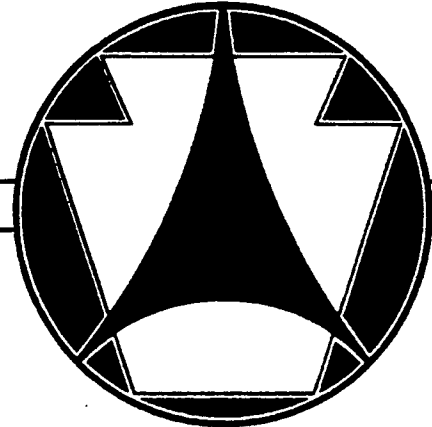




**COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF TRANSPORTATION**

PENNDOT RESEARCH



**EVALUATION OF FB-3 MODIFIED
WEARING COURSE**

**University-Based Research, Education and Technology
Transfer Program
AGREEMENT NO. 359704, WORK ORDER 16**

FINAL REPORT

NOVEMBER 30, 2000

By A. Stonex and D. A. Anderson

PENNSSTATE



Pennsylvania Transportation Institute

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16. Abstract <p>A number of municipalities and townships throughout Pennsylvania have reportedly been using a thin surface layer (2 inches thick) of cold-mixed bituminous concrete material called FB-3 Modified Wearing Course to maintain and/or improve the surfaces of low-volume rural and residential roadways. However, FB-3 Modified Wearing Course is not listed in PennDOT Bulletin 15, <i>Approved Construction Materials</i>, and thus cannot be purchased with Liquid Fuels Tax money. The purpose of this study is to evaluate the performance and suitability of FB-3 Modified Wearing Course, its mixing and placement requirements, and to compare its performance to wearing course materials currently approved by the Pennsylvania Department of Transportation for low-volume roads to provide a rational basis for PennDOT to reject or approve the use of FB-3 Modified Wearing Course by local municipalities.</p> <p>Three private firms participated in this study by suggesting locations, supplying FB-3 Modified Wearing Course material for the selected respective test sections, located in three different parts of Pennsylvania, and paving the test sections in 1999. A total of six test sections were paved using two distinctly different families of FB-3 Modified Wearing Course materials. This report presents information on test section site selection, pre-construction condition surveys, observations of paving operations, and visual condition evaluations performed in spring and fall 2000, for each of the respective test sites. The surface of each test section was videotaped during each condition survey/evaluation. Results of tests on samples of component materials and on samples of the FB-3 Modified mixtures obtained during construction are presented and analyzed.</p> <p>The FB-3 Modified mixtures have generally performed well and it is recommended that FB-3 Modified Wearing Course be approved for use by local municipalities on low-volume and residential roadways. A draft specification and proposed usage guidelines suitable for incorporation into PennDOT Standard Specifications or other pertinent standards or policy documents are included as part of the conclusions and recommendations of this report. These are based on existing specifications for other types of FB mixtures, observed test section performance to date, and material characteristics as determined by laboratory testing.</p>					
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Prepared for

Commonwealth of Pennsylvania
Department of Transportation

By

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1. INTRODUCTION

Local municipalities typically have very limited budgets for maintaining the roadways under their jurisdiction. To save money on low-volume rural and residential roadways, many small municipalities use paving materials and methods that are not currently approved for use by the Pennsylvania Department of Transportation (PennDOT). Another way that municipalities stretch their budgets is by applying for Liquid Fuels Tax money to pay for construction materials to maintain or improve their roadways. However only materials listed in PennDOT Bulletin 15, *Approved Construction Materials*, can be purchased with Liquid Fuels Tax money.

A number of municipalities and townships throughout the state have reportedly been using a thin surface layer (less than 2 in [5 mm] thick) of cold-mixed bituminous concrete material called FB-3 Modified Wearing Course to maintain and/or improve the surfaces of low-volume rural and residential roadways. This material was originally the proprietary product of a single manufacturer, but additional manufacturers have since developed competing variations. However FB-3 Modified Wearing Course is not listed in Bulletin 15 and thus cannot be purchased with Liquid Fuels Tax money.

The purpose of this study was to evaluate the performance and suitability of FB-3 Modified Wearing Course, to evaluate its mixing and placement requirements, and to compare its performance to wearing course materials currently approved by the Department for low-volume roads. This will provide a rational basis for PennDOT to reject or approve use of FB-3 Modified Wearing Course by local municipalities.

The original plan was to place the FB-3 Modified Wearing Course in fall 1998, visually inspect the condition of the respective test sections in spring 1999 and again in spring 2000, and prepare a final report based on the observed condition of the FB-3 Modified Wearing Course after the second winter in-place. However, the notice to proceed was issued too late in the season (November 20, 1998) for paving even with cold-mixed materials, and work on this phase of the study was deferred until early 1999. Therefore, the test sections were evaluated after only one winter in-place, instead of two. However, a second visual condition inspection of all of the test

sections was performed in September 2000 to evaluate the responses of distresses observed in spring 2000 to hot weather trafficking.

Three private firms participated in this study by suggesting locations and supplying FB-3 Modified Wearing Course material for the selected respective test sections located in three different parts of Pennsylvania, and paving the test sections in 1999.

This report presents information on site selection, preconstruction condition surveys, observations of paving operations, and visual condition evaluations performed in spring and fall 2000 for each of the respective test sites. Results of tests on samples of component materials and on samples of the FB-3 Modified mixtures obtained during construction were combined for discussion and analysis. The FB-3 Modified mixtures generally performed well.

A draft specification and proposed usage guidelines suitable for incorporation into PennDOT Standard Specifications or other pertinent standards or policy documents have been included in the conclusions and recommendations section of this report. These are based on existing specifications for other types of FB mixtures, observed performance to date, the characteristics of the material as determined by laboratory testing, and cost data as described herein.

2. SITE SELECTION

Site selection consisted of two phases. The first phase involved a series of three meetings, one with each of the three prospective suppliers of the FB-3 Modified Wearing Course material. Mr. Eugene Smeltzer, manager, PennDOT Municipal Services, and Anne Stonex, NECEPT operations manager, participated in all three meetings.

The purpose of the meetings was to define requirements for test sections and to screen and identify possible candidate locations for the study. The types of roadways and traffic volume for application and evaluation of the FB-3 Modified Wearing Course were defined for all participants. Roadways with high volumes, significant heavy-truck traffic, numerous turns, and/or steep grades were not considered to be appropriate candidates. Dr. Anderson recommended a minimum section length of 1,000 ft (305 m) be required for evaluation of respective FB-3 Modified materials. It was also agreed that the preconstruction condition survey of the selected experimental sections would consist of NECEPT personnel walking and videotaping the existing pavement while providing a running narrative of observations of distress types and severity and indicating landmarks to identify features that may affect overlay performance. Any subsequent preconstruction repairs would also be documented before overlaying.

The second phase of site selection consisted of traveling to the remaining candidate sites to determine which were suitable and to select the locations of the respective test sections within these sites to be included in the study. The candidate pavement sections displayed a range of conditions from good to poor and included some intersections that may enable this study to evaluate specific conditions that are suitable, or not, for use of the FB-3 Modified material.

The reports on both phases of site selection are combined herein for continuity, and are identified by the FB-3 Modified supplier, the county and township in which the respective test section is located.

Heilman Pavement Specialties, Inc./ Armstrong County/ South Buffalo Twp.

The first project meeting was held at NECEPT on March 29, 1999. Mr. Smeltzer, Dr. Anderson and Ms. Stonex met with Mr. Glenn Heilman, vice president of Heilman Pavement Specialties, Inc. (HPSI). Mr. Heilman identified and ranked several selected roadways in South Buffalo and Manor Townships, both in Armstrong County (western PA), as candidates for evaluating the FB-3 Modified Wearing Course material supplied by his firm. He provided copies of maps with locations marked, and proposed job mixture formulas for the cold-mixed (ambient temperature with proprietary emulsified asphalt binder) paving material. Discussion followed to ensure that the proposed sites met the criteria and to identify expected surface preparation and placement methods. It was decided that the ignition oven would be used to determine binder content.

Mr. Heilman indicated that experienced county road crews would construct the proposed test section(s) using FB-3 Modified Wearing Course materials supplied directly by HPSI. No paving contractor would be involved and no control sections of conventional FB paving mixtures were likely to be built. A preliminary walk-through of the Armstrong County sites was scheduled for May 4, 1999 to evaluate suitability and identify specific zones of study.

The meeting for the second phase of site selection started at the South Buffalo Township building at 10:30 a.m. Tuesday, May 4, 1999. The participants were Eugene Smeltzer, manager, PennDOT Bureau of Municipal Services; Vaughn Barnhart, program manager, PennDOT Research Division; Municipal Services Supervisor Allen Williams and Specialist Richard Knapko, PennDOT Engineering District 10-0; South Buffalo Township Supervisors Robert Van Dyke (also the Roadmaster), Vince Venturino, and Randy Cataldi; William and Glenn Heilman, HPSI; and Anne Stonex, NECEPT. Introductions were made and the intent and methods of this study were discussed.

The candidate site in Manor Township was eliminated prior to the meeting because it was a cul-de-sac less than 1,000 ft (305 m) long, with hardly any traffic. Also, the South Buffalo Township supervisors had eliminated all but one of the candidate sections in their jurisdiction from consideration. At least one did not need to be paved yet, and another would have to include

a relatively steep hill to achieve the minimum length of 1,000 ft (305 m). All of the participants went to visually evaluate the remaining candidate, Sradergrove Road.

The proposed resurfacing project on Sradergrove Road extended east from Freeport-Kittanning Road to Baker Road. The western end of this roadway is primarily residential, with a church just outside the proposed project area. The eastern part of the project rises slightly in elevation and borders farmland, including a working dairy farm where milk tanker trucks are loaded about three times each week. The road is also a school bus route and farm tractors frequently drive on it.

The existing pavement structure reportedly consists of clay subgrade covered with some accumulated layers of "tar" with limestone chips, and a nominal 2-in-thick (5-cm-thick) layer of FB-2 Modified surface that was placed in 1991. The bituminous material referred to as tar may consist of various types of road oils, cutbacks, or even paving-grade asphalt, depending on when it was applied. Due to the roadway's transverse profile, the FB-2 Modified mix is only about 1 in (2.5 cm) thick at the middle crown. The width of the FB-2 Modified surface ranges from about 17 to 18-1/2 ft (5.2 to 5.6 m), and average width for this project is about 17-1/2 ft (5.3 m). In 1997 or 1998, the FB-2 Modified surface was sealed. The pavement in the eastbound lane generally appeared to be in relatively good condition, and some minor excavations showed the modified binder was still lively and soft.

In contrast, the westbound lane included some obvious areas of pavement fatigue, minor base failure, and other structural distress. It is interesting to note that the milk tankers are about 1,000 gal (3,785 l) (at least 4 tons [3,629 kg]) lighter when eastbound (coming in) than when westbound (departing). Although the differences in observed pavement distress might be related to these differences in loading, other factors including drainage are also likely to be involved.

The group agreed that the existing range of conditions should provide a good test, particularly because the 1- to 1.5-in-thick (25- to 37.5-mm-thick) FB-3 Modified Wearing Course layer would not be thick enough to significantly improve the structural capacity of the pavement. No repairs to the subgrade or base were planned. The true test of the FB-3 Modified Wearing Course will be how it performs in the areas where the existing pavement structure has already

proved inadequate for the loads it must bear. It is expected that the FB-3 Modified Wearing Course may deform to follow the surface profile of the existing pavement because of its flexibility. The question is, will it rut, shove, bleed, crack, ravel, delaminate, or develop other distresses?

The group decided that two consecutive test sections for this FB-3 Modified product would be designated along Sradergrove Road, for the full width of the roadway (estimated nominal 17-1/2 ft [5.3 m]). The first section would start at the mailbox of address No. 110 on the north side and proceed 1,000 ft (305 m) east. The next would be immediately adjacent and span the next 1,000 ft (305 m) east to the dairy. The township had already marked these distances. Anticipated repairs prior to paving with the FB-3 Modified mix were to be limited to minor improvements to the south-side drainage ditch along the first test section as suggested by Mr. Williams. A scratch course would likely be applied in depressed areas for leveling and to maintain the surface profile for drainage purposes. Township crews were designated to perform the drainage work as well as the paving work.

Project scheduling was discussed. Drainage ditch improvements were planned during the first half of June, to be followed shortly thereafter by two to three days of paving. Ms. Stonex arranged to coordinate NECEPT 's pre-paving condition survey activities with the township and HPSI accordingly. After viewing of several in-place FB Modified pavements in the immediate vicinity (including two of the original candidate locations) and some additional discussion about the particular FB-3 Modified material for this project, the meeting ended at about 1:45 p.m.

Stewart & Tate, Inc. Roadite Division/ York County/ Hopewell and Dover Townships

The second project meeting was held at NECEPT on April 1,1999. Vaughn Barnhart, Dan Walston, and Megan Mattern from PennDOT Research Division joined Mr. Smeltzer and Ms. Stonex in meeting with Harry Brose of Stewart & Tate, Inc. Roadite Division. Mr. Brose informed the group that Stewart & Tate was licensed by HPSI to produce and sell proprietary emulsified asphalt binder for use in the FB-3 Modified Wearing Course mixture for this project.

Stewart & Tate would also produce and place the paving mixture for this project.

Mr. Brose identified two candidate roadways in the York area for evaluating the FB-3 Modified Wearing Course material supplied by his firm. The candidates were Conewago Road in Dover Township and Rinely Road, Hopewell Township Rt. 525 between Plank Road and PA 24 in Hopewell Township. He provided copies of location maps with section dimensions, proposed overlay thickness, and other site information. Mr. Brose described the production, QC testing, and paving operations for the FB-3 Modified mixture. The mixture is typically produced and stockpiled ahead of time. Various methods and plans for sampling and testing were discussed, and their technician will assist NECEPT with sampling as needed. The test section(s) would be set aside within complete projects to be constructed by Stewart & Tate personnel. No control sections of conventional FB paving mixtures were planned.

The meeting for the second phase of site selection, to identify specific test sections within the planned projects, started at 10 a.m. on Monday, April 19 at the Round the Clock Restaurant at the junction of Routes 30 and 83. Mr. Brose took Sherman F. Wright, PennDOT District 8-0 municipal services supervisor, Mr. Smeltzer, Mr. Barnhart, and Stonex to Rinely Road (Hopewell Township Road 525) to meet Mr. Robert Streett, the Hopewell Township roadmaster, and evaluate the site for use in this study.

The pavement on Rinely Road, east of Clark Road (Hopewell Township Road 524) toward Willwert Road (Hopewell Township Road 523), reportedly consisted of a relatively thin layer of 6- to 7-year-old FB-1 binder course that has been seal coated since it was placed over accumulated tar and chip courses. West of Clark Road, toward Hess and Plank Roads, the existing Rinely Road pavement was reportedly a CP-2 surface treatment, consisting of about 1-1/2 gal/yd² ($\approx 6.8 \text{ l/m}^2$) of emulsified asphalt binder covered with an application of 3/4-in (19-mm) aggregate chips, followed by a choke application of nominal 1/2-in (12.5-mm) chips. The surface of Rinely generally appeared to be in relatively decent condition, although some distresses including some localized base movement were observed. Mr. Streett reported that there are underground springs in the immediate vicinity.

It was determined by the group that the test section would be centered at the intersection of Rinely and Clark Roads, extending across the full width of Rinely for at least 500 ft (152.4 m) on each side, to include both of the existing pavement structures at the site. NECEPT was asked to extend the planned on-foot videotape condition survey to cover as much of the total project length as practicable within the time and budget limits of this evaluation project. Little traffic was observed during the site visit, but Rinely is a shortcut that was reported to experience considerable traffic at some times of the day. Traffic control likely would not be available during the condition survey.

All but Mr. Streett then went on to the site on Conewago Road (Dover Township Road 803) that started at Crone Road (T826) and extended 1,500 ft (457 m) east (nearly to Melissa's Hair Design). The surface consisted only of accumulated oil and aggregate chip treatments, with total thickness apparently ranging from about 1 to 1-1/2 in (2.5 to 3.8 mm), based on observations at existing potholes. The existing surface in this section of Conewago was deteriorating, although it was markedly better than other portions of the same road. The road is winding, narrow and hilly, with steep drop-offs alongside. The group identified the approximate limits of an appropriate 1,000-ft-long (305-m-long) test section and decided that it would extend across the full width of the roadway. The poor condition of the existing surface was expected to provide a more stringent environment for the FB-3 Modified material than Rinely Road, but traffic volumes on Conewago Road were expected to be considerably lower.

Later in April, Mr. Smeltzer informed NECEPT that Conewago Road would not be paved with the subject FB-3 Modified Wearing Course material and it was eliminated from this study. At that time, Mr. Smeltzer and Ms. Stonex decided to place both of the Stewart & Tate test sections on Rinely Road, so that a full 1,000-ft-long (305-m-long) section would extend in each direction from Clark Road and thus over each of the existing pavement structures at the site. This neatly accomplished two goals: conformance with the preferred minimum test section length and extension of the videotape condition survey to cover more of the total project length as requested.

Russell Standard Corp./ Washington County/ South Strabane and Carroll Townships

The third project meeting was held at NECEPT on April 2, 1999. Otto Beiter, Leo Sliviak, and Robert Everhart from Russell Standard Corp. met with Mr. Smeltzer, Mr. Barnhart, Dr. Anderson, Ms. Stonex and Xochiquetzal Escobar, a graduate student assigned to this project by NECEPT.

Mr. Beiter started by informing the group that Russell Standard Corp. has been producing and placing FB-3 and FB Modified cold mixtures that have performed well under traffic volumes of up to 8,700 average daily traffic (ADT) versus the PennDOT limit of 1,800 ADT for cold mixes. These traffic volumes are significantly higher than allowed on the test sections for this project. Russell Standard would make the emulsified asphalt binder and also produce and place the paving mixture for this project. Mr. Beiter described the emulsified asphalt binder and aggregate materials, and mix production, testing, and paving operations for the FB-3 Modified mixture. The resulting mixture is not produced and stockpiled ahead of use, as are the other two FB-3 Modified Wearing Course products that are included in this study.

