Field Demonstration of Foamed Asphalt Muscatine County

Final Report for Iowa Highway Research Board Project HR-257

September 1988

Highway Division
Iowa Department of Transportation

Final Report
Iowa Highway Research Board
Project HR-257

Field Demonstration of Foamed Asphalt
Muscatine County

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DISCLAIMER

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ACKNOWLEDGEMENT

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The authors wish to extend appreciation to the Muscatine County Board of Supervisors and the Iowa DOT for their support in developing and conducting this project. We also wish to thank Illinois - Iowa Blacktop Inc. for their participation in the project. The Muscatine County inspection personnel also deserve recognition for the extra effort put forth on the project.

ABSTRACT

The foamed asphalt concept has been around since the 1950's. Rising oil prices have created a renewed interest in this process. The purpose of this project was to construct an asphalt base using the foamed asphalt process and to evaluate its performance.

A 4.2 mile length of Muscatine County road A-91 was selected for the research project. Asphalt contents of 4.5% and 5.5%, moisture contents of 70% and 90% of optimum, and fog, single chip, and double chip seal coats were used in various combinations to lay 9 test sections of 4-inch foamed asphalt base.

After five years of service and evaluation, several conclusions can be made concerning the performance of the foamed asphalt bases.

1. The foamed asphalt process can work as shown by the excellent performance of Sections 2 and 3.
2. Foamed asphalt base requires a well compacted subgrade and a road profile suitable for good drainage of water. Test section failures were mostly due to a poor subgrade and subsurface moisture.
3. When the base is placed in two or more lifts, extreme care must be exercised to insure adequate bonding is achieved between lifts.

Any future research with foamed asphalt should include various asphalt depths in order to determine a thickness/strength relationship for foamed asphalt.

INTRODUCTION

Iowa has recently been investigating using foamed asphalt as a roadway base construction material. The foamed asphalt process is not new to Iowa. Ladis H. Csanyi, Iowa State University, developed the concept and demonstrated it in Iowa in the late 1950's as Iowa Highway Research Board Project HR-20. Today, over 30 years later, high costs for asphalt cement and for transportation of quality aggregate make the economics of foamed asphalt attractive.

The "Foamix" process (for which Conoco holds the U.S. marketing rights) involves injecting 1 to 2 percent water into hot asphalt cement in a special foaming chamber. A foam develops which is 10 to 20 times the original volume of the asphalt cement. Aggregates which may not meet gradation or quality standards for asphalt construction can be mixed with foamed asphalt and placed as a roadway base. Mixing the aggregates without heating and drying is another advantage of foamed asphalt.

Iowa Highway Research Board Project HR-212, "Treating Iowa's Marginal Aggregates and Soils by Foamix Process", conducted by Dah-Yinn Lee of Iowa State University involved a great deal of laboratory work with different Iowa materials and foamed asphalt. Research Project HR-257 was initiated with Muscatine County to incorporate the laboratory data into a field application to evaluate foamed asphalt as a roadway base.

OBJECTIVE

The objectives of the demonstration project were:

1. To evaluate the performance of a base course constructed using foamed asphalt with locally available 3/8" minus limestone tailings and pit run sand.

2. To correlate field strength characteristics and performance of foamed mixes with laboratory strength characteristics and performance.
3. To develop specifications and evaluate inspection and construction procedures.

PROJECT DESCRIPTION

A 4.2 mile section of Muscatine County Road A-91 was selected for the project (Figure 1). The road is located along the base of a bluff above the Mississippi River flood plain. The left portion of the road is in a cut section and the right portion of the road is in a fill section. The structure of the existing roadbed was a 1 1/2-inch built-up seal coat over a 1 1/2-inch limestone base. Average daily traffic is 230 to 240 vehicles per day.

TEST SECTIONS

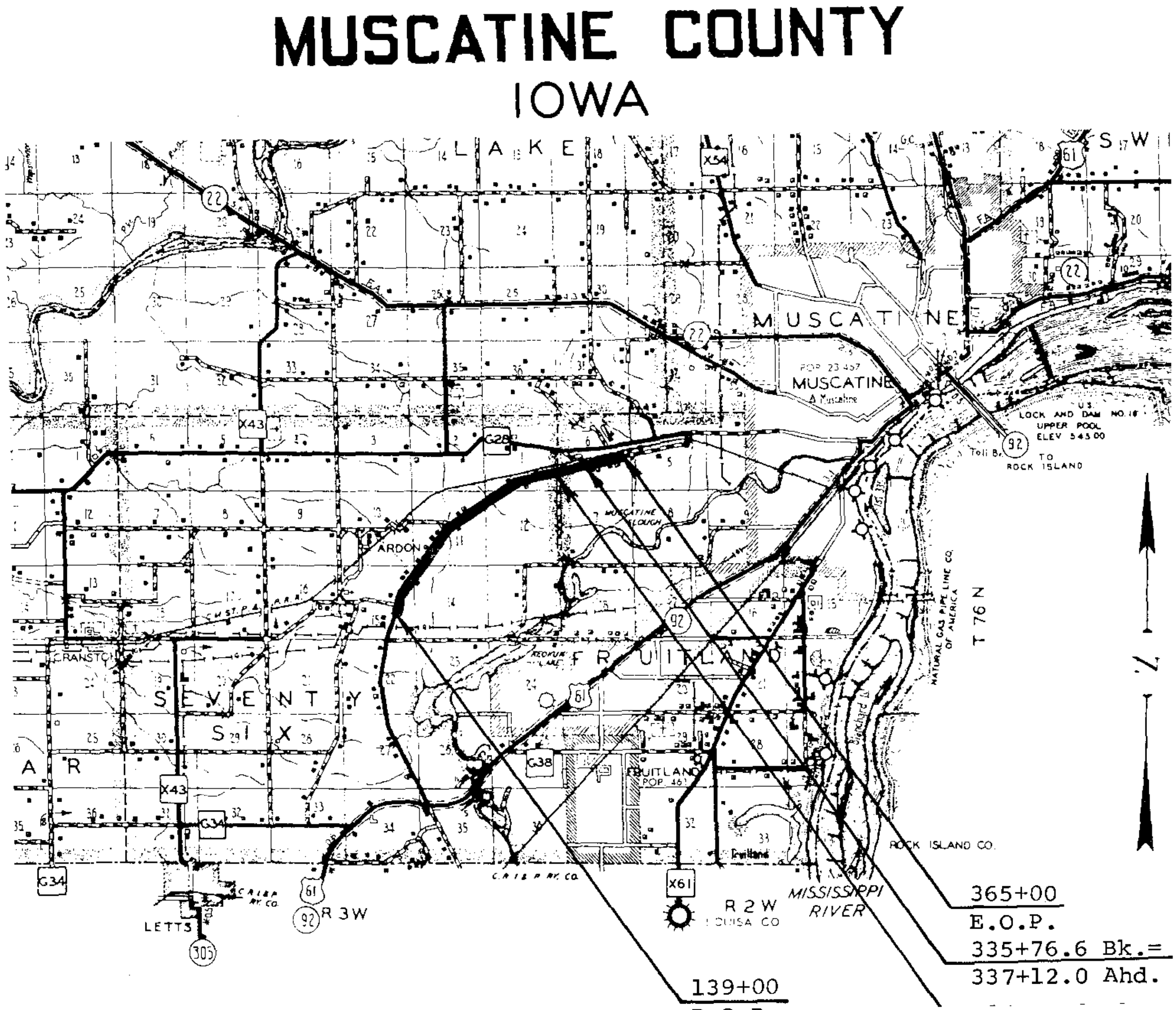
Nine foamed asphalt base test sections were planned and constructed. The base was laid 4 inches thick and 22 feet wide. The sections are listed in TABLE I.

TABLE I
TEST SECTIONS

Section No.	Sta. to Sta.	Asphalt Content (%)	Moisture (% of Optimum)	Surface Treatment
1	139 to 165	4.5	75	fog seal
2	165 to 180	4.5	90	fog seal
3	180 to 194	4.5	90	double chip seal
4	194 to 220	5.0	90	double chip seal
5	220 to 246	5.0	75	double chip seal
6	246 to 278	4.5	75	single chip seal
7	278 to 309	4.5	90	single chip seal
8	309 to 338	4.5	90	single chip seal
9	338 to 365	4.5	75	single chip seal

Figure 1

PROJECT LOCATION



MATERIALS AND PROCEDURES

Laboratory testing by Lee on IHRB Project HR-212 showed that several locally available materials in Iowa are suitable for foamed asphalt. One of the more promising materials is limestone screenings from the production of concrete stone.

