NCAT Report 93-04

EXPERIENCE WITH STONE MATRIX ASPHALT IN THE UNITED STATES

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EXPERIENCE WITH STONE MATRIX ASPHALT IN THE UNITED STATES

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INTRODUCTION

Stone Matrix Asphalt (SMA), which has been used in Europe for approximately 20 years, was first developed to provide resistance to abrasion by studded tires. In the 1970s, studded tires were banned in Germany, and the use of SMA mixtures declined because of the higher material and construction costs and there no longer appeared to be a critical need for these mixtures. Rutting of Hot Mix Asphalt (HMA) became a bigger problem in Germany in the 1980s due to increased tire pressure, wheel loads, and traffic volume, and SMA mixtures began to be used again. Studded tires have continued to be used in Sweden, and SMA mixtures have continued to provide good performance under these severe loading conditions. Other European countries have used SMA mixtures with similar success to that observed in Germany and Sweden.

A study group from the U.S. consisting of contractors, National Asphalt Pavement Association, Asphalt Institute, Federal Highway Administration (FHWA), and State Highway agencies visited Europe in the fall of 1990 to observe the quality of roads in Europe and to discuss construction procedures as well as contracting procedures. One of the items with which this group was most impressed was the performance of SMA mixtures. Based on this trip and the observed performance of SMA mixtures, it was decided shortly after this trip to construct a SMA test section in the US sometime in 1991.

In January 1991 plans were made by the FHWA to help support the construction of a SMA test section in Michigan. This state was selected because the climate was similar to that in Europe and there was much interest in SMA within the state DOT and industry.

DESCRIPTION

SMA mixtures consist of a large coarse aggregate content, fine aggregate, high filler content, asphalt cement with or without a modifier and usually a cellulose or mineral fiber. These mixtures contain a large coarse aggregate content (approximately 70 percent) and enough fine aggregate to help fill the voids in the coarse aggregate. The strength of this mix is gained from stone on stone contact. This mix is designed to have 3-4 percent air voids, and it has a relatively high asphalt content due to the high amount of voids in the mineral aggregate. The mix contains a high filler content (approximately 10 percent passing the No. 200 sieve), and it typically contains a polymer in the asphalt cement or fiber (cellulose or mineral) in the mixture to prevent drainage of the asphalt cement. This mixture has a surface appearance similar to that of an open graded friction course, however it has low in-place air voids similar to that of a dense graded HMA.

The high asphalt content produces a mixture that is easily compacted and that should be durable. If the asphalt content is excessive it will tend to push the aggregate apart and prevent stone on stone contact. An asphalt content that produces 3-4 percent air voids in laboratory compacted samples is desirable.

OBJECTIVE

The objective of this report is to discuss the construction of five SMA sections placed in the U.S. in 1991 and to summarize what was learned from these projects.

SCOPE

Major SMA projects were constructed in the U.S. in 1991 in the following five states: Georgia, Indiana, Michigan, Missouri, and Wisconsin. Other projects were constructed at various locations, but these were the major projects. There were many variations between these projects that should provide a wide base of experience that should be helpful in identifying potential problems and providing solutions to these problems. These projects have been evaluated after being opened to traffic to determine if any premature distresses had occurred. Each of these 5 projects is discussed below in the order that construction occurred.

Wisconsin SMA Construction

The Wisconsin SMA section was constructed on July 10, 1991 in the west bound lane of I-94 located approximately 8 miles west of Waukesha. The SMA at this section was placed 1½ inches thick and contained a polymer called Vestoplast. A copy of the special provisions for this project is provided in Appendix A.

The mix design and construction control data are shown in Table 1. The mix design which was prepared by the Wisconsin DOT was performed using 50-blow Marshall compactive effort and indicated that the optimum asphalt content was 5.7 percent. The hammer used for this compaction had a slanted foot and rotating base. This hammer has been shown to produce a higher density than the mechanical hammer with fixed base which may partially explain the relative low optimum asphalt content (5.7 percent). The use of an asphalt polymer instead of a fiber also results in a slightly lower optimum asphalt content.

A total of four crushed aggregates, including the filler, were used for this mixture which was produced in a batch plant. The capacity of the batch plant was 450 tons/hour however the production rate for the SMA was 185 tons/hour. The Vestoplast was added to the dry aggregate in the pugmill and mixed for 2 seconds before the asphalt cement was added. The dry mixing time was set at 5 seconds and the wet mixing time was set at 45 seconds. The mixture was produced at 290°F and placed at 280°F. Compaction was accomplished with 2 tandem steel wheel rollers. A vibratory roller was tried, but it caused fines and asphalt cement to be pumped to the surface resulting in a flushing problem. The SMA has been observed several times since construction and still appears to have a flushed surface. The SMA mixture has continued to provide satisfactory service, but its performance needs to be closely followed to see if the partially flushed surface continues to flush or if other problems begin to occur.

NCAT observed construction of the test section on I-94 plus some of the earlier work on a smaller project. This test section was observed again in October 1991 to evaluate its performance.

Table 1: Mix Design and Plant Production Data for SMA in Wisconsin

Property	Mix Design	Plant Produced Material
Gradation		
3/4 inch	100	100
1/2 inch	94	94
3/8 inch	70	69
No. 4	28	28
No. 8	20	20
No. 16	16	16
No. 30	14	14
No. 50	13	13
No. 100	12	12
No. 200	10.8	10
Asphalt Content, %	5.7	5.5
Lab Compacted Voids, %	3.1	3.5
In-Place Voids, %	---	6.8
Asphalt Cement Grade	85-100 pen	85-100 pen
Voids in Mineral Aggregate, %	---	17.3
Vestoplast, % of Asphalt Cement	7.0	7.0

Georgia SMA Construction

The SMA sections in Georgia were placed on I-85 in Jackson County in the outside Southbound lane between mileposts 129.5 and 132. The SMA binder course was placed on July 31, 1991, and the SMA surface course mixes were placed September 3 and September 17, 1991. The binder course was subjected to traffic until covered with the SMA surface mixture. This roadway had an AADT count of 35,000 with approximately 40% trucks. A layout of the test sections is shown in Appendix B.

SMA test sections at this site consisted of a fine SMA (aggregate 1) over a coarse SMA and a fine SMA (aggregate 2) over a dense graded binder course mix. The binder course and coarse SMA mixes were 2.25 inches thick and the two fine SMA mixtures were 1.5 inches thick.

The mix design properties and mix production properties as developed by the Georgia DOT are shown in Tables 2 and 3 respectively. There are some minor differences between the SMA properties of the designed mix and properties of the produced mix. These differences indicate the need for checking mix properties during construction and modifying the mixture as needed to meet desired properties.

Table 2: Mix Designs for Georgia SMAs

Test Property	Coarse SMA	Fine SMA Aggregate 1	Fine SMA Aggregate 2
Gradation			
3/4 inch	100		
1/2 inch	62	100	100
3/8 inch	42	78	81
No. 4	---	36	37
No. 8	20	23	23
No. 16	---	---	---
No. 30	---	---	---
No. 50	16	13	12
No. 100	---	---	---
No. 200	10	8	8
Asphalt Cement Grade	AC-30	AC-30	AC-30
Asphalt Cement Additive (Novophalt), % of AC	5.2	5.2	5.2
Asphalt Content, %	5.8	5.5/5.8	5.8/6.0
Quantity of Fiber (Inorphil), % of AC	8.0	7.4-7.0	7.4-5.0
Quantity of Fiber (Inorphil), % of Total Mix	0.42	0.38-0.36	0.38-0.26
Voids in Total Mix, %	4.0	3.9/3.2*	4.0/3.8*

* This reflects % voids at the AC contents shown above.

Table 3: Average Properties of Plant Produced SMAs in Georgia

Property	Coarse SMA	Fine SMA Aggregate 1	Fine SMA Aggregate 2
Gradation			
3/4 inch	100	100	100
1/2 inch	64	99	99
3/8 inch	39	85	83
No. 4	---	45	38
No. 8	22	29	24
No. 50	18	19	16
No. 200	10.0	10.0	10.1
Asphalt Content, %	5.7	5.5	5.6
Lab Compacted Voids, %	4.1	4.1	6.2
In-Place Voids, %	4.0	7.0	6.3

The fine SMA with aggregate 1 had an initial design asphalt content of 5.5 percent and fiber content of 7.4 percent. However, after several loads of SMA had been produced, the design was changed to 5.8 percent asphalt content, and the fiber content was reduced to 7.0 percent. The fine SMA with aggregate 2 had an initial design asphalt content of 5.8 percent and 7.4 percent fiber. After several loads of SMA were produced, the design was changed from 5.8 to 6.0 percent asphalt cement and was changed from 7.4 to 5.0 percent fiber. These changes were made primarily to evaluate the effect of changes in asphalt content and percent fiber on mixture performance.