Mr. Beiter identified seven candidate locations spread throughout five counties for evaluating Russell Standard's FB-3 Modified Wearing Course material. Due to the project limit of two locations per supplier, discussion followed to screen out sections shorter than the minimum test section length of 1,000 ft (305 m). However, sufficient information was not available at this meeting to determine the appropriate candidates. A meeting was set for 9 a.m. on May 3 in order to go see the proposed sites with sections at least 1,000 ft (305 m) long. Section lengths were supplied before the May 3 meeting as promised.

The meeting for the second phase of site selection was necessary to select and visit the most promising project sites to determine if suitable test sections were available, and to identify where to locate the test sections within the selected projects. The meeting started at 9 a.m. on Monday, May 3 at the Eat 'N Park Restaurant on Route 19 South off I-70 West at the Murtland Avenue exit in Washington, PA. Participants were Municipal Services Supervisor Orville Bolbrich, and

Specialists Arthur Battistone and Harold Whyel of PennDOT Engineering District 12-0; D. Reed Mankey, roadmaster, Township of South Strabane; Gary Briceland, Russell Standard Corp.; Gene Smeltzer, and Anne Stonex.

After initial discussion about the intent and methods of this study, it was decided that the most promising sites were located in South Strabane and in Carroll Townships (Washington County) in District 12-0. The group then went to South Strabane Township to look at the proposed roadways in a residential development off U.S. 40. One street was immediately eliminated because it was not contiguous to the other candidate streets. Mr. Smeltzer clarified for the group how liquid fuels funds could only be used for constructing the particular roadways that include the FB-3 Modified experimental sections selected for this study. The other two study candidates, Oak Hill Drive and Swartz Spur, are connected. To ensure sufficient project length, Mr. Mankey suggested adding Park View Drive, which intersects with Oak Hill Drive.

All present agreed that Swartz Spur and Oak Hill and Park View Drives should be included in the study. The test section was set to start at the first flat section of Oak Hill Drive past Swartz Spur and extend 1,000 ft (305 m) into the project for the full width of the roadway. The HMA pavement on these three contiguous streets appeared to be deteriorating, and some localized areas of pavement distress were evident. Only minor (if any) patching would be anticipated prior to paving with the FB-3 Modified Wearing Course material. Mr. Battistone indicated he would like to have a copy of the preconstruction condition survey videotape for future reference. Mr. Mankey remained in South Strabane while the rest of the group went on to Carroll Township.

The group met with Roadmaster Dave Barkey at the Carroll Township office to decide which local roadways to examine. Four were eliminated as too short. The other five, Elmcrest Avenue, Maple Avenue Extension, and Prosser, Diane and Barbara Drives, form a continuous residential pavement, with more than sufficient length for the test section. These five were visually evaluated by the group and selected for this study. The existing FB-1 pavement was reportedly placed over accumulated "tar" and chip layers 10 to 12 years ago. Maximum thickness was supposed to be about 1 in (25 mm), but most of the in-place FB-1 appeared to be as thin (only $\frac{1}{4}$ to $\frac{1}{2}$ in [6.3 to 12.5 mm] thick) as a scratch and level course. This pavement appeared aged and

oxidized, and it was worn completely through in some locations. Traffic was reported to include school buses, garbage trucks and visitors to the nearby Carroll Twp. Recreation Park. The exact location of the test section within this project was left for determination and marking by NECEPT during the preconstruction condition survey expected to be performed in June 1999.

The group expressed satisfaction with the two sites selected and agreed the day's goals were accomplished. Maps of these sites are included in Appendix B. Mr. Briceland then took Mr. Smeltzer and Ms. Stonex to see several in-place FB pavements of various types, ages, and traffic levels on the way back to the restaurant. The meeting ended at about 3:30 p.m. The map in figure 1 shows the locations of the test sites.

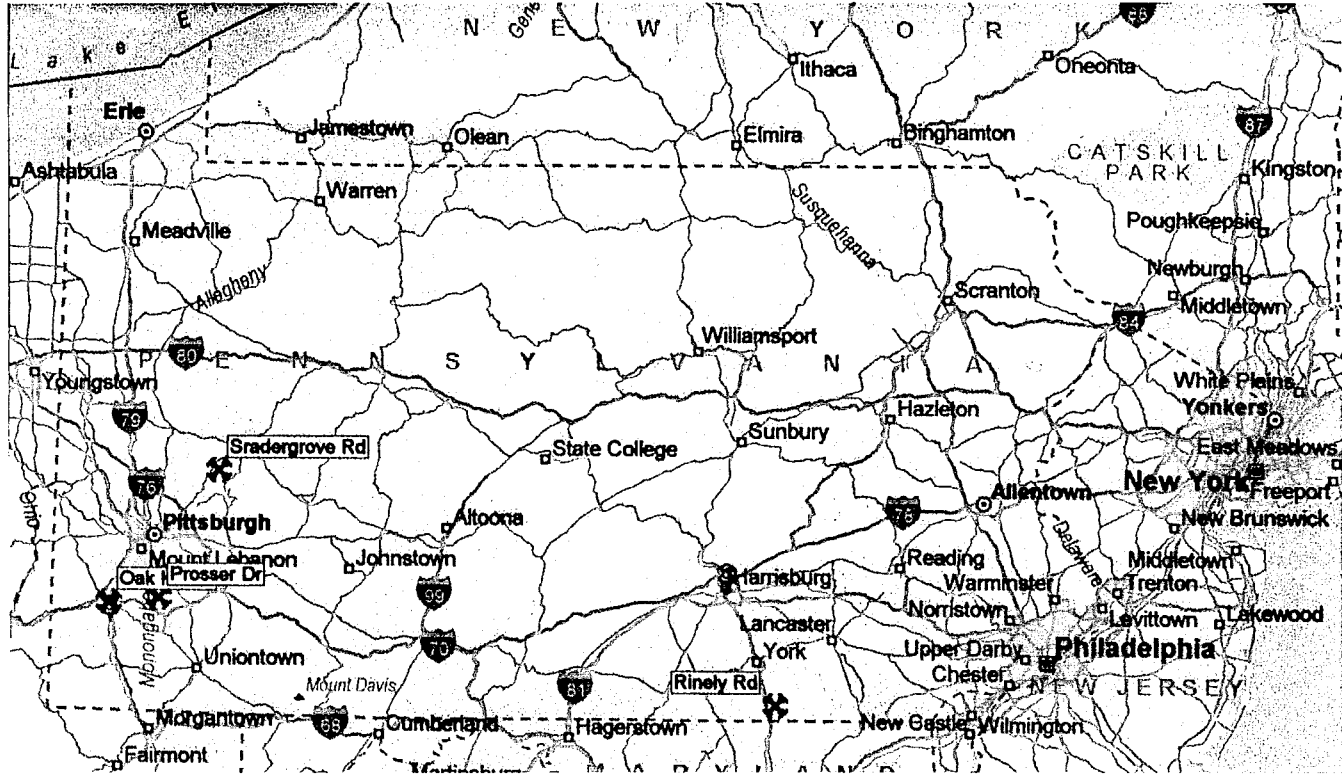


Figure 1. Map indicating locations of the project test sites.

3. PRECONSTRUCTION CONDITION SURVEYS

FB-3 Modified is placed as a thin surface layer, typically 1 to 1.5 in (25 to 37.5 mm) thick. Such thin lifts of cold mix are not expected to significantly increase the structural capacity of existing roadways, but only to provide or restore a satisfactory surface. Furthermore, in this study it was expected that local funds available for surface preparation would be minimal. In most cases, as in this study, the FB-3 is likely to be placed directly on the existing pavement surface with little preparation other than brooming. Thus to evaluate FB-3 performance, it is necessary to be familiar with the condition of the pavement on which it is placed to determine whether distresses observed are really due to properties and behavior of the FB-3 or are simply a reflection of preexisting conditions.

Preconstruction condition surveys were performed on each of the test sections by Ms. Stonex and Mr. Escobar prior to placement of the FB-3 Modified Wearing Course mixtures. All of the test section pavements were nominally two lanes wide. A small-diameter measuring wheel was used to measure approximate 100-ft (30.5-m) intervals for each of the 1,000-ft (305-m) test sections, at which station numbers were spray painted along the pavement edge for reference purposes. Then Ms. Stonex and Mr. Escobar walked the entire length of each test section while Mr. Escobar videotaped the surface appearance of pavement in one lane along with pertinent reference features (house addresses, station marks, etc.) and Ms. Stonex commented on the pavement condition and pointed out particular distresses observed. Upon reaching the end of each test section, they walked back along the other side and repeated this procedure for the opposing lane.

The camcorder used 8-mm film. Separate tapes were used for each test section to avoid confusion. Both the preconstruction condition survey and paving operations are included on the respective section tapes. The sound and images were later transferred to regular VHS videotape. One copy of each videotape will be submitted with the final report. NECEPT will also retain a copy, and copies will be provided to the participating roadmasters and PennDOT districts upon request if funds remain in the work order. Reviewing the videotapes seems to provide a much

better understanding of the pavement condition in the test sections than could a written report supplemented by still photos, perhaps because it better depicts the “context” of each site.

No traffic control was available at any of the sites during the condition surveys. The filming was interrupted to some extent by traffic at all of the sites, but more frequently and at much higher vehicle speeds at the Rinely Road site. That site is the most rural, bordered mostly by fields for crops and cattle grazing. The other locations were more residential, and the Washington County sites were relatively densely developed.

All of the pavement sections surveyed exhibited a common feature not anticipated by the researchers—“auxiliary” wheelpaths that seemed to straddle the center of these roads in addition to the customary wheelpaths in each lane. It should be noted that none of the test sections had painted or marked centerlines when first videotaped. During the preconstruction condition surveys, Ms. Stonex and Mr. Escobar observed the reason for these additional wheelpaths. When there was no oncoming traffic, many of the vehicle operators clearly preferred to drive down the center of the roadways. They only moved into their own lane when necessary to avoid conflicts with other vehicles. This behavior was observed in varying degrees at all of the sites in this study.

Sradergrove Road, South Buffalo Township

The walking visual condition survey for Sradergrove Road was performed the same day that paving began, June 14, 1999. When Ms. Stonex and Mr. Escobar arrived as agreed at 9 a.m., Roadmaster Bob Van Dyke was brooming the pavement to remove any dirt and debris that might interfere with placement of the FB-3 Modified Wearing Course or prevent it from bonding with the existing pavement. It was arranged that the condition survey would start after Mr. Van Dyke was done (about 9:45 a.m.) and paving would commence about noon.

The order of filming was set so as to minimize interference with paving operations should any problems or delays arise with completing the condition survey before noon. The condition survey started at the end of the second test section, the easternmost limit of the project, and

proceeded west to the start of the first test section, located by the mailbox for house address #110. The recording tapes were changed at the transition between the two test sections to maintain the convention that each tape included only one test section.

The general condition of the surface of Sradergrove Road was fair to good, but it was clearly beginning to deteriorate. It appeared to be near that stage in a pavement's life when surface restoration and other types of preventive maintenance are most effective in helping to preserve the existing structure and minimize the rate of deterioration. Distresses observed included:

- Considerable low-severity alligator (fatigue) cracking throughout both test sections and particularly in the westbound lane;
- Localized areas of light to moderate structural distress manifested as fatigue and edge cracking within shallow depressions; and
- Lack of support due to drainage problems, particularly along pavement edges.

It is interesting to note that the lane carrying outbound (westbound) milk tankers showed more structural distress in the form of alligator cracking and depression basins than the opposing lane. It is outside of the scope of this project to determine how much of this difference is a function of loading and how much might be due to other factors such as drainage and subsoil properties. What matters is the response of the FB-3 Modified Wearing Course to such existing site conditions.

Rinely Road, Rt. 525 (Plank Road to PA 24), Hopewell Township

Ms. Stonex and Mr. Escobar performed the walking visual condition survey for Rinely Road on July 7, 1999. This area of the state was severely affected by drought, so that some possible drainage problems may not have been evident. The roadmaster reported that there are springs near the middle of the test section between Plank and Clark Roads, but there were only a few signs of water ponding along the pavement edge.

The overall condition of the pavement surface in both test sections was good. Some minor spot structural distress was observed at isolated locations due to water drainage from adjacent farm

fields or possibly springs. Very little distress was observed on the test section located between Clark and Willwert Road (Rt. 523).

The primary pavement distress observed was flushing and pooling of the chip seal binder at various locations between Clark and Hess Roads. Although it was not a particularly hot day (<80 °F) the sun was shining and the flushed binder was very soft to the touch. Some of the largest pools covered an area of nearly 2 ft² (≈ 0.1 m²), and small ripples were observed that indicated the binder was actually creeping slowly across the pavement surface. The binder seemed to have been modified with an elastomeric material. No rutting, shoving, or structural distress was evident in the areas where the binder was pooled. However, the films of binder on the surface posed a possible safety hazard that necessitated restoring surface frictional characteristics to minimize the potential for skidding accidents. Resurfacing is the easiest and most effective way to do this.

Oak Hill Drive, South Strabane Township

Ms. Stonex and Mr. Escobar performed the walking visual condition survey for Oak Hill Drive during the morning of June 11, 1999. Weather conditions were sunny, hot (80 to >90 °F [27 to >32 °C]) and humid. The overall condition of the pavement was judged to be fair but deteriorating. Pavement distress observed included:

- Aged, brittle, and oxidized appearance;
- Widespread block and transverse cracking of varying severity (low to high);
- Moderate to high severity fatigue (alligator) cracking throughout the intersection with North View Court; and
- Severe raveling at the centerline along the paving joint from North View Court to the far end of the test section.

Transverse (thermal) cracking was also observed along the asphalt concrete gutter along both edges of the pavement. The fact that the transverse cracks in the pavement generally did not line up with those in the gutter simply indicates that the response of the gutter material to thermal stresses differed from that of the roadway pavement surface.

Prosser Drive, Carroll Township

Ms. Stonex and Mr. Escobar performed the walking visual condition survey for Prosser Drive during the afternoon of June 11, 1999. Weather conditions were sunny, hot (>90 °F [>32 °C]), and very humid. The overall condition of the pavement was judged to be fair and deteriorating.

Pavement distress observed included:

- Extremely aged, oxidized, and worn-out surface;
- Moderate- to high-severity raveling, especially along the center crown, where the pavement was worn through in some spots and base material was exposed;
- Extensive moderate- to high-severity longitudinal cracking throughout the test section;
and
- Light- to moderate-severity fatigue (alligator) cracking in various locations.

4. PAVING OPERATIONS

Asphalt cold mixes place fewer demands on paving crews and equipment than do hot mixes. Cold mixes do not require placement and compaction at elevated temperatures, thus coordination with plant production and haul truck delivery rates is less critical, and the pace of work can be slower. This can be a great benefit when work crews are small and equipment resources are limited. Some cold-mixed materials are stockpiled ahead of time so that the plant production rate is not a factor during paving operations, although loading the trucks from stockpiles at a busy plant can cause delays. Other cold mixes may be mixed at portable asphalt plants near the job site. Depending on composition, the binder may either be at ambient or elevated temperatures during mixing, but the aggregates are not heated. Cold mixtures are not rejected due to low or excessive temperature at delivery to the job site. The relatively high total liquid content during placement generally seems to facilitate handwork, but requires time for the mixtures to cure in-place. The FB-3 Modified Wearing Course mixtures studied for this project were readily placed and compacted with conventional asphalt paving equipment. The screed heaters were used by all of the paver operators to facilitate placement, but these devices are not capable of appreciably heating the mixture. The FB-3 mixtures observed did not appear to require much compactive effort compared to dense-graded hot-mix asphalt (HMA). As is typical of well-designed open-graded HMA, one or two coverages with a static steel-drum roller were sufficient to achieve no further visible movement of the new mat.

Sradergrove Road, South Buffalo Township

HPSI had mixed and stockpiled all of the FB-3 Modified Wearing Course material for these test sections the week of June 7, 1999. FB-3 Modified paving began at noon on June 14, 1999 with placement of a scratch and level course to restore the roadway profile along an approximately 1,200-ft-long (366-m-long) section of the northernmost lane. The scratch and level area covered most of the first test section and overlapped into the second. Township trucks hauled the stockpiled FB-3 Modified mixture to Sradergrove Road (see figure 2), and delivered it to the township paver operated by Roadmaster Van Dyke. The paver was an old conventional machine, and identifying markings had been painted over some time ago. The paving crew

consisted of township personnel. There was a minor problem with automatic control of one of the paver's slat conveyors; it was operated manually for placing the scratch and level course. The mechanical problem did not appear to be in any way related to the FB-3 Modified material. The FB-3 Modified mixture had a rich, black appearance and a wormy, lively consistency. The screed spread it as readily as butter. Mr. Heilman of HPSI obtained samples of the FB-3 Modified mixture from the paver hopper that represented each of the three truckloads delivered. Ms. Stonex sealed and delivered the loose mixture samples to PTI for testing. Samples of the proprietary binder were not available.

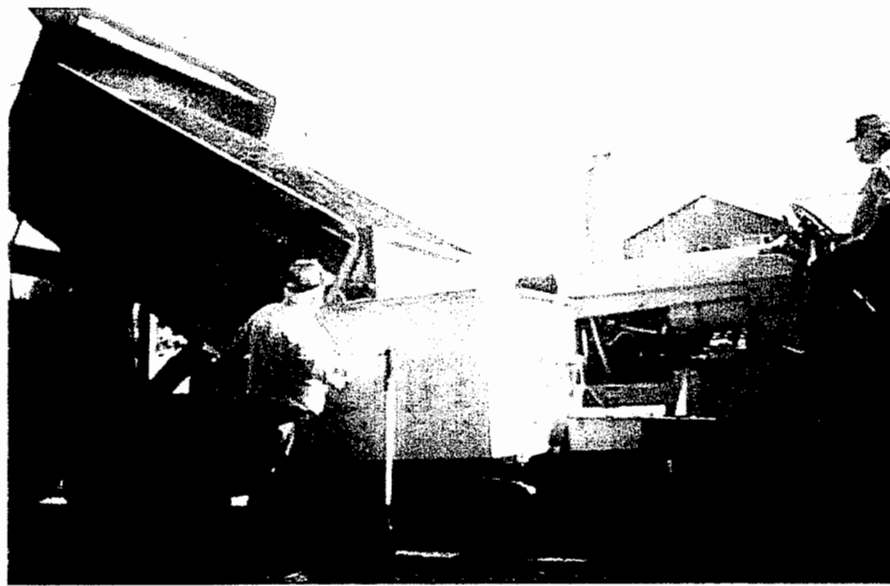


Figure 2. Sradergrove Road - South Buffalo Township paver and haul truck.