Mix Design

Samples of limestone screenings and fill sand were obtained from Muscatine County for preliminary testing. Based on testing by Lee, specifications were developed for an aggregate blend of 50 percent limestone and 50 percent sand (Appendix A).

A pre-bid meeting was held with representatives of Conoco, the Iowa DOT, Muscatine County, an aggregate supplier and several contractors. At the meeting, Conoco representatives expressed concern over the low percentage of minus #200 sieve material specified. Foamed asphalt coats only the fine particles and past experience has shown that an aggregate with 10 to 30 percent passing the #200 sieve provides a satisfactory mix. Subsequently, the aggregate blend was adjusted to 70 percent limestone and 30 percent sand to increase the minus #200 material to a minimum of 8 percent for the combined aggregate. A typical combined aggregate gradation is in Table II.

TABLE II
TYPICAL COMBINED AGGREGATE GRADATION

Sieve Size	Percent Passing
3/8"	99
#4	80
#8	61
#16	49
#30	40
#50	28
#100	17
#200	12

The limestone screenings were from the Wendling Quarries Inc., Moscow quarry and the sand was from Wendling's Atalissa McKillip pit.

Iowa State University developed the job mix with a lab-size foaming unit. Mixes were compacted at room temperature and oven cured at 120°F and 140°F for 3 days before testing. Table III lists the laboratory test results for the project job mixes.

TABLE III
FOAMED ASPHALT MIX DESIGN
HR-257 MUSCATINE COUNTY

Test	Mix No. 1		Mix No. 2		Mix No. 3	
Asph.	AC-5, 400-600 poises (H.L.=19 sec; F.R.=11.3)					
% Asph. in Mix	4.2		4.2		5.6	
% Moisture by wt. agg.	6.8		8.0		7.3	
% of Optimum Moisture	77		91		83	
No. of Marshall Blows	50		50		50	
Marshall Stability - Lbs.	698	650	555	620	425	452
Flow - 0.01 In.	5	6	8	9	7	7
Specific Gravity (cured)	2.03	2.02	2.04	2.03	2.02	2.02
Specific Gravity (dry)	2.03	2.02	2.03	2.02	2.02	2.02
% voids - Calc.	16.8	17.1	16.8	17.0	15.7	15.7
Curing Temp (3 days), °F	120	140	120	140	120	140

Recommendation - 6.8% and 8.0% moisture

4.5% and 5.5% asphalt cement

Plant Operation

The plant accepted for use was a Colenco brand stationary pugmill mixer specially designed to produce foamed asphalt (Figure 2). Special provisions for equipment are in Appendix A.

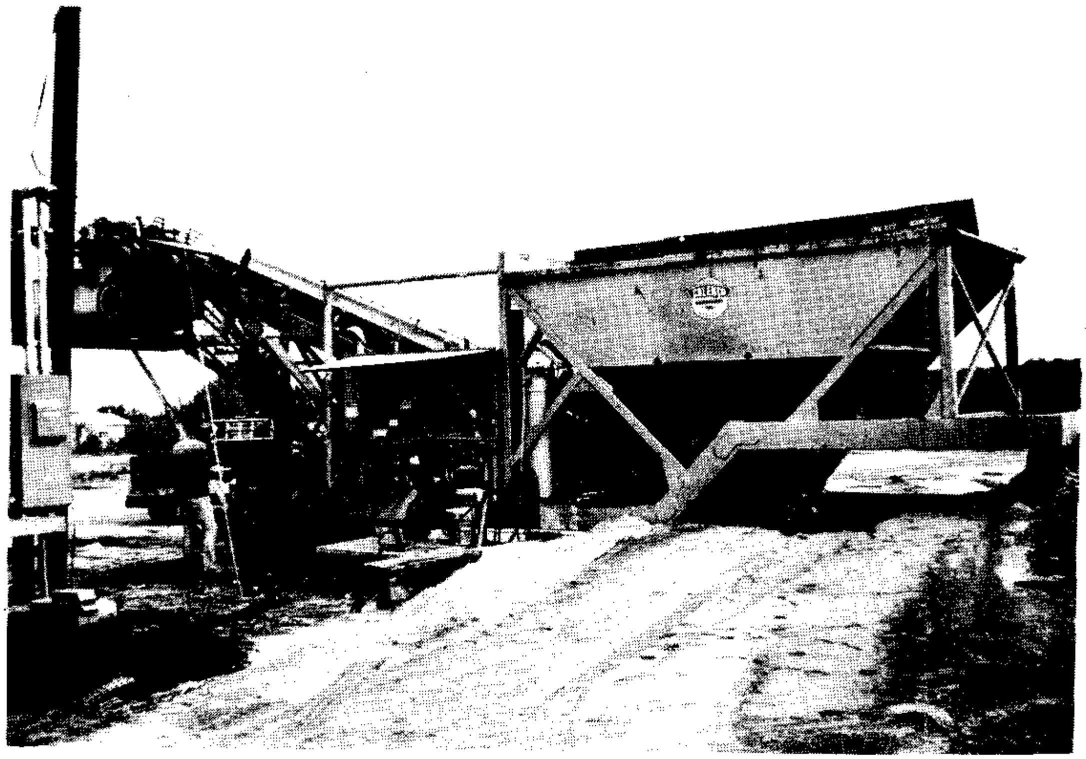


Figure 2 - Stationary Plant With Pugmill Mixer for Foamed Asphalt Production

Aggregate was proportioned through a split bin system. A water feed system above the material conveyor supplied the required amount of water to the aggregate on the conveyor belt (Figure 3). The water for foaming the asphalt cement was delivered through a separate water pump system. The "Foamix" spray head, located above the pugmill, combined asphalt cement at 340^{o}F and a volume of cold water equal to 2 percent of the asphalt volume. The aggregate was sprayed with the foamed asphalt cement as it entered into the twin-shaft pugmill. The mixer produced 180 tons of mix per hour. At this rate the mixing time in the pugmill was less than 12 seconds.

Mix storage bins were not provided, so when no plant-to-project haul trucks were available, mix was stored in a stockpile at the plant site. The stockpile site was surfaced with foamed asphalt to prevent stockpile contamination. All the mix produced during a day was placed the same day.