Comparing the mix design data with the data developed during production for the coarse SMA mixture showed some difference in gradation in the percent passing the 3/8 inch sieve, which was 39 percent during production but was 42 percent during the mix design. The asphalt content and laboratory voids produced in the mix design and in the lab during construction were very close to the same.

There were some differences between the mix design and construction data for the fine SMA (aggregate 1) mixture. The plant produced gradation was significantly finer than the gradation produced during the mix design. During production, the asphalt content was increased slightly to help lower the voids in the SMA mixture. The designed void content was 3.0 percent, but the plant produced lab voids were approximately 4.1 percent.

The gradation for the fine SMA (aggregate 2) was slightly finer during production than in mix design. The difference occurred primarily on the No. 50 and No. 200 sieves. The laboratory compacted voids during production were approximately 3 percent higher than the mix design voids. The asphalt content was raised from 5.8 to 6.0 percent during production to help lower the laboratory compacted voids.

The aggregates used for this project were all crushed. One percent lime was used in the mix as normally required in the state of Georgia for work on Interstate and State Route Highways. Excluding the lime, the coarse SMA mixture had 4 aggregates fed through the cold feeders, and the mineral filler fed through the filler system. The two fine SMA mixtures had 3 aggregates along with the mineral filler.

The mix was produced in a batch plant, and the Inorphil was added 1 bag per batch into the weighhopper. The Novophalt was mixed with the asphalt cement at the plant site and then fed directly into the batch plant pugmill.

Several types of rollers and rolling patterns were used during the course of this project. A rubber tire roller was tried, but it tended to pick up the asphalt cement and fines leaving noticeable marks on the surface. Because of this pick up problem, use of the rubber tire roller was discontinued. A vibratory steel wheel roller was tried and appeared to be successful. The vibratory roller compacted the mixture to lower voids than the non-vibratory steel wheel roller and thus likely improved the durability of the SMA mixture. Breakdown of aggregate underneath the vibratory roller did not appear to be a problem, and the roller did not pump asphalt cement and fines to the surface.

The sections placed in Georgia were inspected in October 1991. At that time, there were no noticeable problems. The surface texture appeared to be excellent. The condition of this pavement has been observed several times since October by various individuals who have reported that performance continues to be excellent.

NCAT's involvement in this project included development of a preliminary mix design for the state of Georgia to be used for comparison with mix designs developed by others. All mix designs produced results similar to that ultimately used by the Georgia DOT. NCAT also observed construction of the SMA base and surface courses and observed performance in October 1991.

Michigan SMA Construction

The Michigan primary SMA sections were constructed during Open House on August 6-7, 1991. Approximately 300 participants observed mixture production and placement. The overriding goal of the Michigan project was to provide and place SMA technology as close as possible to European practice with U.S. equipment and materials. One half of the primary test section was produced with a drum mix plant, and the other half was produced with a batch plant. The thickness of this SMA section was 1½ inches. A layout of the test sections along with special provisions are provided in Appendix C.

For the primary section high quality aggregates were transported approximately 450 miles from the upper peninsula to the project site near Lansing, however, a local aggregate was also used in early SMA test strips. The sections were placed southeast of Lansing on route 52 near the intersection of I-96. This site had a sound base, known pavement history, and provided safety for project observers. The AADT of the M-52 roadway is low, however, the ramps from I-96 to M-52 will test heavy truck traffic turning under stop and go conditions. Michigan plans to use SMA on 3 Interstate roadways in 1992.

Prior to placing the SMA on the primary test sections, the existing HMA was milled to obtain a smooth surface on which to place the SMA mixture. The mix design which was developed by the Michigan DOT was the same for the mix produced in the batch and drum mix plants. The mix design and construction control data are shown in Table 4. The mix produced in the field was considerably finer than the mix design on several sieves. This finer mix resulted in the VMA of laboratory compacted samples during production dropping approximately 2 percent below that measured during mix design, requiring the asphalt content to be lowered slightly. The laboratory compacted voids during early production placed on short test strips typically ranged between one and two percent. For the primary section comprising 80% of the 4,000 tons of SMA placed, the asphalt content was lowered to 6.2 percent, and the voids increased slightly.

The cellulose was added in bulk form to the batch plant but was added in pellet form to the drum mix plant. There were some problems suspected in getting complete melting of the pellets being added to the drum mix plant. However, at all times the fibers performed the function of stabilizing the high bitumen content during construction. The mixing temperature was increased slightly to about 310°F, and the addition of asphalt cement was moved approximately six feet

Table 4: Mix Design and Plant Production Data for SMA in Michigan

Test Property	Mix Design	Batch Plant Produced Material	Drum Mix Plant Produced Material
Gradation			
3/4 inch	100	100	100
1/2 inch	94	95	95
3/8 inch	72	76	78
No. 4	35	42	41
No. 8	24	29	28
No. 16	19	23	22
No. 30	16	19	19
No. 50	14	17	16
No. 100	12	15	14
No. 200	10.4	12.9	12.2
Asphalt Content, %	6.5	6.5±0.2	6.5±0.2
Lab Compacted Voids, %	3.0	1-2	1-2
In-Place Voids, %	---	4.6	3.9
Asphalt Cement Grade	AC-20	AC-20	AC-20
Cellulose, % of Mix	0.3	0.3	0.3
Voids in Mineral Aggregate, %	18.2	16.2	15.9

further up the drum (effectively increasing the wet mix time) to improve breakdown and mixing of the pellets. This modification appeared to solve the problem.

The dry mixing time in the batch plant was set at 20 seconds. It was believed by those working with the mix that this dry mixing time could be reduced some, but the wet mixing time which was set at 35-40 seconds was very important. The plant was set up to produce 2 ton batches which were considerably smaller than that capable of being produced in the plant. Due to the slow rate of feed for the filler, the time required for each batch was approximately 1 minute and 40 seconds. Both plants experienced delays due to the slow rate of filler feed. The mix temperature at the plant was in the range of 310-315°F.

Two rollers were used for compaction. A 12-ton steel wheel roller and a 10-ton vibratory roller in the static mode. The vibratory roller was operated in the vibrating mode, but it tended to pump the asphalt cement and the fines to the surface. Hence, use of the roller in the vibratory mode was discontinued.

As mentioned earlier, some SMA was placed at several small locations prior to construction of the official test sections. The use of Vestoplast and cellulose fibers with local aggregates were tried in some of these earlier small projects. These small projects were constructed primarily to become familiar with the materials and construction methods before construction of the primary test sections, but these small projects will allow comparison of performance for the two aggregate sources as well as the fiber versus polymer modified SMA. Details of these smaller projects are not provided in this report.

NCAT observed construction of this SMA section and observed performance in October 1991. A laboratory study using the materials from this project has been completed and reported elsewhere. This study the sensitivity of SMA mixtures to a change in material measured proportions.

Missouri SMA Construction

The Missouri SMA section was constructed in the westbound outer lane of I-70 in St. Louis. Some of the SMA mixture was produced using cellulose fibers (Arbocel), and some was produced with mineral fibers (Inorphil). The AADT on this road was 55,000 with approximately 10% trucks. The sections were constructed on September 4 and 5 at a thickness of 1½ inches. A layout and special provisions for this project are provided in Appendix D.

The mix design and construction control data are shown in Table 5. The mix design was developed by the Missouri DOT. The plant produced material was slightly finer than the mix design, and the voids in laboratory compacted samples during production were also slightly lower than that measured during mix design, however these small differences are not significant. These differences, however, do again emphasize the need for thoroughly testing the mixture during construction and making changes as needed.

The SMA mixtures were produced in a batch plant at a rate of 150 tons/hour. A total of 5 aggregates, including the filler, were used to produce the SMA mixture. The aggregate used was 100 percent crushed. The cellulose and mineral fibers were added in bulk form to the asphalt mixture. Some problem occurred when adding the fibers to the mixing plant. Initially, some of the fibers were added to the pugmill before the dry aggregate was added which caused some balling up of the fibers and hence did not provide good distribution. When the fibers were added after the aggregate was in the pugmill, complete mixing was obtained. The SMA mixtures were compacted using three tandem steel wheel rollers. Hand work was noticeably more difficult with the SMA mixtures than that normally anticipated with HMA.

Several inspections of this pavement have been made since construction. Some consolidation has occurred, resulting in slight ruts in the wheel path. It is possible that the mix has now stabilized and additional deformation will not occur however, this SMA section will continue to be monitored to determine if the mix has stabilized or if additional deformation occurs.