Paving continued without a pause when a moderately heavy rainstorm began (although videotaping was stopped). The FB-3 mixture already placed was carefully watched for loss of binder, but no stripping, browning, wash-off, or soapsuds were observed. Paving stopped upon completion of the scratch and leveling course, and the paver was taken to get the slat conveyor repaired. Rolling proceeded after the rain stopped. The township compactor is an old, heavy steel drum machine (see figure 3), so heavy that only one coverage was applied to the leveling course. When the flow of water to the drum was interrupted, the drum did pick up a little of the FB-3 surface. Cover aggregate was not applied to the leveling course.

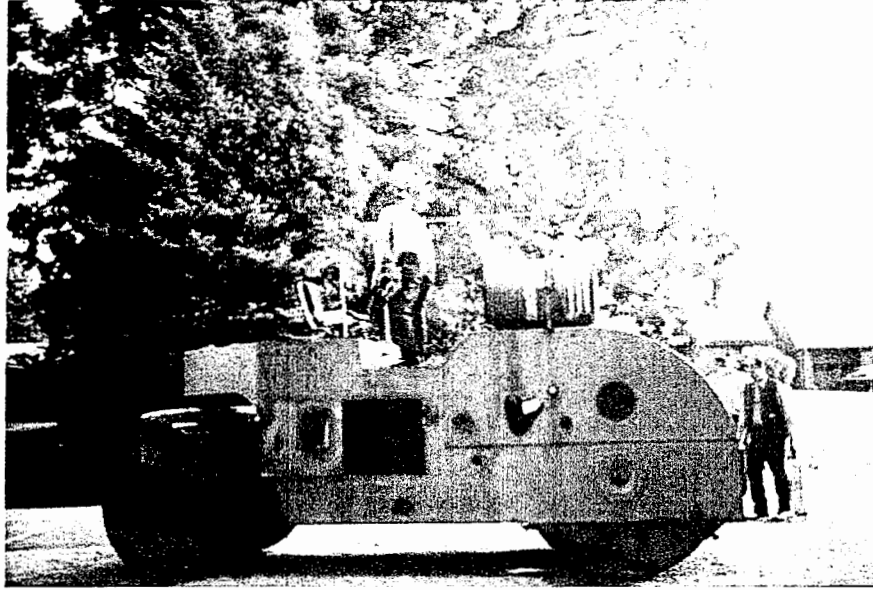


Figure 3. Sradergrove Road – South Buffalo Township roller.

The FB-3 Modified Wearing Course was placed on June 15 and 16, when the weather was sunny and mild. Ms. Stonex returned to the site on June 16 to observe the end of FB-3 paving operations. Considerable handwork was required to align the surface profiles for proper drainage at a driveway entrance where some ditch improvements had just been completed. The mixture was observed to be very amenable to handwork. Placement of the wearing course was completed without any noticeable problems. Compaction of the wearing course was generally completed with one coverage by the heavy township compactor. Water flow to the roller drum was occasionally interrupted, but FB-3 pickup was minimized by the attentiveness of the roller operator. The finished mat looked generally smooth and attractive. The final step was to whirl a light cover of No. 9 stone over the compacted mat to minimize pick up by car and tractor tires during the curing period (see figure 4).

Rinely Road, Rt. 525 (Plank to Clark, Clark to Willwert), Hopewell Township

The FB-3 Modified Wearing Course mixture for this project was produced and stockpiled on June 29, 1999 at the Stewart & Tate facility in York, PA. Mr. Escobar picked up samples of the loose mixture and component aggregate materials on June 30 and delivered them to PTI for laboratory characterization.



Figure 4. Sradergrove Road – Finished FB-3 Modified Wearing Course with white cover aggregate.

Paving began on July 14. Stewart & Tate personnel started by placing a nominal 2- to 3-in-thick (50- to 75-mm-thick) layer (compacted) of a coarser FB binder mix on Rinely Road from Rt. 24 to the limit of existing FB visible near Clark Road. This was placed as leveling course and to restore profile over the existing FB-1 on the second test section between Clark and Willwert Roads (see figure 5). The compacted lift thickness ranged up to 5 or 6 in (125 – 150 mm) along some areas of the pavement edges. Conventional asphalt concrete placement and compaction equipment was used.

Mr. Brose of Stewart & Tate reported that the FB binder mixture going down had been stockpiled since fall 1998. There were no visible signs to distinguish it from a new product—it was black, shiny, and wormy. Ms. Stonex was concerned about its stability after compaction, particularly where the leveling course was thicker than 3 in (75 mm). The amount of movement it exhibited as haul trucks rolled over it indicated substantial potential for rutting in that intermediate layer. The extent of possible rutting seemed to be related to layer thickness, but if the leveling course were to rut, the FB-3 on top of it would follow its profile. Trenching would then be required to determine in what layer the rutting had actually occurred.

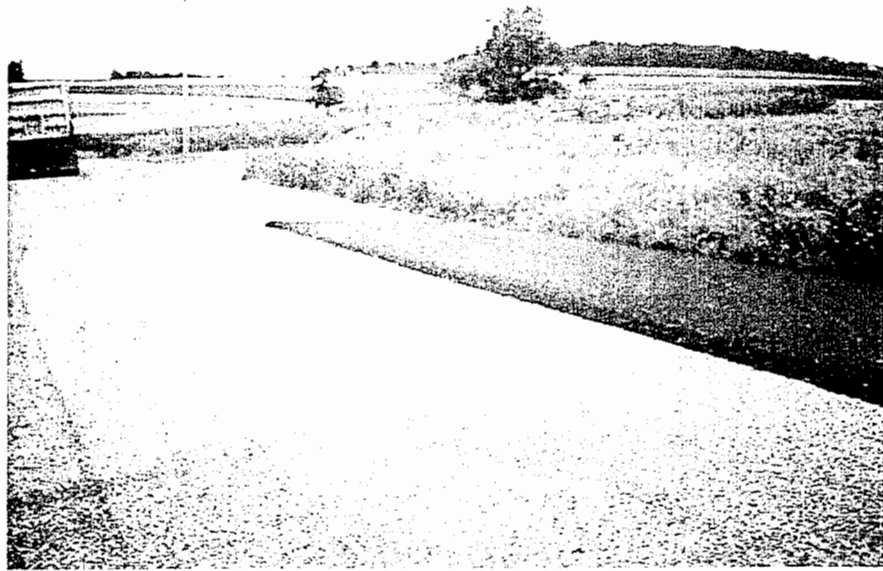


Figure 5. Rinely Road - First lane of FB Binder Course in the second test section.

Due to extensive grade adjustment handwork on the intersection of Rinely and Plank Roads, FB-3 Modified Wearing Course placement did not begin until after 3 p.m. at the Plank Road end of the project. However once started, the FB-3 Modified went down very smoothly and quickly (see figure 6). Compacted thickness was a nominal 1-1/2 in (37.5 mm).

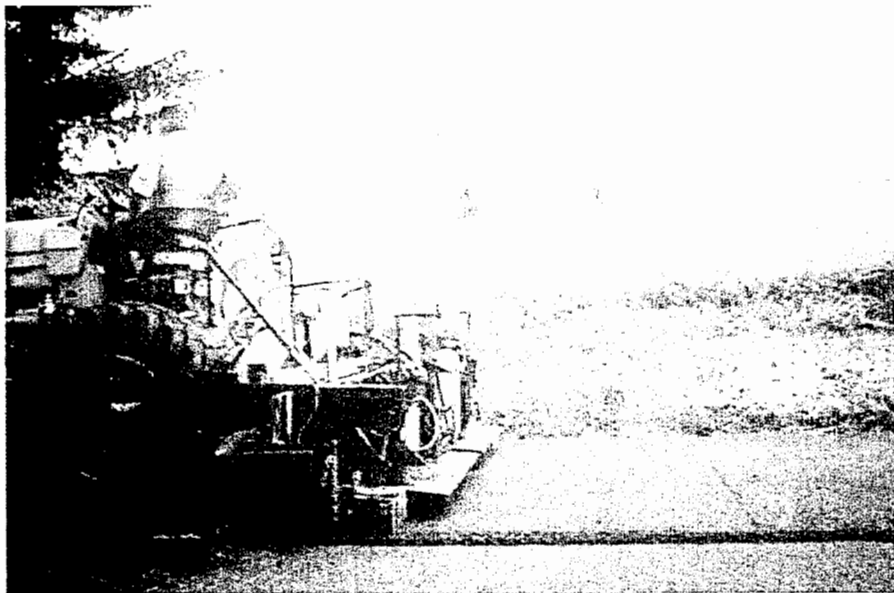


Figure 6. Rinely Road – Paver placing FB-3 Modified Wearing Course.

The mix appeared very uniform, smooth, and attractive and contained enough liquid to literally gleam in the late afternoon sunshine. Although no bleeding or flushing was observed, a light cover of fine aggregate was applied to the new surface with a whirl-type spreader to prevent pickup by vehicle tires. The roadmaster expressed concerns that he would never be able to control speeders that were presented with such a smooth surface. The test section between Clark and Plank Roads was completed by about 6 p.m.

The leveling course on the section from Clark to Willwert had had only about 6 hours to cure in-place before the FB-3 Modified was applied (see figure 7). Although haul trucks were still causing obvious movement in the adjacent lane of that leveling course (see figure 8), there was no apparent deflection under the paver when the FB-3 was placed directly on the new mat of FB binder material. The FB-3 mixture set right up under the compactor and did not appear to move at all after the first coverage by the roller. NECEPT observers were pleasantly surprised that the leveling course did not seem to adversely affect the FB-3 Modified placement. Approximately 1/3 of the second test section had been completed when paving operations were concluded for the day at 7:30 p.m. Due to time and budget constraints, NECEPT personnel were not able to be present for completion of the second FB-3 Modified test section on July 15. However, as the leveling course had not caused any placement problems and it was clear that the same FB-3 stockpiles, personnel, and equipment would be involved, no crisis was anticipated. A brief conversation with the roadmaster later indicated that no problems were encountered in completing FB-3 paving on the second test section (see figure 9).

Oak Hill Drive, South Strabane Township

The FB-3 Modified Wearing Course mixture for this project was produced by Russell Standard Corp. personnel using a small portable mixing plant set up on township property near the job site. The township supplied the No. 8 stone and the sand used in the mix, and Russell Standard provided the No. 9 stone. Mr. Art Battistone, PennDOT Dist. 12-0 Municipal Services Specialist, took Ms. Stonex to the mixing site and sampled the component aggregate materials from the stockpiles for laboratory testing by NECEPT. The stockpiles contained considerable moisture from recent local rains. The FB-3 material was mixed for immediate use and was not stockpiled, as the other FB-3 mixtures previously used for this study had been.



Figure 7. Rinely Road - Long view of roller compacting first test section.

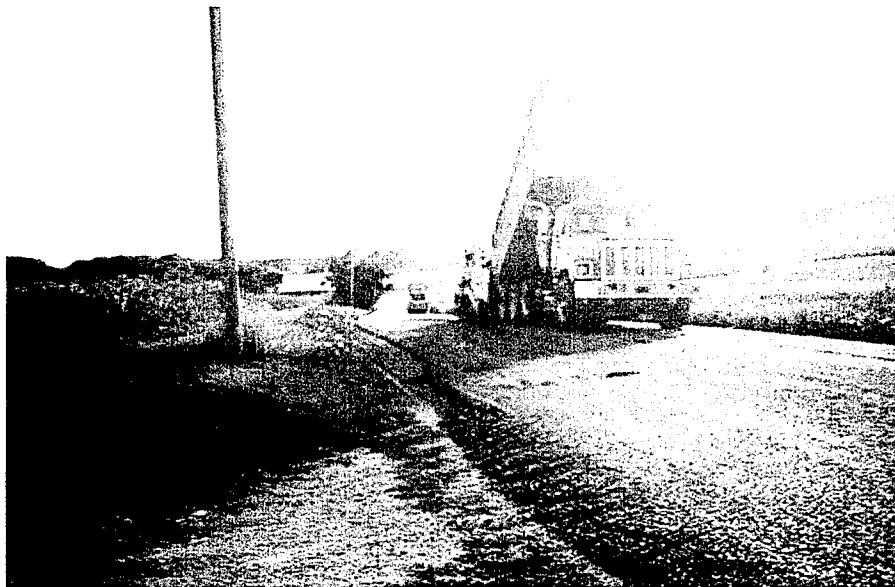


Figure 8. Rinely Road – Haul truck loading paver on and next to FB Binder Course.



Figure 9. Completed portion of second test section after the end of the first day of paving.

The test section was paved on the afternoon of September 30, 1999 between approximately 2 p.m. and 6 p.m. The weather was sunny, temperatures were mild (mid-70s °F [22 – 26 °C]), and there was a slight breeze. Paving started at the far end of the section, where the roadway was widest. A conventional Caterpillar paver with screed extender (see figure 10) was used to place the FB-3 Modified mix.

To maintain the desired surface profile, the paver made a total of three passes in the area between the intersection with North View Court and the end of the test section, which essentially covered the second half of the test section. The middle pass straddled the severely distressed centerline joint observed during the pre-construction survey. Paving proceeded smoothly. Minor auger segregation was observed in a few spot locations, but the paving crew responded quickly to minimize it.

Compaction was accomplished with no more than two coverages of an intermediate sized standard Ingersoll-Rand steel drum static roller (see figure 11). After compaction was completed, a whirl-type spreader was used to apply a light coat of sand to the new surface (see figure 12) to prevent pickup of the uncured FB-3 Modified mixture by vehicle tires.



Figure 10. Oak Hill & Prosser Drives - Conventional Caterpillar paver with extendable screed.

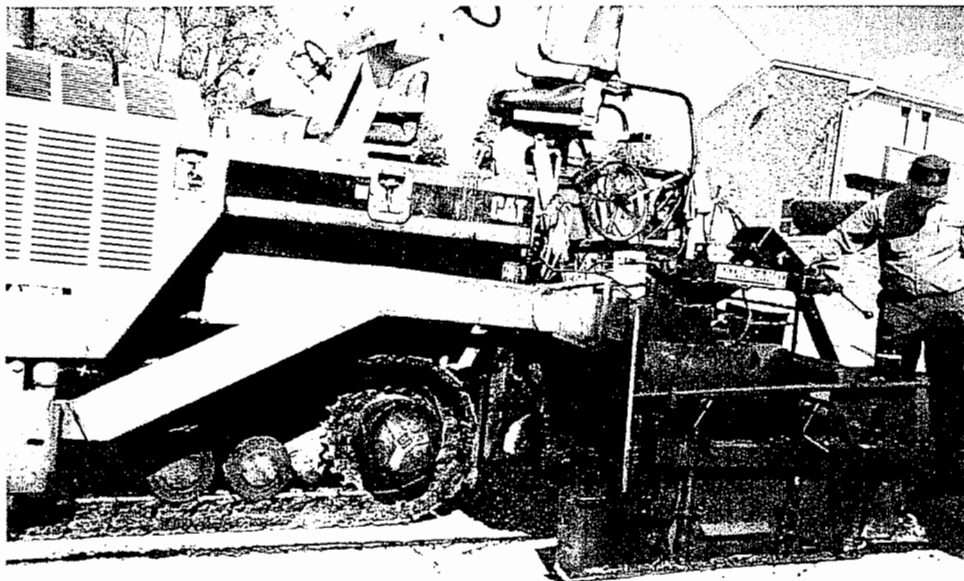


Figure 11. Oak Hill and Prosser Drives – Intermediate-sized steel roller on Oak Hill Drive.



Figure 12. Oak Hill Drive - Finished FB-3 pavement with cover aggregate (from far end of test section).

The roadway in the first half of the test section, between Park View Drive and North View Court, is narrower and was paved in two passes. Paving operations for that portion of the test section were complicated by residents who came home from work and school en masse and began to gawk as soon as they saw the paving equipment. Traffic control efforts were not totally effective and the surface of the new mat was scuffed in several places by residents' vehicle tires. Paving operations on the test section were successfully completed in spite of the crowd and the finished mat had an attractive, uniform appearance before application of the sand cover.

Prosser Drive, Carroll Township

Russell Standard personnel moved the paver and the portable mixing plant to Carroll Township around midday on October 1, after finishing remaining incidental work in South Strabane Twp. The new mixing site was located on Rt. 136, very near the neighborhood containing the final test section on Prosser Drive. The mixing and paving equipment and personnel, as well as the emulsified binder, were the same as for the South Strabane FB-3 Modified test section. However, different aggregate materials were used to produce the FB-3 Modified mixture for the

Prosser Drive test section. Art Battistone, PennDOT District 12-0 municipal services specialist, met Ms. Stonex at the mixing site in Carroll Twp. and sampled the component aggregate materials from the stockpiles for laboratory testing by NECEPT. The stockpiles contained considerable moisture from recent local rains. This FB-3 material was also mixed for immediate use and was not stockpiled.

The plant operator gave Ms. Stonex approximately one quart of the emulsified asphalt binder material being used. The temperature of the binder sample when obtained was elevated—at least 140 °F (60 °C). It was reported that this type of emulsified binder is often heated up to 160 to 170 °F (71 to 77 °C) prior to mixing with the aggregates. However, the aggregates used to make the FB-3 mixtures were pulled directly from the stockpiles and were not heated, so mixing was essentially performed at ambient temperature.