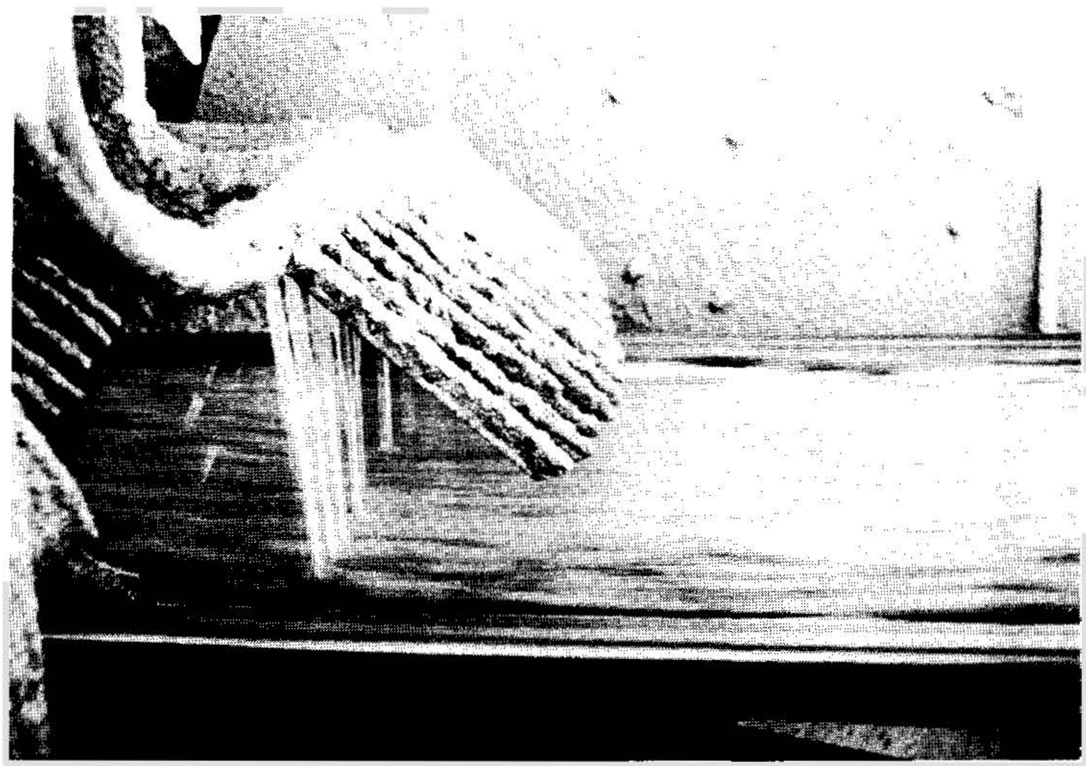


Figure 3 - Aggregate Water Application System

CONSTRUCTION

Illinois-Iowa Blacktop, Inc. of Rock Island, Illinois, was awarded the project. A copy of the project contract is in Appendix B. Construction began in August 1983. The special provisions for the project are in Appendix A.

Preparation of the Subbase

To provide a uniform subbase for paving, the 1 1/2 inch built-up seal coat over a 1 1/2 inch limestone base was scarified full depth, pulverized, relaid and compacted. Scarifying and relaying the roadbed also provided a permeable subbase which allowed water from the fresh foamed asphalt to drain away. Muscatine County maintenance personnel did this portion of the work.

Foamed Asphalt Placement

The contractor began production of foamed asphalt on August 25, 1983 and finished on September 29, 1983. The mix was similar in color to the wet aggregate with little visible evidence of asphalt present in the mix.

Haul distance from the plant to the project was approximately 20 miles. The mix was placed in two 2-inch lifts one lane at a time. Construction began at the west end with section 1. Construction of one section was always completed before the start of another. Loaded trucks traveled on the freshly laid first lift during placement of the second lift. A Barber Greene tamper-bar paver was used to place the mix. The mix laid similar to hot mix, but did not flow like hot mix from the trucks or through the paver (Figure 4). Each time the paver stopped, a depression was created in the mat. Mix was raked into the depressions and along the center line joint. However, raking the mix caused the material to segregate.

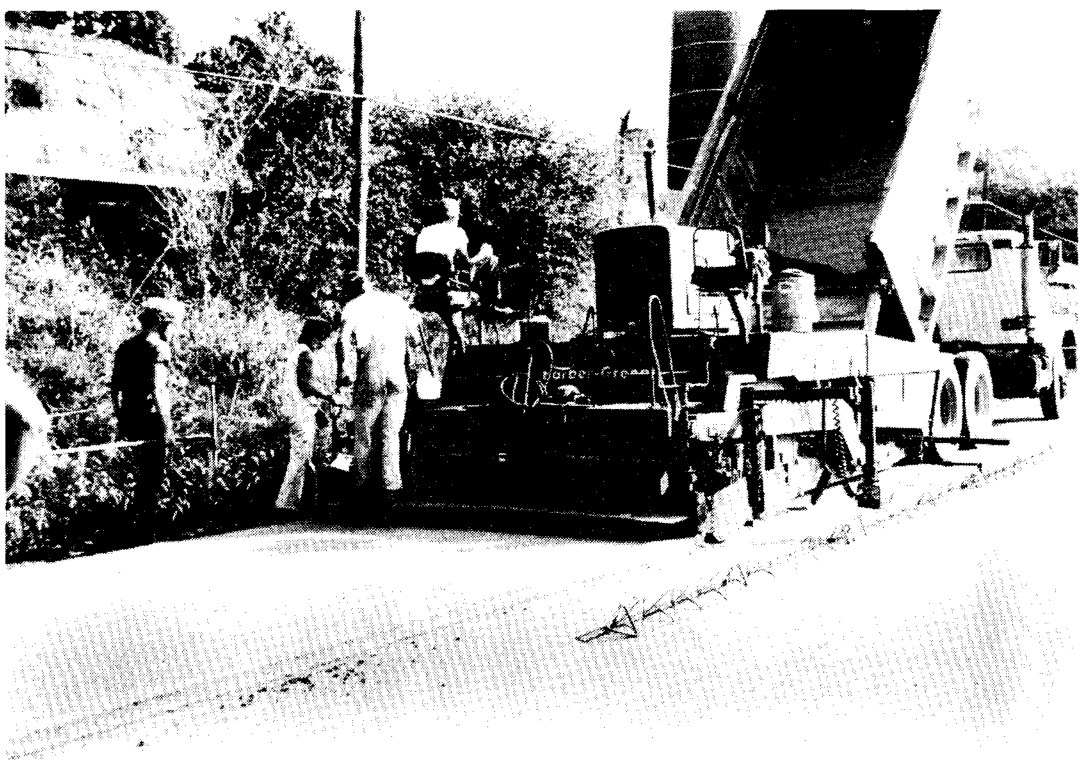


Figure 4 - Foamed Asphalt Placed with a Barber Greene Paver

Compaction was accomplished using a static steel drum roller with a compressive force greater than 200 pounds per inch width. A minimum of four passes was required. The mix tended to shove ahead of the roller drum and a change of direction by the roller produced a bump. The rolling also created hairline transverse cracks at approximately 1-inch intervals. The use of a rubber tired roller and subsequent traffic tended to heal the cracks. The specified density was easily achieved.

After compaction, a pen easily could be pushed through the 4-inch mat to the subbase. As the pavement cured, the binding properties of the asphalt cement became stronger. Curing appeared most rapid during hot, sunny days. The compacted mat changed from a grayish aggregate color to a black color, simular in appearance to asphalt concrete, within 1 to 2 days.

A tack coat was initially planned between the pavement lifts. It was eliminated upon the recommendation of personnel with foamed asphalt experience. During the shouldering operation, the top lift of asphalt on the left side of section 6 began sliding off the first lift. Section 6 was the first section to not have the first and second lifts placed the same day. There was a 5-day delay before the second lift was placed. During this time it rained on the project. For the remainder of the project (sections 8 and 9), a CSS-1 emulsion tack was placed between lifts.

Correction of Problems

The plant operated correctly the first day of production. During the night, lightening struck the plant, causing malfunctions the next day. The asphalt metering system first delivered too much asphalt cement to the mix. After adjustments, the metering system delivered too little asphalt cement to the mix. The major portion of sections 2 and 3 was paved before the problem was corrected. The top lift of the right side of sections 2 and 3 (low A.C. content) had to be removed and replaced. The remainder of the two sections was unacceptably rough. The contractor placed a 1.5 inch thick third lift of foamed asphalt from Sta. 165 to Sta. 194 (sections 2 and 3) to obtain a relatively smooth surface.

To correct the slippage problem on section 6, the top lift of the left side was removed. Due to a delay in correcting the problem, a hot asphaltic concrete mix was used to replace the removed lift. The special provisions specified a minimum 7-day cure for foamed asphalt prior to seal coating. Using hot A.C. concrete allowed the seal coating operation to begin several days sooner.

From the start of mix production, the mixing time in the pugmill and the resulting amount of particle coating were discussed. Several paddles were reversed on the mixing shafts and a dam was placed across the mixer opening to hold the material longer in the pugmill. An anti-foaming counter agent was also added to the asphalt cement to increase the foam half-life for mix placed on section 9. These efforts increased the particle coating only slightly. The effect of extending the mixing time in the pugmill to increase the aggregate coating was not evaluated.

Surface Treatment

The contractor applied the single chip seal coat on October 3 through 5, 1983, on sections 3 to 9. A CRS-2 emulsified asphalt was placed at a rate of 0.29 gal per sq yd. A 3/8-inch limestone cover aggregate was spread at 23.6 lbs per sq yd. The project plans specified a double chip seal coat for sections 3, 4 and 5. The second seal wasn't placed until September 5, 1984 due to the late completion of the first seal. CRS-2 emulsified asphalt was placed at the rate of 0.28 gal per sq yd and 3/8-inch limestone aggregate was spread at 25 lbs per sq yd.

