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FINAL REPORT

ASPHALT RUBBER: A SUMMARY OF THE USE OF CRUMB RUBBER IN HOT MIXES: KANSAS EXPERIENCE 1990 - 2000

Glenn A. Fager, P.E.

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16 Abstract

From 1990 to 1995 a total of 13 projects were constructed using crumb tire rubber. These projects were built in responses to a legislature request to evaluate the feasibility of the use of crumb tire rubber in highway construction. Six projects were changed ordered and seven were administrated through normal bid procedures. The high-density mixes, recycle mixes, and the open graded mixes were employed in the experiment. Five were the modified dry process and eight were of the wet process. A total of approximately 2637 tons or crumb tire rubber were used in all of the 13 projects.

A rating system was established to evaluate the effectiveness of each project. Almost all of the crumb tire rubber came from outside of the state and very little was used from Kansas generated sources.

The report concluded that the use of crumb tire rubber in hot mix asphalt was possible but not economically feasible. Therefore, if the use of crumb tire rubber is mandated in the state of Kansas, it is recommended that another use be tried such as asphalt-rubber seals or burning the tires as a fuel source.

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Final Report

Prepared by

Glenn A. Fager, P.E.
Kansas Department of Transportation

A Report on Research Sponsored By

THE KANSAS DEPARTMENT OF TRANSPORTATION
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ABSTRACT

From 1990 to 1995 a total of 13 projects were constructed using crumb tire rubber. These projects were built in responses to a legislature request to evaluate the feasibility of the use of crumb tire rubber in highway construction. Six projects were changed ordered and seven were administrated through normal bid procedures. The high-density mixes, recycle mixes, and the open graded mixes were employed in the experiment. Five were the modified dry process and eight were of the wet process. A total of approximately 2637 tons of crumb tire rubber were used in all of the 13 projects.

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INTRODUCTION

In response to a State Legislature request, the Kansas Department of Transportation (KDOT) started in 1990 to incorporate ground tire rubber into experimental hot mix overlays. There were three basic reasons why KDOT was interested in using ground tires in hot mix.

1. To determine if it would reduce or retard reflective cracking from old Portland Cement Concrete or bituminous pavements.
2. To determine if it would reduce the amount of pavement rutting.
3. To address the environmental concerns over what could be done with old tires.

Over a five-year construction period (1990-1995), a total of 13 projects were constructed. Of the 13 projects constructed, five have been a modified dry process and eight have been of the wet process. Seven projects have been administrated through normal bid procedures. Six have been constructed through change orders and negotiated prices. Test sections were planned on eight of the 13 projects. Basically, most of these projects allowed KDOT to experiment with several different mix variations. Standard virgin mixes, new gap graded mixes, and even recycle mixes were tried on these projects.

The primary method of determining the amount of asphalt and rubber has been the Marshall method(1). At that time, this was the official mix design method for KDOT, and the one most familiar by the field personnel.

A total of approximately 2637 tons of rubber were used in these hot mix experimental overlays. Very little crumb rubber actually came from Kansas. Most of the rubber was shipped from outside the state. A map of the project locations for these mixes is presented in Figure 1 and will be referenced throughout this report.

HISTORY

KDOT's previous experience with asphalt rubber dates back to five experimental SAM and SAMI projects constructed in 1977, 1978, and 1979. SAMI stands for Stress Absorbing Membrane Interlayer, which consists of an asphalt rubber seal coat followed by a hot mix overlay. SAM stands for Stress Absorbing Membrane, which is an asphalt rubber seal coat left as the wearing surface. The results of the test sections were quite variable. On one project the SAMI test section had fewer cracks than the control section, but on the other three projects, the control section without asphalt rubber performed the best. On the fifth project the same performance was measured for both the control and test sections. The final report stated that none of the projects have an economic justification for the extra cost of using the asphalt rubber. However, later observations by KDOT's field personal did revealed that the SAM or asphalt-rubber seal performed quite well over the years.

In 1986, 16 states participated in a pooled fund study conducted by the Texas Transportation Institute(TTI). Iowa and Kansas were two of the states helping to finance the study. Numerous asphalt rubber projects constructed throughout the United States were reviewed. A report(2), issued by the FHWA in September 1986, concluded that the negative performance of some interlayer installations do not seem to be related to fundamental material properties, but to inappropriate use of the materials.

Based on the results of our test sections and the results of the TTI study, KDOT decided not to construct any more SAM or SAMI test sections, but to continue literature reviews on asphalt rubber. KDOT then decided to construct several asphalt rubber hot mix test sections, to determine if the thicker lifts of asphalt rubber hot mix would perform better than the SAM or SAMI projects.

There are two methods used by KDOT to accomplish this introduction of rubber into the hot mixes. The first process is a wet process and the second a new modified dry process.

WET PROCESS

The wet process is the already familiar MacDonald process. Crumb rubber (Type II or III) is shipped in 22.68

kg (50 lb) bags from a tire supplier or the tire grinding facility. The bags were then broken and the rubber conveyed to a mixing tank where hot asphalt, at approximately 204° C (400° F), was blended with the ambient temperature rubber. A typical blending ratio of 18% rubber and 82% AC-5 was used, but a blend ratio of 16/84 was also tried. The combined asphalt-rubber was then pumped to another heated tank where the blended material was allowed to "react" for 45-90 minutes at approximately 177° C (350° F).

After the asphalt-rubber had been reacted, the material was metered into the mixing chamber of the asphalt concrete production plant at the percentage required by the job mix formula. Both a batch mix plant and drum-drier mix plant were used in KDOT projects.

Trucks used for hauling the paving mixture were tailgate discharge, dump or moving bottom (horizontal discharge) type and compatible with the spreading equipment. At no time were bottom dump trucks used on the projects.

Paving was accomplished by a normal self-propelled, mechanical spreading, and finishing paver. It was capable of distributing the material to not less than the full width of a traffic lane and to the desired depth.

Compaction equipment was self-propelled rollers equipped with pads and a watering system to prevent sticking of the paving mixture to the steel-tired wheel (drums). A minimum of two rollers were used on the projects. Usually there were three steel rollers available. Pneumatic-tire rollers were hardly ever used, due to the increased adhesiveness of the asphalt-rubber binder.

DRY PROCESS (MODIFIED)

The modified dry process was the only process that KDOT elected to try as an alternate to the more expensive and previous described MacDonald (wet) process. It is applicable to a double drum plant mixer, but was tried later on a drum mixer as well. To date, all of the projects constructed under this process used the Ultra Fine rubber or what is commonly referred to as GF-80 rubber.

The process involves the handling of the Ultra Fine GF-80 rubber in bulk form (vs. bags in the wet process) through the use of pressurized truck tankers. The tanker blows the rubber into a storage silo. A gate, located at the bottom of the storage silo, discharges the rubber into a weigh chamber. The weigh chamber continuously measures the weight of the rubber where it can be monitored in the control facility. A vane feeder is also attached to the bottom of the weigh container that will meter the rubber or control the rubber feed rate. This rubber feed rate can be regulated to give the desired rubber mix content at the plant mix production rate. After the vane feeder has metered the ultra fine rubber out of the weigh container, the conveyor or auger system discharges the rubber into the outside mixing chamber of a double drum plant. The rubber is added at the same relative location as the asphalt cement and bag house fines. After hot asphalt is mixed very briefly with the super heated aggregate, the Ultra Fine GF-80 rubber is fed into the mix. The mix is then completely mixed in the outer barrel of the double drum plant. There is no reaction in that the rubberized asphalt is not held at elevated temperatures for 45-90 minutes.

The mix is discharged from the plant and handled very similar to any other mix operation. Typically, steel rollers are used instead of pneumatic rollers, due to the increased potential of rubber in the mat to stick to the rubber tires of the pneumatic rollers.