FB-3 paving in the neighborhood of Prosser Drive started at about 1:00 p.m. and proceeded very smoothly. Again, minor auger segregation was noted at a couple of spot locations but the crew worked to stop it. The test section on Prosser Drive was placed between about 2:30 and 5:30 p.m. It was compacted and sanded in the same manner as Oak Hill Drive, and looked very good upon completion.

5. MATERIALS CHARACTERIZATION

PennDOT Publication 418 (1994), *Seldom Used Specifications*, includes in Section 432 a specification for "Bituminous Paving Course, FB Modified," and identifies that material as "a multi-use product for use as an alternate to Publication 408 FB Specification materials in accordance with the Maintenance Manual and Publication 242 (Pavement Policy Manual)." This specification is for an open-graded, plant-mixed binder or wearing course of bituminous concrete made with a modified asphalt emulsion and nominal maximum aggregate size of 1 in (2.5 cm). Pub. 408 includes specifications for FB-2 and FB-1 plant-mixed wearing and binder courses, which can be mixed either hot or cold, as appropriate for the type of asphalt binder material selected for use. FB mixtures will continue to be used on eligible projects even after full Superpave implementation, according to PennDOT's Revised Superpave Implementation Plan and New Superpave Guidelines dated January 27, 2000.

The FB-3 Modified Wearing Course that is the subject of this study is a more finely graded mixture with nominal maximum aggregate size of 3/8 in (9.5 mm), for which there is no existing Department specification. The trial specification used for this project is included as Appendix A.

Two different types of FB-3 Modified products were studied in this project. The differences in physical properties between them seemed to be primarily due to the binders with which they were made, although some differences in observed performance also appear to be related to use of different aggregate materials. Laboratory test results presented herein generally seem to support the observed differences in how the respective mixtures perform.

The following similarities were noted for both types of FB-3 Modified products:

- In-place, both look like conventional, relatively dense-graded hot-mixed asphalt concrete similar to ID-2 mixtures, although laboratory-compacted specimens have high air void contents ranging from at least 13.2 percent to as high as 24 percent.

- Both provide an aggregate structure that carries the traffic loads without apparent rutting or shoving.
- Both are treated as cold mixes during construction, are readily placed with conventional paving equipment, and do not need special handling. Hand work appears relatively easy where needed.
- Both are easily compacted as open-graded mixtures with no more than two coverages by conventional intermediate-sized static steel-drum rollers.

The primary difference between the two types of FB-3 Modified products studied is:

- One type functions as a low-modulus, elastic, highly flexible mixture in which the modified binder creeps and yields when stressed, while the aggregate skeleton maintains its interlock and structural integrity. This material reportedly may be stockpiled for months before use.
- The other is made with a stiffer, more conventional, emulsified asphalt binder material and appears to behave more like a thin lift of a conventional hot-mixed asphalt concrete mixture. This type is typically not stockpiled prior to use.

LABORATORY TESTING

NECEPT obtained samples of each FB-3 Modified Wearing Course mixture produced for this study, and of each component aggregate material. These materials were characterized by extensive testing by NECEPT to provide the information needed to develop specification recommendations and some idea of expected performance of the respective mixtures. This testing was *not* for purposes of quality assurance or acceptance. The testing performed and the results are described in this section of the report.

NECEPT also obtained a sample of the emulsified asphalt binder used by Russell Standard Corp. However, the modified binder produced by HPSI is a proprietary material that is only available to licensees, and even PennDOT cannot get a sample of that material. Although the HPSI binder could have been recovered from the loose mixture samples in the laboratory, it was likely that its properties would be affected by the procedures and that results of tests on the recovered binder

would not represent the original material. Because of this, no valid comparisons between the two binders could be made. It was therefore decided that neither binder would be characterized as part of this study. If the FB-3 Modified Wearing Course mixtures could perform with a wide range of binders, it would simply indicate that this type of mixture system is relatively robust and would permit more opportunities for prospective users to tailor the mixtures to the needs of specific projects.

Aggregates

The aggregate materials used in the test sections for this study were characterized in order to compare their physical properties with existing specifications for aggregates used in conventional PennDOT HMA surface courses and Superpave consensus properties. Low volume does not mean that the pavement surface will never experience heavy loads—garbage trucks, school buses, and trailers full of corn or hay may use those roadways. Thus the aggregate materials in surface mixtures must be sound and durable enough to provide the necessary structural capacity to withstand such loads even on an occasional basis. However, economy is also an important consideration with respect to the proposed use of FB-3 Modified mixtures.

The FB-3 mixture suppliers provided source information for all of the aggregates. Samples of each aggregate used in each mixture were oven dried, split, and graded by washed sieve analyses according to standard PennDOT and/or AASHTO test methods. Bulk specific gravity and absorption were determined for some of the individual aggregate materials, but typically these determinations were made on the coarse and fine fractions of the composite aggregate blends used in the respective FB-3 mixtures. The “source” properties of some of the aggregates were also tested to measure soundness, durability, and possible presence of deleterious materials. Source property requirements are part of PennDOT’s criteria for approval of aggregates for use in asphalt paving mixtures. The sieve analysis and specific gravity results for the individual aggregate materials are presented in tables 1 through 3.

Table 1. Sieve analysis results for sand aggregates.

Sieve Size (mm)	Sieve Size (in)	PennDOT Bituminous Concrete Sand Type B (408 Sect. 7.03.1(c) Table A)			Oak Hill Dr. MSG 37C-1 % Passing	Oak Hill Dr. MSG 37C-2 % Passing	Prosser Dr. MSG 37C % Passing
		#1 % Passing	#2 % Passing	#3 % Passing			
9.5	3/8	100	-	100	100	100	100
4.75	No. 4	95 - 100	100	80 - 100	98	98	98
2.36	No. 8	70 - 100	95 - 100	65 - 100	85	89	84
1.18	No. 16	40 - 80	85 - 100	40 - 80	72	79	65
0.6	No. 30	20 - 65	65 - 90	20 - 65	55	62	49
0.3	No. 50	7 - 40	30 - 60	7 - 40	17	20	17
0.15	No. 100	2 - 20	5 - 25	2 - 20	3	4	5
0.075	No. 200	0 - 10	0 - 5	1 - 10	1.2	1.4	2.6
Bulk Specific Gravity					2.560	2.560	2.560
Absorption					1.560	1.560	1.560

Table 2. Sieve analysis results for no. 9 aggregates.

Sieve Size (mm)	Sieve Size (in)	AASHTO Spec. % Passing	Sradergrove ALC 10B % Passing	Sradergrove WIN 10A % Passing	Rinely HE6S % Psg	Oak Hill Dr. ALC 10B-1 % Passing	Oak Hill Dr. ALC 10B-2 % Passing	Prosser COM 26C % Passing
9.5	3/8	100	100	100	100	100	100	100
4.75	No. 4	85 - 100	98	100	84*	100	100	94
2.36	No. 8	10 - 40	28	37	17	*5	*5	31
1.18	No. 16	0 - 10	5	4	2	**1	**1	6
0.6	No. 30	---	1	2	1	**1	**1	3
0.3	No. 50	0 - 5	1	2	1	**1	**1	3
0.15	No. 100	---	1	2	1	**1	**1	2
0.075	No. 200	---	0.5	1.7	0.8	1.3	1.1	1.9
Bulk Specific Gravity			2.634	2.661	2.777	2.634	2.634	
Absorption			1.13%	1.63%	0.77%	1.13%	1.13%	

* Value falls outside specified range.

** These values are shown as integers by convention. Decimal values are only reported for the percentage passing the 0.075 mm (No. 200) sieve.

According to Russell Standard Corp. records, the sand used to make the FB-3 Modified mixtures for the test sections on Oak Hill Drive in South Strabane Twp. and on Prosser Drive in Carroll Twp. came from the same source and was ostensibly the same material. The sample obtained from the stockpiles in Carroll Twp. was considerably coarser on two sieves, the 0.6 mm (No. 30) and the 0.3 mm (No. 50) sizes, than the samples obtained from the S. Strabane stockpiles. The reason for the referenced difference in gradation is not an issue for this study. All three samples of sand meet the gradation requirements for PennDOT Bituminous Concrete Sand Type B, #1 and #3. The other two FB-3 Modified mixtures did not include sand.

PennDOT does not have a standard specification for No. 9 stone, so the AASHTO specification is presented in Table 2 for comparison. The HE material is classified as Type 6S anti-skid material. It substantially conforms to the No. 9 grading requirements, but is 1 percent low on the percentage passing the 4.75 mm (No. 4) sieve because the upper limit on this sieve for the Type 6S anti-skid gradation is 85% passing. The ALC 10B material used in the Oak Hill Drive FB-3 mixture does not meet the AASHTO gradation requirements for No. 9 stone. It is too coarse on the 2.36 mm (No. 8) sieve, and much coarser on that sieve size than the same material from the same source that was supplied much earlier in the season for use in the Sradergrove Road FB-3 Modified mixture. The No. 8 aggregate materials meet the PennDOT gradation requirements, except for the percentage of the GLG 03A & B passing the 9.5 mm (3/8 in) sieve.

It should be noted that for the purposes of this study, it is not critical that all of the individual aggregate materials included meet all of the applicable gradation requirements, particularly if the materials are in substantial compliance with existing specifications. The gradation of the combined aggregate blends used in each of the respective FB-3 Modified mixtures is much more important to mixture performance. (That information is presented in this report with the rest of the test results on the various FB-3 Modified mixtures.) However, understanding the physical properties of the component materials is essential for analyzing the performance of the FB-3 Modified systems in this study.

Table 3. Sieve analysis results for no. 8 aggregates.

Sieve Size (mm)	Sieve Size (in)	PennDOT 408 Section 703.2 Table C, % Psg.	Sradergrove GLG 03A & B % Passing	Rinely YOP Roos % Passing	Oak Hill Dr. COM 26C-1 % Passing	Oak Hill Dr. COM 26C-2 % Passing	Prosser COM 26C % Passing
12.5	1/2	100	100	100	100	100	100
9.5	3/8	85 - 100	79*	93	95	96	94
4.75	No. 4	10 - 30	14	26	21	25	28
2.36	No. 8	0 - 10	4	5	4	3	5
1.18	No. 16	0 - 5	3	1	3	2	3
0.6	No. 30	---	3	1	2	2	3
0.3	No. 50	---	3	1	2	2	2
0.15	No. 100	---	2	1	1	1**	2
0.075	No. 200	---	1.0	0.7	1.0	1.1	1.7
Bulk Specific Gravity			2.569	2.727			
Absorption			1.67%	0.43%			

* Value falls outside specified range.

** This value is shown as an integer by convention. Decimal values are only reported for the percentage passing the 0.075 mm (No. 200) sieve.

The Superpave consensus properties that apply to the fine aggregate fraction, material passing the 4.75 mm (No. 4) sieve, are: fine aggregate angularity by AASHTO T304, uncompacted voids; and sand equivalent by AASHTO T176. The Superpave consensus properties that apply to the coarse aggregate fraction, the material retained on the 4.75 mm (No. 4) sieve, are: coarse aggregate angularity, in terms of fractured faces by ASTM D5821; and flat and elongated particles according to ASTM D4791. The consensus property requirements for low-volume roadways, defined as <300,000 ESALs over 20 years, are minimal: only coarse aggregate angularity and sand equivalent apply.

The results of the source and consensus property tests performed are presented in Table 4. The values of consensus property requirements for roadways with volumes <300,000 ESALs over 20 years, and for those with volumes of 300,000 to <3,000,000 ESALs in 20 years, are presented at the bottom of the table for information. PennDOT requirements for source properties for HMA mixtures are also listed. Review of Table 5.4 indicates that the aggregate materials tested exceed the applicable specification requirements for <300,000 ESALs. For all measurements except fine aggregate angularity, the aggregates met or exceeded the requirements for traffic volumes of 300,000 to <3,000,000 ESALs in 20 years.

The No. 9 and sand aggregate materials were tested for fine aggregate angularity (FAA) and the results are presented in Table 4. The No. 8 aggregates were not tested for FAA because they included only 3 to 5% by weight passing the 2.36 mm (No. 8) sieve. Furthermore, four of the five samples of No. 8 were 100% crushed, and the other had 85% particles by weight with one fractured face, so rounded particles were not an issue in any of the mixtures evaluated.

There are 3 standard methods for testing for FAA according to AASHTO T304, but the differences are in sample preparation, not in how the test is performed. NECEPT used Method A to evaluate the individual aggregates, which is based on the use of a standard gradation of the material that passes the 2.36 mm (No. 8) sieve. The actual test procedure is to let the prepared 190-g (0.4-lb) sample flow freely from an inverted pycnometer through a cone-shaped funnel into a cylindrical measure of known volume and weight, then strike-off the excess aggregate above the measure, and determine the uncompacted voids based on the weight of aggregate in the known volume and the bulk specific gravity of that aggregate.

However, none of the samples prepared from the No. 9 aggregates would flow down through the 12.7 ± 0.6 mm (1/2 in) nominal diameter funnel opening without completely blocking it! This was the first time that NECEPT technicians and engineers had encountered such a situation. Gravity is the only force allowed in this test—if the material will not flow down freely to fill the measure, no value of FAA can be determined. The tests were repeated several times in an effort to fill the volumetric measure, but each trial yielded the same result. The results for the No. 9 aggregate materials were thus reported as “blocked funnel” in Table 4. All of the No. 9 aggregates were comprised of 100% crushed particles.

Although values of FAA were not obtained for any of the No. 9 aggregates, the funnel blockages do provide useful information. One-half inch diameter is not a particularly small opening for particles to pass through that have already passed through the openings of a 2.36 mm (No. 8) mesh, or finer, standard sieve. The observed blockages indicate that the aggregate particles must have fallen into some sort of interlocking arrangement as they moved toward or into the funnel opening, and that they did so repeatedly. This indicates that these aggregates tend to array themselves in some sort of structure. In the laboratory, the structure that spontaneously developed in the funnel was sufficient to resist the bearing force exerted by the portion of the sample remaining in the pycnometer directly above it. In some cases, the volume of material remaining in the pycnometer appeared to be as much as 75% of the original 190-gram sample. In other cases more aggregate flowed through, but never enough to fill the measure and obtain a value. The reason for performing the test is to ensure that the fine aggregate fractions have sufficient angularity to provide a stable mixture in-place. The resulting blocked funnels indicate that the No. 9 aggregates probably do.

FB-3 Modified Mixtures

FB-3 Modified mixture samples were sealed in cylinder molds or buckets as soon as they were obtained so as to maintain the total liquids content (asphalt, additives, and water) at the time of sampling for laboratory measurement at a later date. Laboratory procedures performed to characterize the mixtures included: binder residue by evaporation, residual binder content by ignition oven, sieve analysis of the recovered aggregate blends, maximum theoretical specific

Table 4. Aggregate source and consensus property test results.

Test Section Location	Aggregate Designation and Source	Los Angeles Abrasion	Sodium Sulfate Soundness	Total Deleterious Particles	Coarse Aggregate Angularity (1 frac. face)	Fine Aggregate Angularity	Sand Equivalent	Flat & Elongated
Sradergrove Road South Buffalo Twp. Armstrong County	# 9 Allegheny Mineral (ALC 10B)		1%	0		Blocked Funnel	100%	0
	# 9 Winfield Lime & Stone (WIN 10A)		1%	0.60%		Blocked Funnel	100%	0
	# 8 Glacial Sand & Gravel (GLG 03A & 03D)	26.1%	1%	0	85%			0
Rinely Road Hopewell Township York County	HE 6S Tarmac America Hanover		*0	0	100%	Blocked Funnel	100%	0
	# 8 York Building Products - Roosevelt	23.9%		0	100%			0
Oak Hill Drive S. Strabane Twp. Washington County	# 9 Allegheny Mineral (ALC 10B)		1%	0		Blocked Funnel	100%	0
	# 8 Commercial Stone (COM 26C)	35.9% 35.1%	1%	0	100% 100%			0
	Sand G.L.McKnight, Inc. Cunningham (MSG 37C)		1%	0		37.7%	98%	
Prosser Drive Carroll Township Washington County	# 9 Commercial Stone (COM 26C)		3%	0	100%	Blocked Funnel	100%	0
	# 8 Commercial Stone (COM 26C)	23.5%	3%	0	100%			0
	Sand G.L.McKnight, Inc. Cunningham (MSG 37C)		1%	0		39.1%	84%	
Specification Requirements	PennDOT							
	Type A Aggregate	Max. 45%	Max. Loss 10%	Max. 2%	Min. 55%			Max. 15%
	Type B Sand		Max. Loss 15%					
	Superpave							
	Low Volume <300,000 ESALs				Min. 55%	NA	Min. 40%	NA
	300,000 to <3,000,000 ESALs				Min. 75%	Min. 40%	Min. 40%	Max. 10%

* Possible malfunction of scale

gravity, Marshall compaction of loose mixture samples, curing of compacted specimens, bulk specific gravity of compacted specimens, air-void content calculations, and Marshall stability and flow. The Marshall method was used because it has traditionally been one of the two primary methods for designing cold asphalt mixtures (Hveem being the other) and because direct comparisons with the FB-3 Modified data could be made. No data were located regarding application of Superpave technology to cold mixtures.

Binder

For cold mixtures, both total liquids content and residual asphalt binder content are important. Total liquids content affects the consistency and workability of the cold mixture at placement and the curing time, which is the time it takes for the water in the mixture to evaporate. Residual asphalt binder content is related to mixture performance and durability. Although the emulsified asphalt binders were not characterized, it was necessary to determine the residual binder contents of the FB-3 mixtures to characterize the mixtures.

For mixtures made with the HPSI proprietary binder, it was necessary to oven dry splits of the mixture samples to constant weight to determine moisture content before determining residual binder content by ignition oven. This provided information on the total liquids in the mixture as produced. The proprietary HPSI binder was reportedly based on a relatively soft grade of asphalt, 100-220 pen (penetration grade)/AC-5 (viscosity grade) that may meet the requirements for PG 52-28. Additives were not identified.