Sections 1 and 2 received a fog seal on October 10, 1983. An application of 0.05 gal per sq yd of 1:1 dilute CSS-1 emulsified asphalt was used. Because the surface of Section 1 began to ravel after the fog seal was placed, a single chip seal coat was added at the time Sections 3, 4, and 5 received their second seal.

CONSTRUCTION TESTING

Project testing consisted of:

1. Moisture and gradation determination of the aggregates.
2. Foam half-life and foam ratio determination of the foamed asphalt cement.
3. Field and laboratory density determination.
4. Moisture loss determination during cure.

Aggregate Moisture and Gradation Determination

Prior to plant start-up each day, the moisture content of each aggregate stockpile was determined. The amount of additional water needed to reach the target moisture content was then calculated. During production, wet aggregate was obtained from the conveyor belt and tested to verify the combined aggregate moisture content. Moisture determinations are in Appendix C.

The water content was difficult to control because of variations in stockpile moisture and in the plant water metering system. When the moisture content was found to be incorrect, the water pump was adjusted to the correct setting. With close attention, the project mixing moisture content could have been controlled to within 0.75 to 1.00 percent of target.

Both aggregates are by-products of concrete aggregate production. As such, the gradations sometimes varied 1 to 2 percent more than gradations for material produced to meet Iowa DOT standard specifications.

Foam Half-Life and Foam Ratio Determination

The quality of the foamed asphalt cement was checked at least twice daily. A spray nozzle was attached to the outside of the pugmill for asphalt sampling. The nozzle had to be heated and 5 gallons of foamed asphalt flushed through the system before a sample could be obtained.

Foam half-life, the time required for the foamed asphalt cement to deflate to half its initial volume, was checked by filling a 5-gallon container. Timing of the half-life started after the sample was obtained. A ruler was used to determine the point of half volume. The half-life usually ranged from 25 seconds to 35 seconds with twenty seconds specified as the minimum half-life.

The foam ratio, a ratio of the original asphalt cement volume to the volume of the asphalt in the foamed state, was checked using the same 5-gallon sample used for the half-life determination. Suggested plant control specifications from Conoco recommended the following:

> Establish limits for asphalt mass at foam volume ratios of 8 and 15 for foam sample cans. Measure sample container inside diameter and height to the brim or a discernable fill line near it and calculate volume in cubic inches (or cubic centimeter). Divide calculated volume by eight and convert to maximum allowed mass of asphalt in lb (or g) for foam sample (minimum foam ratio) using 0.036 lb/inch^3 (or 1.0 g/cc). Likewise, divide calculated volume by 15 and convert to minimum allowed mass of asphalt in lb (or g) for foam sample (maximum foam ratio). These calculations consider hot asphalt to have a specific gravity of 1.0.

The foam ratio was to be between 1:8 and 1:15. Rather than weigh the sample, the plant inspector allowed the sample to deflate totally and measured the distance from the fill line to the deflated asphalt. The ratio of the depth of asphalt to depth of fill line is the foam ratio. Accuracy of the volume by measuring the asphalt depth was $\pm$ 100 cc for a sample weight of 2400 grams to 1100 grams. The foam ratio ranged from 1:10 to 1:14 on the project.

Field and Laboratory Density Determination

Field densities were obtained by both the nuclear gauge method and the rubber balloon method. Appendix D contains the results of the density testing. At most locations the nuclear and balloon tests were run at different times. Nuclear tests were taken 1 to 2 feet from the balloon "rat hole".

Variations in gradation, moisture content, asphalt content and degree of compaction were all factors which may have caused the wide range of densities.

Target densities were determined from mix obtained at the road. The samples were compacted at room temperature into Marshall specimens at the Iowa DOT, District 5, Materials Laboratory and at I.S.U. Table IV lists the target densities obtained from specimens cured for 3 days at 150^{o}F.

TABLE IV
TARGET DENSITIES
MARSHALL SPECIFIC GRAVITIES

Section No.	Specific Gravity
1	2.07*
2	2.06*
3	2.06*
4	2.08
5	2.14
6	2.08
7	2.10
8	2.10
9	2.07*

*Determined at I.S.U.

Field densities exceeded a specific gravity of 2.10 at 50 percent of the locations when determined by the balloon method and 66 percent of the locations when determined by the nuclear method. The number of field densities exceeding 100 percent of target density indicates a need for a more realistic target density determination.

Moisture Loss Determination

The moisture loss from the base versus time after base placement was determined from samples taken during density testing (Figure 5). Moisture rapidly evaporated from the base during the sunny, 80^{o} to $90^{o}F$ weather. Within 3 to 4 days after placement, most of the water had left the foamed asphalt. Samples taken after 4 days generally had moisture contents ranging from 1 to 3.5 percent. Rain; cool, cloudy weather; and shade tended to slow moisture loss.

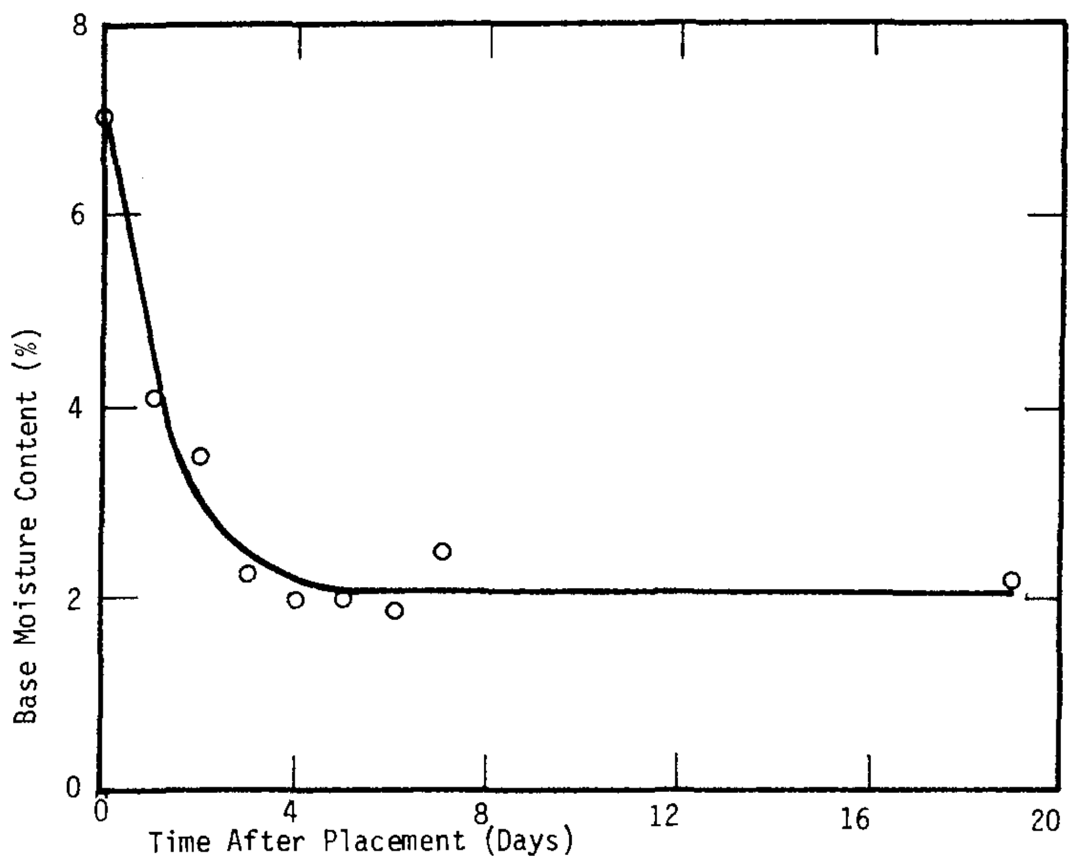


Figure 5 - Base Moistures Loss Over Time

SUGGESTED CONTROL AND SPECIAL PROVISIONS CHANGES

Recommended changes for future foamed asphalt projects in Iowa are:

1. Do not accept a split-bin aggregate proportioning system for two aggregate mixes.

   The plant accepted for the project had a split-bin system. It was evident the system did not provide the desired proportioning accuracy.

