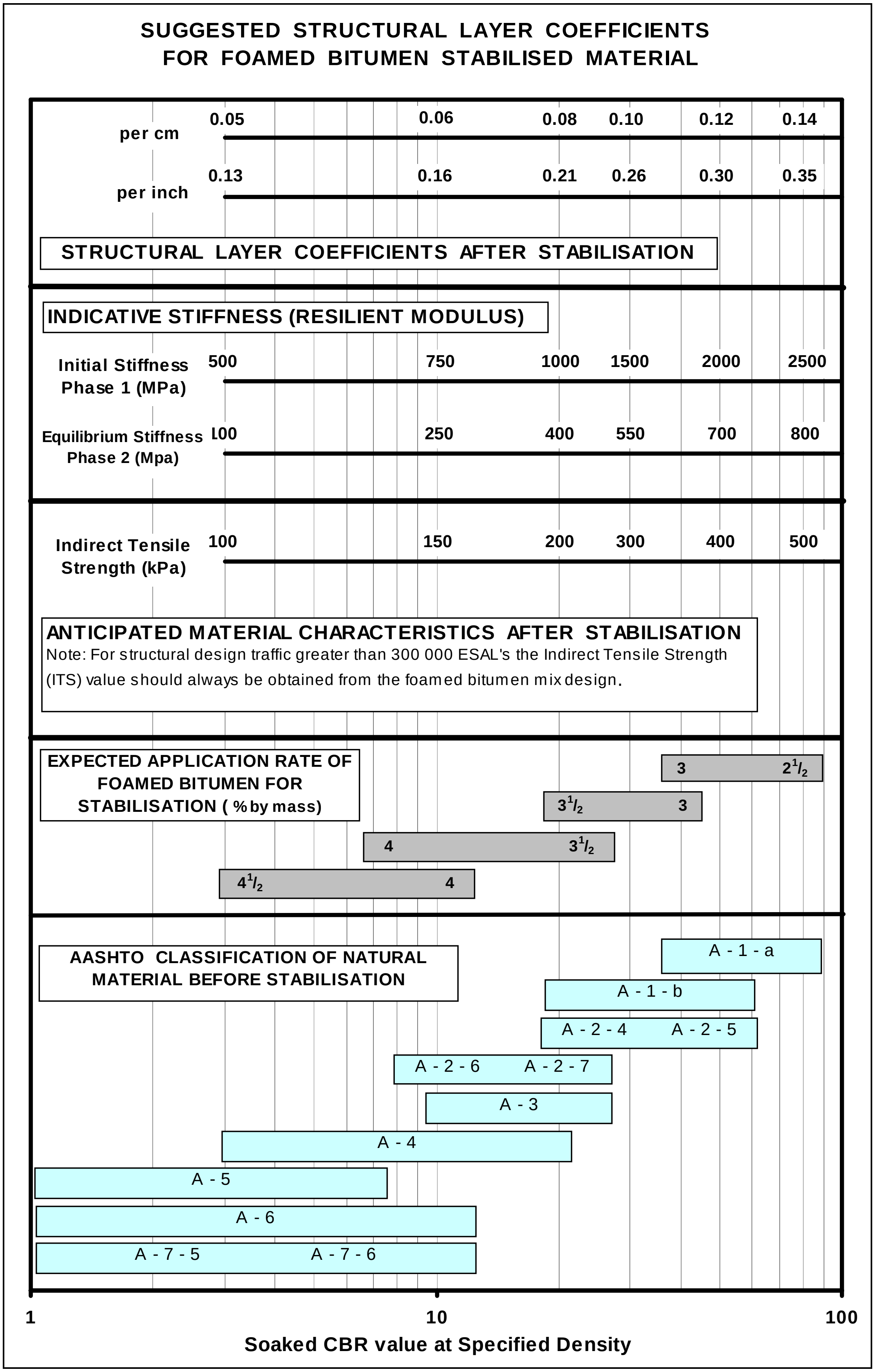


Figure 4. Layer Coefficient ranges for stabilized foamed asphalt materials

Fillmore County CIR with foamed asphalt projects

- **<u>CSAH 8, Length = 3.8 miles:</u>** Located between CSAH 7 and TH 52 (Fountain). Performed with 'foamed asphalt' 52-34 binder. Wearing course is 58-34. The segments were constructed in 2005, and had an ADT of 220. Koch materials collected core samples.
- The existing roadway was reconstructed in 1978, and paved in 1981. The bituminous surface had frequent transverse cracking.

- **<u>CSAH 5, Length = 4.5 miles:</u>** Located from Junction CSAH 4 and approximately 4.5 miles to the north. Performed with 'foamed asphalt' 52-34 binder. Wearing course is 58-34. The segments were constructed in 2005, and had an ADT of 600. Koch materials collected core samples.
- The existing roadway was reconstructed in 1970, last paved in 1988. This segment had up to 14 inches of bituminous with frequent transverse cracking.

- **<u>CSAH 5, Length = 4.5 miles:</u>** Located from the end of the CSAH 5 2005 project to TH 52 (Chatfield). Performed with 'foamed asphalt' 52-34 binder. Wearing course is 58-34. The segments were constructed in 2006, and had an ADT of 980. Koch materials collected core samples.
- The existing roadway was reconstructed in 1964 (mostly), last paved in 1988. This segment had 8-12" of bituminous with frequent transverse cracking.

- **<u>CSAH 8, Length = 4.3 miles:</u>** Located from TH 52 (Fountain) to CSAH 17. Performed with 'foamed asphalt' 52-34 binder. Wearing course is 58-34. The segments were constructed in 2007, and had an ADT of 1100. No cores were taken.
- The existing roadway was reconstructed in 1959 & 1962, last paved in 1983. The segments had frequent transverse cracks and numerous longitudinal cracks in the wheel paths.

    - ➢ All Fillmore County CIR sections using foamed asphalt are performing very well to date. Transverse cracking and rutting appears to be reduced by using foamed asphalt CIR rehab techniques.

Olmsted County CIR with foamed asphalt projects

- **<u>CSAH 24. Length = 3.0 miles:</u>** Constructed in 2004. Located between C.S.A.H. 2 and C.R. 124. PG 52-34 foamed bitumen used for CIR (approx. 4”), at a target add rate of 2% by weight. Two 1.5” lifts of 58-34 for wearing course.

- **<u>CSAH 1, Length = 3.3 miles:</u>** Constructed in 2005. Located between T.H. 30 and 87th St. SW. PG 52-34 foamed bitumen used for CIR (approx. 4”), at a target add rate of 2% by weight. Two 1.5” lifts of 58-34 for wearing course.

- **<u>CSAH 10, Length = 1.3 miles:</u>** Constructed in 2005. Located between I-90 and Dover city limits. PG 52-34 foamed bitumen used for CIR (approx. 4”), at a target add rate of 2% by weight. Two 1.5” lifts of 58-34 for wearing course.

    - ➢ Although the projects are only 2-3 years old, they appear to be wearing well.

NEED MORE INFORMATION ON RECYCLED MATERIALS OR LOW VOLUME ROAD REHABILITATION OR THE MINNESOTA ROAD RESEARCH PROJECT (MN/ROAD)?

Contact: *Minnesota Department of Transportation*

OFFICE OF MATERIALS & ROAD RESEARCH

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MAPLEWOOD, MN 55109

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Mn/ROAD

Office of Materials

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Appendix B

General Design Guidelines for Foamed Asphalt FDR/CIR

S-1 (2331) Full Depth Reclamation with Foamed Asphalt

SPXXXX

This work shall consist of pulverizing and blending the in place bituminous pavement and a portion of the underlying aggregate material and mixing the reclaimed materials in-place with foamed asphalt, water (if required), and other materials (if required). The reclaimed bituminous mixture shall then be placed and compacted in accordance with the applicable Mn/DOT Standard Specifications, the Plans, as directed by the Engineer, and as follows:

Questions about the CIR process are referred to Mn/DOT's Pavement Design Engineer at (651)366-5496.

S-1.1 MATERIALS

Asphalt Stabilizing Agent: Foamed Asphalt shall be produced by using PG 52-34 asphalt binder meeting the requirements of Mn/DOT 3151, and foaming it with specially designed equipment.

Crushed/Sized Bituminous Material: The largest size of the reclaimed material shall not exceed 25% of the depth of the compacted recycled mat. In addition, the crushed and sized bituminous material shall meet the following gradation requirements:

Table 1.

Sieve Size	Percent Passing
37.5 mm (1.5")	98-100%
25 mm (1.0")	90-100%
75 mm (#200)	7-15%

Note: 3% foamed asphalt content by weight of milled bituminous material shall be used for bidding purposes. The actual foamed asphalt content shall be adjusted based on the quantity necessary to meet design requirements.

Water: Shall be clear and free of deleterious materials, such as: acid, oil, alkali, organic material, salt, sugar, or other harmful materials. Water for this item shall be considered incidental for which no additional compensation shall be made.

Mineral Stabilizing Agents – If necessary, additives may be used to meet the requirements in Table 1. In the case that an additive is used, the type and allowable usage percentage must be described in the submitted design recommendation. Mineral additives must meet the following criteria:

1. Portland cement shall meet ASTM Type I
2. Fly ash shall come from an approved source
3. Hydrated lime shall meet the requirements of Mn/DOT 3106
4. Limestone fines shall come from limestone crushing operations

Additional Aggregate - Based on the results of the mix design or other requirements, the Contractor shall determine if additional aggregate is required. Any additional aggregate shall meet the requirements of Mn/DOT 3149.