PROJECT EVALUATION CRITERIA

A listing of the projects is in chronical order. Each projects was evaluated based on formal crack surveys or by field observations. Some of the early projects had formal crack and rut surveys. Each project was given a rating from a four (highest) to a zero (lowest) based on its field performance. If a project's performance was outstanding, the rating would be a four. An average rating would be a two and a project that performed unsatisfactory would be rated zero. The grade presented was based on the (somewhat) subjective opinion of the author and KDOT personnel. But, that opinion is also based on the objective results of the crack surveys, rut measurements, skid numbers, falling weight deflectometer (FWD), and comments from the field personnel.

Some projects are described in detail along with the final results or conclusions. The project was then given a grade (four to zero). Some of the later projects did not receive a formal evaluation. Very little testing was accomplished on the mixes that went into the projects. These later projects were also given a grade based on only their field performance.

An overall rating for all of the 13 projects was calculated. Of course the overall rating will not be a whole number, therefore, the following range would be used to determine the overall project performance.

RATING	LEVEL OF PERFORMANCE
0 - 0.5	Unsatisfactory (Worse performance than conventional mix)
0.5 - 1.5	Marginal (Below satisfactory)
1.5 - 2.5	Satisfactory (Same performance as conventional mix)
2.5 - 3.5	Very Good (Above satisfactory)
3.5 - 4.0	Outstanding (Much better performance than conventional mix)

1990 HOT MIX PROJECTS

Two 1990 projects to be constructed in Kansas were located on US-75 south of Topeka and on K-2 southwest of Wichita. The Topeka project (Figure 1, No. 1-1990) was constructed over an old Portland Cement Concrete Pavement and the Wichita project (Figure 1, No. 2-1990) was placed over an old bituminous pavement. These were not highly experimental projects involving a great amount of testing. International Surfacing, Inc., of Phoenix, Arizona, was the subcontractor and did the preliminary mix design. The sections were constructed using their guide specifications and appropriate items from KDOT's Standard Specifications. The final field results from both projects will be summarized at the end of the 1990 project listing (After No. 2-1990).

No. 1-1990 / US-75 / Wet

The Topeka project began about 8.1 km (5 miles) south of Topeka and continued on south into Osage County. The test and control sections were located in the two northbound lanes and are shown in Figure 2. The two thicker sections were constructed 0.8 km (0.5 miles) long and received two base course lifts of 44 mm (1.75") BM-1B and one lift of a 19 mm (0.75 ") BM-1T, for a total of 108 mm (4.25") thick over the old PCCP. The two thinner sections, each 1.61 km (1 mile), received one lift of 44 mm (1.75") BM-1B and one lift of 19 mm (0.75") BM-1T, a total thickness of 64 mm (2.5"). The rest of the project was constructed 64 mm (2.5") thick as shown in the thin section. The 1989 traffic count on this 4-lane roadway was 6,610 annual average daily traffic (AADT).

The BM-1B base course mix is predominately a crushed limestone mix that has been used for the previous two years to reduce rutting. Most of the time the mix has been placed approximately 38 mm (1.5") thick. The 19 mm (1.5") BM-1T surface course is normally used for skid resistance on overlay projects for roadways with greater than 5,000 vehicles per day. It contains approximately 50% crushed limestone with 40% chat for skid resistance. These same two mixes were also used on the Wichita project. The asphalt-rubber was placed using a drum mix plant, in which the contractor had a new pipe installed in the drum near the existing asphalt supply line.

No. 2-1990 / K-2 / Wet

On this project, asphalt-rubber was placed near Viola, which is located approximately 21 km (13 mi) southwest of the city of Wichita. Shown in Figure 3 are the typical sections consisting of 57 mm (2.25") of BM-1B and 19 mm (0.75") of BM-1T, for a total of 76 mm (3.0"). The thinner sections consisted of 38 mm (1.5") of BM-1B and 19 mm (0.75") of BM-1T, for a total of 57 mm (2.25").

The existing bituminous pavement had numerous transverse, longitudinal, and block cracks. Many of the transverse cracks had secondary cracks. Generally, there were slight depressions associated with these secondary cracks. Most of the roadways were on a straight alignment and flat grade.

Results (No. 1 & 2)

1) The cost of the two mixes in both projects is presented in Tables 1 and 3. It is obvious that the asphalt-rubber mixes will cost substantially more than the asphalt only mixes. Both projects were small test sections with low pay quantities. They were also experimental with several unknowns to the contracting and state agencies. The cost was calculated and payments were made under change orders and not under low bid price conditions. Therefore, it would be expected that cost for constructing an asphalt-rubber test section would be quite high. Later project studies did indicate that the increased cost of asphalt-rubber mixes over conventional mixes could be reduced from 250% down to only a 30-50% cost increase.

2) Tables 2 and 4 present the crack and rut data for the US-75 and K-2 projects, respectively. For the first three years, the asphalt-rubber sections on both projects cracked more than the asphalt only section. For the next three years, the cracking accelerated in the asphalt only section. Both the thin and thick overlays of US-75 and K-2 projects revealed the same cracking trend.

Final rut measurements were completed in May 1996 on both projects. Four separate comparisons showed a decrease in the amount of rutting in the asphalt-rubber sections when compared to the asphalt only sections. None of the eight sections had major rutting. Two of the asphalt only sections on the K-2 project had minor rutting (Code 1). The other six sections had rutting less than the 6.35 mm limit. It appears that asphalt-rubber may reduce rutting.

3) Skid data was collected on the projects. Based on the collected numbers, it was determined that there was no significant difference between skid numbers obtained from an asphalt pavement and those taken on an asphalt-rubber pavement.

Based on the less than satisfactory performance of all of the test sections in US-75 and K-2 experiments and the expense of the asphalt-rubber mixes, both projects were each given a rating of one.

1991 HOT MIX PROJECTS

Due to the high cost in the construction of the 1990 small 2.4 km (1.5 mile) test sections, a larger and complete asphalt-rubber overlay was constructed. The principal idea was to determine if the volume of material, and the normal state competitive bidding procedures, would reduce the overall cost.

No. 3-1991 / US-24 / Wet

The wet process was used and the sub-contractor (International Surfacing Inc.) again completed the design. The sub-contractor also accomplished the blending and reacting of the asphalt-rubber. As in the 1990 projects a BM-1T mix was again used on most of the project. However, two@1-mile test sections were also designed and constructed after the total project had been awarded to the successful bidder. One of the test mixes was gap graded. The aggregate gradation increased the voids in the mineral aggregate (VMA), which in turn allowed room for more asphalt-rubber into the mix.

The second test mix on this project was a normal BM-1T, but with asphalt-rubber. This mix was also constructed on the rest of the project. A control section was constructed with a BM-1T mix using only asphalt as the binder. The location of the third project is indicated in Figure 1 (No. 3-1991). Table 5 gives a description of the aggregate, binder content, and cost data. Approximately 18.8 km (11.7 miles) of a 25 mm (1") overlay was constructed on US-24 in Jefferson and Douglas Counties.

Results (No. 3)

Table 6 presents the crack survey & wheel path rut measurement data. The complete project received an overlay in 1998 that negated any further crack & rut measurements. But, as of June 5, 1997, the asphalt rubber gap graded section had essentially no cracking. This was six years after construction. Even though the cost for this particular project was 2.75 times higher than a normal asphalt overlay, the increase in cost may be justified by the increase in service life. At this time, it is still undetermined what the actual life of the asphalt rubber gap graded mix would be as the whole project had to be overlaid. The factors used to determine the timing of the new overlay came from the condition of the pavement from outside the asphalt rubber gap graded test section.

Based on the unusually high field performance of no cracking or rutting in the gap graded test section, this experiment was given the highest rating of a four.

A noise study was completed on the US-24, US-75, and K-2 projects. The study was conducted in 1991, which was one year after construction had been completed on both projects.