2. Require the quantity of water for mixing be controlled within 1.0 percent of the target moisture content.

   Without covered stockpiles, the moisture content was difficult to maintain. Lee found that 65 to 85 percent of optimum moisture content (AASHTO T-99) constituted the optimum mixing moisture content for foamed asphalt mixtures. With close inspection, water content could be controlled within the optimum mixing moisture content range.

3. Specify a minimum mixing time in the pugmill.

   The plant production was limited only by the maximum rate at which the limestone screenings would pass through the bin gate. It is felt that increasing the mixing time in the pugmill would allow more thorough mixing of the two aggregates and a more even distribution of asphalt throughout the mix.

4. Require trial mixing before project start-up and during the project as requested by the engineer.

   Conoco provides ranges for foam ratio and half-life to produce proper foamed asphalt. However, it appeared that within the ranges specified, mix quality could vary.

Trial mixing would provide for a target foam ratio and half-life. Trial mixing would also allow the engineer to determine a proper mixing time.

5. Specify compaction to continue until 100 percent of target dry density is achieved as measured by balloon or nuclear methods. Target dry density shall be determined from a test strip compacted to maximum density.

   The field placement and compaction of the foamed asphalt imparts a different type of compactive effort than Marshall or Proctor compaction. Cores taken from the roadway have asphalt relatively well dispersed throughout the aggregate. Specimens compacted and cured in the laboratory with field mix are gray with a black, spotted appearance. The asphalt appeared to be unevenly dispersed.

6. Specify a cutoff date of October 1 for foamed asphalt construction in Iowa.

PROJECT COSTS

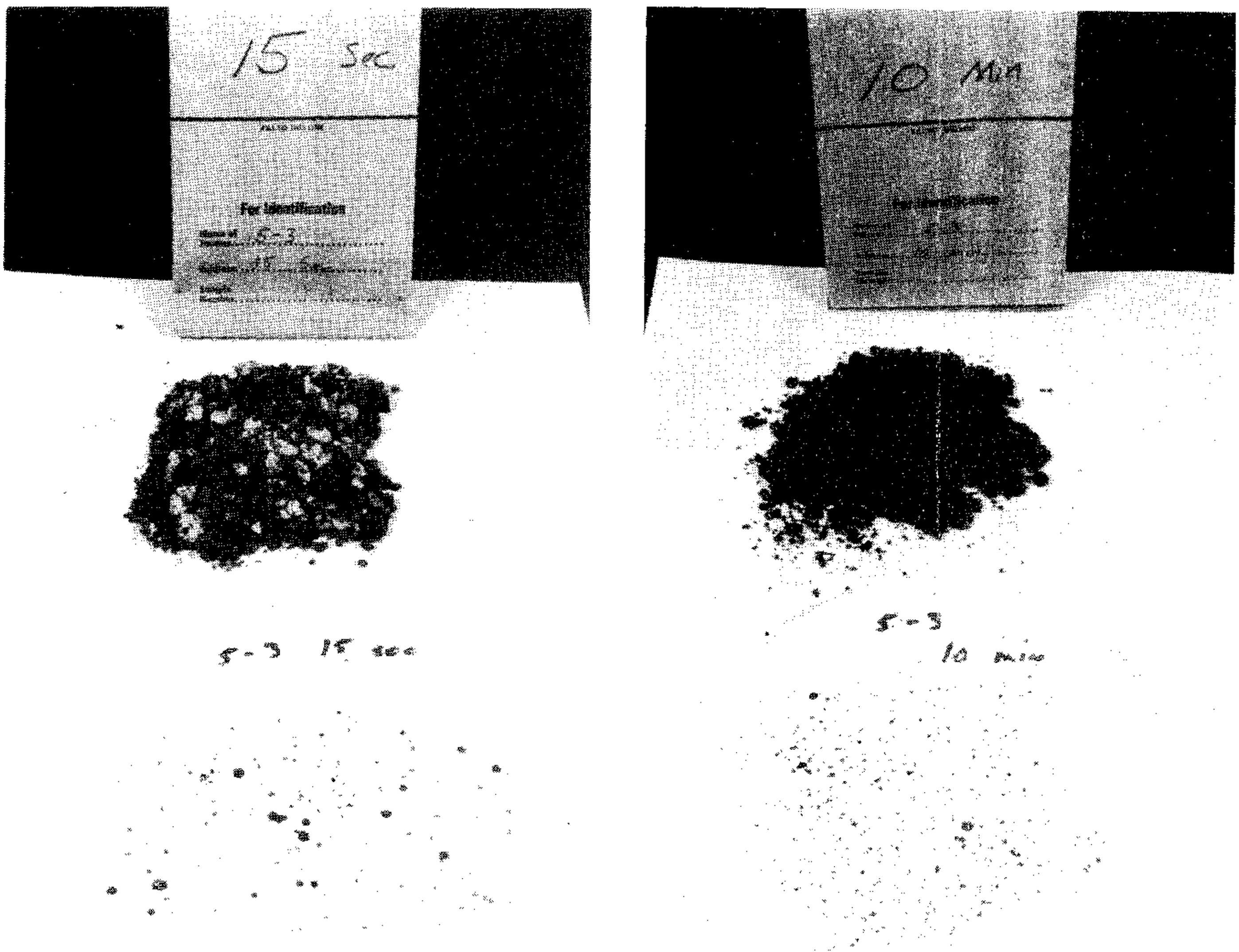
The in-place bid price for the 4-inch foamed asphalt base, including a single chip seal, was $27.64 per ton using a 4.5 percent asphalt cement mix. Illinois-Iowa Blacktop placed 2600 tons of Type B asphaltic concrete base adjacent to the research project in 1984. The bid price was $28.14 per ton for the 5.35 percent asphalt cement hot mix. Commonly, research projects involving unique construction techniques and sections of short length will be bid high by contractors. The frequent changeovers and uncertainty of success result in the higher prices.

CONSTUCTION SUMMARY

The project was completed with only a few construction problems. The most significant problems were:

1. Difficulty controlling mixing moisture content.
2. A variable degree of compaction.
3. A rough riding surface.
4. Slippage between the base lifts on one section.

The problems were basically caused by a lack of knowledge and experience with foamed asphalt.



Mixing Time-15 seconds   Mixing Time-10 minutes

Figure 6 - Comparison of Laboratory Mixing Time on Degree of Particle Coating by Foamed Asphalt

EVALUATION

The foamed asphalt base was evaluated for a period of five years. Testing included annual crack surveys and road rater tests and biannual road meter tests. Also, visual surveys of the general condition of the pavement were made each year.

Crack Survey

The annual crack surveys revealed a progressively increasing level of short, tight, longitudinal cracks extending throughout much of the length of the pavement. The cracking began along the shoulder and progressed inward, sometimes reaching beyond the centerline. It was not uncommon to find the cracks extending to the quarter point on either side of the pavement and running longitudinally several hundred feet along the length of the pavement.

Very little transverse cracking or large, open, longitudinal cracking occurred. The large majority of the cracks were of the short, longitudinal, almost alligator-like variety described previously.

Some sections exhibited less cracking than others. In order to quantify the cracking performance of each section a rating system was established. Three researchers familier with the project were asked to rank each section, giving the best section a 9 and the worst section a 1. The three scores given to each section were then added. The total was then divided by the maximum possible rating, 27, to obtain the section's crack rating. Table VI lists the results of this system analysis.

TABLE VI
CRACK SURVEY
SECTION PERFORMANCE RATING

Section	Rank			Total	Crack Rating Percent
1	5	3	3	II	40.7
2	9	9	8	26	96.3
3	8	8	9	25	92.6
4	7	7	6	20	74.1
5	6	6	7	19	70.4
6	2	2	2	6	22.2
7	1	1	1	3	11.1
8	4	5	5	14	51.9
9	3	4	4	11	40.7

The better performance of sections 2 and 3 was due to the fact these sections had an additional 1.5 inch lift of foamed asphalt placed during construction. Also, a major reason for the poor crack performance of sections 6 and 7 was the inadequate bonding between lifts. As stated earlier, the second lift on these sections was placed five days after the first lift. No tack coat was used to bond these lifts. Apparently, a dirt film formed over the first lift and prevented bonding. A significant amount of slippage cracks had formed soon after construction. It is believed the decrease in base strength due to inadequate bonding also resulted in the excessive longitudinal cracking of these sections.