Mix Design:

The Plans shall specify the mix design(s) for the reclaimed mixture, and to what portion of the roadway the mix design(s) shall be applied. More than one mix design may be necessary due to variations in pavement section along the Project length. Cores should be taken along the Project length, at appropriate intervals, to establish the degree of pavement section variability. The mix design(s) shall establish the depth of milling, the amount and type of added material, the amount of residual asphalt to incorporate into the milled material, and the optimum laboratory compaction moisture content. The temperature of the asphalt binder and the amount of foaming water to add shall be specified by the mix design as well.

S-1.2 CONSTRUCTION REQUIREMENTS

A. Equipment

Reclaiming Machine:

The Road Reclaimer

The Contractor shall furnish a self-propelled machine designed to pulverize the in-place bituminous pavement structure to the specified gradation. It shall be capable of uniformly blending the pulverized material with the underlying aggregate base material to the depths shown in the Plans. This machine shall have automatic depth and cross-slope controls and maintain a constant cutting depth. The automatic depth controls shall maintain the cutting depth to within plus or minus 6 mm [**1/4 inch**] of the depth shown on the Plans. The Road Reclaimer shall be fitted with equipment capable of adequately mixing the reclaimed pavement while injecting the foamed asphalt material as detailed in the Mixing/Injecting portion of this specification. The equipment shall provide a positive means for accurately controlling the rate of flow and total delivery of the asphalt stabilizing agent into the mixture in relation to the speed of the reclaiming machine and quantity of material being recycled. The asphalt foaming system shall accurately and uniformly add the specified percent of water to the hot asphalt binder. The equipment shall be fitted with a test nozzle to provide field samples of foamed asphalt.

Mixing/Injecting

All reclaimed materials, additional aggregate, and mineral stabilizing agents shall be mixed properly to provide a homogenous material prior to injecting the foamed asphalt. The Reclaiming Machine shall be capable of automatically metering liquids with a variation of not more than plus or minus 0.2 percent by weight of foamed asphalt. The foamed asphalt pump should be of sufficient capacity to allow asphalt contents up to 6% by weight of pulverized bituminous material. The unit shall be equipped with facilities so that the Contractor can verify and calibrate these items by a method acceptable to the Engineer. The reclaimed roadway materials shall meet the gradation requirements in Mn/DOT 3149, and shall be injected with foamed asphalt as determined by the submitted mix design. Prior to compaction, the FDR with foamed asphalt materials may be shaped with a motor grader to meet the necessary profile and cross-slope. The stabilized reclaimed materials can then be compacted using ordinary compaction.

Rollers:

The Rollers shall meet the requirements of Mn/DOT 2360.6C1, 2360.6C2, 2360.6C3, or 2360.6C4.

Pneumatic-Tired Roller

The Pneumatic-Tired Roller shall be self-propelled and weigh 28 to 33 metric tons (**25 to 30 tons**). The time arrangement shall be such that compaction will be obtained over the full width of the roller with each pass.

Pad Foot Vibratory Roller

The Pad Foot Vibratory Roller shall weigh at least 11,300 kg (**25,000 pounds**) and be allowed for use on a performance basis.

Steel-Wheeled Roller

The Steel-Wheeled Roller shall weigh 28 to 33 metric tons (**25 to 30** ton), and be equipped with a watering device to prevent material from adhering to the rollers.

Motor Grader:

The Motor Grader shall be self-propelled with a minimum 3.6 m (**12 feet**) wide blade, and shall meet the requirements of Mn/DOT specification 2360.5C2c.

B. Construction Operations

The Contractor shall perform foamed asphalt stabilized reclamation between the dates of May 1 and October 1 unless otherwise specified.

Vegetation: Grass and other vegetation shall be removed from cracks in the pavement structure and also from the edges of the existing pavement to prevent contamination of the pulverized bituminous material. Vegetation removed from the pavement shall be disposed of properly according to the appropriate Mn/DOT 2104.3.

Pulverizing: The existing pavement shall be reclaimed to the required depth and width as indicated on the Plans. The reclamation shall be performed in a manner that does not disturb the material in the existing roadway below the planned depth.

Mixing/Injecting: The stabilized reclaimed layer shall be produced by injecting the foamed asphalt into the pulverized pavement and base materials and then compacting to specification. More than one pass of the reclaiming machine is allowed if additional mixing of the reclaimed material is necessary to meet moisture requirements, or to obtain a uniform mixture. If multiple passes of the equipment are required to reclaim the pavement material to the desired width, a minimum 6 inch (150 mm) overlap between the passes shall be used. The asphalt stabilizer application system shall be capable of adjusting for the width of recycling reclaiming such that overlapped mixture maintains the designed residual asphalt content.

The asphalt foaming system shall accurately and uniformly add the specified percent of water to the hot asphalt binder. The equipment shall be fitted with a test nozzle to provide field samples of foamed asphalt. Tankers supplying the hot asphalt binder shall be equipped with a thermometer to continuously measure the temperature of the asphalt in the bottom third of the tank.

Final shaping: The material shall be spread using a self-propelled motor grader meeting the requirements in S-1.2. The reclaimed material shall be spread without segregation to the lines and grades established by the Plans.

Compaction: Compacting of the recycled mix shall be completed using rollers and motor grader/s meeting the requirements of S-1.2. The initial compaction will be completed with combination of pad foot roller and motor grader until the pad foot roller has walked out of the foamed asphalt stabilized material. Rolling patterns shall be established to achieve a maximum density determined by nuclear density testing. Rolling shall continue until very little displacement occurs in the stabilized material. The rolling patterns shall be re-checked with nuclear moisture-density gauge every day of production or anytime that appearance of the stabilized layer changes. Double drum steel roller(s), either operating in a static or vibratory mode, shall do final rolling to eliminate pneumatic tire marks and to achieve density. Vibratory mode should only be used if it is shown not to damage the pavement structure. The selected rolling pattern shall be followed unless changes in the reclaimed mix or placement conditions occur and a new rolling pattern is established at that time. Rolling or roller patterns shall change when major displacement and/or cracking of the reclaimed material occurs. Rolling shall start no more than 30 minutes behind the final mixing.

The nuclear moisture-density testing device shall be furnished and operated by the Contractor. The furnishing of the nuclear moisture-density testing device and operator shall be considered incidental to the furnishing and placing of the FDR bituminous mixture and shall not be compensated for separately.

Any damage to the completed foamed asphalt material shall be repaired by the Contractor prior to the placement of the hot mix asphalt (HMA) concrete surface course or other applicable surface treatment, as directed by the Engineer. The FDR with foamed asphalt shall be allowed to cure for 2 days before placing the HMA surface course, or other applicable surface treatment.

The Contractor shall reshape and compact the in-place aggregate shoulder prior to placing the first overlay course, in accordance with Mn/DOT 2105.3G. Compaction shall be achieved by the Quality Compaction Method in accordance with Mn/DOT 2211.3C2.

C. Quality Control/Quality Assurance

The Contractor or supplier shall be responsible for the quality control.
Mn/DOT shall be responsible for quality assurance.

Quality Control

Pulverized Bituminous Material Sizing – Gradations shall be performed each working day on the moist millings (which must be air dried) using the following sieves:

37.5 mm (**1.5 inch**)
25 mm (**1 inch**)
75 µm (**#200**)

The Contractor shall be responsible for gradation control by testing the reclaimed material at a rate of at least 1 test per lane-mile or portion thereof, (one test per 5,890 m² (**7,040 square yards**)), with a minimum of 2 tests per day. The Contractor shall provide gradation test results to the Engineer within first 500 feet of production, and within 500 feet of failing gradations. The Contractor is responsible for adjusting production to maintain gradation control. The gradation requirement applies to the reclaimed material before it is mixed with the foamed asphalt.

In addition to the gradations, a sample shall be obtained each day, before addition of foamed asphalt, for every 0.8 km [**½ mile**] of reclaimed roadway and screened using a 31.5 mm [**1.5 inch**] sieve (or smaller sieve if required) to determine if the material is meeting the maximum particle size requirement.

Foamed Asphalt – Foamed Asphalt percent content by weight shall be checked as close as practicable to the point of every gradation and screening sample taken. The location, foamed asphalt content, and corresponding gradation sample number shall be recorded and reported to the Engineer. Foamed asphalt content shall be recorded whenever it has changed. Changes in percent foamed asphalt content shall be made based upon mix design recommendations.

Compaction Water – The contractor shall determine the amount of additional water necessary to facilitate uniform mixing of the reclaimed material to achieve a stable reclaimed layer that exceeds the minimum specified density. The water may be added prior to, or concurrently with, the injection of the foamed asphalt. Adding water to facilitate uniform mixing shall not adversely affect the performance of the foamed asphalt.

Depth of Pulverization – The nominal depth shall be checked on both outside vertical faces of the cut each 0.2 km [**1/8 mile**]. The station and nominal depth observed shall be recorded.

Recycled Material Compacted Density – A wet density shall be determined using a nuclear moisture-density gauge generally following the procedures for ASTM D2950, backscatter measurement. A rolling pattern will be established such that a maximum density is achieved with the rollers specified based on relative nuclear density readings. However, care shall be taken not to over-roll the mat based on visual observations of check cracking or shoving. A new rolling pattern shall be established if the recycled material changes significantly.

Quality Assurance

Pulverized Bituminous Material Sizing – One gradation shall be performed each day on the moist millings. The sample of the reclaimed, unstabilized pavement shall be air dried before performing the gradation.