The peak or highest noise levels generated by an individual vehicle passing by at controlled speeds and operating modes were obtained on the test sections. All measurements were taken when conditions were dry and on days when wind was not a factor. Microphones were calibrated and located 50′ from the centerline of the near lane that was used by the test vehicles. Because the test sections were under traffic, measurements were taken when the test vehicle was the only significant noise source on the control or test sections. Data used for developing the graphs consists of three passes at 55 m.p.h. in three modes of operation: cruising, accelerating, and rolling. Both a car and medium truck were utilized.

An interval report of the results were published in January 1992. The report concluded that there was a slight decrease in noise levels associated with the asphalt-rubber pavement on the US-75 and K-2 sites. An average of the overall data indicates a noise level of 69.73 dB for asphalt-rubber and 72.04 dB for the asphalt only pavement. This is a 2.31 dB decrease in noise level of high density asphalt-rubber pavements vs. asphalt-only pavements.

However, on the US-24 project, the asphalt rubber pavement produced the highest readings with the car and medium truck while the asphalt rubber (open-graded) indicated a slight decrease. The data for the heavy truck on US-24 indicates a slight non-detectable decrease in generated noise on the asphalt rubber, (84.2 vs. 84.9); however, a larger decrease for the open graded rubber asphalt, (82.5 vs. 84.9). The cruise and accelerating data for the heavy truck indicates that the mechanics of the truck dominate the tire pavement interaction and should not be considered a good test for the purpose of this study. In fact, the "roll by" should give the best indication of the pavement-tire interaction even though the engine, transmission, rear end and suspension would still be generating an uncertain amount of noise. Until exhaust and engine noise is quieted, little benefit can be expected by reducing tire-pavement noise.

No. 4-1991/ US-24/ Dry

Costs still remain high for the wet process and competitive bidding on larger quantities did not appreciably reduce the cost of the overall mix. Therefore, in order to reduce the cost and still incorporate rubber directly into the mix, a proposal from a contractor was approved to experiment with the use of crumb rubber as a fine aggregate (Modified Dry Process). The contractor owned a double drum counterflow hot mix plant, and the rubber could be fed so that it would not blow out with the exit exhaust. The ultra fine rubber was shipped from Mississippi and stored in a plant silo. When the plant was operating, the rubber was fed through a vane feeder to approximately the same location that recycled asphalt pavement (RAP) would be introduced into the plant.

Three test sections and one control section were constructed and the location is as indicated in Figure 1 (No. 4-1991). This was the fourth crumb rubber project, but the first using this new modified dry method. Even though the rubber was added separately to the mix, it was designed as part of the liquid binder. A 10% asphalt-rubber mix was computed as ten parts rubber (by weight) to 90 parts asphalt.

No major problems were encountered with the rubberized asphalt overlay. The mix was a 51 mm (2") KDOT BM-2A (low traffic surface course) laid over a milled surface.

Table 7 gives the data on the cost of the asphalt mix and three rubberized asphalt mixes, excluding mobilization. Due to the relatively small quantity of rubber used on the project, the mobilization cost was a major expense. If the project had been larger with a greater utilization of rubber then the cost of mobilization would have been less significant. (Also, in Table 7, the mix cost excluded indirect costs such as tack coats, stripping, etc.) The effect of these indirect costs would be relatively small.

Results (No. 4)

Table 8 presents the crack survey and wheel path rut measurement data. Cracking occurred in all of the sections. The asphalt-rubber sections with 5% rubber content cracked more than the asphalt only section. However, the 7.5% and 10% rubber section did perform slightly better than the asphalt only section. None of the test or control sections rutted.

Based on the crack surveys and the apparent inability of the rubber to reduce the cracking to any appreciable extent, the performance of this experimental project was rated as a <u>one</u>.

No. 5-1991 / US-59 / Dry

The fifth project was a continuation of experimentation with the new dry process. The project was a hot mix recycle that was started in 1991, but not finished until 1992 (Figure 1, No. 5-1991). This was the first attempt to introduce rubber into a hot recycle mix by this process. Previous KDOT products using the fine rubber involved virgin aggregates with a viscosity graded asphalt cement.

This project was originally set to add the fine rubber to both a 30% Reclaimed Asphalt Pavement(RAP)/70% Virgin Aggregate mix, and 50% RAP/50% Virgin Aggregate. Both mixes would have control sections where no rubber would be added. The plan was to build a total of five test sections and two control sections.

As in the previous dry process, the rubber was added directly into the mix with no pre-blending or reacting with the liquid asphalt. The amount of rubber to be added was calculated as a percentage of the <u>total</u> liquid binder (asphalt added plus asphalt in the RAP). This calculation could also be expressed as a blend ratio. A 10% asphalt-rubber mix blend ratio was computed as ten parts rubber (by weight) to 90 parts asphalt. Using this example for the asphalt-rubber recycle mixes, the 90 parts asphalt would include the asphalt added at the plant <u>plus</u> the asphalt in the RAP. If more asphalt was added at the plant, then more rubber needed to be added to comply with the overall blend ratio.

The project was complicated further by the fact that two different additives were used for the two different mixes. An AC-5 was used in the 30/70 mix, and a RA-100 asphalt rejuvenator was added to the 50/50 mix.

Construction began during the late fall of 1991. The existing 3.35 m (11') road was first milled to a depth of 38 mm (1.5"). Bituminous shoulders were extended 0.46 m (1 1/2') at a depth of 114 mm (4-1/2"), which widen the total roadway to 9.1 m (30 '). Cold weather prevented the project from completion, but a 38 mm (1.5") lift of the control and test sections were finished before winter shutdown. Severe raveling did occur on the first lift, but it was uncertain whether this was due to the rubber in the mix or the cool weather at the time of construction. The surface was "smoke coated" with a diluted asphalt emulsion by state maintenance forces. This was to control the raveling and keep the wheel paths from "shelling out."

During the winter, a decision to increase the binder content was made in order to counteract the effects of the raveling. Also construction would first be completed on other portions of the project so that the top and final lift would be constructed during warmer months of the construction season.

The 30% RAP/70% Virgin test and control sections were constructed without any major problems. The rubber asphalt content was increased beyond what was originally recommended, and this appeared to help reduce the tendency of the mix to ravel. The mix did appear to be tender and was somewhat difficult to compact. The section with 10% rubber looked better and had better workability.

Major problems occurred in the 50/50 mix. When the rubber asphalt was increased, the rubber had to be substantially increased in order to maintain the overall blend ratio. The resulting mix still appeared to be dry and would not adhere to the aggregates. Apparently the additional rubber absorbed the RA-100 and prevented proper coating of the aggregates. Various percentage of additives were tried in the southbound lane, but none proved effective. Finally a tanker load of AC-5 was ordered and used in the opposite lane the following day. This proved to be much more effective in coating the aggregates. The 50/50 mix had to use an AC-5 instead of an RA-100 in order to finish the test sections.

If rubber is to be added in a hot recycle project, it should not be tied to the total asphalt content as a blend ratio. It should be based on the weight of RAP and virgin aggregate (i.e. 10 lbs rubber per ton of virgin aggregate and RAP). The percent new asphalt could then be changed (increased or decreased) without affecting the rate of rubber utilization. Estimated quantities would be more accurate and production yield rates would be more manageable.

Results (No. 5)

A crack survey and rut survey was accomplished between 1993 to 1997 and the data is presented in Table 9. The crack surveys revealed that the control section performed better than the test sections. Therefore, this experimental project was rated as a one.

1992 HOT MIX PROJECTS

In 1992 the hot recycle project on US-59 in Allen County was finished. Three additional rubber projects were also completed, bringing the total KDOT rubber projects to eight. Initial crack survey results on the 1990 and 1991 projects indicated that the gap graded mix may prove more beneficial with regard to pavement cracking. Therefore, two more rubber projects were constructed using a gap-graded mix.