NCAT observed construction of this SMA test section. Most information in this report was obtained from Missouri's report on the SMA project (l).

Table 5: Mix Design and Plant Production Data for SMA in Missouri

	Mix Design		Plant Produced Material	
Property	**Cellulose**	**Mineral Fiber**	**Cellulose**	**Mineral Fiber**
Gradation				
3/4 inch	100	100	100	100
1/2 inch	96	96	96	96
3/8 inch	76	76	79	79
No. 4	34	34	36	36
No. 8	20	20	21	21
No. 16	15	15	16	16
No. 30	13	13	14	14
No. 50	13	13	13	13
No. 100	12	12	12	12
No. 200	9.6	9.6	10.4	10.4
Fiber Type	**Cellulose**	**Mineral Fiber**	**Cellulose**	**Mineral Fiber**
Fiber Content, % of total mix	0.3	0.3	0.3	0.5
Asphalt Content, %	6.4*	6.2	6.4**	6.2
Lab Compacted Voids, %	3.9*	4.2	3.4	4.2
In-Place Voids, %	---	---	6.5-7.0	8.0
Asphalt Cement Grade	AC-20	AC-20	AC-20	AC-20
Voids in Mineral Aggregate, %	18.4*	18.5	18.4**	18.4

* The mix design with cellulose originally contained 6.5% asphalt, 3.8% lab compacted voids, and 18.5% VMA. The asphalt content was later adjusted to 6.4% producing the properties shown above.

** The plant produced materials originally contained 6.5% asphalt cement and 18.5% VMA. The asphalt content was later adjusted producing the data shown above.

Indiana SMA Construction

A section of SMA was placed on Interstate 70 in Indiana during October 1991. This roadway had an AADT of 29,000 with 35 percent of the traffic being trucks. A layout of the test section and special provisions are provided in Appendix E. The mix design for the SMA mixture as developed by The Heritage Group is shown in Table 6.

This SMA mix contained no fibers but used a multigrade asphalt cement to maintain the thick asphalt cement film on the aggregate particles. The aggregate used was 100 percent crushed, however the gradation was somewhat different from other SMA mixes. This mixture had 31 percent passing the 3/8 inch sieve, whereas the other four projects had approximately 70-80 percent passing this sieve. The percent passing the remaining sieves was approximately equal to that for the other 4 SMA projects. This low percentage passing the 3/8 inch sieve should provide a high VMA and allow a high asphalt content to be added. The mix was designed using the 50-blow Marshall test.

Table 6: Mix Design for SMA Mixture Used in Indiana

Test Property	Mix Design
Gradation	
3/4 inch	100
1/2 inch	95
3/8 inch	31
No. 4	25
No. 8	24
No. 16	19
No. 30	15
No. 50	13
No. 100	11
No. 200	9.8
Asphalt Cement Grade	Multigrade 20-40
Asphalt Content, %	6.5
Voids in Total Mix, %	3.6
Voids in Mineral Aggregate, %	16.8

The SMA mixture was produced in a drum mix plant at a temperature between 280 and 320°F. The mix has been observed since construction and performance continues to be good. NCAT was not involved in the planning nor construction of this project. All information presented here was obtained from the Indiana DOT and The Heritage Group.

SUMMARY OF OBSERVATIONS

1. Aggregates used to date have been 100 percent crushed. No natural sands have been used. The L.A. Abrasion of the aggregates used have been relatively low (usually 20-30). The requirements for L.A. Abrasion should probably be the same as that required for open graded friction courses since the aggregate will be subjected to similar loading conditions. All mix designs for SMA mixes to date have had 94-100 percent passing the 1/2 inch sieve, 28-37 percent passing the No. 4 sieve, 12-14 percent passing the No. 50 sieve, and 8-11 percent passing the No. 200 sieve. A summary of gradations for the 5 projects is shown in Figure 1. Notice that the gradations used for all projects except Georgia (coarse) and Indiana were very similar. These two mixes had a much lower percentage of aggregates passing the 3/8 inch sieve than the other 4 mixes. A change in gradation during production can greatly affect the mixture properties such as voids. The

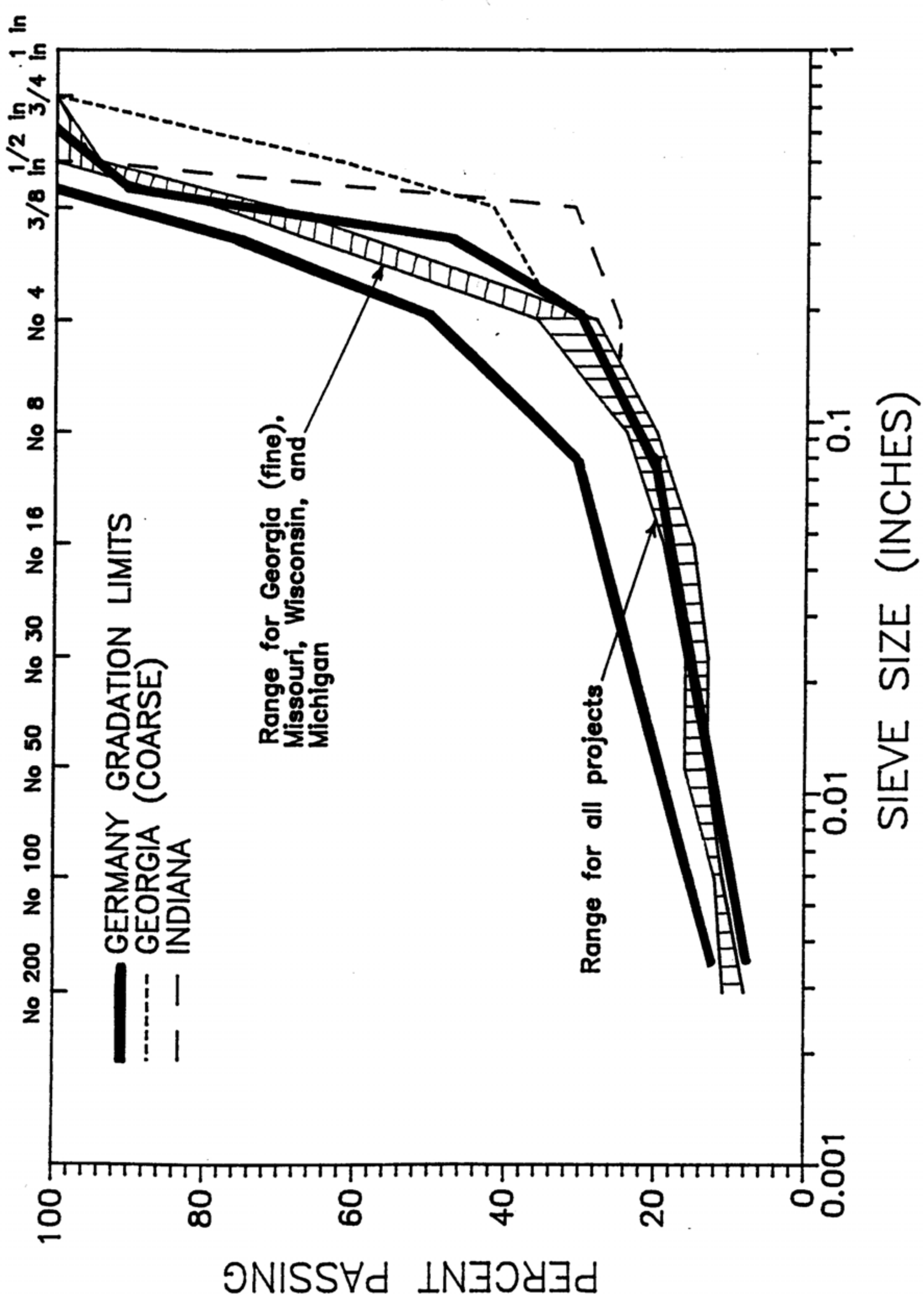


Figure 1. Summary of Gradation Used on SMA Projects Constructed in the U.S. in 1991.

voids in SMA mixtures appear to be more affected by gradation changes especially on the No. 4 and No. 8 sieves than the voids in dense graded HMA.

2. The asphalt cement grades used to date have been AC-20, AC-30, 85-100 pen, and Multigrade asphalt cement. Two of the asphalt cements contained modifiers (Novophalt in Georgia and Vestoplast in Wisconsin). The additive content was 5.2 % of AC for Novophalt and 7.0% of AC for Vestoplast.