The Russell Standard Corp. binder sample was tested for residue by evaporation according to ASTM D 244. The emulsified binder is reportedly made from an AC-20 base (similar to PG 64-22) that has been softened with mineral spirits. Samples of the mixtures made with this binder were dried to constant weight in a standard forced draft oven prior to undergoing the ignition oven procedure, but the recorded moisture contents of these mixtures could not be located for determination of total liquids content. Therefore the data are presented in two tables. Table 5 includes stockpile moisture and represents total liquids content for the subject mixtures and Table 6 does not.

Table 5. Total liquids in mixture.

FB-3 Modified Identification	Mass Weight Loss of Mixture by Evaporation	Residual Binder Content by Ignition Oven	Total Liquids in Mixture as Placed
Sradergrove Rd.	16.0%	3.3%	19.30%
Rinely Road.	17.0%	3.6%	20.60%

Table 6. Total liquids in binder.

FB-3 Modified Identification	Binder Residue by Evaporation	Residual Binder Content by Ignition Oven	*Total Liquids in Binder During Mixing
Oak Hill Drive	33.3%	5.15%	15.5%
Prosser Drive	33.3%	5.8%	17.4%

* Does not include moisture content of component aggregates.

The aggregate stockpiles used to make the Russell Standard Corp. mixtures had very recently been exposed to rain, and it was clear that water was added with the aggregate during mixing. Based on the available absorption data for the aggregate materials used on Oak Hill and Prosser Drives and observations of the stockpiles during mixing, it is reasonable to assume that about 3 to 4% water by weight of aggregate was added to these mixtures. This would make the total liquid content of the Oak Hill and Prosser Drive mixtures similar to that shown in Table 5.

Mixture Properties

After the ignition oven burned off the asphalt binder coating, sieve analyses were performed on the recovered aggregate blends to determine the gradations of the respective mixture samples. The results are presented in Table 7 and Figure 13, along with residual binder content and specific gravity and absorption results for the coarse and fine fractions of the composite aggregate blend.

The mixture used on Sradergrove Road consisted of equal proportions of the No. 8 and No. 9 aggregates, and the No. 9 component was comprised of equal proportions of two different No. 9 aggregates. The Rinely Road mixture was similarly constituted, but used only one type of No. 9 stone, the HE 6S aggregate. Residual binder contents appeared relatively low at 3.3% and 3.6%, based on a mix design target of 4%. However all aggregate particles were coated and these FB-3 Modified surfaces do not appear lean. The mixtures reported for Oak Hill and Prosser Drives consisted of equal proportions of the No. 8 and respective No. 9 aggregate materials (each approximately 44% of the composite aggregate blend) and 12% sand by aggregate weight to permit higher residual binder content. Residual binder contents varied from 5.15 to 5.8%, which are similar to contents for HMA mixtures.

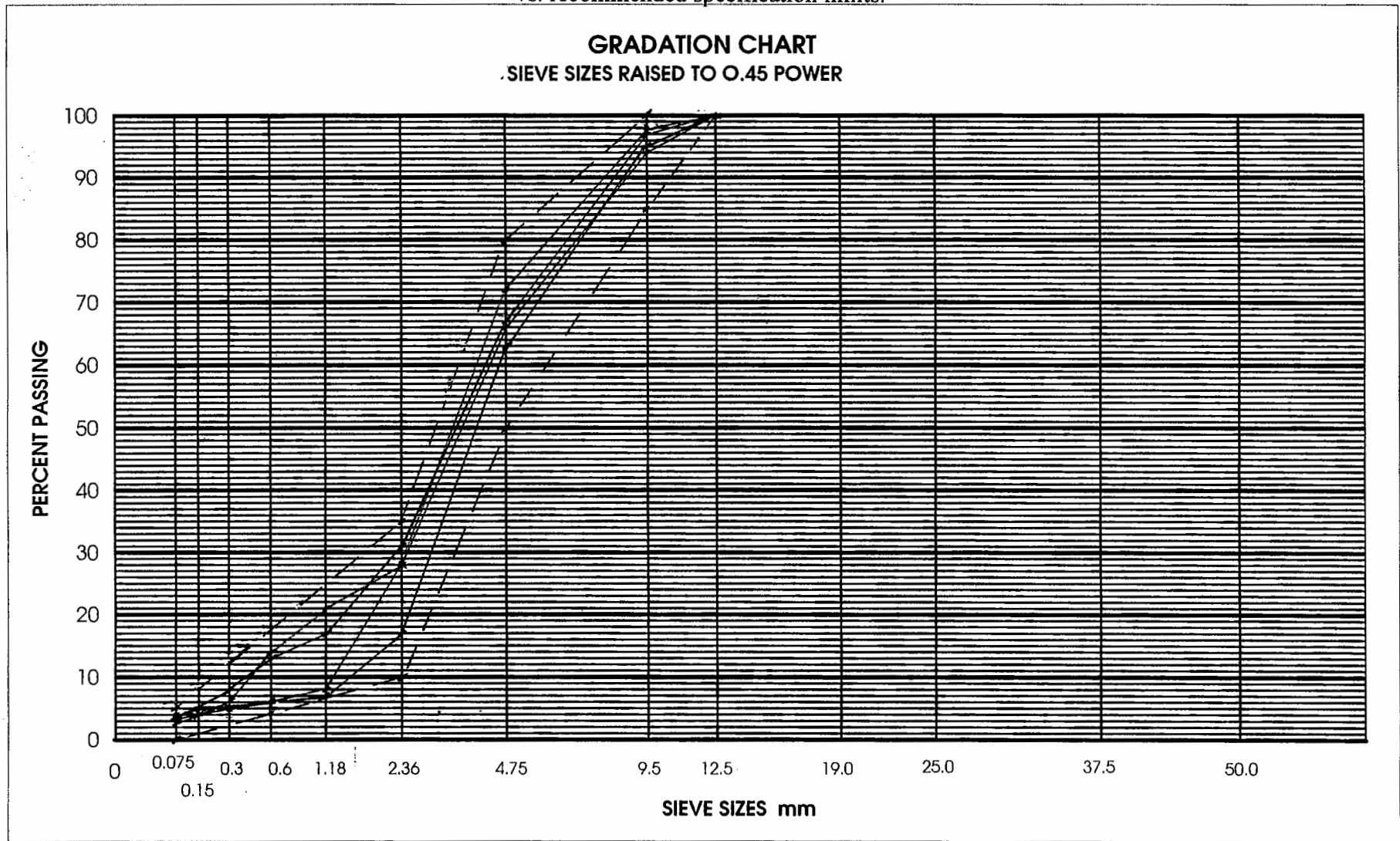
Table 7. FB-3 mixture gradation and residual asphalt binder content.

Sieve Size (mm)	Sieve Size (in)	Trial FB-3 Gradation Specification (% Passing)	Sradergrove (% Passing)	Rinely Rd. (% Passing)	Oak Hill Dr. (% Passing)	Prosser Dr. (% Passing)
12.5	1/2	100	100	100	100	100
9.5	3/8	85 – 100	94	95	98	97
6.3	1/4		76	78	83	79
4.75	No. 4	50 – 80	66	63	72	67
2.36	No. 8	15 – 40	28	17	28	31
1.18	No. 16		8	7	21	17
0.6	No. 30		6	6	14	13
0.3	No. 50		5	5	6	8
0.15	No. 100		4	5	4	5
0.075	No. 200	0 - 5	3.4	4.0	3.3	3.8
Residual Binder Content			3.3%	3.6%	5.15%	5.8%
Coarse Fraction, retained 4.75 mm (No. 4)						
Bulk Specific Gravity of Aggregate Blend			2.575		2.614	2.634
Absorption			1.84%	NA	1.11%	0.93%
Fine Fraction, passing 4.75 mm (No. 4)						
Bulk Specific Gravity of Aggregate Blend			2.637		2.528	2.607
Absorption			1.13%	NA	1.69%	1.85%

All of the mixtures comply with the trial gradation specification and gradations are generally similar, with some variations noted as follows. The gradation of the coarse (retained 4.75 mm, No. 4) fraction of all the mixtures is similar, although the Oak Hill and Prosser mixtures are slightly finer. The gradations diverge from the 4.75 mm (No. 4) through the 0.6 mm (No. 30) sieve sizes. The Rinely Road mixture has the lowest percent passing the 2.36 mm (No. 8) of all of the mixtures, but is very similar to the Sradergrove mixture from the 1.18 mm (No. 16) through the 0.075 mm (No. 200) sieve sizes. Both of these mixtures are much coarser than the Oak Hill and Prosser Drive mixtures from the 1.18 mm (No. 16) through the 0.6 mm (No. 30) sieve sizes because they contain no sand, but gradation of all of the mixtures converges for the 0.3 mm (No. 50) and finer sieve sizes. The Oak Hill mixture gradation shows a slight hump at 1.18 mm (No. 16), but the mix was not tender during construction.

NECEPT had originally planned to compact Marshall-sized specimens, 100 mm (4 in) in diameter by approximately 63 mm (2.5 in) high, of each mixture using the gyratory compactor at the lowest level of Superpave design gyrations. Those specimens would then be tested for

Figure 13. FB-3 Modified mixtures – Composite aggregate gradation from ignition oven specimens vs. recommended specification limits.



40

Recommended
FB-3 Specification

— Sradergrove Road —

— Rinely Road —

— Oak Hill Drive

— Prosser Drive

Marshall stability and flow. However, laboratory scheduling and logistics forced a change in plans, and the specimens were compacted with 25 blows-per-face by a standard Marshall hammer. The low blow count was intended to replicate the minimal static compaction applied in the field. For dense-graded cold mixes, a compactive effort of 35 or 50 blows-per-face is more typical, but such mixtures are typically rolled more extensively than the mixtures in this study.

The Sradergrove and Rinely Road mixture samples were still very soft and workable at the ambient laboratory temperature of about 25 °C (77 °F) and were compacted at that temperature. The Oak Hill and Prosser mixtures had stiffened somewhat in their containers and were gently heated in a forced-draft oven until they reached a consistency similar to that of the other two mixtures prior to compaction. The temperature of the Oak Hill and Prosser mixture samples at compaction did not exceed 50 °C (122 °F). After compaction, all specimens of all mixtures were cured in their molds (without end plates) for 4 days in a forced draft oven at 100 °C (212 °F). After cooling, the specimens were extruded from the molds and cured in air at ambient laboratory temperature for 7 days. The heights of the compacted specimens were then measured, and bulk specific gravity was determined according to AASHTO T166. Maximum theoretical specific gravity values for the respective mixtures were determined from loose samples according to AASHTO T209 and air-void content and absorption were calculated.

The bulk specific gravity results indicated that water absorption was higher than 2 percent for all of the mixtures. This created a dilemma. While the high absorption renders the bulk specific gravity results inaccurate and makes it necessary to coat the specimens with paraffin or parafilm to make an accurate determination, the remains of the surface coating would interfere with Marshall testing. The purpose of the coating is to keep the water from penetrating the interconnecting voids within the specimen that are part of the total specimen volume needed to calculate the bulk specific gravity. Excessive water penetration causes the calculated volume to be lower than the actual volume, which ripples through the voids analysis to result in higher-than-actual values of bulk specific gravity that yield lower-than-actual-air-void content results. The procedure in such cases is to dry the saturated compacted specimens to constant weight, thoroughly coat the entire surface of each to waterproof them, and repeat the test and calculations

with some additional steps to account for the coating. The specimens were set aside to be tested later, after coating according to AASHTO T275, to obtain a better estimate of the air-void content of the subject mixtures. Results for these specimens are shown in Table 8 as the Sradergrove and Oak Hill mixture specimens, for which there are no corresponding Marshall stability and flow results.

For each mixture, three new specimens were fabricated and cured as previously described for testing Marshall stability and flow at 25 °C (77 °F). Because no coating was applied to interfere with stability and flow testing, the measured air voids content data presented in Table 8 for specimens that also list Marshall results should be treated as minimum values because of the high water absorption. The measured air-void content ranges from 12.3 to 19.5% by volume. The Rinely Road mixture exhibited the highest air-void content, and the Oak Hill Drive mixture showed the lowest.

To develop better estimates of actual air void content for the Marshall specimens, the volume of water absorbed in excess of 2% of specimen volume was converted to specimen volume to better estimate the respective values of bulk specific gravity. Air voids contents were calculated from measured dry weights and the newly calculated specimen volume values. The results are shown in Table 8 in the column labeled "Estimated Air Voids Content" and range from about 3 to 5% higher than the values measured without paraffin coating; the higher the water absorption, the greater was the change. Unfortunately, test results for the specimens that had been set aside for paraffin coating and redetermination of bulk specific gravity values after coating could not be located to support the validity of these estimates.

The results of all tests performed on all compacted specimens are presented in Table 8. Although there is some scatter in the property data, the only important difference among the test results for the various mixtures is a striking difference in Marshall stability results between the mixtures made with the soft-based HPSI binder and those made with the more conventional emulsified binder.

The Marshall stability results are listed in Table 8 as "corrected" values, except for the Rinely Road specimens. Correction factors are included in the Marshall procedure to account for

Table 8. Marshall specimen data.

Sample Source	Bulk Specific Gravity	Maximum Theoretical Specific Gravity	Measured Air Voids Content %	Estimated Air Voids Content %	Water Absorption %	Specimen Height (mm)	Corrected Marshall Stability (lbs)	Marshall Flow (0.01 inch)
Sradergrove	2.055	2.493	17.6	22.1	7.8	NA	NA	NA
Sradergrove	2.149	2.493	13.8	17.8	6.9	NA	NA	NA
Sradergrove	2.163	2.493	13.2	17.2	6.8	NA	NA	NA
Sradergrove	2.127	2.493	14.7	19.8	8.5	69.25	760	27
Sradergrove	2.112	2.493	15.3	19.8	7.6	69.17	830	30
Sradergrove	2.151	2.493	13.7	18.0	7.3	69.25	865	32
AVERAGE	2.126		14.7	19.1	7.5		818	30
Rinely Rd.	2.155	2.626	17.9	22.2	7.5	NA	*950	18
Rinely Rd.	2.114	2.626	19.5	24.0	7.9	NA	*870	22
Rinely Rd.	2.201	2.626	16.2	21.0	8.2	NA	*790	29
AVERAGE	2.157		17.9	22.4	7.9		*870	23
Oak Hill Dr.	2.133	2.493	14.4	17.8	6.1	NA	NA	NA
Oak Hill Dr.	2.186	2.493	12.3	15.8	6.1	NA	NA	NA
Oak Hill Dr.	2.186	2.493	12.3	15.9	6.2	NA	NA	NA
Oak Hill Dr.	2.181	2.493	12.5	16.2	6.4	NA	NA	NA
Oak Hill Dr.	2.137	2.493	14.3	17.9	6.4	68.28	5765	20
Oak Hill Dr.	2.119	2.493	15.0	19.0	7.0	69.85	4830	27
Oak Hill Dr.	2.151	2.493	13.7	18.8	8.2	69.45	4755	24
AVERAGE	2.156		13.5	17.3	6.6		5117	24
Prosser Dr.	2.051	2.473	17.1	19.1	4.6	66.82	3675	28
Prosser Dr.	2.056	2.473	16.9	18.7	4.2	65.77	4280	24
Prosser Dr.	2.083	2.473	15.8	18.1	4.8	65.21	4115	26
AVERAGE	2.063		16.6	18.6	4.5		4023	26

*Uncorrected stability values are reported in these cells because height measurements are not available.

variations in specimen height and volume that affect the geometry of the test specimen, which affects the stability measurements. Specimen geometry (height and diameter) is considered more critical to test results and in this case is also more reliable, due to high air-void content and the effects of water absorption on volume calculations, so corrections were made based on measured height of individual compacted test specimens compared to the standard of 63.5 mm (2.5 in). All of the corrections applied reduced the measured stability values. Height measurements for the Rinely Road specimens could not be located, but based on heights of the other specimens the measured stability of the Rinely specimens should be treated as a maximum value. It is clear that they responded similarly to the stability test as the Sradergrove specimens. For purposes of the analysis, the corrected stability results for the Sradergrove mix are the basis for comparison.

The average stability of the Oak Hill Drive specimens, 5,117 lb (22,760 N), is more than six times that of the average of the Sradergrove specimens, 818 lb (3,639 N). The average stability of the Prosser Drive specimens, 4,023 lb (17,895 N), is nearly five times larger than the average of the Sradergrove specimens. This means that the mixes made with the stiffer AC-20 based emulsified binder were stiffer than the mixtures made with the softer base binder. This would be expected. It does not mean that there is anything wrong with the Sradergrove or Rinely mixes, or that they are weak. The HPSI binder is formulated specifically to behave differently than conventional emulsified binders. It was expected that stability values of mixtures made with it would be $\leq 1,200$ lb (5,338 N). According to Asphalt Institute MS-19, minimum stability for asphalt cold mixtures is typically 500 lb (2,224 N). The mixtures all behaved in the same general manner as expected, although the Oak Hill and Prosser mixtures yielded considerably higher stability results than anticipated.

It should be noted that the relationship between Marshall stability and performance has been proved tenuous. This is one of the reasons that the Superpave system is replacing the Marshall method of mixture design. Some pavements with high Marshall stability results $> 3,000$ lb (13,345 N) in the lab have rutted or shoved and have performed poorly in the field. Pavements with very low Marshall stability results $< 1,000$ lb (4,448 N) are often low-modulus materials, but historically some have performed very well even as thin overlays that experience high traffic volumes and heavy truck traffic. However, the test does provide some information on mixture response and stiffness, and allows comparisons with hot mixes and other types of cold mixes.