No. 6-1992 / US-54 / Wet

The sixth project was the wet process in which competitive bids were received on a 29.8 km (18.5 mile) project on US-54 in Kingman County (Figure 1, No. 6-1992). This project did not contain any test or control sections. The mix on this wet process project was designed and the binder reacted by International Surfacing, Inc. Costs were still high when compared to a normal paving grade asphalt cement. This project contained some rubber from a Kansas generated source or supply.

Results (No. 6)

The results were less than favorable. Extensive repairs were necessary after approximately two years. Water was entering the mix and causing deterioration in the asphalt-rubber and the base mix. The project was overlaid in 1996 by KDOT maintenance forces. This project had a life of only four years, which is unsatisfactory and was rated a "zero."

No. 7-1992 / K-16 / Dry

The seventh project, (Figure 1, No. 7-1992) incorporating a gap-graded mix and a BM-1B mix, used the double-drum dry process in which prices were again negotiated and several test sections built. The method of determining rubber content on this project was changed and based on weight of dry aggregate. The asphalt cement and rubber were varied independently of each other. The three test sections and control section of the BM-1B mix were built with increased amounts of asphalt and/or rubber.

Three test sections and one control section were also built using the gap gradation as previously described. The 0.8 km (0.5 mi) control section contained asphalt without rubber. Severe problems were encountered with the gap graded asphalt only mix. The asphalt would drain down from the aggregates and stick to the truck beds. When rubber was added to the mix this "drain down" problem was substantially reduced. This mix very closely resembled a Stone Mastic Asphalt (SMA) mix gradation. The major difference was that rubber (instead of fibers in a SMA mix) was used to control the amount of binder runoff of the aggregate. This allowed a thick asphalt-rubber film coating of the aggregates. Table 10 lists the mix and cost data of the control and test sections.

Results (No. 7)

No formal crack surveys were conducted on the project. However, informal site inspections were completed on the following dates:

1) March 30, 1993 BM-1B Mix

In the high asphalt-rubber mixes, some indications of bleeding, less cracking & no rutting.

Gap-Graded Mix

Some raveling in the lower asphalt-rubber content. Less cracking and no rutting in the high asphalt-content mixes.

2) Sept. 30, 1993 -BM-1B Mix

No rutting, less cracking, but some bleeding in the higher asphalt-rubber content sections.

-Gap-Graded Mix

Most test sections look good.

3) Aug. 7, 1995 -BM-1B Mix
No rutting but some cracking in all sections. Bleeding in the high asphalt-rubber sections.
-Gap Graded Mix
No rutting or bleeding. Raveling and cracking in the lower asphalt-rubber section.

4) July 3, 1997 -BM-1B Mix
No rutting but some cracking. Starting to form potholes on the low asphalt-rubber section.
-Gap Graded Mix
Some raveling in the low asphalt-rubber section. A few spot bleeding areas in the high asphalt-rubber sections. Cracking in all areas.

In 1998 the project was overlaid again, therefore it can be concluded that the asphalt-rubber sections would be expected to have a life of six years or more. Some of the test sections looked good at the time of the overlay and they would probably last longer than six years. It should be noted that when a section of roadway is overlaid, all of the test sections are overlaid at the same time regardless of the condition of the short test section. The rating of this experimental project was a three.

No. 8-1992 / I-70 / Dry

The last project was constructed on I-70 in Wabaunsee County (Figure 1, No. 8-1992). The project was built late in the construction season. The contractor was willing to try to use a normal drum mixer instead of a double drum mixer, incorporating the ultra fine rubber into the mix. Rubber was again vane fed from a silo, but air blown into a coater placed at the discharged end of a drum mixer. The rubber was not introduced into the mix inside the drum dryer where the hot gases could remove the fine rubber from the mixing chamber.

Results (No. 8)

No formal crack and rut surveys were conducted on this project. The main purpose for this project was to determine that the ultra-fine rubber could be added to a drum feed asphalt plant. This experimental project was given a rating of a two.

At the end of 1992, KDOT felt there was some evidence that full depth asphalt-rubber pavements may have longer serviceable life than conventional asphalt only pavements. Up until 1993, all of the rubber projects had been thin overlays (25-38 mm). In addition, there was some question as to whether the cracking performance of the asphalt-rubber mixes could be effectively evaluated due to the influence of the underlying layer. It wasn't until 1994 that the next project was let for construction.

1994 HOT MIX PROJECTS

No. 9- 1994 / US-54 / Wet

This project was a test section built on US-54 in Kiowa County. Three test sections were constructed using both a gap-graded base and a gap-graded surface mix. These test sections were built among several other different test sections that were constructed for other purposes. These wet mixes were designed and reacted by the subcontractor (International Surfacing Inc). The main contractor constructed the three test sections as follows:

Test Section No. 1 (Designated KDOT #3)	40mm ARS 240mm BM-2C
Test Section No. 2 (Designated KDOT #5)	40mm ARS 60mm ARB 200mm DGAB
Test Section No. 3 (Designated KDOT #6)	40mm ARS 60mm ARB 200mm BM-2C

Results (No. 9)

By 1996, major rutting had occurred in all of the rubber test sections. Cores were submitted for laboratory analysis, and the results concluded the rutting was due to both mix instability and densification in the wheel paths. Due to the premature rutting and extensive maintenance on the roadway, this experimental project was given a rating of a zero.

No. 10 and 11-1994

The next two projects in 1994 (Figure 1, No. 10 & 11-1994) were of the wet process in which competitive bids were received. The mixes in these wet process projects were designed and the binder reacted by a subcontractor (International Surfacing, Inc.). Mix cost was still high when compared to a normal paving grade asphalt cement mix.

The first project was a 40 mm ARS overlay on K-32 which is a lower traffic road in Leavenworth County. The second project was a 25 mm ARS overlay on a major street in Kansas City (US-56 or Shawnee Mission Parkway).

Results (No. 10 and 11) As of May 2000, both projects are still providing service to traffic although maintenance patching has been necessary on K-32. The project on K-32 was given a rating of a two. Due to the high and slow traffic in the Kansas City area, the project on US-56 was given a rating of a three.

No. 12-1994 / I-135 / Wet / NEPT KS 9401 (Final Report)

In 1994, a 15.25 km full depth asphalt-rubber project was constructed on I-135 in McPherson County, Kansas (Figure 1, No.12-1994). An adjoining 16.22 km full depth conventional asphalt only project was also constructed on I-135. There were four main reasons why KDOT was interested in constructing an asphalt-rubber project of this magnitude.

1. To determine if the full depth gap graded asphalt-rubber mix would reduce thermal cracking.

2. To determine if the mix would reduce the amount of pavement rutting.

3. To address the environmental concerns over the disposal of scrap tires.

4. To further develop equipment, mixes, and procedures that will comply with Section 1038 of the 1991 Intermodel Surface Transportation Efficiency Act (ISTEA), but produce a cost effective mix when compared to a conventional asphalt only mix. The project would have to be large enough so innovative construction equipment, methods, and procedures would also be cost effective. Also, actual cost data would be available on a large project and not on just test sections.

PROJECT DESIGN

The preliminary design of the 15.25 km project began as early as 1989. In May 1990, a pavement investigation report presented five different reconstruction strategies. Life cycle cost were computed over a period of 30 years with anticipated construction (overlays) occurring at estimated intervals of time. Most major reconstruction projects would include a Portland Cement Concrete (PCC) pavement and a Full Depth Bituminous (FDBIT) pavement alternate. At that time, asphalt-rubber in hot mix was not a considered option. However, field personnel were not satisfied with the early transverse cracking in FDBIT pavements. Therefore, the preferred construction practice was PCC pavement.

By 1992, KDOT had attained limited success in the reduction of early transverse cracking with the gap graded asphalt-rubber hot mix. There was also some interest in construction of FDBIT ACR pavement. The size of the project lends itself to reduced prices on the cost of the asphalt-rubber.