3. Two types of fibers have been used in the U.S. These fibers include cellulose (Arbocel) in Missouri, Michigan, and Wisconsin and mineral fiber (Inorphil) in Georgia and Missouri. The fiber content used so far has been 0.3 percent of total mix for cellulose and 7-8 percent of asphalt cement for the mineral fiber. Fibers have been added in bulk in batch plants and in pellet form in drum mix plants. The pellets contain a hard base asphalt cement which must be considered when computing the fiber content being added. On one of the projects, some problems were encountered when it appeared the pellets did not completely breakdown in the mix. However at all times the fibers performed the function of stabilizing the relatively high bitumen content during the construction process. Complete pellet breakdown was achieved, but those involved with production of SMA should ensure this problem does not occur on future projects.

4. All mix designs in the U.S. have been performed with 50 blows with the Marshall hammer. SMA mixtures compact quickly, so additional blows would not likely significantly increase the density. Additional compaction would also cause excessive breakdown in the aggregate. SMA mixtures have been designed to have as low as 3 percent voids in some cases and as high as 4 percent voids in others. Hotter climates should probably design closer to 4 percent voids, and colder climates should design closer to 3 percent voids. The voids in laboratory compacted samples must be determined during construction and the mix modified, if necessary, to ensure the desired void content is obtained. SMA mixtures appear to be able to tolerate lower voids than dense graded HMA, but care must be exercised to keep voids above 3 percent to provide some margin of safety against rutting.

5. Batch plants and drum mix plants have been used successfully to produce SMA mixtures. Mixtures have been produced using 3-5 individual stockpiles. Aggregate gradations have generally been slightly finer during construction than in mix design, which tends to close the voids. Hence, adjustments must be made during construction to obtain the desired voids. The addition of high filler content (typically 7-12 percent depending on gradation of filler) may reduce the production rate if provisions are not made at the plant to add high filler content. On one of the projects production in a 750 TPH drum mix plant was reduced to 315 TPH due to limitations of the mineral filler system. Fibers have been added in bulk form directly into the pugmill in a batch plant and are fed in pellet form through the RAP feeder (1/2 way down drum) for a drum mix plant. A longer mixing time is required for SMA mixtures containing fibers than that required for dense graded HMA. The dry mixing time may require a slight increase in time but it is more important that the wet mixing time be increased to a satisfactory level. Total mixing times have typically been 1 minute or less per batch.

6. All SMA surface mixes to date have been 1½ inches thick. In at least two cases, SMA binder courses were covered with SMA surface courses. Most mixes have been compacted with steel wheel non-vibratory rollers. Vibratory rollers have been tried with success on some jobs but have created problems on other projects. Rubber tire rollers have been tried but appeared to pick up too much asphalt cement and fines. Based on this observation, rubber tire rollers should not be used to compact SMA mixtures. Initial in-place voids have typically been in the 5-7 percent range.

7. The Europeans often use fine chips on the surface of SMA mixtures to improve initial skid resistance. Chips have been tried in at least one place in the United States, but it appears that the chips are not needed. As the SMA mixes age and the surface asphalt cement is worn off the microtexture begins to provide a good frictional surface and, the skid resistance tends to improve.

8. Performance to date has been good, however, the SMA mixtures have not been down long enough to fully evaluate performance. Some apparent flushing has occurred on one project, and some consolidation on another, but this does not appear to have caused significant problems to date.

RECOMMENDATIONS

1. A generic specification for SMA is needed for the mixture and for the various components (fibers, polymers).

2. Performance data for SMA must be collected during the next few years to help identify problems and to provide answers to these problems. The cost effectiveness of SMA needs to be determined.

3. A task group is needed to provide some direction to use of SMA in the U.S. This task group, as a minimum, should consist of FHWA, State DOTS, and Industry.

REFERENCES

1. McDaniel, Pat. “Stone Mastic Asphalt-Missouri’s Experimental Project Using European Technology,” MO.91-05, February 1992.

Appendix A

SMA Mixtures in Wisconsin

Wisconsin DOT
SMA
STONE MASTIC ASPHALT PROVISIONS

Materials Specifications

Mineral Aggregate

The aggregates shall conform to the following gradation requirements.

	Total % Passing by Weight	
Sieve Size	Mix Design	Field Tolerance Single Test
3/4 inch	100	
1/2 inch	90-97	(± 6%)
3/8 inch	50-75	(± 5%)
No. 4	20-40	(± 5%)
No. 8	15-25	(± 4%)
No. 16	10-25	(± 4%)
No. 30	10-21	(± 3%)
No. 50	9-18	(± 3%)
No. 100	8-16	(± 3%)
No. 200	8-12	(± 2%)

Coarse aggregate should be crushed, relatively non-absorptive stone and unless otherwise stipulated, should conform to the following quality requirements:

Los Angeles abrasion, AASHTO T 96	45% max.
Sodium sulfate soundness loss (5 cycles), AASHTO T 104	12% max.

Particles retained on or above the No. 4 sieve shall have at least:

One Fractured Face	90% min.
Two Fractured Faces	60% min.

Fine aggregate should consist of 100% crushed aggregate. The aggregates passing the No. 200 sieve shall not have a plasticity index of more than three.

Mineral filler should consist of finely divided mineral matter such as rock dust or other suitable material. At the time of use it should be sufficiently dry to flow freely and essentially free from agglomerations. Filler should be free from organic impurities and the portion passing the No.

200 sieve shall not have a plasticity index of more than three.

Asphalt

Asphalt cement shall be AC 85-1OO and shall be mixed at a temperature as required to achieve a kinematic viscosity of 150 to 300 centistokes. Mixing temperature may have to be increased to achieve proper blending of the aggregates, asphalt, and additive but should not exceed 350°F.

Mix Design Requirements

Utilizing the proposed project materials, the Marshall procedure (the Department's Test Method No. 1559, Standard Method of Asphaltic Mix Design) will be performed to determine an optimum asphalt content. This asphalt content will be that combination of materials, compacted using a 50 blow Marshall, that results in an air void concent of 3.0%.

The mixture should also satisfy the following design parameters. Note that these values will provide a general guideline.

Marshall[1]

-Stability, lbs.	1500 min.
-Flow, 0.01 inch (0.25 mm)	8 - 14
-VM_3 percent[2]	3
-VMA[3]	15 min.
-Compaction, number of blows at each side of test specimen	50

[1]Marshall procedures are in accordance with the Department's Test Method No. 1559.
[2] VTM (Voids in Total Mix) is based on AASHTO T 166, T 209, and T 269. Maximum density will be based on AASHTO T 209.
[3] VMA to be determined based on bulk specific gravity of aggregates.

Selected materials will be subjected to the water sensitivity test as described in ASTM D-4867. Minimum required Tensile Strength Ratio is 70 percent.

Construction Requirements

Batch Plant should conform co the typical requirements of AASHTO M 156. The maximum mixing temperature should not exceed 350°F. Mixing time will be that required to properly blend the aggregate, additive, and asphalt cement.

Hauling equipment and paver should be of a type normally used for the transport and placement of dense grade asphalt hot mix.

Until appropriate storage considerations are determined, holding of mix should be limited to that of a very temporary nature associated with that of a surge hopper.

Proper surface preparation should be followed prior to placement of the SMA surface course. Proper preparation includes items such as tack coat, and a clean broomed and dry surface.

Placement of the mix should only take place when the surface upon which the mix is co be placed and the ambient temperature are both a minimum of 50°F. The paving speed will be adjusted as required to get density and satisfactory results.

Rollers should be approximately 10-12 ton steel wheeled rollers of the type used normally for the compaction of dense grade asphalt hot mix. Vibratory and pneumatic tired rolling should not be used.

Pavement should be compacted to a maximum theoretical density as determined by AASHTO T 209 of 94% (± 2%), this will result in approximately 6% air voids in the pavement immediately after compaction. Compaction should be monitored with a nuclear density gauge and verified with pavement cores. A test section should be constructed, off site to examine placement and compaction peculiarities and calibrate the nuclear density device, prior to placing mainline pavement.

While limited information is currently available related to SMA surface tenderness, it is advisable to keep traffic off the newly placed surface for some period to allow cooling of the surface to maximum temperature of 140°F.