Road Rater

The road rater is used to measure pavement and subgrade strength. The output is in terms of a structural number. A structural number of 3 is equivalent to 6 inches of new portland cement concrete.

Road rater tests were run annually on each section. The results show sections 2, 3, 8, and 9, had 80% structural numbers of 2.0 and above each year. In 1984, sections 1, 4, 6, and 7 had 80% structural numbers ranging from 1.65 to 1.95. These values dropped to between 1.45 and 1.60 in 1987. Section 5 had values between these two sets of sections (See Appendix E). All of these values should support local passenger car and light truck traffic. However, very few 18 KIP E.S.A.L. vehicles would be abe to travel the road each day should the pavement be expected to last twenty years.

Road Meter

The road meter measures the smoothness of the pavement. Output is in terms of a Present Serviceability Index (PSI) value ranging from 0 to 5. A value of 5 represents a perfectly smooth surface (like glass) and a 0 represents an extremely rough surface. A new asphalt cement concrete pavement surface would be expected to have a PSI of at least 4.0. Road meter runs were made biannually on the project as a whole (no attempt was made to test the individual sections). Results are shown in Table VII.

TABLE VII
ROAD METER RESULTS

	PSI Value	
Year	Left Lane	Right Lane
1984	2.88	2.84
1986	2.94	2.85
1988	2.96	2.93

These values obviously are not as high as would be expected from a new asphalt pavement. However, they are well above the level which would indicate rehabilitation is required.

ANALYSIS

Initial observation of the crack survey results would seem to indicate the foamed asphalt did not perform well. However, after investigating the causes of the cracking, it becomes apparent the foamed asphalt base was not the most important factor. Several factors are believed to have led to the cracking.

First, due to a lack of available R.O.W. the shoulder width was very narrow in many places. The lack of shoulder offered little support for the edge of the pavement. The lack of support allowed the edge to be separated from the rest of the pavement by traffic loads near the shoulder, resulting in a series of small, longitudinal cracks. As the outer edge of pavement was separated, a new unsupported edge was formed. This, in turn, was separated from the pavement. This pattern was repeated and the cracking progressed toward the centerline.

Second, the type of crack pattern, a series of small, tight, interconnected longitudinal cracks similar in appearance to alligator cracking, suggests a major cause of the cracking was due to poor subbase and/or subgrade support. There were several areas along the left lane where drainage was inadequate. Water would be held in the ditch and left to seep into the subsurface layers. This would weaken the subbase and subgrade and lead to the alligator crack pattern found on the surface.

Also, there were very few transverse cracks or wide, open longitudinal cracks. Visual inspections did not uncover any significant rutting problems. If the foamed asphalt base was structurally inadequate, this transverse and open longitudinal cracking and rutting would have been more severe.

CONCLUSIONS

After five years of service and evaluation, several conclusions can be made concerning the performance of the foamed asphalt bases.

1. The foamed asphalt process can work as shown by the excellent performance of Sections 2 and 3.
2. Foamed asphalt base requires a well compacted subgrade and a road profile suitable for good drainage of water. Test section failures were mostly due to a poor subgrade and subsurface moisture.
3. When the base is placed in two or more lifts, extreme care must be exercised to insure adequate bonding is achieved between lifts.

Any future research with foamed asphalt should include various asphalt depths in order to determine a thickness/strength relationship for foamed asphalt.

RECOMMENDATIONS

The success of this project, especially sections 2 and 3, shows that foamed asphalt paving can be successfully used on secondary roadways to construct a stable base from nonspecification materials. The performance of sections 6 and 7 show debonding can result between lifts not placed the same day and not tack coated. Future projects involving foamed asphalt need to include various asphalt depths in order to determine an optimum foamed asphalt thickness.

Current low world oil prices probably makes the foamed asphalt paving technique inappropriate. However, as oil prices rise and quality aggregate supplies diminish, the process will become much more economical.

APPENDIX A
Special Provisions

Iowa Department of Transportation

SPECIAL PROVISIONS
FOR
FOAMED ASPHALT CONCRETE BASE

Muscatine County Project FM-70(4)--55-70
Research Project HR 257

July 6, 1983

THE STANDARD SPECIFICATIONS OF THE IOWA DEPARTMENT OF TRANSPORTATION, SERIES OF 1977, SHALL APPLY TO THIS PROJECT EXCEPT AS AMENDED BY THE FOLLOWING ADDITIONS. THESE ARE SPECIAL PROVISIONS AND THEY SHALL PREVAIL OVER THOSE PUBLISHED IN THE STANDARD SPECIFICATIONS.

494.01 GENERAL. The work on this project consists of the construction of a foamed asphalt concrete base, using fine limestone and sand, together with variations of surface treatment. This project is a demonstration research project and is based on research reported to the Iowa Highway Research Board under Project HR-212, "Treating Iowa's Marginal Aggregates and Soils by Foamix Process". This specification describes the foamed asphalt base and the variations in the surface treatment which are not described elsewhere in the specifications and modifications to other standard specifications relating to this project.

As the project is of a research nature, certain requirements may be changed by the engineer in order to make the project more meaningful.

Foamed Asphalt Concrete Base is a mixture of moistened, unheated aggregates, and asphalt cement, combined while the asphalt cement is in a foamed state.

The Continental Oil Company has proprietary rights to the foamed asphalt process and a royalty fee may be required to use this process. The royalty fee, if any, shall be paid by the contractor and will be considered incidental to the construction of the base. Inquiries concerning this process may be directed to Conoco, Mr. Roy Hodson, 5717 East Ferguson Drive, Los Angeles, California, 90022, or telephone (213)723-2121.

The asphalt cement shall be foamed and the materials mixed in a stationary plant with equipment and according to the procedure outlined by the Conoco Foamed Asphalt Process. The contractor may propose to the engineer the use of an alternate, stationary plant designed for a similar mixing process. The proposal may be submitted prior to the letting date.

494.02 MATERIALS. The foamed asphalt base mixture shall meet the following requirements.

A. Aggregates shall be sand and crushed limestone. Limestone shall be from a source meeting quality requirements of Section 4126. Each aggregate shall be within the following gradation limits.

Sieve Size	Crushed Limestone Percent Passing	Sand Percent Passing
1/2 inch	100	100
3/8 inch	90-100	95-100
#4	75-90	
#8	50-66	90-100
#30	28-40	40-55
#200	10-17	0-2

B. Asphalt Cement shall meet requirements of Section 4137 for Grade AC-5. The asphalt cement should not contain an anti-foaming agent. Use of an anti-foaming counter agent will be required, if necessary.

C. Mixture. The aggregate shall be composed of 50 percent crushed limestone and 50 percent sand.

The quantity of AC to be added will be set by the engineer, based on a job-mix formula, and this shall be controlled within 0.4 percentage points of the amount intended, based on tank stick measurements. The basic AC contents in the test sections are 4.5 and 5.0 percent. The moisture content shall be controlled according to 494.04.

494.03 EQUIPMENT. The contractor shall provide all equipment necessary for the construction of the base as specified. Equipment used shall meet requirements of 2001.01 and the following.

A. Proportioning Equipment shall meet appropriate requirements of 2205.04.

B. Mixing Plant. The mixing of the foamed asphalt base shall be accomplished in a stationary plant with a pugmill mixer specifically designed to produce foamed asphalt materials.

The plant shall have a positive-driven feed to proportion the aggregate from the bin or bins in a synchronized volume proportioning method with automatic controls. It shall be equipped with suitable pumps, proportioning, metering and weighing devices whose function shall be interlocked by automatic controls to assure proper foamed asphalt to aggregate ratio. The plant shall contain any other necessary equipment to produce the base mixture on a quality-controlled basis.

The foam chamber shall be mounted above the header spray bar and proper nozzles included to produce the necessary foaming action to assure maximum penetration of foam to aggregate.