An initial cost analysis on three alternatives revealed that the asphalt-rubber could be competitive when compared to PCC pavement. There was also some interest in determining whether FDBIT ACR pavement would perform better than asphalt only pavement. FDBIT pavement (without rubber) was not a considered option due to the potential of early cracking.

The five strategies were reduced to three plans as indicated in Table 11. The method of structural design was AASHTO and the design factors were layer coefficients. Initial cost estimates were based on historical construction bid data except for the asphalt-rubber. Based on a limited number of small projects, the best estimate for the asphalt-rubber binder of a larger project was $ 300/metric ton. A 30-year life cycle cost period was used for all three plans. The construction rehabilitation actions at 10 and 20 years are also presented in

Table 11. The present worth cost of these 10 and 20 year actions, are projected back to the overall 30 year life cycle cost.

Strategy C was approved as the most feasible construction option. Some reconstruction into the subgrade would be necessary at five bridge locations in order to maintain adequate bridge clearance.

The asphalt rubber project was committed to letting in 1993 with two rubber alternates. Alternate #1 allowed bids for a Type III reacted (wet process) crumb rubber modified bituminous pavement. Alternate #2 allowed bids for a Type VI (Ultra Fine) rubber to be added in the outside drum of a double drum hot mix plant. The fine rubber powder could also be added in the pugmill of a batch or continuous flow plant (drum mixer). Alternate #2 would not involve any specified reaction time, although it was expected that some of the very fine rubber would experience some degree of asphalt-rubber reaction. This alternate was considered as the dry process of adding rubber to the bituminous mix, although it actually may be a modified dry process. The possibility of using a Type VI (Ultra Fine) rubber in the wet process was not considered due to cost and the unknowns. Type VI rubber is approximately two to three times more expensive than Type III rubber. If this third process was considered, it would probably not be cost competitive to the other two processes. Also, alternate No's 1 and 2 had already been used on previous KDOT projects as referenced in a previous report (3). Local contractors had the ability to construct pavement using either one of the two alternatives.

Two different aggregate mixes would be used on the project. One would be an asphalt-rubber base (ARB) and an asphalt-rubber surface (ARS). Both of these aggregate gradations contain high voids in the mineral aggregate (VMA). This will allow thick asphalt rubber film in the mix. This should in turn give favorable thermal cracking characteristics.

There was one bid for alternate #1 (Wet process) and two bids for alternate #2 (Ultra Fine Dry process). Table 12 presents the cost breakdown for the two alternates. The wet process was approximately $2/ton less than the ultra fine dry process. However, for comparison purposes only, it was approximately $12.90/metric ton or 60% more than the bid prices on a conventional asphalt only mix.

TEST SECTIONS

Control and Test Sections were also laid out and constructed in the northbound lanes. Figures 4 through 7 show cross sections of each section. Test Section #1 (Figure 4) was a complete reconstructed section using a 150 mm lime treated subgrade and a 360 mm asphalt rubber mix (320 mm asphalt rubber base plus 40 mm asphalt rubber surface). These typical sections had to be constructed under the five bridge overpasses in order to provide proper bridge clearances. Therefore, a test section from this particular design was incorporated into the overall research project. The 1.85 m and 3.1 m shoulders in this section and in the other three sections were built using asphalt only mixes. Test Section #1 contained a 225 mm conventional asphalt only mix on the shoulders.

Test Section #2 (Figure 5) was a short segment that was 180 mm of asphalt-rubber over rubblized PCC pavement. Edge drains were added to remove any water that was trapped or accumulated in the rubblized concrete. The shoulders were built using an asphalt only binder. This short test section was added to the construction project to possibly determine if a thickness reduction in the asphalt rubber would perform equally well to the other test and control sections.

Most of the project was constructed as indicated in Test Section #3 (Figure 6). The only difference between section #2 and section #3, is that section #3 is 45 mm thicker. The asphalt only shoulders were also built to normal design thickness of 225 mm.

The control section (Figure 7) was a 225 mm asphalt only overlay on rubblized PCC pavement. Shoulders were of the same overall thickness and edge drains were also installed next to the rubblized PCC pavement.

The mixes that were used in the control and test sections are characterized in Table 13. There were a total of six mixes used in the control and test sections. Both the Marshall and U.S. Corp Gyratory (GTM) were used to select the binder content. A 75 blow Marshall was used for the mainline and 50 blows were used for the shoulders. The volumetric characteristics of the Marshall method was used more than the GTM. The GTM was primarily used during the construction phase to possibly provide future historical data.

CONSTRUCTION

Construction started in July 1993, but due to the rains, the paving did not start until early April 1994. The southbound lanes of the four lane 15.25 km interstate project was constructed first. Once the southbound lanes have been constructed, the northbound lanes were built including the control and test sections.

The entire length of the old 220 mm concrete surface was rubblized by a pavement breaker. After the pavement breaker reduced the former driving surface into fairly large size pieces, a modified steel wheel roller smoothed it out as much as possible. Edge drains with outlets were installed along the edge of the rubblized section. The small areas that were completely removed did not incorporate any edge drains.

The asphalt-rubber overlays went well with no appreciable problems with the mix or specifications. A good full day's construction would permit approximately 4000 tons of asphalt-rubber to be mixed, reacted, hauled to the paver, spread and compacted. Only one drum mix plant was used on the project. The plant could accommodate either asphalt only <u>or</u> asphalt rubber mixes in minimal change over time.

REACTION PROCESS

The main contractor and the equipment manufacturer worked together to build an asphalt rubber reaction mixing plant. Figure 8 is an overall schematic of the process. The major components can be described as follows:

1. Rubber Tank Silo:

Originally, rubber was shipped in large 900 kg bags and transported to the mixing tank through an elevator/conveyor system. This proved very awkward so a sealed storage silo was installed at the plant. Pressurized tanker trucks could now transport and handle the rubber with little danger from moisture contamination. A weight pot and van feeder installed at the bottom of the silo would weigh the rubber and then feed it into a pneumatic line that would in turn blow it into a mixing/reaction tank.

2. Mixing/Reaction Tank (34,069 Liters):

Rubber that was fed into the mixing and reaction tank was reacted for 45-90 minutes with AC-10. Hot AC-10 at 200°C was supplied from a 37,854 liter storage tank, which in turn was supplied from asphalt tanker trucks. Reaction of the asphalt rubber was periodically checked with a Haake viscosimeter. Once a viscosity of 1000-4000 cps was attained, the reaction was considered complete and the reacted asphalt rubber was then pumped into a 68,137 liter storage tank. Typically, 22,712 liters of AC-10 was reacted with 3.67 metric tons of crumb rubber for an approximate 16/84 rubber/asphalt blend ratio. Later in the project, the blend ratio was reduced to 13/87. The asphalt rubber reaction was a "batch" process, but the process thereafter was considered a continuous flow process.

3. Storage Tank (68,137 Liters):

The only purpose of the storage tank was to keep the asphalt rubber heated before it was pumped and metered into a drum mixer to complete the asphalt rubber bituminous mix process. A 3630 bituminous mix metric ton day would require the storage tank to be charged 9.4 times (with the 22,712 liters of AC-10 and 3.67 metric tons of rubber).

4. Hot Oil Heater:

Probably one of the more important components of the reaction plants is the hot oil heater. A special circulating oil was heated to approximately 205°C and circulated through heating coils in the 34,069 liter mixing/reaction and 68,137 liter storage tanks. Additionally, the hot oil circulated through jackets that surround almost all of the asphalt only and asphalt rubber circulation pipes. This kept the supply and transfer lines hot. After completion of the heating circuit, the oil was returned to the oil heater to begin the circulation process over again. The heated oil <u>never</u> came into direct contact or was mixed with the asphalt nor with the asphalt rubber.

The complete process started when AC-10 was shipped from the refinery and pumped into the 37,854 liter storage tank. It was kept hot until the asphalt rubber was needed on the project. The AC-10 was then pumped into the 34,069 liter mixing/reaction tank. Rubber was than pneumatically added while the mixture was agitated within the tank. Samples were taken at periodic intervals and checked for viscosity.