Foamed Asphalt – The bituminous material used for foaming shall be of the performance grade PG 52-34 and shall meet Mn/DOT 3151. The temperature of the bituminous material shall remain at the optimum temperature, within substantial compliance, as determined by the mix design. Non-certified suppliers shall have every load sampled. Certified suppliers shall have the first load sampled, and then one sample per 189,271 liters [**50,000 gallons**] (approximately 180 metric tons [**200 tons**]) for certified suppliers. Samples shall be obtained from the shipping trailers in the presence of the Engineer or an Agency Inspector.

Mix Design: The Plans will specify the mix design for the reclaimed mixture. The mix design shall be derived from roadway materials obtained directly from the Project site. More than one mix design may be required based on information gathered from cores taken before the start of the Project. Representative samples of the roadway pavement section(s) for performing the mix design(s) shall be obtained from cores and/or test pits. The mix design shall establish the depth of milling, the amount of added material, the optimum compaction moisture, and the optimum asphalt temperature and water content for foaming.

D. Restrictions

Full Depth Reclamation with foamed asphalt operations shall not proceed unless the atmospheric temperature measured in the shade and away from artificial heat is 10°C [**50^0 F**] and rising. Also, the weather shall not be foggy or rainy. Foamed asphalt operations shall not proceed if freezing temperatures are expected within 48 hours after placement of any portion of the Project.

The hot mix bituminous overlay shall be placed on the stabilized FDR within 15 days.

E. Thickness and Surface Requirements

Upon completion of placement and compaction, the finished surface shall show no variations greater than 12 mm [**1/2 inch**] from the edge of a 3 meter [**10 foot**] straightedge resting on any two points and laid parallel to and/or at right angles to the centerline. *All deviations from this tolerance shall be corrected at no additional cost to the Department.*

During the curing period, the surface of the full depth reclaimed bituminous mixture may be sealed, if necessary, to prevent raveling. A minimum amount of emulsion should be employed since the intent is not to seal the surface such that curing is precluded. Fog sealing shall be accomplished with CSS-1H emulsion applied at an approximate rate of 0.23 to 0.45 liters per square meter [**0.05 to 0.10 gallons per square yard**] of dilute asphalt emulsion (50/50 mix of emulsion and water by volume). The fog seal, if required, shall be applied in accordance with Mn/DOT 2355.3. The Project Engineer shall be contacted prior to fog sealing. If, in the opinion of the Engineer, the recycled base surface is not subject to raveling prior to the application of the sealant, the Engineer has the right, as provided in Mn/DOT 1402, to delete the item, Fog Seal, from the Contract and not be subject to a value engineering proposal by the Contractor.

The Contractor shall be responsible for maintaining the finished surface of the FDR with foamed asphalt in a smooth, compacted condition free of ruts, distortion, potholes, loose aggregate, and to the grade and cross-section tolerances previously stated, until the first bituminous course required by the Contract is completed. All loose aggregate that develops on the surface of the reclaimed pavement shall be removed by power brooming. A rotary power broom capable of cleaning the road surface and removing loose particles shall be provided within 24 hours notice, if directed by the Engineer. The Power Broom shall be operated in such a way as to avoid causing any damage to the stabilized reclaimed pavement material.

The Contractor shall repair any of the previously mentioned deficiencies to the completed full depth reclaimed bituminous mixture to the satisfaction of the Engineer. Said repair(s) shall be made at no additional cost to the Department. Failure to perform corrections shall be considered unacceptable work as per Mn/DOT 1512.

S-1.3 METHOD OF MEASUREMENT

The FDR with Foamed Asphalt pavement layer shall be measured by the Square meter [**Square yard**].

The Bituminous Material for Mixture of the type shown on the Plans or as specified in the Special Provisions will be measured by the Metric ton [**ton**].

The Mineral Stabilizing Agent will be measured by the Metric ton [**ton**], dry weight.

Bituminous Material for Fog Seal applied on the road will be measured by volume **diluted** at 15 degrees Celsius [**60 degrees Fahrenheit**] in Liters [**Gallons**].

S-1.4 BASIS OF PAYMENT

Payment for the accepted quantities of full depth reclamation bituminous mixture at the Contract bid prices per unit of material shall be compensation in full for all costs of constructing the full depth reclamation bituminous mixture as specified, including any additives as permitted or required.

The accepted quantity of Full Depth Reclamation with Foamed Asphalt Mixture will be paid for at the Contract bid price per Square meter [**Square yard**] complete and in place.

The accepted quantity of Bituminous Material for Mixture of the type shown on the Plans will be paid for at the Contract bid price per Metric ton [**ton**] complete and in place.

The accepted quantity of Bituminous Material for Fog Seal will be paid for at the Contract bid price per liter [**gallon**] **diluted** complete and in place.

Payment for the full depth reclamation bituminous mixture will be made on the basis of the following schedule:

Item No.	Item	Unit
2360.XXX	Full Depth Reclamation with Foamed Asphalt	Square meter [**Square yard**]
2321.503	Bituminous Material for Mixture	Metric ton [**Ton**]
2355.502	Bituminous Material (CSS-1H) for Fog Seal **Diluted**	Liter [**Gallon**]

S-1 (2331) COLD IN-PLACE RECYCLE (CIR) WITH FOAMED ASPHALT, FULL RECYCLING TRAIN MIX DESIGN

SPXXXX-XXX

This work shall consist of milling the existing bituminous surface to the depth and width shown on the plans, crushing, screening, and mixing the reclaimed asphalt pavement (RAP) with foamed asphalt, water (if required), and other additives (if required), and placing the cold in-place recycled bituminous mixture and compacting in accordance with the applicable Mn/DOT Standard Specifications, the Plans, as directed by the Engineer, and as follows:

Questions about the CIR process are referred to Mn/DOT's Pavement Design Engineer at (651)366-5496.

S-1.1 MATERIALS

Asphalt Stabilizing Agent: Foamed Asphalt shall be produced by using PG 52-34 asphalt binder meeting the requirements of Mn/DOT 3151, and foaming it with specially designed equipment.

Crushed/Sized Bituminous Material: The largest size of the reclaimed material shall not exceed 50% of the depth of the compacted recycled mat. In addition, the crushed and sized bituminous material shall meet the following gradation requirements:

Table 1.

Sieve Size	Percent Passing
31.5 mm (1.25")	98-100%
25 mm (1.0")	90-100%
75 µm (#200)	7-15%

Note: 2% foamed asphalt content by weight of milled bituminous material shall be used for bidding purposes, if an asphalt content is not specified by the Plans or mix design. The actual foamed asphalt content shall be adjusted based on the quantity necessary to meet density and other requirements.

Water: Shall be clear and free of deleterious materials, such as: acid, oil, alkali, organic material, salt, sugar, or other harmful materials. Water for this item shall be considered incidental for which no additional compensation shall be made.

Mineral Stabilizing Agents: If necessary, additives may be used to meet strength, gradation, or other requirements. The type and allowable usage percentage of any Mineral Stabilizing Agents shall be explicitly described for each pavement section based on cores taken before the start of the Project. Mineral Stabilizing Agents must meet the following criteria:

1. Portland cement shall meet ASTM Type I
2. Fly ash shall come from an approved source
3. Hydrated lime shall meet the requirements of Mn/DOT Specification 3106
4. Limestone fines shall come from limestone crushing operations

Additional Aggregate: RAP or virgin aggregate material may be added if the material meets the requirements in Table 2. The type (RAP, virgin, or mix of the two) and allowable usage percentage of Additional Aggregate shall be explicitly described for each pavement section based on cores taken before the start of the Project.. Any additional RAP or virgin aggregate material shall be considered incidental for which no additional compensation shall be made.

The crushed RAP shall be free from vegetation and all other deleterious materials, including silt and clay balls. It shall meet the requirements for Deleterious Materials given in Table 2. The crushed RAP shall not exceed the maximum size requirement in S-1.1 "Crushed/sized bituminous material", and when blended with the design millings shall produce a product which meets the specifications given in Table 1.

Table 2. Additional Aggregate		
Tests	Method	Limit
Deleterious Materials: Clay Lumps and Friable Particles in Aggregate, % max	ASTM C 142 or AASHTO T112	0.2 recommended
Maximum size, 100% Passing, Sieve Size	ASTM C 136 or AASHTO T 27	31.5 mm [**1.25"**]

Mix Design: Unless otherwise stated, a preconstruction mix design shall not be performed for foamed asphalt CIR. If a mix design is performed, then the mix design shall be derived from roadway materials obtained directly from the Project site. Cores should be taken along the Project length, at appropriate intervals, to establish the degree of pavement section variability. The mix design(s) shall establish the depth of milling, the amount and type of added material, the amount of residual asphalt to incorporate into the reclaimed material, and the optimum laboratory compaction moisture content. The temperature of the asphalt binder and the amount of foaming water to add shall also be specified by the mix design(s). The job mix design(s) shall meet the criteria of Table 1 and be submitted to the Engineer.

S-1.2 CONSTRUCTION REQUIREMENTS

A. Equipment

A Full Recycling Train is required. This is a multi-unit train with milling, screening/crushing, and mixing units, used to process the material.

Milling: The Contractor shall furnish a self-propelled machine capable of milling the existing bituminous surface to the depth shown on the Plans, in a single pass, and to a minimum width of not less than 3.8 m [**12.5 feet**]. This machine shall have automatic depth and cross-slope controls and maintain a constant cutting depth. The automatic depth controls shall maintain the cutting depth to within plus or minus 6 mm [**1/4 inch**] of the depth shown on the Plans.