The spray header shall be equipped with an external sampling valve with same nozzle size as in the header to conveniently take samples of foam in a 5-gallon container to accurately measure the foam halflife and stability.

A plant designed for a similar mixing process or modifications to these requirements may be approved, as provided in 494.01.

C. Spreading Equipment. Article 2001.19 shall apply.

D. Compaction Equipment shall meet requirements of 2001.05B, C, or F. A smooth faced, steel or pneumatic - tired roller shall be used for finish rolling.

494.04 PROPORTION AND MIXING. The materials shall be proportioned in such a manner that a uniform mixture results and each aggregate is controlled within 5 percent of the intended quantity and the asphalt cement and water is controlled within 0.4 percentage points of the percent intended. Blending of the aggregates shall be accomplished before the asphalt is added.

Prior to foaming, the asphalt cement shall be heated to between 325 and 375 degrees F, unless otherwise directed by the engineer.

The asphalt cement shall be foamed immediately prior to mixing with the aggregates according to the procedure outlined by the Conoco Foamed Asphalt Process. The estimated quantity of water required for proper foaming is 2 percent of the liquid asphalt cement, by volume. Water shall be adjusted to provide a foam halflife of 20 seconds, as determined by the engineer.

The mixture is to be produced at 75 and 90 percent of optimum moisture, as designated on the plans for specific test sections. If the aggregate has less moisture than necessary for the mixture to meet the required percentage of optimum moisture, water shall be added to the aggregate prior to mixing with the foam. The water may be added through a metered and controlled spray system prior to entering the mixing chamber. Water shall not be added separately within the mixing chamber.

494.05 CONSTRUCTION. The construction of the foamed asphalt base shall be as follows:

A. Subgrade. The existing road surface is a soil-aggregate material covered by several bituminous seal coats. The County will scarify the existing surface to a depth of approximately 3 inches, and pulverize, relay, and compact the scarified material to proper crown and cross section. The contractor shall reshape the subgrade to proper crown, if necessary, and shall finish roll the surface.

B. Base. The contractor shall spread the foamed asphalt concrete base mixture to the width and thickness shown on the plans. The intention of this specification is placement of the full thickness in one lift. However, the contractor may place the base in two lifts.

The mixture shall be promptly compacted. Compaction shall continue until maximum consolidation is achieved, and the engineer may utilize nuclear testing equipment to determine this. In any case, compaction shall be at least 94 percent of Marshall density. If placed in two lifts, compaction of the first lift shall be to at least 92 percent of Marshall density. The Marshall density will be based on tests by the district laboratory on field-mixed samples.

C. Surface. Bituminous seal coats shall be applied in accord with the plans and Section 2307. A fog seal and a one-course and a two-course seal coat will be required, as designated on the plans.

D. Shoulders shall be constructed in accord with the plans and Article 2303.17.

494.06 LIMITATIONS. Foamed asphalt base shall be placed with an aggregate and air temperature of not less than 50 degrees F.

Should rain prevail and aggregate stockpiles retain moisture in excess of the required optimum moisture, time will be allowed to drain and dry the aggregate to meet requirements of the specifications.

The foamed asphalt base shall be allowed to cure for 7 days before the bituminous surface treatment is applied, or longer if so directed by the engineer.

494.07 METHOD OF MEASUREMENT. The engineer will compute the quantity of foamed asphalt concrete base, satisfactorily placed, as provided in 2303.19A. The engineer will compute the quantity of asphalt cement used in the foamed asphalt base, as provided in 2303.19B.

494.08 BASIS OF PAYMENT. For the quantity of foamed asphalt concrete base furnished and placed, the contractor will be paid the contract price per ton. Such payment shall be full compensation for furnishing all aggregate and water, for mixing and placing, for subgrade work that is necessary, and for the cost, if any, for the right to use equipment and procedures protected by patents.

For the number of tons of asphalt cement used in the foamed asphalt concrete base, the contractor will be paid the contract price per ton.

Bituminous seal coats will be measured and paid for according to Section 2307.

Granular surfacing of shoulders will be measured and paid for according to 2303.19G and 2303.20G.

APPENDIX B
Project Contract

COST CENTER 801000 OBJECT 260

PROJ NO FM-70(4)--55-70 COUNTY MUSCATINE

RES ENGR ROBERT SIMMERING ADDRESS MUSCATINE

LETTING DATE JULY 6, 1983 LIQUIDATED DAMAGES $140.00

SPECIAL PROV 11/9/82 #915, 3/17/83 #920, 10/11/77 #815,
7/6/83 SP-494, 7/6/83 SP-486

DATE STARTED ______ FIELD COMP ______ CERT. COMP 11-83

FORM 000019 5-77 14-363

CONTRACT

NO. 21452

TYPE OF WORK ASPH. CEMENT CONC. PAV'T. PROJECT NO. FM-70(4)--55-70

MILES 4.169 COST CENTER 801000 OBJECT 260

COUNTY MUSCATINE

ON SECONDARY ROAD FROM NEAR THE CENTER OF THE SE 1/4
SEC. 15-76-3 NORTHEASTERLY 4.2 MILES TO NEAR THE E 1/4 COR. SEC. 6-76-2

THIS AGREEMENT MADE AND ENTERED BY AND BETWEEN THE COUNTY OF MUSCATINE, IOWA

PARTY OF THE FIRST PART, AND

ILLINOIS-IOWA BLACKTOP, INC. OF ROCK ISLAND, ILLINOIS 20250

PARTY OF THE SECOND PART

WITNESSETH, THAT THE PARTY OF THE SECOND PART FOR AND IN CONSIDERATION OF $ ***391,961.80 PAYABLE AS SET FORTH IN THE SPECIFICATIONS CONSTITUTING A PART OF THIS CONTRACT HEREBY AGREES TO CONSTRUCT VARIOUS ITEMS OF WORK AND OR TO SUPPLY VARIOUS MATERIALS OR SUPPLIES IN ACCORDANCE WITH THE PLANS AND SPECIFICATIONS THEREFOR AND IN THE LOCATIONS DESIGNATED IN THE NOTICE TO BIDDERS AS FOLLOWS

ITEM NO.	ITEM	QUANTITY	UNIT	UNIT PRICE	AMOUNT
1	PRIMER OR TACK-COAT BITUMEN	2,750	GALS.	.85	2,337.50
2	BASE, FOAM ASPHALT CONCRETE	12,300	TONS	17.45	214,635.00
3	ASPHALT CEMENT	583	TONS	176.00	102,608.00
4	BINDER BITUMEN	22,187	GALS.	.90	19,968.30
5	AGGREGATE, COVER, ON ROAD 3/8 IN.	980	TONS	14.60	14,308.00
6	~~SHOULDERS, GRANULAR SURFACING OF~~	~~3,620~~	~~TONS~~	~~10.25~~	~~37,105.00~~
7	SAMPLES		LUMP SUM		1,000.00
				GRAND TOTAL	$391,961.80

PARTY OF THE SECOND PART CERTIFIES BY HIS SIGNATURE ON THIS CONTRACT, UNDER PAIN OF PENALTIES FOR FALSE CERTIFICATION, THAT HE HAS COMPLIED WITH 324.17(8) OF THE 1975 CODE OF IOWA AS AMENDED IF APPLICABLE.

SAID SPECIFICATIONS AND PLANS ARE HEREBY MADE A PART OF AND THE BASIS OF THIS AGREEMENT, AND A TRUE COPY OF SAID PLANS AND SPECIFICATIONS IS NOW ON FILE IN THE OFFICE OF THE PARTY OF THE FIRST PART UNDER DATE OF JUNE 30, 1983

THAT IN CONSIDERATION OF THE FOREGOING THE PARTY OF THE FIRST PART HEREBY AGREES TO PAY THE PARTY OF THE SECOND PART, PROMPTLY AND ACCORDING TO THE REQUIREMENTS OF THE SPECIFICATIONS THE AMOUNTS SET FORTH SUBJECT TO THE CONDITIONS AS SET FORTH IN THE SPECIFICATIONS.