After the reaction was complete, the now reacted asphalt rubber was transferred into a storage tank. After transfer or charging of the storage tank, the reaction tank was then free to accept another batch to be reacted. The storage tank held the supply of reacted asphalt rubber for a continuous hot mix operation.

The batching and transferring would continue just as fast as the asphalt rubber could be reacted. The production capability of this plant was 320 metric tons reacted asphalt rubber mix per hour at a 16/84 blend ratio. Rubber contents for this project typically varied from 16/84 down to 13/87 rubber/asphalt blend ratios.

The asphalt rubber test sections were completed and opened to traffic on Nov. 23, 1994. The asphalt only control section had to be delayed for winter shutdown, but was finished in 1995.

Laboratory Testing

Almost all of the research laboratory testing was conducted on the rubber mixes. The Marshall design method (*1*) selected the asphalt rubber content, but rutting, permeability, and thermal characteristics were measured as well. The U.S. Corps Gyratory Compactor (GTM) could possibly address the rutting potential. Mix permeability would be related to future detrimental effects of moisture getting into the pavement and causing damage. The thermal characteristics would be measured through the use of a Thermal Stress Restrained Specimen Test (TSRST).

The GTM is both a compactor and testing machine. To conduct the test, specimens are clamped in the mold chuck. Vertical pressure is applied to the specimen through a vertical ram and roller bearing mounted head. Vertical pressure is automatically maintained during the test. Gyratory motion is then applied to the sample by two rollers. One moves around the top surface of the chuck flange and the other around the lower surface. The elevation of the lower roller is adjustable to allow setting of any gyratory angle or degree of shear strain. The interaction of the vertical pressure and the movement of the rollers around the chuck flange gives the mold and its test specimen the rolling undulating motion that kneads the test materials in ways that closely approach the pressures and wear of highway use. Motion of the chuck mold is recorded and this motion is affected by the plasticity of the test material. In other words, the GTM acts as both compactor and shear tester. Results of testing include direct measurement of unit weight and stability.

Test data from the GTM are read out in the form of a gyrograph chart. The gyrograph shows, in a close-spaced oscillating pattern, the variable gyrating motion of the test mold and its specimens. It is a recording of the shear strain of the test sample during the compaction test.

The density is monitored through the compaction process. It is directly affected by the ram pressure, angle of gyration, and number of revolutions. On most hot mix projects, the Kansas Department of Transportation (KDOT) has typically used 827 Kpa Ram pressure at a 1° initial gyratory angle. For interstate projects 60 revolutions have correlated well with 75-blow Marshall. Hot mix placed on shoulders and most low traffic roads use a 50 blow Marshall to select the asphalt content and this has correlated well to 45 revolutions on the GTM. Using the GTM to design asphalt rubber mixes would depend upon the anticipated densities that these mixes would be expected to attain in a few years. The densities of the now in place asphalt rubber pavements should be monitored over a time period to establish the design densities for future GTM compactions. At the present time, only 50 and 75 blow Marshall densities can be used for design purposes. Due to the viscosity of the asphalt rubber mixes, it is reasonable to expect a lower "design" revolution and/or initial gyratory angle. It is anticipated that the design density for the asphalt-rubber mixes would be lower than normal asphalt only mixes.

Figure 9 presents a collective plot of the GTM compaction density data. Gyratory Stability Index (GSI) is defined as the ratio of the maximum gyratory angle to the minimum intermediate gyratory angle, at any selected number of revolutions. A GSI in excess of 1.00 indicates a progressive increase in plasticity during densification. An increase in this index at a particular density indicates an excessive binder content for the compaction effort employed and foretells instability of the bituminous mixture for any particular pressure, angle, and number of employed revolutions.

Equilibrium compaction is defined as a point on the gyrograph where the rate of change in density reaches 16 $kg/m^3/100$ revolutions. This rate of change is considered an equilibrium condition for the applied initial gyratory angle and ram pressure. For the equilibrium condition, the number of revolutions is therefore not a mix design factor or parameter.

Figure 9 is a plot of the GSI's compaction configurations (angles, revolutions, and equilibrium conditions). A least squares line through the data points indicates mix instability above 2150 Kg/m^3. Field nuclear meter densities average 2165 Kg/m^3. Figure 9 indicates that if the field pavement densities increased, then the GSI would exceed 1.00 substantially, and rutting could be expected.

Permeability and TSRST tests were completed on both the asphalt rubber surface and base. Air and water permeability data was measured on field Marshall specimens that had been compacted by 75 blows/side of a Marshall hammer. All of the plugs indicated a high permeability. TSRST data was measured on the field rubber mixes that were recompacted to various densities using a kneading compactor. The TSRST determines the tensile strength and temperature at fracture of compacted bituminous mixtures by measuring the tensile load in a 5 cm diameter specimen that is cooled at 10°C/hour. The ends are restrained from contracting, therefore the test simulates the field cooling conditions. TSRST data is presented at the top of Table 14. The asphalt rubber mix compares favorably with other Kansas mixes (both asphalt and asphalt rubber) are presented for comparative purposes.

Cost Data

Tables 11, 12, 15, and 16 list most of the cost considerations for this project. Table 11 gives the strategies and cost estimates that revealed why asphalt-rubber pavements may be cost effective when compared only to PCCP pavements.

Table 12 presents the cost comparison of the wet (reacted) process, when compared to the dry method using the ultra-fine rubber. This cost comparison is applicable only to large projects (i.e. 172,000 metric tons of asphalt-rubber).

Table 15 is a cost comparison of asphalt-rubber mixes as compared to asphalt only mixes. Both the surface and base of each mix showed that the asphalt-rubber mix would cost 45% to 56% more than an asphalt only mix. However, Table 16 indicates that the total cost per kilometer may result in less of a percentage increase. In Table 16, the control section should be directly compared to an "equal" asphalt-rubber section, which is Test Section #3. For comparison, a 27% increase in construction cost is realized. If the asphalt-rubber thickness was reduced from 225 mm to 180 mm (as indicated in Figure 5), the cost per kilometer of the thin or reduced section would actually be slightly less than the asphalt only control section.

There were two cost effective strategies for this project when asphalt-rubber was compared to asphalt only pavements. PCCP comparison was not considered as there was no actual PCCP pavements built in the immediate area.

First, in order for asphalt-rubber pavements to become cost effective when compared to an equally thick asphalt only pavement, the life of the asphalt-rubber should last 27% longer. Second, the cost effectiveness could be applied to reducing the thickness of asphalt-rubber section. A reduction of 45 mm in the asphalt-rubber section (Test Section #2) would result in an equal cost of the asphalt-rubber section to asphalt only section. In this case, the life of the 185 mm asphalt-rubber section (Test Section #2) would also have to be equal to the 225 mm asphalt only control section.

Results (No. 12)

The projects were surveyed and cored on June 12, 1995. This was after six months, one winter, and approximately 137,000 Equivalent Single Axle Loads (ESAL's). There were no cracks, raveling, flushing, or rutting. All visual observations indicate that the pavement is performing satisfactory. Core analysis indicates that permeabilities remain high, but there was no indication of moisture damage. Average densities in between wheel paths (IWP) were 2020 kg/m^3 and in the wheel path (WP) were 2073 kg/m^3. On Figure 9, the location of the WP density (2073 kg/m^3) indicates a GSI of 1.00. Under the GTM design concept, the pavement should not rut until the pavement densities exceed at least 2100 kg/m^3. Whether 2100 kg/m^3 will be exceeded can only be determined after the pavement has experienced a considerable number of traffic ESAL's. Later in the year there were signs that the pavement was starting to flush and rut. The field personnel became concerned, and a slurry seal was applied to the whole road (including the test sections) through an emergency work order. However, monitoring of the test section continued through crack and rut surveys as well as FWD testing.