Crushing/sizing: The material shall be crushed and sized prior to mixing with foamed asphalt. The unit shall have a "closed circuit" system capable of continuously returning oversize material to the crusher. All of the reclaimed asphalt pavement (100%) shall be processed to the maximum size requirements as specified.

Mixing: The pug mill type mixing unit shall be equipped with a continuous weighing system of the milled and sized material, coupled/interlocked to a computer controlled liquid metering device for the foamed asphalt and other additives. The machine shall be capable of automatically metering liquids with a variation of not more than plus or minus 0.2 percent by weight of mix from the specified percentage. The unit shall be equipped with facilities so that the Contractor can verify and calibrate these items by a method acceptable to the Engineer.

Pick-up machine: The pick-up machine shall be capable of removing the entire windrow of cold in-place recycled bituminous material down to the remaining underlying material.

Paver: The paver shall meet the requirements of Mn/DOT2360.5C2a.

Alternatively to the equipment listed in Mixing, Pick-up machine, and Paver, a self-propelled paver with on-board pugmill and asphalt tank may be used. Millings must be added directly to the hopper. The paver shall be equipped with a belt scale for the continuous weighing of the pulverized and sized bituminous material and a coupled/interlocked computer controlled liquid metering device. The mixing unit shall be an on-board completely self-contained pugmill. The liquid metering device shall be capable of automatically adjusting the injection rate of foamed asphalt to compensate for any variation in the weight of pulverized material coming into the mixer. The metering device shall deliver the amount of foamed asphalt to within ± 0.2 percent of the required amount by weight of pulverized bituminous material (for example, if the design requires 3.0 percent, the metering device shall maintain between 2.8 percent to 3.2 percent). Also, automatic digital readings shall be displayed for both the flow rate and total amount of pulverized bituminous material and foamed asphalt in appropriate units of weight and time.

Rollers: The rollers shall meet the requirements of Mn/DOT2360.6C1, 2360.6C2, 2360.6C3, or 2360.6C4. A minimum of two rollers shall be required. When cold in-place recycling depths of 75 mm [**3 inches**] or more, one of the two rollers shall be a 28 to 33 metric ton [**25 to 30 ton**] pneumatic roller equipped with a watering device to prevent material from adhering to the tires. The 28 to 33 metric ton [**25 to 30 ton**] pneumatic roller should be used for breakdown rolling.

Distributor: The distributor shall meet the requirements of Mn/DOT 2321.3C1.

Broom: A self-propelled power broom for removal of loose particles and other materials from the CIR surface. The broom shall have positive control on the downward pressure applied to the surface.

B. Construction Operations

Vegetation: Grass and other vegetation shall be removed from cracks in the pavement structure and also from the edges of the existing pavement to prevent contamination of the pulverized bituminous material. Vegetation removed from the pavement shall be disposed of properly according to the appropriate Mn/DOT 2104.3.

Milling: The existing pavement shall be milled to the required depth and width as indicated on the Plans. Recycling shall be performed in a manner that does not disturb the remaining portion of pavement or its underlying material. The milling operation shall be conducted so that no fines are left along the vertical faces of the cut.

When a paving fabric is encountered during the CIR operation, the Contractor shall make the necessary adjustments in equipment or operations so that at least ninety percent (90%) of the shredded fabric in the recycled material is no more that 3200 mm^2 [**5 square inches**]. Additionally, no fabric piece shall have any dimension exceeding a length of 100 mm [**4 inches**]. These changes may include, but are not limited to, adjusting the milling rate and adding or removing screens in order to obtain a specification recycled material. The Contractor shall be required to waste material containing over-sized pieces of paving fabric. If a paving fabric is encountered that was not identified in the plans, then any adjustments to the mix design and/or equipment shall be considered extra work.

Mixing: The recycled material shall be produced through a mixing unit capable of processing the pulverized material and foamed asphalt and water to a homogeneous mixture. The foamed asphalt and water shall be incorporated into the pulverized bituminous material at the initial rate determined by the mix design(s), or the Engineer. The total water content may include the amount added at the milling head, and may also include addition at the mixing unit if available.

Paver: Heating of the paver screed will not be permitted. A pick-up machine may be used to transfer the windrowed material into the paver hopper if using a conventional paver. The pickup machine must be within 45 m [**150 feet**] of the mixing unit. The recycled material shall be spread in one continuous pass, without segregation, and to the lines and grades established by the Engineer.

Compaction: Compaction shall be by Ordinary Compaction Method as described in 2360.6C. Any reference in 2360.6C to HMA shall be construed to apply to CIR.

After the completion of compaction of the recycled material, no traffic, including that of the Contractor, shall be permitted on the completed recycled material for at least two (2) hours. After two hours rolling traffic may be permitted on the recycled material. This time may be adjusted by the Engineer to allow sufficient cure so traffic will not initiate raveling. After opening to traffic, the surface of the recycled pavement shall be maintained in a condition suitable for the safe movement of traffic. All loose particles that may develop on the pavement surface shall be removed by power brooming.

The area shall be allowed to cure such that the moisture content is reduced to 1.5 percent or less, by total weight of mix, (this may take approximately 7 to 10 days) before placing final surfacing. If the moisture content is above 1.5 percent by weight yet below 2.5 percent by weight, and has not changed by more than 0.2 percent over a period of five days, the Engineer may allow surfacing to proceed. If the moisture content is above 2.5% after 20 calendar days since placement, contact Mn/DOT's Pavement Design Engineer for guidance.

The final surfacing shall be placed on the CIR bituminous mixture within 15 days unless the moisture content exceeds the limit described in this section.

The Contractor shall reshape and compact the in-place aggregate shoulder prior to placing the first overlay course, in accordance with Mn/DOT 2105.3G. Compaction shall be achieved by the Quality Compaction Method in accordance with Mn/DOT 2211.3C2.

C. Quality Control/Quality Assurance

The Contractor or supplier shall be responsible for Quality Control.
Mn/DOT shall be responsible for Quality Assurance.

Quality Control

Pulverized Bituminous Material Sizing: A minimum of two (2) gradations shall be performed each day on moist millings sampled from the reclaiming machine. The moist millings should be air dried before performing the gradation. The resulting gradation shall be compared to the mix design gradations to determine any necessary changes to foamed asphalt content (see Appendix 1). Sampling procedures shall be in accordance with ASTM D979 or AASHTO T168.

In addition to the gradations, a sample shall be obtained each day, before addition of foamed asphalt, for every 0.8 km [**½ mile**] of reclaimed roadway and screened using a 31.5 mm [**1.25 inch**] sieve (or smaller sieve if required) to determine if the material is meeting the maximum particle size requirement.

Foamed Asphalt Content: Foamed Asphalt content shall be checked and recorded for each segment in which the percentage is changed. Foamed asphalt content shall be checked with sufficient frequency to detect any changes.. Foamed asphalt content can be checked from the belt scale totalizer and asphalt pump totalizer.

Water Content: Water content at the milling head shall be checked and recorded for each segment in which the percentage is changed. This information shall be gathered from the water metering device, which can be checked from the belt scale totalizer to verify daily quantities used. Water content changes shall be made based on mixture consistency, coating, and dispersion of the recycled materials.

Mixture Testing: On the first full day of recycling, samples will be gathered for testing mixture results from the design given as described in Table 1, Appendix 1. The samples should be taken following ASTM D3665 and D979. If samples of the foamed asphalt/recycled asphalt pavement mixture are taken, the specimens must be compacted within 15 minutes of sampling and tested. The samples must be screened through a 25.0 mm [**1 inch**] screen if 100 mm [**4 inch**] specimens are to be compacted. If samples of recycled asphalt pavement are taken prior to addition of foamed asphalt, they must be put into a sealed plastic container to not allow any loss of moisture. Samples must be mixed with the field emulsion within 24 hours and tested as required in Table 1, Appendix 1. The results shall be provided to the Project Engineer. If the results fail to meet the design criteria, daily sampling will continue until the mix meets the design specifications.

Depth of Pulverization (Milling): The nominal depth shall be checked on both outside vertical faces of the cut each 0.2 km [**1/8 mile**]. The station and depth shall be recorded.

Note: this density paragraph seems to conflict with compaction in sect B

Recycled Material Compacted Density: A wet density shall be determined using a nuclear moisture-density gauge following the procedures for ASTM D2950, backscatter measurement. A rolling pattern will be established such that a maximum density is achieved with the rollers specified, based on relative nuclear moisture-density readings. However, care should be taken not to over-roll the mat based on visual observations of check cracking or shoving. A new rolling pattern shall be established if the material being recycled changes.

Contractor's Gradation Quality Control (QC): The Contractor shall be responsible for gradation control by testing the reclaimed material at a rate of 1 test per lane-mile or portion thereof, (5,890 m² (**7,040 square yards**)), with a minimum of 1 test per day. The Contractor shall provide gradation test results to the Engineer within first 500 feet of production, and within 500 feet of failing gradations. The Contractor is responsible for adjusting production to maintain gradation control. This gradation requirement applies to the reclaimed material before it is mixed with the foamed asphalt.

Quality Assurance

Pulverized Bituminous Material Sizing: A minimum of two (2) gradations shall be performed each day on the moist millings (which must be air dried). The resulting gradation shall be compared to the mix design gradations to determine any necessary changes to foamed asphalt content (see Appendix 1). Sampling procedures shall be in accordance with ASTM D979 or AASHTO T168.

Foamed Asphalt – The bituminous material used for foaming shall be of the performance grade PG 52-34 and shall meet Mn/DOT 3151. The temperature of the bituminous material shall remain at the optimum temperature, within substantial compliance, as determined by the mix design. Non-certified suppliers shall have every load sampled. Certified suppliers shall have the first load sampled, and then one sample per 189,271 liters [**50,000 gallons**] (approximately 180 metric tons [**200 tons**]) for certified suppliers. Samples shall be obtained from the shipping trailers in the presence of the Engineer or an Agency Inspector.