The flow values were surprisingly similar across the board. It was expected that the stiffer Oak Hill and Prosser Drive mixtures would have relatively low flow values that would fall in the range of 12 to 16 units, the upper end of the range for conventional HMA mixtures. Instead, flow values for these mixtures ranged from 20 to 28, averaging 25. The values for the mixtures with the HPSI binder ranged from 18 to 32, with an average just over 26. Such values were expected for the mixtures with the softer binder, but they are essentially the same as for the stiffer Oak Hill and Prosser Drive mixtures in this study.

The high flow values obtained for all of the mixtures are likely related to the fact that inspection of the insides of the cured specimens after testing to failure showed that the centers of all specimens were still very soft and sticky, regardless of binder type. Apparently the specimens were not fully cured in spite of the 4 days in the molds in a 100°C (212°F) oven and 7 days unmolded at ambient temperature. However, the HPSI binder in the original pavements on Sradergrove and Rinely Roads prior to overlaying with the FB-3 Modified Wearing Course was still soft and sticky under the surface skin after several years in place. When are such mixtures cured and when should they be tested? The scope of this investigation does not address that issue. However, the results obtained for the mixtures with each respective binder type were reasonably consistent and appear valid, particularly with respect to observed field condition in spring/summer 2000. Thus the results presented herein seem to represent these pavements in their early stages after construction.

6. FB-3 MODIFIED CONDITION OBSERVATIONS

SPRING 2000

In April, May, and June 2000, all of the test sections for this study were visually inspected to evaluate the condition of the FB-3 Modified Wearing Courses after one winter of exposure to traffic, the environment, and snow removal measures. Descriptions of test section conditions follow. Overall, the FB-3 surfaces appeared to be performing well, but two types of pavement distress were observed at various locations:

- Low-severity reflection of structural distress from the original pavement surface; and
- Tire scuff marks.

The tire scuffs occurred primarily in the mixtures with the softer HPSI binder. Low-severity reflective cracking was observed in spot locations in mixtures made with each type of binder. The test section with the most widespread reflective cracking, and the most severe occurrence thereof, and the test section that had no reflective cracking, were both made with the stiffer binder.

Sradergrove Road, South Buffalo Township

On May 3, 2000, Mr. Smeltzer and Ms. Stonex met at Sradergrove Road and visually evaluated the two adjacent 1,000-ft (305-m) test sections by walking their lengths. Also present were Bill and Glenn Heilman, Heilman Pavement Specialties, the FB-3 Modified material supplier; Allen Williams, PennDOT Municipal Services supervisor, Dist. 10-0; Steve Fulk, PennDOT MTD Central Lab; and Elizabeth Hunter, NECEPT. Stations were marked and the condition of the pavement was videotaped as for the original pre-construction condition survey.

Hairline reflective cracks were observed at five locations of previous structural distress (according to review of the pre-construction condition survey videotape) and along FB-3 Modified edges bordering two portland cement concrete driveways (see figure 14). The FB-3 Modified pavement otherwise generally appeared to be in very good condition, but a number of tire scuffs of varying depths were observed throughout both test sections (see figure 15). These scuff marks are roughly circular and were caused by vehicle tires when the brakes were applied during turning movements. The scuffs seemed primarily surficial and cosmetic in May, except

for one relatively large one that was up to 1/2-in (12.5-mm) deep. There were also some gouges caused by the construction equipment used to install fire hydrants along the shoulders after construction of the FB-3 Modified Wearing Course.



Figure 14. Sradergrove Road – Most severe reflective cracking observed.



Figure 15. Sradergrove Road – Typical condition, including tire scuffs.

The group decided that the condition of these FB-3 Modified test sections indicated a need for further observation after hot weather trafficking in late August or September, to evaluate subsequent improvement or deterioration of the observed distresses. Some of the surface scuffs and hairline cracks could either heal under the further kneading action of vehicle tires in hot weather, or continue to deteriorate either gradually or rapidly. Such subsequent observations should help provide the remaining information needed to refine recommendations for use, better identify limitations, and improve estimates of serviceable life of thin FB-3 Modified overlays.

Rinely Road, Rt. 525 (Plank Road to PA 24), Hopewell Township

On April 27, 2000, Mr. Smeltzer met with Ms. Stonex to visually evaluate the test sections on Rinely Road in York County by walking their lengths. Bob Streett, the Hopewell Township Roadmaster, Harry Brose and Nick Taylor of Stewart & Tate Roadite Division, and Beth Hunter of PTI were also present. The overall condition was very good. Stations were marked and the condition of the pavement was videotaped as for the original pre-construction condition survey.

Mr. Streett provided some very interesting information about the performance of the FB-3 Modified mixture before and after it cured. Apparently there are not many recreational opportunities for local youth in this rural area and new pavement surfaces attract attention. The night after the paving of the test sections was completed, the section between Clark and Willwert Roads heading uphill towards Clark Road was reportedly the site of a hole-shot contest to see whose car could tear up the most new pavement by accelerating from a dead stop. Several tire tracks' worth of the FB-3 Modified Wearing Course material were displaced during the evening's festivities. Mr. Streett reported that the following morning, township personnel shoveled the displaced FB-3 mixture back into the wheel tracks and used a small roller to recompact it and repair the damage. After this happened several more times, the roller was parked at the intersection of Clark and Rinely Roads each night. Over the next month or so, the nightly and daily rituals of patching out and patching up were repeated, until the pavement cured sufficiently to stand up to the abuse. Repairs were not made after the last "acceleration event," so there is one remaining visible tire streak in the surface of that section of the pavement (see figure 16). It should be noted that this is located in the second test section, where the FB-3 was placed directly over the layer of coarser FB binder course placed the same day and there were

concerns about stability of both the new pavement layers. No rutting was observed in either of the test sections.



Figure 16. Rinely Road - Tire track from the final hole shot in the 2nd test section.

Mr. Streett also informed the group that the pavements in his jurisdiction experienced the worst damage in years during the winter of 1999-2000 due to the amount of temperature cycling that occurred. An example is Willwert Road that intersects with Rinely at the end of the second test section. Whole sections of Willwert Road literally blew up and completely disintegrated (see figure 17).

However, the test sections show only one minor area of structural distress, in an area in the first test section where the original pavement was distressed due to poor drainage from an adjacent agricultural field (see figure 18). The only other defects noted were numerous surface mars, scuffs, and gouges that generally seemed merely cosmetic. The scuffs were much the same as those observed on Sradergrove Road. The question was whether most of these would be healed by traffic in warm weather, or if they would begin to ravel or deteriorate. The observed condition indicated a need for further evaluation after hot weather trafficking to answer this question.



Figure 17. Willwert Road pavement – Example of blow-up from freeze-thaw cycling.



Figure 18. Rinely Road – Reflected crack and typical surface appearance in 1st test section.

The pools of binder that were observed on the original pavement surface in the first test section did not appear to have migrated into the FB-3 Modified surface layer by April 2000. Had a

layer of HMA been placed over those pools, the excess binder on the surface would have been drawn up through the hot-mix layer, resulting in flushing and “fat spots” in the new surface immediately upon compaction. This did not happen when the cold mix was placed or subsequently, which may be another benefit of such mixtures – it may be possible to use such mixtures for overlays of pavements that have been heavily crack-sealed.

Oak Hill Drive, South Strabane Township

On June 8, 2000, Mr. Smeltzer and Ms. Stonex met with PennDOT District 12-0 Municipal Services personnel, including Supervisor Orville Bolbrich, and Specialists Art Battistone and Harold Whyel, in Washington, PA, prior to performing the visual evaluation of the Russell Standard test sections in South Strabane and Carroll Townships in Washington County. Also present were Gary Briceland, of Russell Standard and Casey Cauley, of NECEPT. Reed Mankey, the roadmaster of South Strabane Twp., was not able to participate due to other commitments. All present went to visually evaluate the 1,000-ft (305-m) test section on Oak Hill Drive in South Strabane Township by walking its length. Stations were marked and the condition of the pavement was videotaped as for the original pre-construction condition survey.

Extensive low-severity, hairline transverse and block cracks were observed at various locations throughout the test section, particularly at the intersection near the section midpoint where cracking was clearly reflective. The cracks at the other locations were later verified to be reflective by checking the pre-construction pavement condition video. The FB-3 Modified overlay remained well bonded to the existing bituminous curb. Only a few minor isolated tire scuffs were observed.

This site contained the most extensive distress observed in any of the test sections in this study in the form of generally low-severity reflection of block and alligator cracking (structural distress) in the original pavement. There is also a low to moderate severity reflection of the severely distressed centerline joint in the original underlying pavement (see figure 19). The distress looked like a poor paving joint in the last 500 ft (152.4 m) of the FB-3 Modified Wearing Course test section, but the videotape of paving operations showed that the paver had made three passes

to spread the FB-3 Modified in that part of the test section and maintain surface profile. The paver had straddled the centerline so that there was no centerline joint in the new surface layer (see figure 20). The pre-construction condition videotape verified the distress in the original pavement.

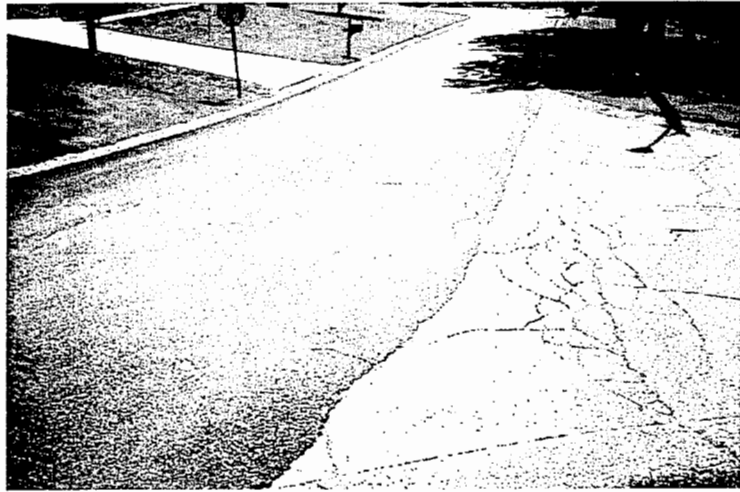


Figure 19. Intersection of Oak Hill Drive and North View Court - Reflection cracks in FB-3 and structural distress in original pavement.



Figure 20. Oak Hill Drive – Underlying centerline joint reflected in FB-3.

Many of the reflection cracks observed in the test section (except the reflected centerline crack in the last 500 ft [152.4 m]) were so fine that it appeared possible that a number of them could

heal during hot weather trafficking. The group decided that the observed conditions indicated the need for a further evaluation after hot weather trafficking to see if the cracks healed, propagated, or stayed in the same condition. Reflection cracks that did heal would be expected to recur, but would be starting a fresh cycle rather than having already developed for a year.

Prosser Drive, Carroll Township

On June 8, after completing the inspection of Oak Hill Drive, Mr. Smeltzer, Mr. Battistone and Ms. Stonex proceeded on to visually evaluate the condition of the FB-3 Modified Wearing Course test section on Prosser Drive by walking its length. Mr. Dave Barkey, the Carroll Township roadmaster, met with the group at the test section. Stations were marked and the condition of the pavement was videotaped as for the original pre-construction condition survey.

The original surface on Prosser Drive before FB-3 placement was in about the same condition as the original surface of Oak Hill Drive had been. However, the only distress observed in the FB-3 Modified Wearing Course test section on Prosser Drive was limited to gouges caused by heavy equipment used to construct a new portland cement concrete driveway for one of the homes within several days after the FB-3 was placed. No reflective cracks or other distress could be found in the test section, although three people looked very hard for any distress. The surface looked great (see figures 21 and 22). The light color of the cover aggregate makes the surface appear slightly corrugated, but that is a visual effect only; the surface is smooth.



Figure 21. Prosser Drive from beginning of the test section to its crest.



Figure 22. Prosser Drive from the crest of the rise to the far end of the test section.

Discussion of Differing Performance Between Oak Hill and Prosser Drive FB-3 Mixtures

This difference in performance of these two mixtures with respect to reflective cracking is of particular interest, because the same crew of people; the same mixing, placing, and compaction equipment; and the same binder were used to make and place both mixtures. Also, both test sections are in purely residential neighborhoods, are located fairly close to each other, and reportedly have very similar climate conditions. It is possible that there may have been some differences in actual thickness of the FB-3, but based on observations during paving, there is likely to be as much variability within each test section as between them. The paving crew checked mat thickness frequently at both sites. What caused the difference?

There was very little difference between the Oak Hill and Prosser component materials—the same binder and same sources of No. 8 stone and sand were used. In fact, the same proportions of No. 8 (44%), No. 9 (44%) and sand (12%) were used in both mixtures. The only difference was the No. 9 stone. The No. 9 stone used in the Oak Hill Drive mixture was ALC 10B (limestone) from Allegheny Mineral, that was substituted by Russell Standard for a No. 9 aggregate material that South Strabane Township had ordered for its own use but rejected for excessive fines content. This same ALC 10B No. 9 aggregate was also used in the Sradergrove Road mixture that exhibited some very minor low-severity reflective cracking, but the gradation of the ALC 10B

varied considerably between the two jobs according to sieve analysis results (presented in table 2). The No. 9 stone used in the Prosser mixture came from the same source as the No. 8 stone used in both the Oak Hill and Prosser Drive mixtures, Commercial Stone COM 26C. It is possible that the ALC 10B No. 9 limestone aggregate may have contributed some additional stiffening effect, either by increasing absorption of the asphalt binder or through some unidentified interaction within the Oak Hill FB-3 mixture.

There were some differences in the properties of the respective Oak Hill and Prosser FB-3 mixtures that may account for the difference in performance with respect to reflective cracking. The Oak Hill mixture had the overall finest (i.e., densest) gradation and the lowest measured (average 13.5%) and estimated air-void (average 17.3%) content of all of the mixtures in the study. The residual binder content of the Oak Hill mixture was considerably lower than that of the Prosser mixture, 5.15% versus 5.8%. The Oak Hill Drive mixture also exhibited the three highest Marshall stability values (average 5,117 lb [22,760 N]) of all of the mixtures and was apparently the stiffest mixture in this study. It appears that it may have been stiff enough to act in a somewhat brittle manner during cold weather. This mixture behaved in-place very much like a very thin conventional HMA overlay in its response to underlying distress, although the reflective cracking observed was generally low severity and hairline. The higher binder content in the Prosser mixture may in itself have been sufficient to make that mixture more resistant to reflective cracking than was the Oak Hill FB-3 mixture.

SEPTEMBER 2000

In September 2000, all of the test sections were again visually inspected to determine any changes in condition. Of particular interest was whether the specific pavement distresses observed in Spring 2000 had improved, worsened, or remained relatively constant. This section discusses what was observed and performance expectations of the respective test sections.

Rinely Road, Rt. 525 (Plank Road to PA 24), Hopewell Township

On September 6, 2000, Ms. Stonex and Ms. Hunter performed another visual condition survey of the test sections on Rinely Road in York County by walking their lengths. Mr. Smeltzer and

Steve Fulk had planned to be there, but conflicts prevented them from coming. Stations were marked within the two test sections and the condition of the pavement was videotaped as for the original pre-construction and subsequent spring 2000 condition surveys. Weather conditions were mild during this site visit; temperatures were in the low to mid-70s °F and it was partly sunny.

The overall condition of the FB-3 Modified pavement surface was generally very good (see figure 23). Although some changes had occurred since the spring inspection, they were not unexpected based on site conditions, materials characterization data, and previous field observations of the original site pavements and of the in-place FB-3 Modified Wearing Course.



Figure 23. Rinely Road test section 1 - Overall appearance from far end looking towards origin.

Mr. Bob Streett, Hopewell Township roadmaster, joined the NECEPT personnel at the test sections and provided useful information about site conditions that related closely to observed pavement surface condition. He stated that he was very pleased with the overall performance of the FB-3 Modified Wearing Course. Mr. Streett informed Ms. Stonex that the local weather had been very hot and muggy for most of the summer and that when it was not hot, it was raining. The test sections reportedly received considerable rainfall since the April condition survey. His assessment of the condition of the sections closely agreed with NECEPT's observations.

Changes were most apparent in the first test section between Clark and Plank Roads. In two spot locations the chip seal binder that had been pooled on the original surface had apparently worked up through the thin FB-3 Modified Wearing Course as a result of hot weather trafficking (see figure 24). Had the thin overlay been a hot mix, that pooled chip seal binder on the underlying surface would have come up through the overlay during compaction operations as does crack sealer. Instead, it took almost a year for any of that binder to surface. When viewed it was not distributed thickly or widely enough so as to create significant potential for skidding accidents. The underlying loose binder will only migrate up through the overlay when sufficiently warm to flow, but it is expected to continue to migrate over time.



Figure 24. Rinely Road test section 1 - Original reflection crack and chip seal binder that has migrated up to FB-3 surface.

There had been only one area of structural distress in the original pavement, located about halfway through the first section along the pavement edge in an area where water draining from adjacent fields and nearby underground springs tends to pond and weaken the subgrade. A small (3-4 ft long [0.9-1.2 m long]) hairline reflection crack was observed in the FB-3 wearing course in this area in April 2000. By September 6, the original reflection crack had widened slightly, although the opening was still less than $\frac{1}{4}$ in (6.3 mm) wide, which is the typical minimum width for sealing. However, intermittent hairline cracking was observed that extended from the location of the original crack for a distance of up to 70 ft (21 m) toward the farm road and mailbox, with a possible total of up to 50 lf (15.2 m) of very fine new hairline cracking. This

cracking near the unsupported edge of the original and FB-3 Modified pavements is expected to further develop over time. The rate of crack development will depend on the moisture content of the subgrade, other site environmental conditions, traffic, and the FB-3 mixture properties.