Table 17 reveals that all of the test sections did not crack over a six year period. Most of the rutting occurred in Test Section No. 1. The least rutting was in the section that contained the reduced asphalt-rubber thickness.

Table 18 presents the Falling Weight Deflectometer (FWD) analysis over a six year period. It becomes very clear that the thick ARB over lime treated subgrade has the lowest modulus. The test section with the reduced thickness has approximately the same modulus as the testing section with 45 mm extra ARB.

Based on the variable results, this project was given an average rating of a two.

1995 HOT MIX PROJECT

The last project to be constructed in Kansas was on US-75 in Brown County (See Figure 1, No. 13-1995). It was a low bid project with no test sections.

No. 13-1995 / US-75 / Dry

Both the Marshall and the U.S. Corps Gyratory (GTM) were used to design the mix. The Marshall indicated acceptable air voids up through 10.0% AC-5. The maximum asphalt-rubber content was 9.53% and the VMA was 22.15% at the design asphalt content of 9.0%. GTM compactions were completed at the same percentages as the Marshall design. All of the GTM compactions indicated a stable mix up through 10%.

Results (No. 13)

The project flushed badly in the wheel paths, but it did not rut. An investigation revealed that the gradation of the aggregate had changed and this caused part of the bleeding problem. The total cause of the problem with the pavement and as to why it bled so severely remains unknown. Conversations with other agencies suggested an incompatibility of the asphalt cement with the rubber. The skid trailer tested the roadway in the wheel path and in between wheel paths. Skid numbers were acceptable in between the wheel path, but extremely low in the wheel path. It was obvious that some form of action was immediately necessary and that the additional work would have to be paid through a force account. It was decided that a high skid resistant material known as expanded shale (or lightweight aggregate) would be spread in the wheel path thereby resulting in higher skid numbers. Even though the wheel paths were severely bleeding, the lightweight aggregate raveled and would not stay in the wheel path. A second force account emergency project was let except a heater-scarifer was used to preheat the surface and additional lightweight was added to the surface. This attempt proved successful, and the skid numbers improved to an exceptable level. Due the immense safety problems and the high cost overruns, this project was rated a <u>zero</u>.

SUMMARY

1. On large projects, cost estimates of asphalt-rubber pavements are competitive to PCCP pavement in certain locations of the state. However, cost estimates also indicate that asphalt-rubber will be more expensive than asphalt only pavements. Unless the performance of asphalt-rubber can be improved on a consistent basis, the use of crumb tire rubber in asphalt should not be implemented. The overall expense of an "asphalt-rubber project" might be comparable to an "asphalt only project", if the thickness of the asphalt-rubber can be reduced and still yield equivalent performance. Also, one mix did yield a longer performance life, which could make the product equally cost effective on a life cycle cost basis.

2. Asphalt-rubber projects are more expensive than asphalt only projects. Even on large projects, the increased cost for the wet process will remain approximately 50% higher than conventional mixes.

3. The thermal fracture temperature of asphalt-rubber mixes can be compared to a conventional AC-5 or AC-10 mix. Asphalt-Rubber mixes have higher (poorer) fracture temperatures than a Superpave mix using a PG 64-34 binder.

4. Rubber in a gap-graded mix will prevent asphalt from draining off of the aggregates during construction. This will allow thick film on the aggregates and help retard the tendency of the mix to stick to truck beds, etc.

5. On hot recycle projects using the dry process, rubber addition rates should be based only on the weight of dry virgin aggregates and RAP. Rubber and RA-100 are very reactive in a hot recycle mix. Rubber appears to have absorbed most of the RA-100, thereby causing a dryer than normal mix. An AC-5 with rubber will reduce the asphalt absorption and improve aggregate coating.

6. Tables 2, 4, 6, 8, and 9 give the crack survey results on several of the projects. From these results it is apparent that rubber will not inhibit the development of cracks in the higher density mixes. However, the gap-graded mixes do show the greatest potential in reducing the amount of cracking.

CONCLUSIONS

1. Based on the laboratory testing and field pavement condition surveys, the use of crumb tire rubber in bituminous mixes is not economically feasible.

2. If the introduction of crumb rubber into asphalt is to be attempted in the future, no specific recommendations can be made from a study of these 13 projects. Several (approximately nine) techniques and methods were tried, but no specific action could be determined as a proven method for success. For every successful attempt, there was an unsuccessful disaster. Using crumb tire rubber in seals or as a fuel source in a cement kiln may be more successfully implemented.

REFERENCES

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3. Fager, G., "Use of Rubber in Asphalt Pavements: Kansas Experience," Transportation Research Record 1436, TRB, National Research Council, Washington D.C., 1994, pp. 88-97.

TABLE 1. Mix & Cost Data, US-75, Osage County, No. 1-1990

MIX	DESCRIPTION	BINDER CONTENT (AGGREGATE BASED) (%)	COST DATA (MIX) (%/TON)
BM-1B	Asphalt Only 85% Crushed Limestone 15% Sand	4.75% AC-10	17.09
BM-1B	Asphalt Rubber 85% Crushed Limestone 15% Sand	6.16% ACR 16% Type III Rubber 84% AC-5	46.18
BM-1T	Asphalt Only 47% Crushed Limestone 40% Chat (Mine Tailings) 13% Sand	5.5% AC-10	19.97
BM-1T	Asphalt Rubber 47% Crushed Limestone 40% Chat (Mine Tailings) 13% Sand	6.3% ACR 16% Type III Rubber 84% AC-5	49.22

TABLE 2. Crack and Rut Survey, US-75, Osage County, No.1-1990

SURVEY DATE (Mo/Day/Yr)	TRANSVERSE CRACKING (PERCENT OF ORIGINAL)			
	THIN OVERLAY		THICK OVERLAY	
	CONTROL SECTION (Asphalt Only) 19mm Surface BM-1T 44mm Base BM-1B	TEST SECTION (Asphalt-Rubber) 19mm Surface BM-1T 44mm Base BM-1B	CONTROL SECTION (Asphalt Only) 19mm Surface BM-1T 89mm Base BM-1B	TEST SECTION (Asphalt-Rubber) 19mm Surface BM-1T 89mm Base BM-1B
6/20/1990	0 (Construction)	0 (Construction)	0 (Construction)	0 (Construction)
10/04/1990	0	0	0	0
01/17/1991	31	47	1	10
05/02/1991	34	62	5	27
10/03/1991	31	62	3	25
05/21/1992	50	62.3	4	39
10/06/1992	39	58.5	3	34
04/16/1993	58	70.7	23	40
04/18/1994	61	75	41	42
05/02/1995	98	81	87	51
05/22/1996	218	90	198	64
WHEEL PATH RUTTING (As of 5/22/96)	1.43 mm ESD=.52 mm N=8	0.86 mm ESD=0.76mm N=8	1.05 mm ESD=0.89 mm N=8	1.32 mm ESD=1.17 mm N=8

TABLE 3. Mix & Cost Data, K-2, Sedgwick County, No. 2-1990

MIX	DESCRIPTION	BINDER CONTENT (AGGREGATE BASED) (%)	COST DATA (MIX) (%/TON)
BM-1B	Asphalt Only 75% Crushed Limestone 25% Sand	5.0% AC-20	17.60
BM-1B	Asphalt Rubber 75% Crushed Limestone 25% Sand	6.6% ACR 18% Type III Rubber 82% AC-5	44.64
BM-1T	Asphalt Only 36% Crushed Limestone 40% Chat (Mine Tailings) 24% Sand	5.75% AC-20	19.64
BM-1T	Asphalt Rubber 36% Crushed Limestone 40% Chat (Mine Tailings) 24% Sand	7.4% ACR 18% Type III Rubber 82% AC-5	49.45