D. Restrictions

Cold In-Place recycling operations shall not proceed unless the atmospheric temperature measured in the shade and away from artificial heat sources is 10°C [**50^0 F**] and rising. Also, the weather shall not be foggy or rainy. The weather forecast shall not call for freezing temperature within 48 hours after placement of any portion of the Project.

The hot mix bituminous overlay shall be placed on the CIR bituminous mixture within 30 days.

E. Thickness and Surface Requirements

Upon completion of placement and compaction, the finished surface shall show no variations greater than 6 mm [**1/4 inch**] from the edge of a 3 meter [**10 foot**] straightedge resting on any two points and laid parallel to and/or at right angles to the centerline. *All deviations from this tolerance shall be corrected at no additional cost to the Department.*

During the curing period, the surface of the cold in-place recycled bituminous mixture may be sealed, if necessary, to prevent raveling, as determined by the Engineer. A minimum amount of emulsion should be employed since the intent is to not seal the surface such that curing is precluded. Fog sealing shall be accomplished with CSS-1H or CSS-1 emulsion applied at an approximate rate of 0.23 to 0.45 liters per square meter [**0.05 to 0.10 gallons per square yard**] of dilute asphalt emulsion (50/50 mix of emulsion and water by volume). The fog seal, if required, shall be applied in accordance with Mn/DOT 2355.3. If fog sealing is required, it shall be considered extra work.

The Contractor shall be responsible for maintaining the finished surface of the cold in-place recycled material in a smooth, compacted condition free of distortion, potholes, loose aggregate, and to the grade and cross-section shown in the plans. Rutting shall not exceed ¼" over a 10' straightedge in any direction. All loose aggregate that develops on the surface of the recycled pavement shall be removed by power brooming. A rotary power broom capable of cleaning the road surface and removing loose particles shall be provided within 24 hours notice, if directed by the Engineer.

The Contractor shall repair any deficiencies to the completed cold in-place recycled bituminous mixture to the satisfaction of the Engineer. Said repair(s) shall be incidental work for which no direct compensation will be made therefore.

S-1.3 **METHOD OF MEASUREMENT**

Cold In-place Recycle Bituminous Mixture shall be measured by the Square meter [**Square yard**].

The Bituminous Material for Mixture of the type shown on the Plans or as specified in the special provisions will be measured by the Metric ton [**ton**] of undiluted bituminous material.

Note to designer: An emulsion content of 3% by weight of the milled bituminous material shall be used for bidding purposes prior to the completed design. The actual emulsion content will be adjusted based on the quantity necessary to meet the design requirements in Table 1.

S-1.4 **BASIS OF PAYMENT**

Payment for the accepted quantities of cold in-place recycle bituminous mixture at the Contract bid prices per unit of material shall be compensation in full for all costs of constructing the cold in-place recycled bituminous mixture as specified, including all costs for furnishing and incorporating any material required, any equipment and labor required, any costs associated with sampling the existing road and traffic control, testing and developing the required mix designs, and all water, materials or additives required.

The accepted quantity of Cold In-place Recycle Bituminous Mixture will be paid for at the Contract bid price per Square meter [**Square yard**] complete and in place.

The accepted quantity of Bituminous Material for Mixture of the type shown on the Plans will be paid for at the Contract bid price per Metric ton [**ton**] complete and in place.

Payment for the cold in-place recycled bituminous mixture will be made on the basis of the following schedule:

Item No.	Item	Unit
2331.604	Cold In-place Recycle Bituminous Mixture	Square meter [**Square yard**]
2331.609	Bituminous Material for Mixture	Metric ton [**Ton**]

S-1.5 **APPENDIX 1**

Mix Design Procedures for CIR (Cold In-place Recycling) Material

The mix design for CIR with foamed asphalt shall be performed by a laboratory with the proper equipment for determining a foamed asphalt mix design. The primary steps in the mix design process are:

- Determine the optimum foaming characteristics of the asphalt binder.
- Determine the optimum moisture content of the RAP for compaction.
- Prepare, compact, and cure CIR mixture over a range of foamed asphalt contents.
- Determine the optimum foamed asphalt content for the CIR mixture.

1. Determine the optimum foaming characteristics

By foaming the asphalt binder, the viscosity of the asphalt is significantly reduced to permit uniform mixing with cold RAP material. The ability to foam asphalt is controlled by the asphalt binder temperature and the amount of water injected into the asphalt. These values generally range from 280 to 320ºF (135 to 160ºC) and 1.5 to 3.5% injected water. Expansion ratio and half-life of the foamed asphalt are measured to determine the optimal asphalt-water ratio and asphalt temperature. The foam expansion ratio will increase (5 times to 15 times) as the amount of water injected increases. The half-life of the foam decreases (15 seconds to 5 seconds) as the amount of water injected increases. These conflicting conditions are merged to select the best foam properties for the project. An expansion ratio of 10 and half-life of 10 seconds are suitable for most CIR projects, in general.

2. Determine the optimum compaction moisture

CIR mixture is compacted to a maximum density through the lubricating effect of the free moisture in the mixture. The compaction moisture is not the same as the moisture injected into the asphalt binder to create foam. To determine the optimum compaction moisture, a group of RAP samples are compacted with different moisture contents. The resulting dry densities are plotted to determine the optimum moisture required for compaction. Mix designs prepared over the last several years indicate that the moisture required to achieve maximum RAP density is approximately 4 percent. Once the optimum moisture content is determined, the value is adjusted down slightly to account for the foamed asphalt added to the mixture

3. Prepare mixture

The bulk sample of RAP may require additional processing to achieve a gradation that passes the 1 inch (25 mm) sieve. The RAP is dried in open pans at room temperature, sieved into 3 size fractions (+3/8 inch, +1/8 inch, pan)(+9.5 mm, +2.36 mm, pan), and re-blended to achieve uniform samples. Prepare a blending chart to determine what amounts of foamed asphalt will be added to the RAP. A minimum of three foamed asphalt contents should be selected. The preferred contents are 1.5%, 2.0%, 2.5%, and 3.0%. Each batch should have sufficient mixture to compact three 4 inch (100 mm) gyratory samples. The dry RAP sample and compaction water are added to the mixing bowl and mixed for 45 to 60 seconds. The foamed asphalt is sprayed into the damp RAP while the mixer continues to mix the sample. Continue mixing for an additional 60 seconds.

4. Compact and cure mixtures

The gyratory compactor is used to compact each sample to 25 gyrations. Extrude the specimen and place it in the oven to cure at 105ºF (40ºC) for 72 hours. Remove the specimens from the oven and allow them to cool to room temperature.

5. Test mixtures

Measure the volume and mass of each specimen and determine the density. Sort the specimens into equal sublots based on height and density for further testing. Dry condition the samples of one sublot in an oven at 77ºF (25ºC) for 2 hours. The other sublot of specimens are placed in a 77ºF (25ºC) water bath for 20 minutes, vacuum saturated (50mm Hg) for 50 minutes, and then allowed to rest in the 77ºF (25ºC) bath for an additional 10 minutes. Perform the indirect tensile test (IDT) and calculate the average IDT strength for each sublot. Plot the average IDT wet and dry strength for each foamed asphalt content.

6. Mix design report

The mix design report will provide the results for optimum foam characteristics, optimum compaction moisture content, and optimum foamed asphalt content. Specific report values include:

- Asphalt binder temperature for foaming (ºF or ºC).

- Percent injection water for foaming (% of asphalt by weight).
- Optimum compaction moisture content (% of dry RAP by weight).
- Optimum asphalt foam content (% of dry RAP by weight).

S-1.6 APPENDIX 2

Procedures for performing AASHTO TP9-96 for CIR Design Specimens

NOTE: Procedure for critical cold temperature selection

Specification temperature shall be chosen using FHWA LTPPBind software (Version 2.1) using the weather station closest to the Project. The required temperature for the specification is the coldest temperature at the top of the CIR layer in the pavement structure. Use 98 percent reliability.

Perform the indirect tensile testing (IDT) according to AASHTO TP9-96 with the following exceptions:

1. Specimens using the medium gradation shall be 150 mm [**6 inches**] in diameter and at least 115 mm [**4.5 inches**] in height and compacted to air voids +/- 1 percent of design air voids at the design emulsion content. A trial specimen is suggested for this. Test specimens shall be cured at 60ºC [**140°F**] no less than 48 hours and no more than 72 hours. Check specimen mass every 2 hours after 48-hour cure to check with compliance of no more than 0.05% change in mass in 2 hours. After curing, two specimens shall be cut from each compacted specimen to 50 mm [**2 inches**] in height. Perform bulk specific gravity after cutting.

2. Instead of three specimens, two specimens are the minimum required at each of three temperatures.

3. Select two temperatures at 10ºC [**50°F**] intervals that bracket the required specification. For example, if the required specification temperature is –25ºC [**-13°F**], then select testing temperatures of –20ºC [**-4°F**] and –30ºC [**-22°F**]. A temperature of –10ºC [**14°F**] or –40ºC [**-40°F**] should then be selected to complete the third required temperature.

4. The tensile strength test shall be carried out on each specimen directly after the tensile creep test at the same temperature as the creep test.

5. The environmental chamber must be capable of temperatures down to –40ºC [**-40°F**].

6. The critical cracking temperature is defined as the intersection of the calculated pavement thermal stress curve (derived from the creep data) and the tensile strength line (the line connecting the results of the average tensile strength at the two temperatures).