As expected, most of the minor tire scuffs were no longer evident due to the kneading action of vehicle tires. Moderately severe scuffs generally did not manifest much change in appearance. Also as expected, the most severe scuffs and gouges previously observed had worsened somewhat. However, no loose stone remained in these cavities, and the surrounding FB-3 Modified mix felt as hard as the rest of the surface—it did not move or ravel when scuffed by foot. It is expected that these scars will collect moisture and further deteriorate over time, particularly over multiple freeze-thaw cycles. This is not a serious problem—such small spot locations can easily be patched with cold patch when necessary. The surface texture throughout the first test section has a slightly open appearance because it contains only No. 8 and No. 9 stone and no sand. If the mixture were prone to stripping, the numerous freeze-thaw cycles that so badly damaged Willwert Road and the hot wet site conditions reported for the summer should have exacerbated the tendency. However, there was no visible indication of stripping in the FB-3 mixture in either of the test sections on Rinely Road.

The only place that any new tire scuffs or gouges were observed was where vehicles turned at the intersection of Rinely and Clark Roads at the beginning of the second test section. Mr. Streett verified that all of the other scuffs (except for the final hole shot) had occurred within a few days of FB-3 Modified placement. He stated that heavily loaded trucks that were transporting freshly harvested wheat from a nearby farm during the hottest part of the summer had caused the new scuffs at the intersection. This represents extreme loading conditions for which the FB-3 Modified mixtures were never designed, nor intended to endure. The HPSI binder may simply have been too soft to handle such severe loading conditions. As can be seen in figure 25, the truck tire scuffs appear to affect only the FB-3 material that was located directly under them. There are no visible humps or any indication of shoving or plastic flow in the mixture immediately adjacent to those tire tracks, as would accompany rutting. Although it is possible that any such humps might have been flattened by traffic, there is no sign that any humps had been there.



Figure 25. Wheat truck damage to FB-3 Modified on Rinely Road at Clark Road intersection as viewed from Clark Road.

Oak Hill Drive, South Strabane Township

On September 20, 2000, Mr. Smeltzer met with Ms. Stonex to evaluate the test sections on Oak Hill and Prosser Drives. Also present were Art Battistone, of PennDOT District 12 Municipal Services, and the roadmaster of South Strabane Township, Reed Mankey, who provided weather and usage information. Mr. Mankey stated that he has been very pleased with the performance of the FB-3 Modified Wearing Course and plans to continue using it. He has had prior experience with FB-3 Modified mixtures and stated that they are easy to patch with a variety of materials. However, he has indicated he would prefer to use it for mainline paving rather than in residential areas for a reason totally unrelated to technical issues. Apparently there is considerable integral bituminous curb and gutter in some of the older neighborhoods, and new residents have complained that the FB-3 Modified Wearing Course does not “match” their appearance.

According to Mr. Mankey, temperatures were much milder in South Strabane in 2000 than in 1999, and reportedly never reached 90°F (32 °C). The first part of the summer was particularly wet, but overall there was reportedly not much more rain than usual. Based on this information, it was not expected that any of the previously observed reflection cracks were likely to have

improved significantly. During the condition survey, the weather was sunny and warmed up to the mid-70s °F (22-26 °C).

The transverse reflection cracks in the first half of the test section on Oak Hill Drive between Park View Drive and the intersection with North View Court showed some very interesting changes. On each side of the roadway, these transverse cracks had mostly disappeared along the outer $\pm 30\%$ of the total pavement width. It appears that the kneading action of tires helped heal the outer portions of many of the transverse reflective cracks (see figure 26). There is some occasional parking along the street, but most of the time the full width of the pavement is available for traffic. In some cases it was easy to see where the crack had previously extended to near the edge of the pavement, in others, not. However, in the center $\pm 40\%$ of the pavement area, the same cracks that had healed on the outside had opened up from generally fine or hairline to at least $\frac{1}{4}$ in (6.3 mm) wide. It is not clear why such a wide area behaved so differently. Although it seems that the main inside wheel path should have tracked closer to the center and left a narrower span of the remaining transverse cracks, the observations may simply indicate that the vehicles tend to hug the curb more closely than expected in this particular part of the test section.



Figure 26. Oak Hill Drive - Transverse crack in center of roadway where ends of crack have healed.

Some of the reflection cracks in the FB-3 Modified surface at the intersection with North View Court have widened somewhat, but no raveling or deterioration of the edges was apparent (see figure 27). The reflected scallop-shaped cracks along the edge of the FB-3 overlay of the original pavement became more pronounced. The FB-3 remained very tightly bonded to the underlying pavement and along the existing bituminous curb and gutter even where it was tapered down to single-stone thickness to match existing grade and profile, and at intersections.



Figure 27. Oak Hill Drive - Reflection cracking in FB-3 Modified surface (on left) at the intersection with North View Court (on right).

The reflected centerline joint in the second half of the test section after the intersection with North View Court showed some surprising changes that cannot be easily distinguished in photographs. In June, the FB-3 surface profile had conformed to that of the underlying pavement profile and had formed a short peak along the length of the reflected centerline joint. Low-to moderate-severity reflective cracking was observed in the FB-3 mixture along that raised peak. Most of the observers expected that significant deterioration of the FB-3 wearing course would occur along this joint; it reminded some of a zipper waiting to be unzipped. That did not happen during the relatively cool, wet summer weather. The primary reason seems to be the neighborhood traffic pattern.

Observation of the FB-3 surface indicates that within the first 50-100 ft (15-30 m) past the intersection, the inside wheel paths of traffic heading up the hill begin to run directly over the

centerline (see figure 28). The “zone of influence” of the raised underlying distressed centerline area varies from about 0.7 to 1 ft (0.2 to 0.3 m) wide and is still readily discernible. However, the reflected centerline cracks in the FB-3 surface were no longer evident from the approach to the curve nearly to the intersection with Park Terrace Drive, about 870 ft (265 m) into the test section (see figure 29). Furthermore, the FB-3 surface no longer peaked at the center. It appears that the kneading action of tires as the vehicles travel up the hill and around the curve flattened the peak and healed the reflective cracks along the underlying centerline, at least for the time being.



Figure 28. Oak Hill Drive - Reflected centerline joint in 2nd half of the test section, looking uphill just past North View Court and approaching curve.

In colder weather, the FB-3 surface is stiff enough that it will likely crack again along the underlying joint. Close observation of the centerline area indicated minor segregation in the FB-3 Modified surface that may be due to loss of some fines from the mixture during the flattening and kneading of the cracked peak by the tires.

Near the intersection with Park Terrace Drive, the centerline cracks reappear in the FB-3 Modified surface and the pavement looks nearly the same as it did in June 2000. There are only a few homes on this end section of Oak Hill Drive, so most of the incoming traffic turns off before or at Park Terrace. Thus this part of the test section is not exposed to enough traffic to knead the FB-3 surface back together. Environmental conditions and snow removal equipment



Figure 29. Oak Hill Drive - Centerline viewed from approach to curve in the 2nd half of the test section, looking downhill toward North View Court and beginning of test section.

rather than traffic will be the primary causes of distress at the far end of the FB-3 Modified Wearing Course test section on Oak Hill Drive.

It is surprising that so many of the cracks in this FB-3 test section were so significantly affected by a relatively small volume of residential traffic, considering how stiff the laboratory tests indicated this particular FB-3 Modified mixture to be. Neither NECEPT nor the PennDOT Municipal Services representatives expected the observed improvement along the reflected centerline joint. An additional trip will be required to videotape the condition of this test section, as there was too much distress for a single person to properly complete this activity. The field of view of the camcorder is too narrow for the operator to maintain the overall perspective on the location and severity of the pavement distress that is needed for the accompanying narration of observations.

Prosser Drive, Carroll Township

Prosser Drive looked almost exactly the same as it had in June 2000 and exhibited very little distress (see figure 30). The previously painted station numbers were even still discernible. Weather conditions were reportedly very similar to those experienced at Oak Hill Drive. After

diligent searching, only one low-severity crack was found in the entire test section. It was a longitudinal crack located near the edge of the FB-3 Modified surface at a driveway transition that was most likely due to straddling differing underlying materials. Although there were some severe longitudinal cracks in the original surface, there are as yet no signs of any reflecting through the FB-3 wearing course. The only other distress noted was limited to a few tire scuffs near driveways and intersections and the marks from the equipment that constructed a PCC driveway that were made within a few days after the FB-3 was placed, before it was fully cured. The FB-3 Modified wearing course on Prosser Drive looked as if it could perform well for possibly up to 5 years before major maintenance would be required. Because there was so little distress, Ms. Stonex was able to videotape the condition of the Prosser Drive test section without assistance.

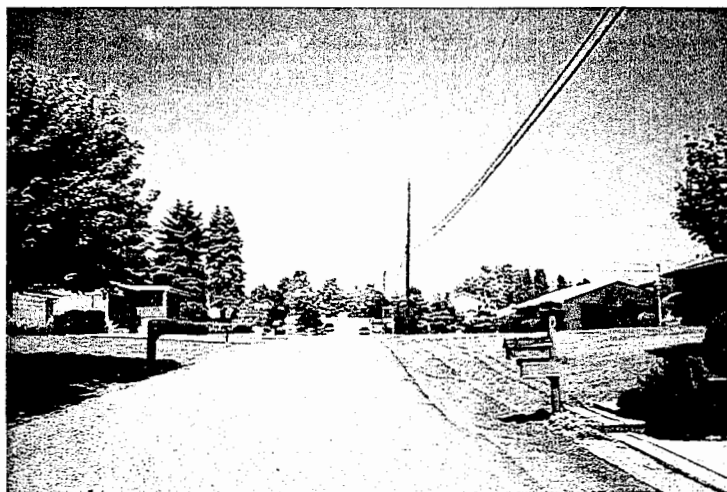


Figure 30. Prosser Drive - Overall appearance of FB-3 test section.

Sradergrove Road, South Buffalo Township

On September 26, Mr. Smeltzer met with Ms. Stonex and Ms. Hunter to evaluate the test sections on Sradergrove Road. Stations were marked within the two test sections and the condition of the pavement was videotaped as for the original pre-construction and subsequent spring 2000 condition surveys. Weather conditions were windy and cold (mid-40s °F [5-8 °C]) and started out very rainy. The rain subsided and the roadway surface dried out gradually during

the videotaping. The South Buffalo Township Roadmaster, Mr. Bob Van Dyke, stopped by the test sections briefly and reported that the weather during the summer had been relatively cool, with only a few days at or above 90 °F (32 °C), and very wet.

The condition of most of the tire scuffs observed in May did not seem to have changed much. The cool and often overcast weather did not promote much healing of even the minor mars on the surface. A couple of the most severe scuffs had deteriorated slightly, but did not contain any loose stones and were firm to the touch. One relatively fresh scuff was observed; it looked as if a single tire had spun so hard that it had dug almost through the FB-3 surface layer at that location. There was loose FB-3 material in the scuff and on the adjacent surface. Near the transition to the second test section, some piece of equipment (possibly a trailer or bulldozer blade) had dragged along the center crown and scraped off the crown for at least 12 ft (3.66 m) (see figure 31). No information was available on the cause of damage at either location.



Figure 31. Sradergrove Road - Scraped off crown at the beginning of test section 2.

The FB-3 Modified surface generally looked good but it did show some effects of the wet summer weather. The most obvious were numerous rust stains from the iron-containing aggregate particles that were scattered over the entire surface of both test sections (see figure 32). When observed, this was still just a cosmetic problem, as it seems that very few of these particles have popped out of the mixture yet. Where rust stains were observed, the rusting particles were

almost always readily distinguishable embedded in the pavement surface. However, in most asphalt paving mixtures, even surface treatments, the expansion of such particles due to oxidation typically results in pop-outs and/or cracks (i.e., pavement distress). The binder in this FB-3 Modified Wearing Course mixture may be soft enough to yield and creep sufficiently to minimize these typical problems. The binder is still very sticky and appears to generally adhere well to the aggregates in the mixture and to the substrate, which might further minimize pop-outs of rusty particles. However, pop-outs or cracks would typically be expected to develop over time. No stripping was evident.



Figure 32. Sradergrove Road - Overall appearance from the far end of test section 1 toward the beginning.

Another effect of the wet summer was apparent loss of support along the edges of pavement that resulted in longitudinal cracks usually located within 12-18 in (0.3-0.46 m) of the edges of the FB-3 overlay. The parts of the test sections where drainage improvements had been made generally manifested noticeably fewer edge cracks. When the FB-3 overlay was placed, it was typically extended past the edge of the original pavement directly onto the shoulders. When two adjacent underlying materials differ greatly in strength, it is almost impossible to avoid cracking in the overlay along the boundary between them and particularly when there is also difference in height at that boundary. Another example of the effects of differences in support is where the FB-3 was placed over the end slabs of a PCC driveway. In May, the reflection cracks were just beginning to show at a few points along the edge. By September 26, reflective cracks completely outlined the slabs and joints. HMA pavements don't perform much differently in

such cases than did the FB-3—they also crack along unsupported edges and at the boundaries of underlying structures or of materials with differing strengths. The edge cracks observed are generally low severity, but it is expected that they will continue to develop over time and will require periodic maintenance, consisting of sealing and patching as needed.

Loss of support due to wet site conditions was not limited to the edges of the pavement in the test sections. Some of the areas of the original pavement where base failures had already been observed also showed further development. In May, five locations were noted where pre-existing structural distress was either already reflecting through into the FB-3 or seemed imminent (see figure 33). In September, two small areas of low severity alligator cracking had noticeably worsened while the one pictured in the Spring 2000 section of this report appeared about the same. The two areas that worsened are very close to each other, near the transition between the two test sections. The pavement surface there is slightly depressed across the entire roadway due to previous base failure. One suspect intermittent longitudinal crack did not develop into block or alligator cracking, and the other area where it had been expected that the FB-3 wearing course would develop structural distress could not be found. It is possible that drainage improvements may have helped delay development of structural distress in some parts of the overlay.



Figure 33. Sradergrove Road – Reflected fatigue cracking.

Mr. Van Dyke reported that he is very pleased with the FB-3 Modified Wearing Course test sections and wishes that he had been able to overlay the portion of Sradergrove Road between Freeport-Kitanning Road and the beginning of the test section, which is steadily deteriorating.

Summary

In most cases, the conditions of the respective FB-3 Modified Wearing Course pavements observed during September 2000 were much as had been expected, based on site conditions, materials characterization data, and previous field observations of the original site pavements and of the in-place FB-3 Modified Wearing Courses. The test section pavements all appear to be performing relatively well. It must be remembered that these FB-3 Modified Wearing Courses are not really structural materials and should not be expected to perform as anything other than an improved surface for roadways with low volumes of traffic and relatively few heavy loads.

There were a few surprises in the field: two relatively new scuffs in pavements placed more than 1 year earlier; apparent healing of portions of cracks within the stiff mixture on Oak Hill Drive; the apparent lack of stripping in all of these relatively open FB-3 mixtures, particularly those with low residual binder contents; and the strong adhesion of all of the FB-3 Modified mixtures used in the study to the various substrates ranging from dirt shoulders to PCC driveways and bituminous curb-and-gutter.

7. COST DATA

The reason for this study was to determine if FB-3 Modified Wearing Course mixtures can provide alternative low-volume pavement surfaces for municipalities. The results to date presented in this report indicate that they can. However, another very important criterion for use is whether the FB-3 materials are economical or affordable. It is thus necessary to compare costs for conventional materials with those for the FB-3 that might replace them in some circumstances.

PennDOT Municipal Services representatives in the districts in which the test sections were located were asked to provide information on costs of various bituminous products to municipalities in their areas. These are not the same costs that are listed in PennDOT Bulletin 50, "*Construction Cost Catalog of Standard Construction Items.*" The responses are presented in Table 9, in terms of cost per square yard for surface treatments and chip seals, and in terms of cost per square yard per inch of thickness and cost per ton for asphalt paving mixtures. Conversions were based on a factor of 110 lb/yd²/in (59.8 kg/m²/ 25 mm) for ID-2 and ID-3 HMA materials and 100 lb/yd²/in (54.3 kg/m²/ 25 mm) for the FB-3 Modified Wearing Course materials, based on typical compacted unit weights of the respective materials. It should be noted that many municipal projects are relatively small, and small projects can be very expensive. Unit rates are typically high for small quantities and discounted only for large quantities. Ranges shown in Table 9 reflect the spread in unit rates for small and large projects based on limited data.

Clearly unit prices for various materials differ across Pennsylvania. The costs of the FB-3 mixtures generally appear reasonable compared to surface treatments and hot mixes and don't seem to fluctuate more than the other costs. Should FB-3 Modified Wearing Course be approved by PennDOT, costs are expected to vary according to the demand for the materials.

Table 9. Cost data for comparison.

Type of Material	District 8-0	District 10-0	District 12-0
Surface Treatment (per square yard)	\$1.09	\$0.75-\$1.00	\$1.30-1.55
Chip Seals (single) (per/square yard)	\$0.65	\$0.48-\$0.60	\$0.85-\$1.70* (*includes some double seals)
FB-3 Wearing (per square yard per inch thick) (per ton)	\$2.05 \$40.90	\$1.75 \$34.95	\$1.70 \$34.00
ID-2 Hot Mix Asphalt (per square yard per inch thick) (per ton)		\$1.97 \$35.80	\$2.07-\$2.63 \$35.57-\$47.87
ID-3 Hot Mix Asphalt (per square yard per inch thick) (per ton)	\$1.73 \$31.41		

8. CONCLUSIONS AND RECOMMENDATIONS

The results of this limited study to date indicate that the FB-3 Modified Wearing Course system can perform relatively well as a surface for low-volume or low-capacity roadways in rural and residential areas in Pennsylvania. It appears that FB-3 mixtures can be engineered to meet specific project needs by selecting from a range of emulsified asphalt products for use as the binder. Based on observations and laboratory test results, this study bracketed the full range of binder materials that could feasibly be included in the proposed FB-3 Modified Wearing Course mixture system, from the very soft, highly modified HPSI binder to the more conventional emulsion system with slight modification by more customary means.

It is therefore recommended that the FB-3 Modified Wearing Course system be approved for municipal use on low-volume and low-capacity roadways. This would allow purchase of such materials with Liquid Fuels Tax money. A proposed specification that includes the full range of products studied is included at the end of this section of the report for implementation purposes, should the Department choose to approve the municipal use of FB-3 Modified Wearing Course materials for low-volume or low-capacity roadways.