THE PARTIES HERETO AGREE THAT THE NOTICE AND INSTRUCTIONS TO BIDDERS, THE PROPOSAL FILED HEREIN, THE GENERAL SPECIFICATIONS OF THE IOWA DEPARTMENT OF TRANSPORTATION FOR 1977 TOGETHER WITH SPECIAL PROVISIONS ATTACHED, TOGETHER WITH THE GENERAL AND DETAILED PLANS, IF ANY, FOR SAID PROJECT FM-70(4)--55-70 TOGETHER WITH SECOND PARTY'S PERFORMANCE BOND ARE MADE A PART HEREOF, AND TOGETHER WITH THIS INSTRUMENT CONSTITUTE THE CONTRACT BETWEEN THE PARTIES HERETO

THAT IT IS FURTHER UNDERSTOOD AND AGREED BY THE PARTIES OF THIS CONTRACT THAT THE ABOVE WORK SHALL BE COMMENCED OR COMPLETED IN ACCORDANCE WITH THE FOLLOWING SCHEDULE

APPROX. OR SPECIFIED STARTING DATE OR NUMBER OF WORKING DAYS	SPECIFIED COMPLETION DATE OR NUMBER OF WORKING DAYS
40 WORKING DAYS	OCT. 14, 1983

THAT TIME IS THE ESSENCE OF THIS CONTRACT AND THAT SAID CONTRACT CONTAINS ALL OF THE TERMS AND CONDITIONS AGREED UPON BY THE PARTIES HERETO

IN WITNESS WHEREOF THE PARTIES HERETO HAVE SET THEIR HANDS FOR THE PURPOSES HEREIN EXPRESSED TO THIS AND THREE OTHER IDENTICAL INSTRUMENTS AS OF THE ______ DAY OF ______, 19__

COUNTY OF MUSCATINE, IOWA

BY ______

PARTY OF THE FIRST PART

~~ILLINOIS-IOWA BLACKTOP, INC. OF~~ ROCK ISLAND, ILLINOIS

BY ______

PARTY OF THE SECOND PART

APPENDIX C
Aggregate Moisture Content Determination

AGGREGATE STOCKPILE MOISTURE CONTENT DETERMINATION

DATE	TIME	COARSE AGG. % MOISTURE	FINE AGG. % MOISTURE
8/26	12:30 PM	1.3	4.4
8/29	7:00 AM	1.9	4.0
8/29	1:30 PM	3.4	4.4
8/31	6:30 AM	7.6	6.0
9/2	7:00 AM	3.5	---
9/7	7:00 AM	5.6*	5.1*
9/7	12:00 PM	5.2*	5.5*
9/8	7:30 AM	5.2*	6.7*
9/9	8:30 AM	3.6	7.1
9/9	12:30 PM	6.7*	5.5*
9/9	3:00 PM	5.5	5.2
9/10	7:00 AM	6.0*	7.2*
9/10	9:00 AM	5.3	7.1
9/23	10:55 AM	6.6*	6.7*
9/23	12:00 PM	6.5	6.6
9/26	11:00 AM	5.5*	5.3*
9/26	PM	5.2	5.2
9/27	10:00 AM	5.2	5.9

* Moisture by pycnometer

COMBINED AGGREGATE MOISTURE CONTENT DETERMINATION AFTER ADDING WATER

DATE	TIME	% MOISTURE	% INTENDED
8/26	1:00	4.38	6.75
8/29	10:30	11.61[1]	8.10
8/31	11:00	10.50[2]	8.10
9/1	10:00	7.12	6.75
9/2	12:00	6.42	6.75
9/7	11:00	10.00[2]	8.1
9/8	1:00	9.78	8.1
9/9	2:00	9.16	6.75
9/23	1:30	7.33	6.75
9/26	11:40	7.47	6.75
9/27	9:10	7.80	8.10

1. Plant control not working
2. Rain day before.

APPENDIX D
Foamed Asphalt Field Densities

FOAMED ASPHALT FIELD DENSITIES

Location	NUCLEAR GAUGE			RUBBER BALLOON			
	Date Tested	Percent Water	Dry Density (#/CF)	Date Tested	Percent Water	Dry Density (#/CF)	Placement Date
Sec. 1							
141+00 5' Rt.	---	---	---	9/1	1.81	126.1	8/25
145+00 7' Lt.	---	---	---	9/1	2.20	134.5	8/25
151+50 4' Rt.	---	---	---	9/1	1.45	128.6	8/26
155+00 2' Rt.	9/1	1.81	133.6	9/1	1.16	132.4	8/26
159+90 9' Rt.	9/1	3.30	134.6	9/1	2.35	134.3	8/26
163+00 6' Lt.	9/1	---	139.1	9/1	1.34	133.0	8/26
156+00 2' Lt.	9/1	1.62	138.3	9/1	1.08	142.2	8/26
Sec. 2							
168+60 7' Rt.	9/1	-- -	134.1	9/1	2.29	136.1	8/29
176+00 5' Lt.	9/2	---	136.6	9/2	1.37	137.4	8/29
Sec. 3							
181+00 8' Rt.	9/2	---	133.4	9/2	2.80	135.8	8/29
185+00 7' Lt.	9/2	---	137.5	9/2	2.13	136.8	8/29
189+00 3' Rt.	9/2	---	138.4	9/2	1.69	138.2	8/29
Sec. 4							
201+00 7' Lt.	9/2	-- -	135.4	9/2	5.50	133.7	8/31
203+00 9' Rt.	9/7	4.29	133.5	9/2	7.80	129.1	8/31
207+00 5' Lt.	9/7	2.15	132.2	9/2	3.60	132.9	8/31
212+00 2' Rt.	9/7	2.43	130.5	9/2	3.20	132.1	8/31
215+00 4' Lt.	9/7	1.83	132.1	9/2	4.60	133.0	8/31
Sec. 5							
226+00 8' Rt.	9/7	2.68	133.7	9/7	1.58	140.0	9/2
229+00 3' Lt.	9/8	1.88	134.1	9/7	1.89	128.5	9/2
232+00 7' Rt.	9/8	2.90	128.6	9/7	3.67	130.4	9/2
238+00 6' Lt.	9/8	1.48	131.6	9/7	1.25	128.8	9/2
243+00 4' Rt.	9/8	1.44	135.5	9/7	0.96	129.8	9/2
Sec. 6							
249+00 5' Rt.	9/9	2.06	124.6	9/8	4.87	125.4	9/7
258+00 5' Lt.	9/9	1.93	132.0	9/8	3.08	128.8	9/7
262+00 8' Rt.	9/9	2.34	127.0	9/8	4.51	125.4	9/7
265+00 2' Lt.	9/9	1.55	133.3	9/8	1.95	126.1	9/7
270+00 7' Rt.	9/9	1.52	128.0	9/8	3.24	128.7	9/7
Sec. 7							
281+50 5' Rt.	9/27	3.68	125.0	9/9	5.61	122.2	9/8
288+00 8' Lt.	9/27	4.78	130.9	9/9	4.42	129.4	9/8
295+00 3' Rt.	9/27	1.32	133.8	9/9	2.74	133.2	9/8
301+50 6' Lt.	9/28	1.39	128.4	9/9	3.90	127.5	9/8
303+00 4' Rt.	9/28	4.44	128.5	9/9	4.69	130.6	9/8
Sec. 8							
310+00 2' Rt.	9/28	1.02	133.0	9/10	3.17	133.5	9/9
313+00 8' Lt.	9/28	1.67	130.9	9/10	4.62	132.6	9/9
317+00 5' Rt.	9/28	1.99	130.7	9/10	4.84	132.2	9/9
321+00 3' Lt.	9/28	1.33	131.4	9/10	4.66	135.8	9/9
325+00 8' Rt.	9/28	1.84	136.2	9/10	4.71	140.9	9/9
337+00 3' Rt.	9/27	5.16	130.5	9/27	5.09	129.8	9/23, 9
Sec. 9							
340+00 5' Lt.	9/27	2.32	127.0	9/27	5.01	115.7	9/23, 9
345+80 7' Rt.	9/27	2.76	132.8	9/27	6.16	123.1	9/23, 9
354+00 7' Lt.	---	---	---	9/27	5.63	118.2	9/23, 9
360+00 2' Rt.	9/27	5.05	131.5	9/27	7.28	127.4	9/23, 9