S-1.7 APPENDIX 3

Procedures for Performing the Raveling Test on Recycled Asphalt Specimens

The apparatus used for the raveling test is a modified A-120 Hobart mixer and abrasion head (including hose) used in the Wet Track Abrasion of Slurry Surfaces Test (ISSA TB-100). The rotation speed for the raveling test is not modified from ISSA TB-100. The ring weight is removed from the abrasion head for the raveling test below. The weight of the abrasion head and hose in contact with the specimen should be 600 +/- 15g [**21.2 +/- 0.5 ounces**]. The prepared sample must be able to be secured under the abrasion head, and centered for accurate result, allowing for free movement vertically of the abrasion head. The device used for securing and centering the sample must allow a minimum of 10 mm [**0.4 inch**] of the sample to be available for abrasion. The Hobart mixer will need to be modified to allow the sample to fit properly for abrasion. The modification may be accomplished by adjusting the abrasion head height, or the height of the secured sample. A Raveling Test Adapter can be purchased through Precision Machine and Welding, Salina, KS, (785) 823-8760. Please reference the Hobart Model number A-120 when ordering. The C-100 and N-50 Models are not acceptable for this test procedure due to differences in size and speed of rotation.

1. Split out two recycled asphalt samples from the medium gradation, or field sample, to a quantity of 2700 g [**6 pounds**] in mass [**weight**]. The 2700 g [**6 pounds**] is an approximate weight to give 70 +/- 5 mm [**2.8 +/- 0.2 inches**] of height after compaction.

2. The recycled asphalt sample should be placed in a container of adequate size for mixing.

3. Field or design moisture contents should be added to each of the recycled asphalt samples and mixed for 60 seconds.

4. The design emulsion content shall be added to each of the recycled asphalt samples and mixed for 60 seconds.

5. The samples shall be placed immediately into a 150 mm [**6 inch**] gyratory compaction mold and compacted to 20 gyrations. If the sample height is not 70 +/- 5 mm [**2.8 +/- 0.2 inches**], the recycled asphalt weight should be adjusted.

6. After compaction, the samples shall be removed from the compaction mold and placed on a flat pan to cure at ambient lab temperature (18-24ºC [**65-75ºF**]) for 4 hours +/- 5 minutes.

7. The specimens shall be weighed after the curing, just prior to testing.

8. The specimens shall be placed on the raveling test apparatus. Care should be taken that the specimen is centered and well supported. The area of the hose in contact with the specimen should not have been previously used. It is allowable to rotate the hose to an unworn section for testing. The abrasion head (with hose) shall be free to move vertically downward a minimum of 5 mm [**0.2 inches**] if abrasion allows.

9. The samples shall be abraded for 15 minutes and immediately weighed.

10. The % Raveling loss shall be determined as follows: ((Wt. Prior to test – Wt. After abrasion)/Wt. Prior to test) * 100.

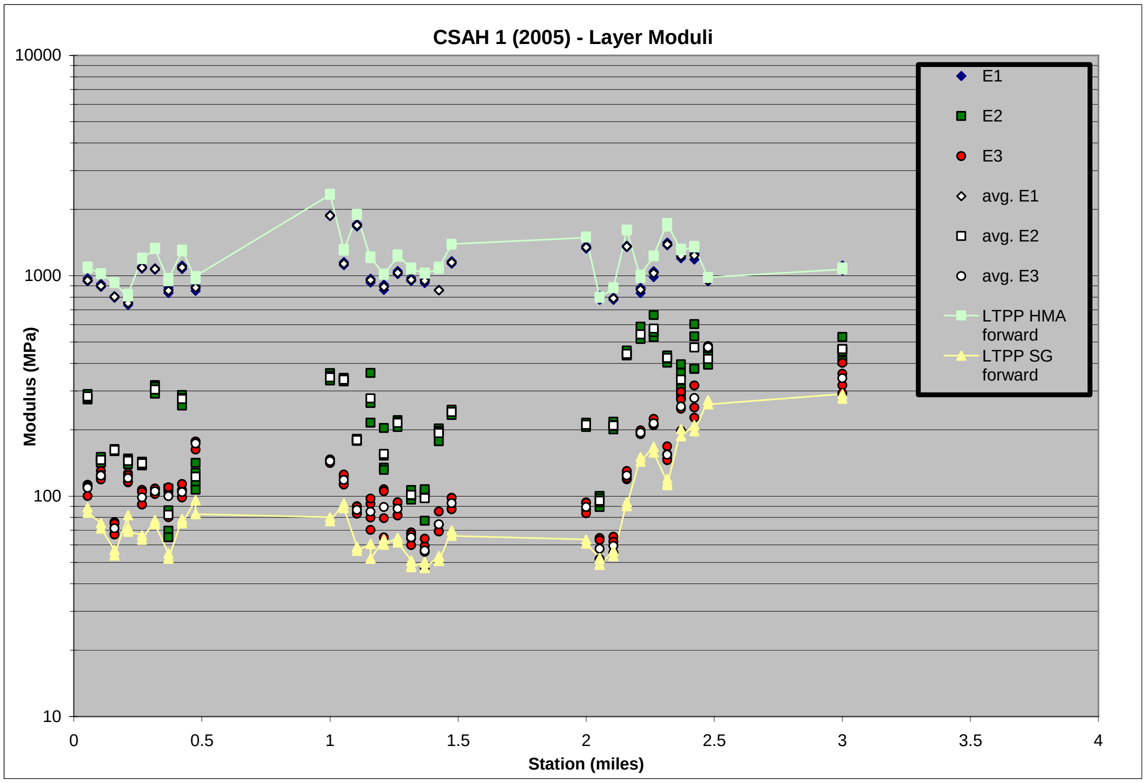
11. The average of the two specimens shall be reported as the % Raveling loss. There should not be a difference of 0.5% Raveling Loss between the two test specimens for proper precision. A difference of >0.5 percent will require the test to be repeated. If both of the samples have a Raveling Loss of >10% the numbers shall be averaged and the precision rule will be waived.

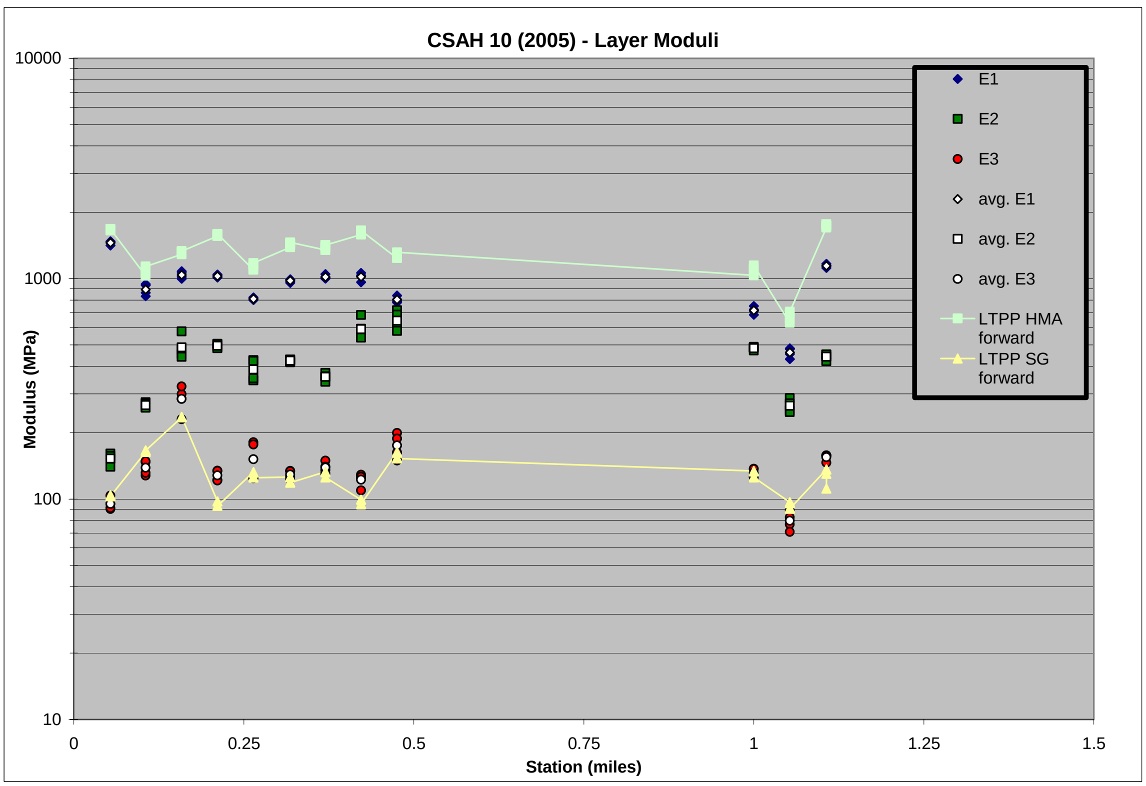
Note: If field mix samples are taken, Steps 2, 3, and 4 shall be omitted.