It must be remembered that these FB-3 Modified Wearing Courses are cold-mixed materials that are not really structural in nature. Such materials should not be expected to perform as anything other than improved surfaces for roadways with low volumes of traffic and relatively few heavy loads. The manufacturers do not recommend placing FB-3 mixtures in compacted lifts greater than 1.5 in (37.5 mm) thick because of the small stone size (nominal maximum 3/8 in [9.5 mm] according to the Superpave system). Although FB-3 wearing course mixtures may look very much like some conventional ID-2 mixtures, FB-3 mixtures are not structurally equivalent to hot-mixed asphalt (HMA). These cold mixtures will not remedy structural inadequacies or compensate for structural damage that has occurred. Such damage will reflect through the FB-3 Modified Wearing Course, over time if not right away. However, there are many circumstances for which it is not necessary to use HMA in order to provide an appropriate pavement surface or

restore surface frictional characteristics or ride quality, and particularly for low-volume rural and municipal roadways.

This study attempted to represent the range of conditions in which the FB-3 mixtures might be used, by varying the locations/climates and the types and conditions of the original in-place pavements as described in this report. Further efforts to represent expected use included minimal preparation of the existing pavements prior to overlaying with the FB-3 wearing course. Most municipalities don't have the fiscal resources or sufficient personnel, time, and/or equipment to make extensive base or surface repairs to most of their roadways prior to overlaying. Therefore, only one of the six test sections (Rinely Road test section 2) received any extensive preparation prior to overlaying with the FB-3 mixtures. A short (about 20-25 ft long [6-7.6 m long]) section of scratch and level course was applied only over the culvert located midway through Rinely Road test section 1. Part of the Sradergrove Road sections received a very thin ($\leq \frac{3}{4}$ -in [19mm] thick) scratch and level application of the same FB-3 Modified mixture used for the wearing course to restore profile. All of the rest of all sections were at most broomed prior to overlaying—no crack filling, sealing, or other surface or base preparation was performed. Drainage improvements were made to some of the test sections either as part of the FB-3 Modified paving project, or afterward as part of continuing efforts. Such improvements benefit the entire pavement structure, including performance of the FB-3 Modified Wearing Course.

The HPSI binder was formulated specifically to provide elasticity and flexibility to reduce the potential for permanent deformation and fatigue, and to allow the binder to creep to minimize low-temperature cracking. Its use results in a highly modified mixture that readily supports traffic. The aggregates used with this binder are a 50-50 blend of crushed AASHTO No. 8 and No. 9 stone that provides air-void contents similar to those of open-graded friction courses, and a somewhat rough and open surface appearance compared to dense-graded hot mixes. Residual binder contents are quite low, averaging about 3.5% by weight. However, due to the very soft binder, the surfaces of these mixtures tend to accumulate tire scuffs and various scrapes that mar their appearance.

These softer binders could be used in many locations where cosmetics are not an issue, but careful consideration should be given as to whether such soft binders should be used in residential neighborhoods where the appearance of the pavement may be rated as very important. The soft binder would not be suitable for the surface pavement in a parking lot where there are many simultaneous braking and turning maneuvers that would cause scuffing, and where tires dwell on one spot for long periods of time. It should be possible to stiffen the HPSI-type binder somewhat without sacrificing too much of its elasticity and flexibility. Use of aggregate that contains sufficient iron to rust in-place is not recommended.

More conventional emulsified binders can also be used to provide a somewhat stiffer binder and FB-3 mixtures that perform more like a thin layer of HMA. In this type of formulation, 12% sand was added to a 50-50 blend of crushed AASHTO No. 8 and No. 9 stones, which made the resulting FB-3 mixtures somewhat less open-graded and required more residual binder to coat the sand. There appears to be some risk that such mixtures may become too stiff to resist thermal or reflective cracking as occurred on Oak Hill Drive. However, the resulting mixtures are not prone to surface scuffing or marring and, as long as cracking can be limited, they can maintain an attractive surface appearance. On Oak Hill Drive, some healing of reflected cracks was observed; there may be recurring cycles of cracking and healing in that FB-3 mixture over time. In locations where there is significant distress in the existing pavement or where low-temperature cracking is a threat, conventional emulsions could be based on a somewhat softer PG 58-28 (similar to AC-10) instead of PG 64-22 asphalt cement to reduce the potential for cracking without making the binder too soft to perform as desired.

It is important to allow FB-3 Modified Wearing Course systems to be engineered as appropriate for the intended use, if these materials are to provide the greatest benefit to their prospective users (expected to be municipalities). Therefore, the proposed specification included at the end of this section does not restrict the types of modifiers that may be used to make the binder, or place limits on the resulting binder properties, as long as the base asphalt cement materials conform to the performance-grade (PG) requirements according to PennDOT Bulletin 25 and the resulting FB-3 Modified Wearing Course mixture performs. There is one environmental constraint that limits constituent oil distillates to not more than 12% by total binder volume.

Whatever type of binder system is selected, the aggregate structure in the mixture is what ultimately carries the traffic loads. According to the materials characterization findings, the quality of the aggregate materials used in the mixtures in this study exceeded the minimum PennDOT requirements for Type A Aggregate for use in HMA, and the Superpave requirements for low traffic volume <300,000 ESALs, that includes all of the test sections. Except for fine aggregate angularity (FAA) the aggregate properties also met the physical requirements for the next traffic level, 300,000 to <3,000,000 ESALs. However, without FAA values for the No. 9 aggregate materials that blocked the funnels, there is no way to prove that the 4.75 mm (No. 4) fraction of the composite aggregate blends of the various FB-3 mixtures met the standard even though engineering judgment indicates sufficient angularity.

The proposed specification for FB-3 Modified Wearing Course is a modification of the PennDOT Seldom Used Specification SSU0432A for Bituminous Paving Course, FB Modified. It includes requirements for Type A aggregate and for the only two aggregate consensus properties that apply to the <300,000 ESALs category, coarse aggregate angularity (CAA, by one fractured face) and sand equivalent.

The specification value for CAA is recommended to be a minimum of 75%, which is higher than the minimum Type A and Superpave requirement of 55%. There are two reasons for this. None of the aggregates in the FB-3 mixtures studied had less than 85% particles by weight with one fractured face, so setting the minimum at 55% would put the aggregate quality too far outside the range of the materials studied. Furthermore, as there are essentially no limits placed on the binder properties, it is important to ensure that there is adequate aggregate structure to carry occasional heavy loads without rutting or shoving. Although the need for economy for the users is understood, it is neither difficult nor expensive to obtain Type A, No. 8, and No. 9 aggregate materials in Pennsylvania that include at least 75% crushed particles. The FB-3 costs shown in Table 9 reflect the quality of material used in this study and generally fall between surface treatments and hot mixes as expected.

The minimum residual binder content in the proposed specification has been set at 3.5% by weight, which is very low. The only reason that such a low value was considered is that it represents the average residual binder content of the HPSI binder in the mixtures in the test sections on Rinely and Sradergrove Roads. The FB-3 Modified Wearing Course mixtures on the test sections at these locations generally appear to be performing well and do not give any indication of stripping as yet. Therefore, although this minimum value seems almost uncomfortably low, it must be allowed at least until additional data indicate that an increase is required. The primary risk of using too low a binder content is increased potential for raveling and stripping of the mixture in-place. Application of a fog seal or similar surface treatment is an effective and relatively inexpensive remedy, should either of these distresses occur. No maximum binder content was specified because the mixtures are sufficiently open-graded that there is little risk of flushing or bleeding within the range of residual binder contents that are typically considered economically feasible. It is unlikely that any supplier would want to include higher residual binder contents than required for hot-mixed asphalt paving mixtures.

The FB-3 Modified mixtures used in this study appeared easy to place and very forgiving with respect to workmanship compared to HMA. These materials can readily be placed by small crews with limited experience using basic paving equipment. Compaction is accomplished relatively quickly and easily in the static mode and mixture temperature at placement is not an issue with cold-mixed materials. Thus the fact that small jobs do not take precedence at the plant and haul trucks are often delayed while waiting to be loaded does not result in placement problems for cold mixes as for HMA.

It may be possible to use FB-3 Modified Wearing Course mixtures in areas of heavier traffic, up to 3,000,000 ESALs over 20 years, if the constituent aggregate materials meet corresponding quality requirements for HMA including the appropriate levels of consensus properties. However, such higher traffic volume roadways were beyond the scope of this study, and further test sections would be needed to verify performance for such use, preferably over a period of considerably longer than 16 months. Caution should always be exercised when extrapolating from limited experience and data—these may no longer apply when conditions change. Serious

consideration would also have to be given to the type of binder system selected for use in higher-volume pavement surfaces.

The recommendations herein and in the following specification are based on materials characterization test results and field performance observed to date. A major limitation of this study is time. Performance was only monitored for a maximum of about 16 months, which is a very short time in the life of a pavement, even a thin cold-mixed overlay. It is strongly recommended that local Municipal Services representatives who are familiar with this study should monitor the condition of the test sections periodically to assess performance and compare it to expectations as described herein. Copies of the videotaped condition surveys of the original pavements that were overlaid provide information that should always be considered in future condition evaluations of the FB-3 Modified Wearing Course test sections. Such follow-up will provide additional performance data over time that can be used as needed to modify the proposed specification or the basic guidelines for use presented in this report.

**SPECIFICATION
BITUMINOUS WEARING COURSE, FB-3 MODIFIED**

1. **DESCRIPTION** – This work is construction of a wearing course of plant-mixed bituminous concrete, using a modified asphalt cement, on a prepared surface.
2. **MATERIAL** – Section 432 Bituminous Paving Course, FB-Modified (Seldom Used Specification S94 (SSU0432A)) modified as follows:

Section 432.2 Material;

- (a) Bituminous Material. Add the following:

The base bituminous material shall meet the requirements of standard specification for performance graded asphalt binder, AASHTO MP-1 except as revised in Department Bulletin 25.

- (b) Aggregates. Add the following:

Fine Aggregate: Determine sand equivalent value in accordance with AASHTO T176.
Minimum sand equivalent value = 40%

Course Aggregate: Minimum 75% crushed fragments in accordance with PTM 621

- (d) Composition of the Mixture.

3. Acceptance of the Mixture. Add the following mix composition to Table A, Section 401.2(d) for FB-3 Modified:

Aggregate, Total Percent by Weight	
<u>Sieve Size</u>	<u>% Passing</u>
½ in	100
3/8 in	85 - 100
#4	50 - 80
#8	10 - 35
#200	0 - 5

Bitumen % By Weight (Minimum Residue)

Stone or Gravel	3.5%
Slag	4.5%

3. **CONSTRUCTION** – Section 432.3

4. **MEASUREMENT AND PAYMENT** –

- (a) Bituminous Wearing Course FB-3 Modified. Square Yard or Ton
- (b) Scratch Course. Ton
- (c) Leveling Course. Ton

NOTE: Copy of Seldom Used Specifications S94 (SSU0432A) attached

SECTION 432
SPECIFICATION FOR BITUMINOUS PAVING COURSE, FB-MODIFIED
(SELDOM USED SPECIFICATION S94 (SSU0432A))

432.1 **DESCRIPTION** – This work is construction of a wearing course or binder course of plant-mixed bituminous concrete, using a modified asphalt cement, on a prepared surface.

432.2 **MATERIAL** – Section 401.2, modified as follows:

(a) Bituminous Material. Add the following:

Modify or use appropriate modifiers, if necessary, to obtain a mix which results in a pavement meeting the performance criteria specified in Sections 432.3 (b) 2. and 432.3 (s) and which does not exceed 12% oil distillate by volume of the total bituminous binder material when tested in accordance with the procedure specified in Section 432.2 (d).

(b) Aggregates. Revise to read:

- Fine Aggregates -- Section 703.1
- Course Aggregate, Type A -- Section 703.2

(d) Composition of Mixture. Add the following:

Test the completed mixture, sampled within 30 seconds of discharge at the plant and placed in a sealed container, in accordance with AASHTO-T59, Sections 9 thru 13; however, modify the procedure outlined in Section 12 by weighing 850 grams of a representative sample of the mixture and 50 ml of distilled water in the previously weighed aluminum-alloy still (including lid, clamp, thermometers and gaskets, if gasket is used). This test method will be used for quantitative determination of the percentage of oil distillates in the bituminous mixture by using a ratio of the volume of oil distillate (ml) to the total volume of bituminous binder material (ml) including residual asphalt cement, oil distillates, and water, excluding the 50 ml added for testing. The oil distillate obtained using this test method can be further tested employing qualitative analysis such as gas chromatography (GC) or gas chromatography-mass spectrometry (GS-MS).

2. Uniformity. Replace with the following: Perform tests for bitumen content and aggregate gradation as established in the quality control plan, sampled in accordance with PTM No. 1.

3. Acceptance of the Mixture. Replace with the following:

Obtain material certification from the material producer as specified in Section 106.03.
(b) 3. Certify using a Department form CS-4171 or TR-465. Send certification to the Inspector-in-Charge within one working day following quality control tests for bitumen content determination and sieve analysis of the mixture.

Also, add the following mix composition to Table A for FB Modified:

Aggregate, Total Percent by Weight

<u>Sieve Size</u>	<u>% Passing</u>
1 ½ in	100
1 in	90 – 100
½ in	55 – 80
#4	15 – 45
#8	0 – 20
#200	0 – 5

Bitumen % by Weight (Minimum Residue)

- Stone or Gravel 3.5%
- Slag 4.5%

432.3 CONSTRUCTION – Section 401.3, except as follows:

(b) Bituminous Mixing Plant.

1. Plant Requirements. Obtain plant approval from the Department, prior to manufacturing material. Equipment for developing the design and control tests, in accordance with the Department's modified Marshall method, is not required.

Use a synchronized, volume-proportioning or weight-proportioning, stationary or portable plant meeting the following requirements:

- Aggregate bins and a bituminous tank of sufficient capacity, with heating facilities when required, to assure a constant supply and proper proportioning of materials.
 - Capable of mixing materials to obtain a uniform coating of particles and a thorough distribution of bituminous material throughout the aggregate.
 - Positive-driven feed to proportion coarse and fine aggregate from bins and positive pump to proportion bituminous material coming from the tank.
 - Feeder and pump, synchronized to discharge coarse and fine aggregate and bituminous material in desired proportions for mixing, calibrated prior to actual use.
2. Preparation of Mixture. Coat the aggregate with bituminous material sufficiently forming a film of adequate thickness to provide the required binding properties. Requirements for mixing time and determining the percentage of the aggregate coated, as specified in Bulletin 27, Chapter 1, do not apply. Instead, add the required quantities

of aggregate and bituminous material to the mixer, and mix the material to obtain a uniform coating of particles and a thorough distribution of bituminous material. Provide completed mixture which is workable within the ambient temperature range of 32F to 110F; yields a durable pavement; is temperature stable without drain-down of bitumen from aggregate; passes all required testing criteria as specified in Bulletin 25, Appendix A; and performs to the satisfaction of the Engineer.

- (d) Bituminous Pavers. The requirement for a heated unit does not apply when the bituminous material used is an emulsified asphalt.
- (f) Preparation of Existing Surface. Tack coat requirements apply only when designated in the contract.
- (g) Spreading and Finishing. Revise as follows:

Delete the First, second, and last paragraphs.

Revise the third paragraph to read:

Spread courses to the loose depth needed to obtain the required compacted depth. Spread and strike off the mixture using mechanical equipment for the entire lane width or as much lane as may be practical. Adjust screed assemblies to provide the required cross section and depth.

- (h) Compaction. Revise as follows:

Revise the first paragraph to read:

After the courses have been spread uniformly, compact with a power roller until the mixture is compressed to a firm, even surface. Intermediate rolling with a pneumatic-tire roller is not required, but may be used if approved by the Engineer. Roll the surface when the mixture is in proper condition and when rolling will not cause undue displacement, cracking, or shoving. Use suitable rollers, roller combinations, and rolling patterns to provide required compaction. Continuously roll until the specified compaction is obtained and roller marks are eliminated. Operate rollers slowly enough to avoid displacement of mixture and satisfactorily correct displacement resulting from reversing roller direction or from other causes.

Delete the second paragraph.

Revise the last sentence in the fifth paragraph to read:

Replace with fresh mixture and compact to conform to the surrounding area.

- (i) Density Acceptance. Density acceptance will be determined based on nonmovement of material under compaction equipment.

(j) Joints.

1. Longitudinal Joints. Revise as follows:

Delete the second paragraph.

Revise the fourth paragraph to read:

When compacting the joint, shift the static steel-wheel roller onto the previously placed lane so only 1 or 2 inches of the drive wheel extends over the uncompacted material. Continue to roll along this line, shifting position gradually across the joint until the joint has been rolled with the entire width of the drive wheel. Roll with steel-wheel and pneumatic-tire rollers until a thoroughly compacted neat joint is obtained.

2. Transverse Joints. Delete the seventh sentence.

(n) Protection of Courses. Add the following:

While the surface is still tacky and before opening to traffic, uniformly spread a layer of fine aggregate on the surface at a rate of 3 to 5 pounds per square yard. Sweep and roll, as directed.

(p) Defective Work. Revise to read:

Unless otherwise directed in writing by the District Engineer, remove and replace pavement deficient in compaction as specified in Section 432.3(h), or surface tolerance as specified in Section 432.3(k), or depth, where applicable, as specified in Section 401.3(m), or residual asphalt content as specified in Section 432.2(d).

(q) Verification samples. Delete this section.

(r) Retesting. Delete this section. Add the following new subsection:

(s) General Performance. Provide completed pavement which performs to the satisfaction of the engineer without bleeding, rutting, pushing, shoving, raveling, stripping, or showing other types of pavement distress or unsatisfactory performance. Remove and replace unsatisfactory material at no additional cost to the Department.

432.4 MEASUREMENT AND PAYMENT –

- (a) Bituminous Wearing Course FB Modified. Square Yard or Ton
- (b) Scratch Course. Ton
- (c) Leveling Course. Ton