LLL:a12010

Appendix B

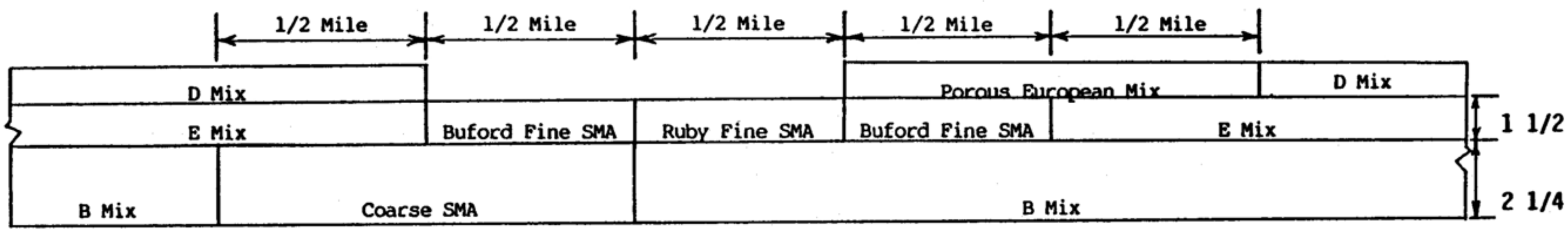
SMA in Georgia

STONE MASTIC AND POROUS EUROPEAN ASPHALT MIX

TEST SECTION

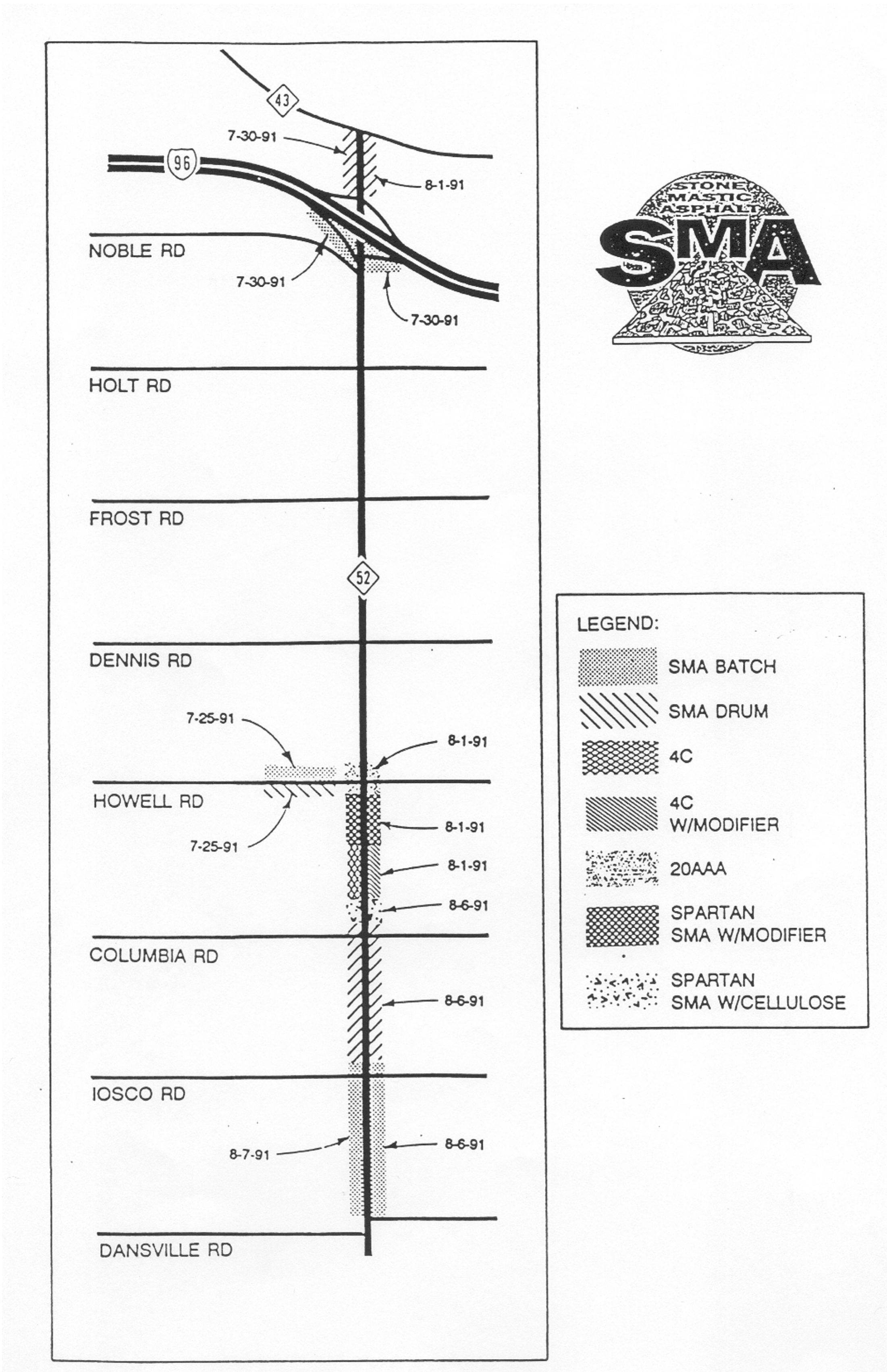
IR-85-2 (127) 02 and IR-85-2 (130) 02

BARROW/JACKSON/BANKS



Appendix C

SMA Mixtures in Michigan



43
96
52
7-30-91
8-1-91
NOBLE RD
7-30-91
7-30-91
HOLT RD
FROST RD
DENNIS RD
7-25-91
8-1-91
HOWELL RD
7-25-91
8-1-91
8-1-91
8-6-91
COLUMBIA RD
8-6-91
IOSCO RD
8-7-91
8-6-91
DANSVILLE RD
STONE MASTIC ASPHALT
SMA
LEGEND:
SMA BATCH
SMA DRUM
4C
4C W/MODIFIER
20AAA
SPARTAN SMA W/MODIFIER
SPARTAN SMA W/CELLULOSE

MICHIGAN
DEPARTMENT OF TRANSPORTATION
BUREAU OF HIGHWAYS

SPECIAL PROVISION
FOR
BITUMINOUS MIXTURE STONE MASTIC ASPHALT (SMA)

M&T:DJV l of 3 05-17-91
CS 33092/JN 32597A

A. Description.

This work shall consist of furnishing a bituminous mixture from a batch plant and drum plant in accordance with the requirements of the 1990 Standard Specifications and supplemental specifications except where modified herein.

B. Materials.

Coarse Aggregate - Coarse aggregate for the Bituminous Mixture Stone Mastic Asphalt (SMA) will be furnished by MDOT. The Contractor will be responsible for transporting the aggregate from MDOT Pit No. 36-40 at Iron River, Michigan to the batch plant and drum plant used for the project. The Contractor will also be responsible for having the aggregate split at each plant into the following fractions: Retained 3/8”, Passing 3/8"-Retained #4, Passing #4-Retained #8, Passing #8. Refer to the Special Provision on transporting the coarse aggregate for the SMA mixture for quantities. Unused coarse aggregate will be the property of, and removed by, MDOT.

Filler - The filler in the SMA mixture will be a limestone dust provided by the Contractor. This filler should consist of finely divided mineral matter—such as rock dust from limestone. At the time of use it shall be sufficiently dry to flow freely and be free from agglomerations. This filler shall be free of organic impurities and have a plasticity index not greater then 4.0. This filler shall have maximum percent retained on the No. 100 sieve of 4.0 percent and maximum retained on the No. 200 of 15.0 percent. Estimated quantity of filler necessary is 10 percent of the total mixture; refer to plans for estimate of mixture required for the project.

Fibers - Cellulose fibers for the SMA mixture will be furnished by MDOT including delivery to the Contractor’s batch and drum plant locations. The Contractor will be responsible for safe storage of these fiber materials providing protection from moisture and contamination. Loose cellulose fibers (in plastic bags) will be used at the batch plant. The Contractor shall introduce the loose fibers at the amount specified on the job-mix-formula (JMF) (O.3 percent by weight of mix) directly into the pugmill and allow for uniform mixing during dry mix. Pelletized cellulose fibers will be used at the drum plant. Pelletized cellulose consists of 50 percent asphalt cement and 50 percent cellulose fibers by weight and shall be introduced at the amount specified on the JMF. The Contractor is responsible to uniformly introduce the cellulose pellets to the aggregate after the flame of the burner and allow uniform mixing prior to the introduction of the asphalt cement.