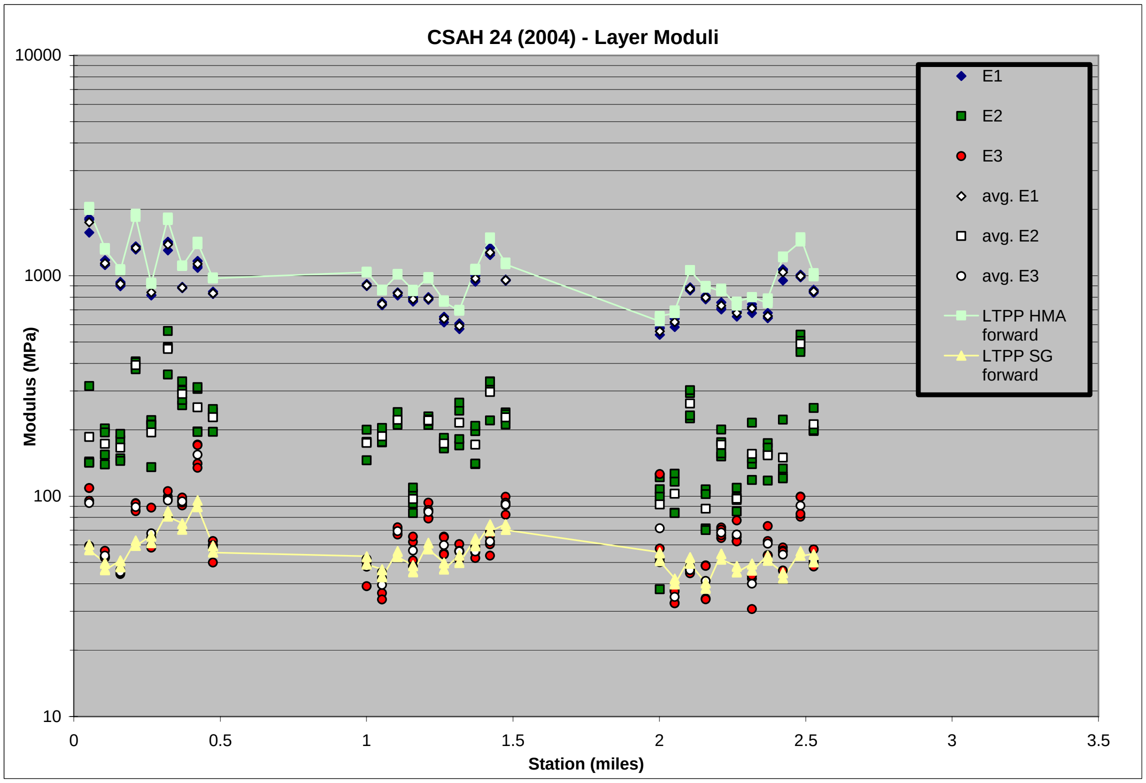
S-1.8 For questions about the CIR process contact Mn/DOT Pavement Engineer at (651)366-5496.

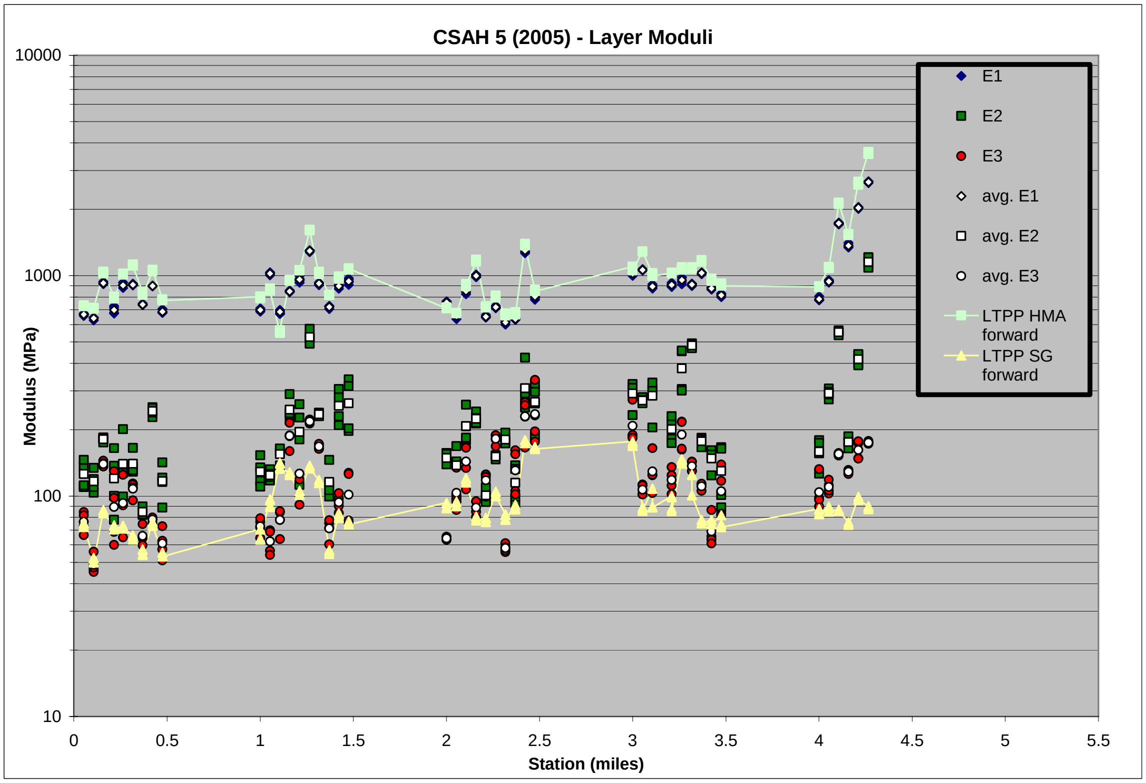
Appendix C

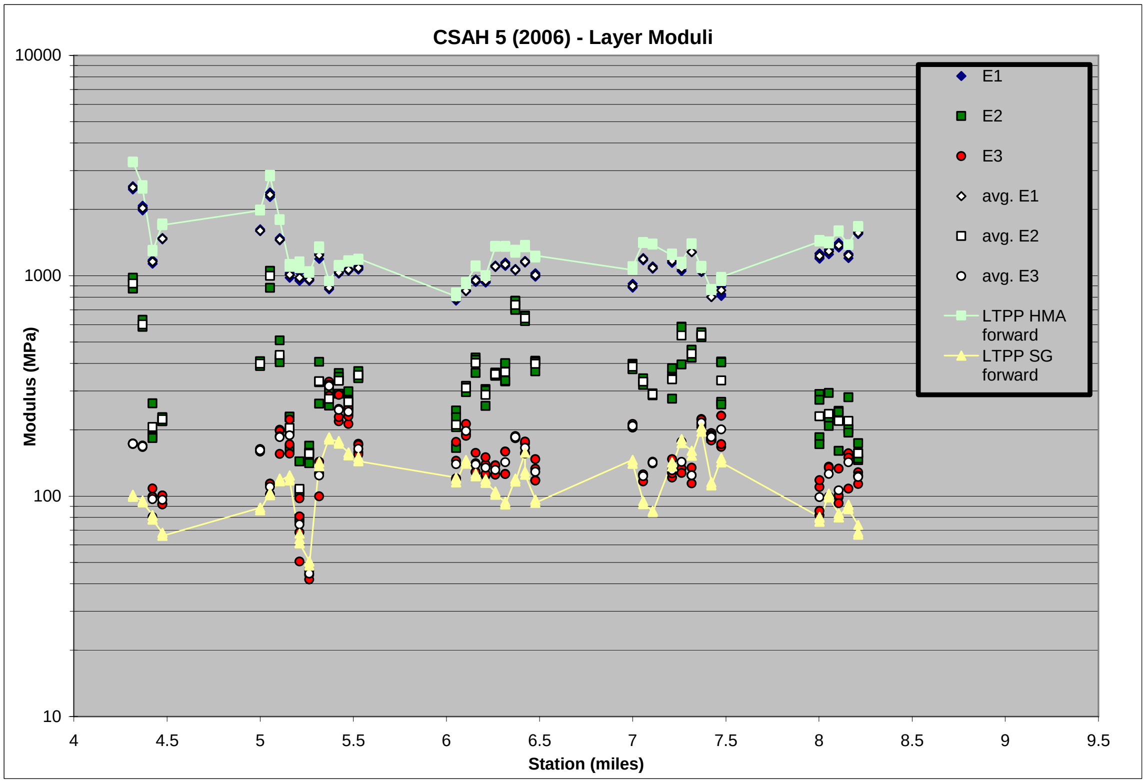
Graphs of Back- and Forward-Calculated Moduli
Fillmore and Olmsted County
Foamed Asphalt Projects


CSAH 1 (2005) - Layer Moduli
10000
1000
100
10
Modulus (MPa)
0
0.5
1
1.5
2
2.5
3
3.5
4
Station (miles)
E1
E2
E3
avg. E1
avg. E2
avg. E3
LTPP HMA forward
LTPP SG forward