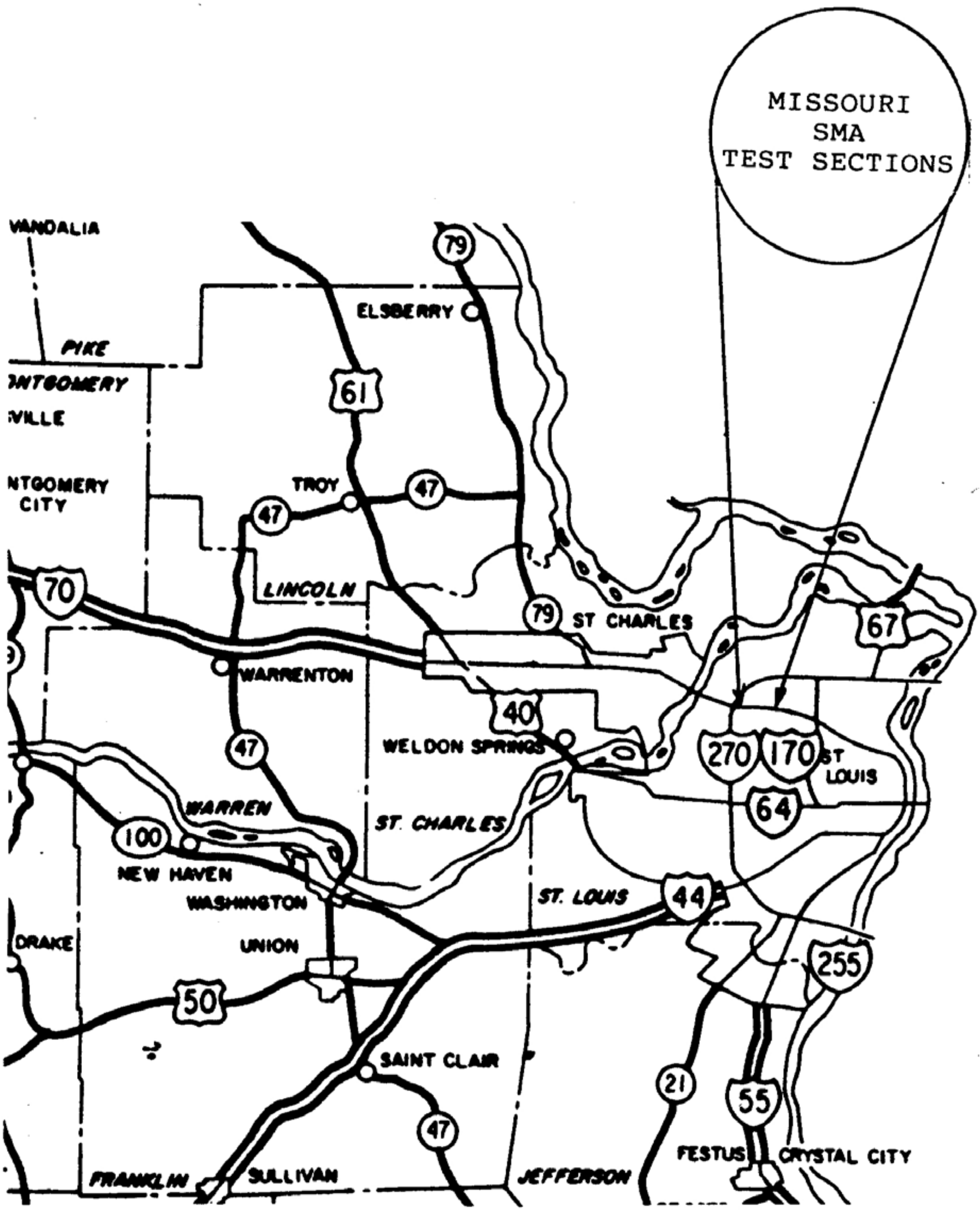
Asphalt Cement - Asphalt Cement for the SMA mixture shall be an AC-20 provided by the Contractor from either Marathon or Amoco. The Contractor shall procure and store the AC-20 in such a way that the batch plant and drum plant can run and place the SMA mixture on the same day between 6 a.m. and 6 p.m. to accommodate tours of the demonstration site.

i. Measurement and Payment - The completed work for BITUMINOUS MIXTURE STONE MASTIC ASPHALT (SMA) will be measured and paid for at the contract unit price for the following contract item (pay item).

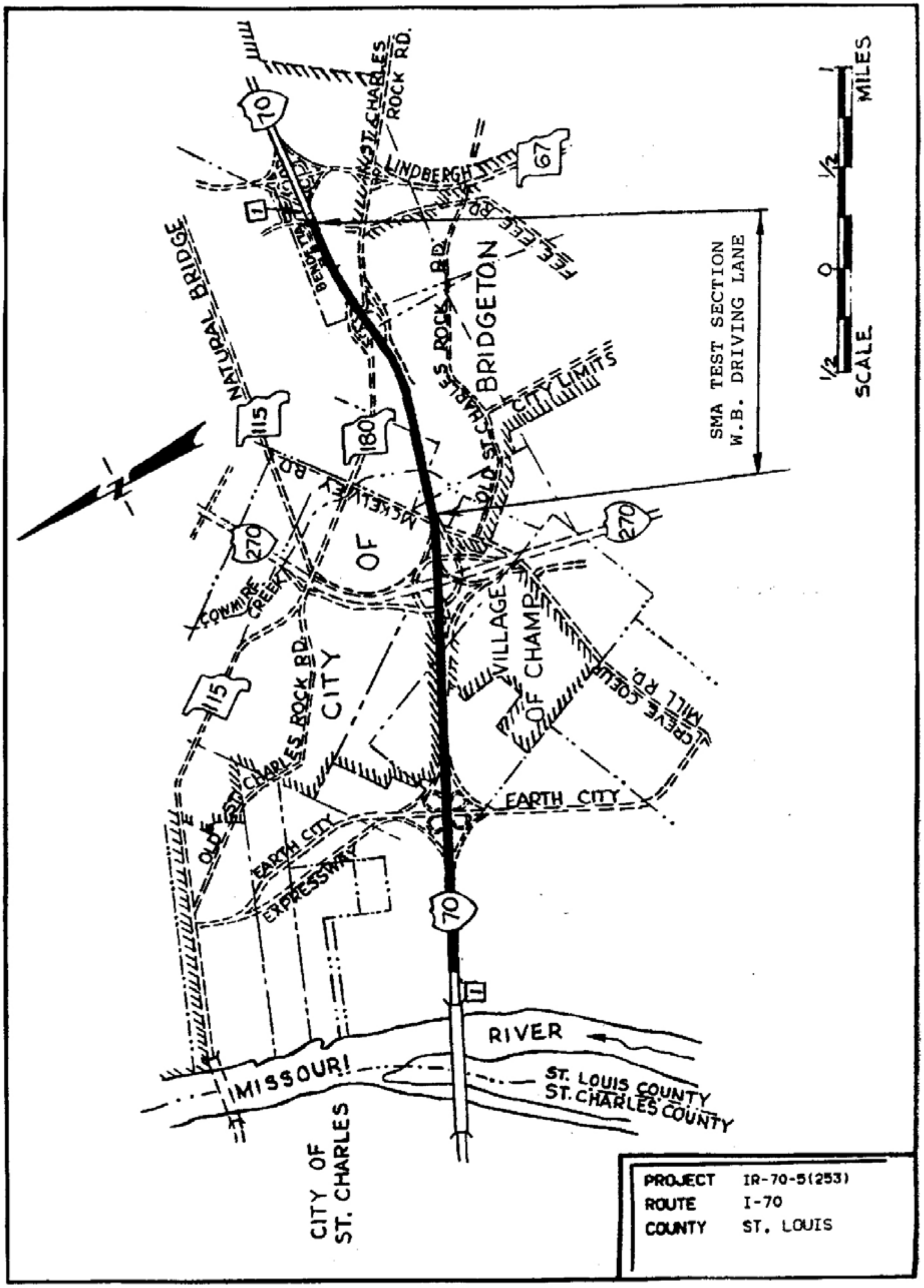
Pay Item	Pay Unit
Bituminous Mixture Stone Mastic Asphalt (SMA)	Ton

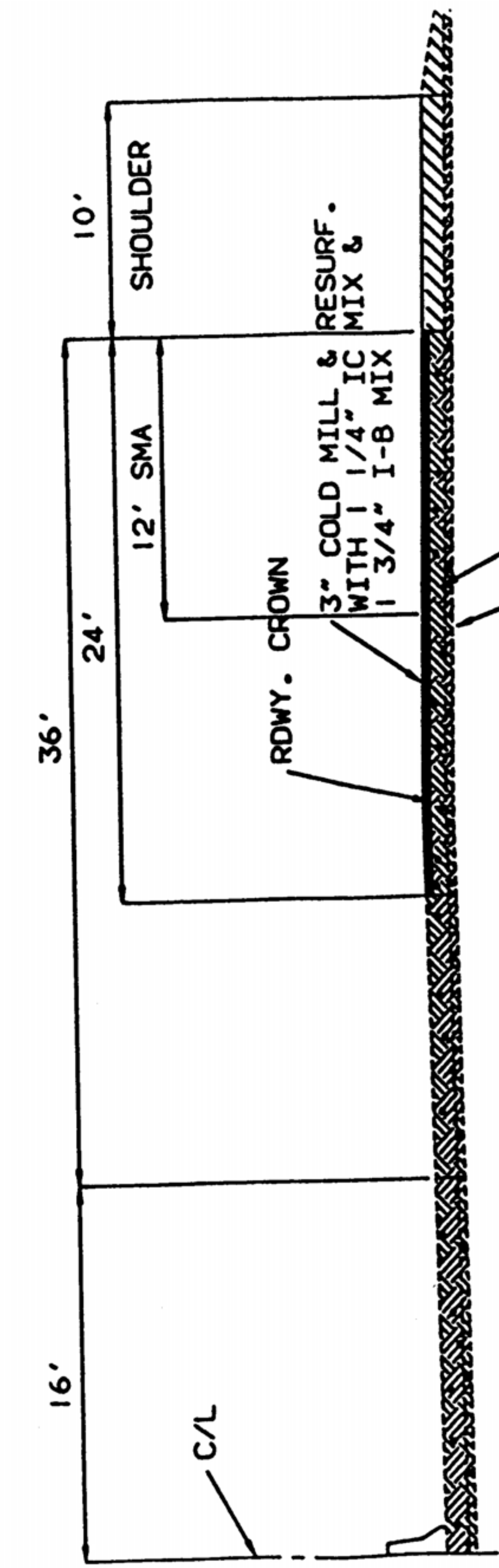
Appendix D

SMA Mixtures in Missouri



MISSOURI
SMA
TEST SECTIONS
VANDALIA
PIKE
ELSBERRY
TROY
LINCOLN
ST CHARLES
WARRENTON
WELDON SPRINGS
ST LOUIS
WARREN
ST. CHARLES
NEW HAVEN
WASHINGTON
ST. LOUIS
DRAKE
UNION
SAINT CLAIR
FRANKLIN
SULLIVAN
JEFFERSON
FESTUS
CRYSTAL CITY


SMA TEST SECTION
W.B. DRIVING LANE
SCALE
MILES
BRIDGETON
VILLAGE OF CHAMP
CITY OF
CITY
CITY LIMITS
NATURAL BRIDGE
LINDBERGH
ST. CHARLES ROCK RD.
FEE FEE RD.
EARTH CITY
EARTH CITY EXPRESSWAY
COWMIRE CREEK
CREVE COEUR MILL RD.
MISSOURI RIVER
ST. LOUIS COUNTY
ST. CHARLES COUNTY
CITY OF ST. CHARLES
PROJECT IR-70-5(253)
ROUTE I-70
COUNTY ST. LOUIS


10'
SHOULDER
3" COLD MILL & RESURF.
WITH 1 1/4" IC MIX &
1 3/4" I-B MIX
9" REINF. CONC.
4" BASE
12' SMA
24'
RDWY. CROWN
36'
16'
C/L

<u>Project</u>: **IR-70-5(253)**

<u>Route</u>: **I-70**

<u>County</u>: **St. Louis**

As requested by the Missouri Highway and Transportation Department (MHTD), Fred Weber Construction, Inc. agrees to furnish or perform the following to effect an asphaltic concrete overlay test section.

1.0 DESCRIPTION. This item shall consist of the mix design, materials, equipment, and construction procedures necessary for producing and placing one course of stone mastic asphalt (SMA) in conformity with the lines and grades shown on the plans or as designated by the engineer.

1.1 Unless otherwise stated, specification section references are from the version, in effect at the time of this contract, of the Missouri Standard Specifications for Highway Construction and its supplements.

1.2 SMA shall meet all the requirements for asphaltic concrete in Sec 403 and Sec 404, except as modified herein.

2.0 TEST SECTION. The test sections shall be in the westbound right lane from Lindbergh Boulevard to Route I-270. Each of the two test sections shall be 12 feet wide, approximately .9 mile long and shall be in the same lane end-to-end. The plan thickness of SMA mixture, compacted in place shall be a minimum 1 1/4 inches.

3.0 MATERIALS. All materials shall conform to Division 1000, Materials Details unless otherwise noted.

3.1 Asphalt Cement. The grade selected shall be determined by MHTD based on the Central Laboratory test results. The contractor shall be responsible for procuring and storing the asphalt cement.

3.2 Fibers. Fibers shall be either cellulose fibers provided by ScanRoad, Inc. or mineral fibers provided by Fiberand Corporation. Loose cellulose or mineral fibers in plastic bags will be used at the batch plant.

4.0 MIX DESIGN. The mix design will be performed by the Department’s Central Laboratory and the job mix formula will be provided to the contractor.

4.1 Type and source of mixture components selected by the Department shall not be subject to change. The amount of asphalt cement and fibers will be determined by the mix design.

4.2 Prior to mixing with fibers and asphalt cement, the total combined aggregate, including mineral filler, shall meet the following gradation for the SMA mixture.

Percent Passing by Weight

Sieve Size	SMA	Tolerance
3/4 inch	100	---
1/2 inch	96	± 5.0
3/8 inch	76	± 4.0
No. 4	33	± 3.0
No. 8	20	± 3.0
No. 16	15	± 3.0
No. 30	14	± 3.0
No. 50	13	± 2.0
No. 100	12	± 2.0
No. 200	10	± 2.0

4.2.1 The addition of hydrated lime will not be required.

5.0 EQUIPMENT. All equipment shall conform to Sec 403 and 404 unless otherwise noted.

5.1 Mixing Plant. A batch-type bituminous mixing plant shall be used in the production of the SMA mixture. The batch plant shall include a minimum of five cold aggregate feeders excluding mineral filler and a minimum of four separate hot bins.

5.2 Rollers. Three-wheel or two-wheel tandem type steel wheel rollers shall be used. All rollers shall be used in the static mode. A pneumatic tired roller will not be allowed.

6.0 PREPARATION OF MIXTURE. Preparation of the mixture shall be as set forth in Sec 404, except for the following requirements or modifications.

6.1 The predetermined number of press-packs of fiber material required in the mixture shall be added to the mineral aggregates either in the weigh hopper or in the pugmill. If added in the pugmill, they shall be added at the same time or immediately after the mineral aggregates but before the asphalt cement is added.

6.2 If fibers are added in the weigh hopper, the mineral aggregates and fibers shall be dry mixed for a maximum of 10 seconds. If the fibers are added to the mineral aggregates in the pugmill, the minimum dry mix time shall be 15 seconds of which at least 6 seconds but not more than 10 seconds shall be after all fibers have been added.

6.3 If mineral fibers are used in the SMA mixture, the wet mixing period shall be as specified in Sec 404. If cellulose fibers are used, the wet mixing period shall be increased 10-20 seconds to allow the cellulose fibers to expand and to ensure the adequate distribution of the fibers and binder.

6.4 Batch mixing temperature shall be started at 320 to 330°F and may be increased if needed to attain a homogeneous mixture, but the mixing temperature shall not exceed 350°F or a temperature at which any smoking of the mix occurs, whichever is lower. The final mixture, when discharged from the pugmill, shall have a minimum temperature of 290°F and a moisture content not exceeding 0.50 percent by weight of mixture.

6.5 The dry and wet mixing times and batch mixing temperatures shall be as specified by the engineer.

6.6 The quantity of asphalt cement determined by calculation or tests on final mixture shall not vary more than ± 0.5 percentage point from the approved job mix formula.

7.0 MIX STORAGE. Considering the tendency of the asphalt cement in SMA to drain from the mix, storage of the SMA mixture shall be limited to the intermittent holding of the mix in the surge hopper while loading of trucks is performed.

8.0 CONSTRUCTION . Construction requirements shall be as set forth in Section 403, including application of tack and prime coat, except for the following modifications and additional requirements.

8.1 Weather Limitations. The SMA mixture shall not be placed when either the air temperature or the temperature of the surface on which the mixture is to be placed is below 50°F.

8.2 Transportation of Mixture. Maximum haul distance of the SMA mixture is 30 miles. Truck beds shall be clean of materials such as mud, dirt, and aggregates. Just prior to loading of the mixture, the truck bed shall be sprayed with a light application of an approved truck bed release agent to reduce sticking of the mixture to the truck bed.

8.3 Spreading and Finishing. The mixture, when delivered to the spreading and finishing machine, shall have a temperature of not less than 275°F and be within 25°F of that specified by the engineer. The screed heater shall be used at all times during placement of the mixture unless otherwise stated by the engineer. The pavers forward speed shall not exceed 40 feet per minute. The paver speed shall be such that delivery of mixture to the paver is continuous.