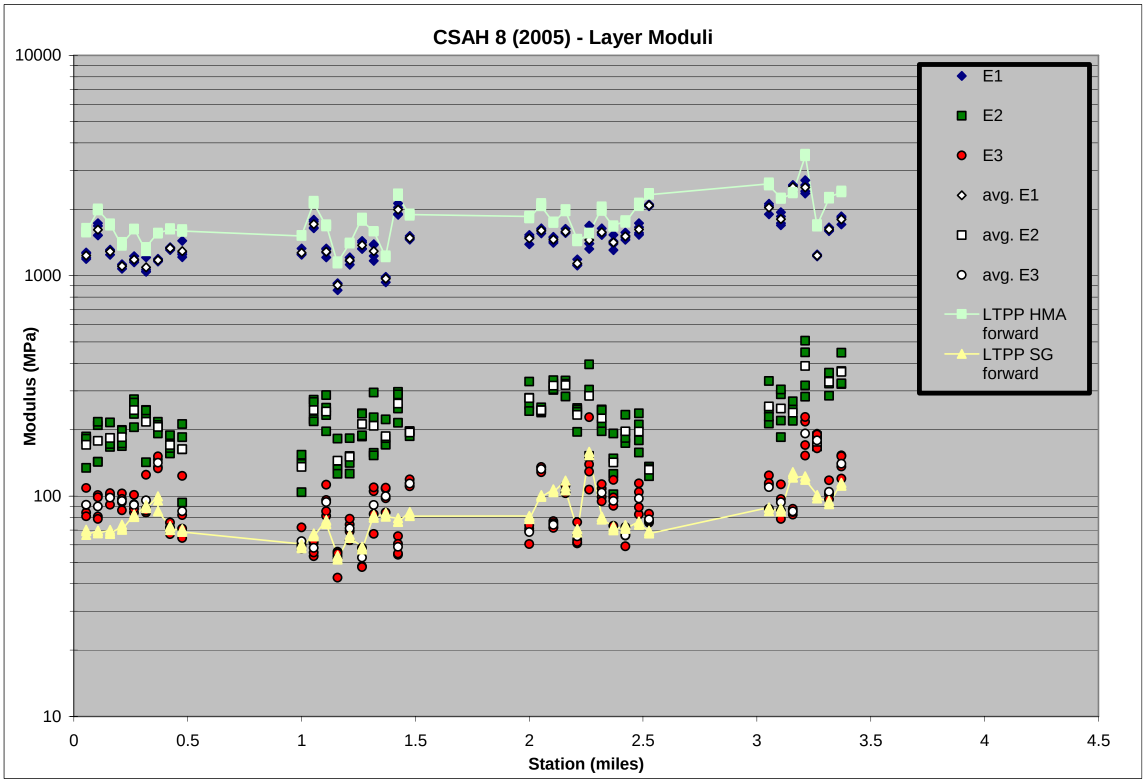

CSAH 10 (2005) - Layer Moduli
10000
1000
100
10
Modulus (MPa)
0
0.25
0.5
0.75
1
1.25
1.5
Station (miles)
E1
E2
E3
avg. E1
avg. E2
avg. E3
LTPP HMA forward
LTPP SG forward


CSAH 24 (2004) - Layer Moduli
Modulus (MPa)
10000
1000
100
10
0
0.5
1
1.5
2
2.5
3
3.5
Station (miles)
E1
E2
E3
avg. E1
avg. E2
avg. E3
LTPP HMA forward
LTPP SG forward

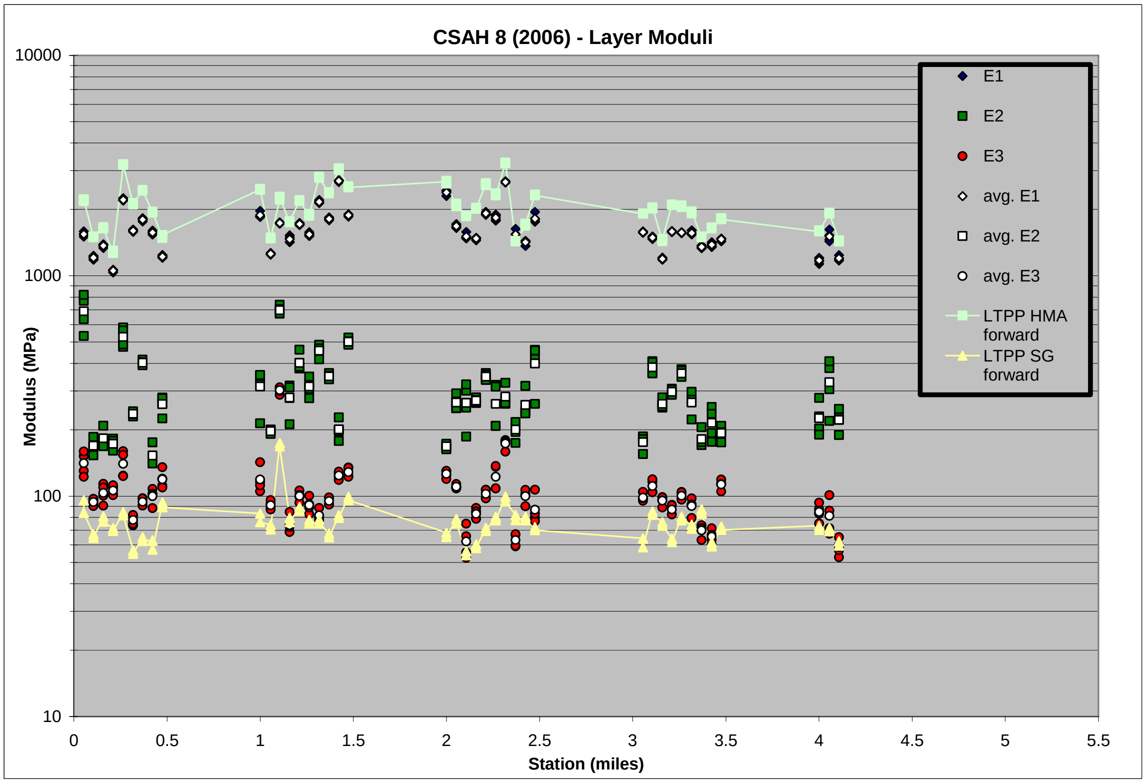

CSAH 5 (2005) - Layer Moduli
Modulus (MPa)
10000
1000
100
10
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
Station (miles)
E1
E2
E3
avg. E1
avg. E2
avg. E3
LTPP HMA forward
LTPP SG forward

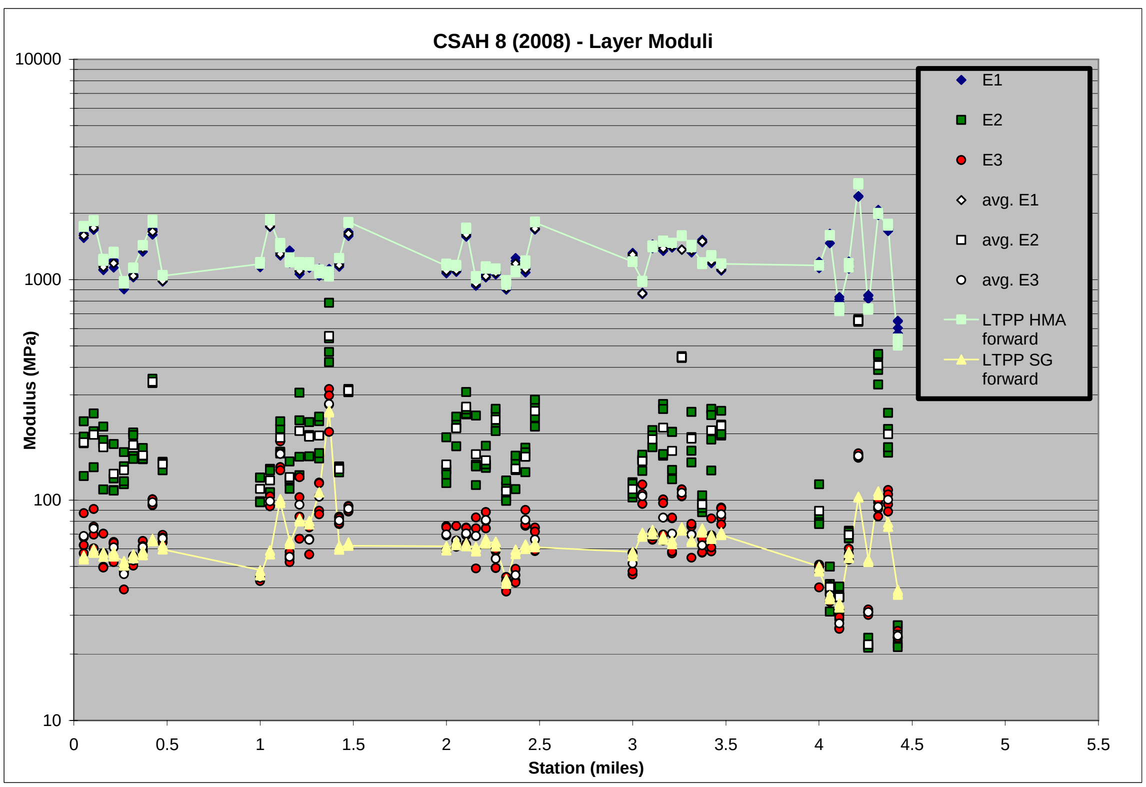


CSAH 5 (2006) - Layer Moduli
Modulus (MPa)
Station (miles)
10000
1000
100
10
4
4.5
5
5.5
6
6.5
7
7.5
8
8.5
9
9.5
E1
E2
E3
avg. E1
avg. E2
avg. E3
LTPP HMA forward
LTPP SG forward



CSAH 8 (2005) - Layer Moduli
Modulus (MPa)
Station (miles)
10000
1000
100
10
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
E1
E2
E3
avg. E1
avg. E2
avg. E3
LTPP HMA forward
LTPP SG forward


CSAH 8 (2006) - Layer Moduli
Modulus (MPa)
Station (miles)
10000
1000
100
10
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
E1
E2
E3
avg. E1
avg. E2
avg. E3
LTPP HMA forward
LTPP SG forward


CSAH 8 (2008) - Layer Moduli
Modulus (MPa)
Station (miles)
10000
1000
100
10
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
E1
E2
E3
avg. E1
avg. E2
avg. E3
LTPP HMA forward
LTPP SG forward