8.4 Compaction. Rolling shall begin immediately after the mix has been placed. The engineer will monitor compacted density with a nuclear density gauge. Rolling shall be continued until all roller marks are eliminated and a minimum density of 97 percent of a plant specimen made in the proportions of the job mix formula in accordance with AASHTO T 245, is attained. Density will be determined by a specific gravity method.

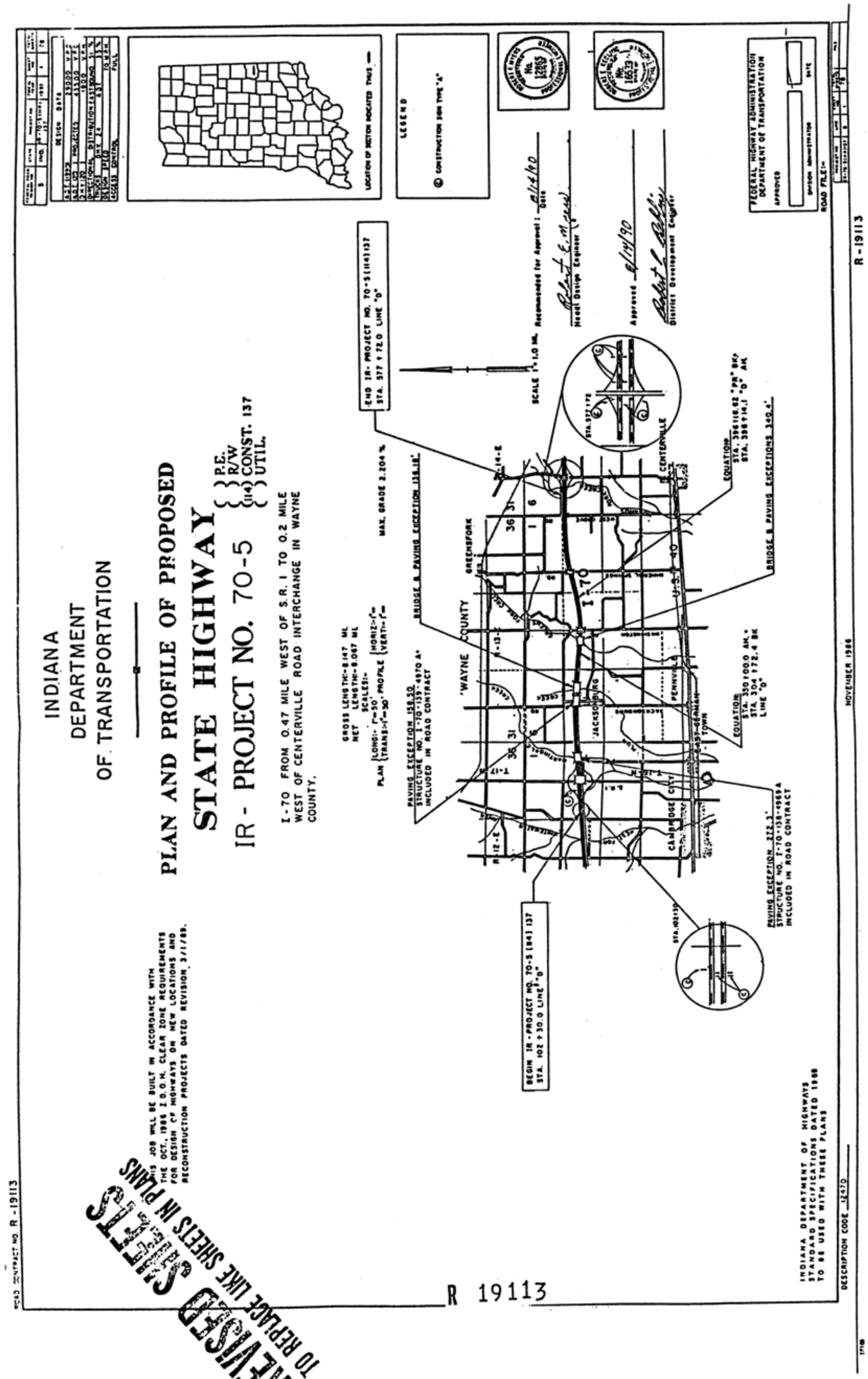
9.0 BASIS OF PAYMENT. Payment for the above described work including all materials, equipment, labor and any other incidental work necessary to complete this item shall be considered as completely covered unit price as set out in this proposal. The accepted quantities of SMA will be paid for at the unit price for the following pay items.

Description	Estimated Quantity	Price Per Unit
Asphalt Cement, AC-20, tons	68	
Mineral Aggregate, SMA mixture, tons	965	
Mineral Fibers, pound	5440	
Cellulose Fibers, pound	3180	

The above estimated quantities are based on 1.8 miles of 1½" thick, 12-foot wide SMA surface layer.

Appendix E

SMA Mixtures in Indiana


INDIANA
DEPARTMENT
OF TRANSPORTATION
PLAN AND PROFILE OF PROPOSED
STATE HIGHWAY
IR - PROJECT NO. 70-5
P.E.
R/W
(114) CONST. 137
UTIL.
I-70 FROM 0.47 MILE WEST OF S.R. 1 TO 0.2 MILE WEST OF CENTERVILLE ROAD INTERCHANGE IN WAYNE COUNTY.
WAYNE COUNTY
GREENSFORK
JACKSON
CENTERVILLE
PENNVILLE
CAMBRIDGE CITY
I-70
U.S. 40
REVISED SHEETS
TO REPLACE LIKE SHEETS IN PLANS
R 19113
R - 19113
NOVEMBER 1986
LEGEND
FEDERAL HIGHWAY ADMINISTRATION
DEPARTMENT OF TRANSPORTATION

Special Provisions
for
Bituminous Mixture Stone Mastic Asphalt (SMA)

DESCRIPTION

This work shall consist of designing, mixing, placing and compacting 165 #/yd^2 of stone mastic asphalt (SW+) bituminous mixture in accordance with section 401.04(c) and the following requirements.

MATERIALS

Aggregates for the SMA mixture shall consist of dolomite coarse aggregate, dolomite sand and mineral filler. The dolomite coarse aggregate and dolomite sand shall be produced from carbonate rock containing at least 10.3 percent elemental magnesium when tested as set out in Indiana Test Method No. 205. Mineral filler shall consist of dust produced by crushing stone.

Asphalt cement shall be MG 20-40 in accordance with the following:

Characteristic	Requirement	ASTM Test Method
Viscosity @ 140°F, P., 1 sec.$^{-1}$	2000-6000	D-4957
Viscosity @ 275°F, P., 10 sec.$^{-1}$	10-30	D-4957
Penetration @ 77°F, dmm	35-65	D-5*
Penetration @ 39°F, 200g, 60 sec., dmm	15-35	D-5*
Flash Point, °F	475+	D-92
Volubility in Organic Solvent, %	99+	D-2042
Softening Point, °F	140+	3-36*
Test After Thin Film Oven Test		
Viscosity @ 140°F, P., 1 sec.$^{-1}$	2000-10000	D-4957
Aging Index Vis. ATFOT/Vis. BTFOT	2.5-	

* Pouring temperature shall be in accordance with ASTM D-4957.

JOB MIX FORMULAE

The Contractor shall submit a job mix formula and mix design for approval by the Engineer. The optimum bitumen content shall be the bitumen content that produces 2-4 percent air voids determined in accordance with ASTM D-3203.

BITUMINOUS MIX TEMPERATURE

The temperature of the mixture at discharge from the mixer shall be from 280 to 320°F. The mixture shall be placed at a temperature of not less than 270°F.

ACCEPTANCE OF MIXTURE

Acceptance of mixture for gradation and bitumen content will be determined on the basis of extraction and gradation tests performed the Engineer. Acceptance tolerances from the job mix formula for each sieve and bitumen content shall be as follows:

Sieve Size %	Passing
1/2”	± 6.0
No. 4	± 5.0
No. 30	± 4.0
No. 200	± 3.0
Bitumen Content	± 0.4%

COMPACTION

Compaction shall start immediately after the mix has been placed and be obtained with steel-wheeled rollers. The rolling pattern shall be determined from a test strip in accordance with Indiana Test Method No. 577. Compaction will be controlled in accordance with 401.12(a).

BASIS OF PAYMENT

Payment for accepted quantities, complete in place, will be made at the contract price for:

Pay Item	Pay Unit
Bituminous Surface 11, HV (SMA)	Ton