TABLE 4. Crack & Rut Survey, K-2, Sedgwick County, No. 2-1990

	TRANSVERSE CRACKING (PERCENT OF ORIGINAL)			
	THIN OVERLAY		THICK OVERLAY	
SURVEY DATE (Mo/Day/Yr)	CONTROL SECTION (Asphalt Only) 19mm Surface BM-1T 38mm Base BM-1B	TEST SECTION (Asphalt-Rubber) 19mm Surface BM-1T 38mm Base BM-1B	CONTROL SECTION (Asphalt Only) 19mm Surface BM-1T 57mm Base BM-1B	TEST SECTION (Asphalt-Rubber) 19mm Surface BM-1T 57mm Base BM-1B
8/29/1990	0 (Construction)	0 (Construction)	0 (Construction)	0 (Construction)
10/31/1990	0	0	0	0
01/18/1991	0	0	0	.4
10/02/1991	0	0	0	.2
05/01/1992	.4	5.6	0	1.6
12/02/1992	3.4	6.4	.4	2.9
05/04/1993	28.5	32.1	10.2	24.8
07/18/1995	41.8	31.2	31.0	24.4
05/16/1996	75.9	37.5	63.1	32.7
WHEEL PATH RUTTING (As of 5/16/96)	6.71 mm ESD=1.27 mm N=40	3.70 mm ESD=3.33mm N=24	6.61 mm ESD=1.53 mm N=24	3.33 mm ESD=2.81 mm N=20

TABLE 5. Mix & Cost Data, US-24, Jefferson County, No. 3-1991

MIX	DESCRIPTION	BINDER CONTENT (AGGREGATE BASED) (%)	COST DATA (MIX) ($/TON)
BM-1T	Asphalt Only 45% Crushed Limestone 40% Chat (Mine tailings) 15% Sand	5.25% AC-10	21.05
BM-1T	Asphalt-Rubber 45% Crushed Limestone 40% Chat (Mine tailings) 15% Sand	6.9 18% Type II Rubber 82% AC-5	48.97
BM-Gap Graded	Asphalt-Rubber 60% Crushed Limestone 40% Chat (Mine Tailings)	8.9% AC-10 18% Type II Rubber 82% AC-5	57.71

TABLE 6 Crack & Rut Survey, US-24, Jefferson County, No. 3-1991

	TOTAL CRACKING (PERCENT OF ORIGINAL)		
SURVEY DATE (Mo/Day/Yr)	CONTROL SECTION (5.25% Asphalt Only) 25mm Surface BM-1T	TEST SECTION (6.9% Asphalt-Rubber) 25mm Surface BM-1T	TEST SECTION (8.9% Asphalt-Rubber) 25mm Surface Gap Graded
05/30/1991	0 (Construction)	0 (Construction)	0 (Construction)
10/03/1991	.7	0	0
05/21/1992	18.7	3.0	0
10/06/1992	15.4	2.8	0.3
04/19/1993	71.3	30.9	0
10/27/1993	49.2	12.8	0
05/05/1994	82.8	30.4	0
09/27/1994	96.2	(Maintenance Patch)	0
05/09/1995	124.6		0
05/23/1996	(Maintenance Patch)		0.5
06/05/1997			0.8
RUTTING DEPTH (As of 5/23/96)	0.05”	0.07”	0.15”

1” = 25.4mm

TABLE 7. Mix & Cost Data, US-24, Mitchell County, No. 4-1991

MIX	DESCRIPTION	BINDER CONTENT (AGGREGATE BASED) (%)	COST DATA (MIX) (% / TON)
BM-2A	Asphalt Only 66% Crushed Limestone 34% Sand	5.25% AC-10	20.22
BM-2A (3 Binder Contents)	Asphalt Rubber 66% Crushed Limestone 34% Sand	5.5% ACR 5% Ultra Fine Rubber 95% AC-10	21.96
		5.5% ACR 7.5% Ultra Fine Rubber 92.5% AC-10	22.70
		5.5% ACR 10% Ultra Fine Rubber 90% AC-10	23.44

TABLE 8. Crack & Rut Survey, US-24, Mitchell County, No. 4-1991

SURVEY DATE (Mo/Day/Yr)	TOTAL CRACKING (PERCENT OF ORIGINAL)			
	CONTROL SECTION (Asphalt Only)	TEST SECTION (95% Asphalt) (5% Fine Rubber)	CONTROL SECTION (92.5% Asphalt) (7.5% Fine Rubber)	TEST SECTION (90% Asphalt) (10% Fine Rubber)
05/28/1991	0 (Construction)	0 (Construction)	0 (Construction)	0 (Construction)
12/05/1991	38.5	87.8	70.4	21.3
07/30/1992	47.7	87.4	73.5	41.7
07/19/1993	91.4	131.1	99.6	119.0
08/01/1994	112.1	133.1	100.6	138.0

TABLE 9. Crack & Rut Survey, US-59, Allen County, No. 5-1991

SURVEY DATE (Mo/Day/Yr)	TRANSVERSE CRACKING (PERCENT OF ORIGINAL)		
	CONTROL SECTION (0% Rubber) (30% RAP) (70% AGG)	TEST SECTION (10% Rubber) (30% RAP) (70% AGG)	CONTROL SECTION (12.5% Rubber) (30% RAP) (70% AGG)
04/20/1993	1.4	9.6	4.2
04/27/1994	0.6	7.3	2.7
05/15/1995	1.1	17.9	8.1
04/30/1996	24.0	184.2	69.6
05/09/1997	72.9	184.5	112.9

TABLE 10. Mix & Cost Data, K-16, Jackson County, No. 7-1992

MIX	DESCRIPTION	BINDER CONTENT (AGGREGATE BASED) (%)	COST DATA (MIX) (%/TON)
BM-1B	Asphalt Only 80% Crushed Limestone 20% Sand	5.5% AC-10	17.67
BM-1B	Asphalt Rubber 80% Crushed Limestone 20% Sand	5.0% AC-10 1.0% Ultra Fine Rubber	24.27
		6.0% AC-10 1.0% Ultra Fine Rubber	24.79
		7.0% AC-10 1.0% Ultra Fine Rubber	25.29
BM-Gap Graded	Asphalt Only 100% Crushed Limestone	6.0% AC-10	20.55
BM-Gap Graded (3 Binder Contents)	Asphalt-Rubber 100% Crushed Limestone	8.0% AC-10 1.0% Ultra Fine Rubber	28.30
		8.0% AC-10 1.5% Ultra Fine Rubber	31.59
		8.5% AC-10 1.5% Ultra Fine Rubber	31.80

Table 11. Construction Strategies and Cost Estimates, I-135, McPherson County, No. 12-1994

STRATEGY	ACTION	COST INITIAL ($/Km)	COST 30 YEAR LIFE CYCLE ($/Km)
A	Complete Reconstruction 360 mm Asphalt-Rubber 250 mm Fly Ash Treated Subgrades 10 Years @ 75 mm Overlay 20 Years @ 50 mm Mill followed by a 75 mm Overlay	731,250	987,500
B	Complete Reconstruction 250 mm Portland Cement Concrete Pavement (PCCP) 100 mm Portland Cement Treated Base 250 mm Fly Ash Treated Subgrade 20 Years @ 100 mm Overlay	768,750	1,006,250
C	Use Existing Portland Cement Concrete Pavement 230 mm Asphalt-Rubber Rubblized PCCP Under Overpass 355 mm Asphalt-Rubber 150 mm Lime Treated Subgrade 10 Years @ 75 mm Overlay 20 Years @ 50 mm Mill follow by a 75 mm Overlay	600,000	850,000

25.4 mm = 1 in
1 km = 0.6 mi

Table 12. Contract Bid Cost Alternate, I-135, McPherson County, No. 12-1994

Description	Contractor #1	Contractor #2	Contractor #3
	\$/Metric Ton	\$/Metric Ton	\$/Metric Ton
Aggregate for ARB	20.00	18.52	19.10
Aggregate for ARS	25.00	22.90	21.90
Alternate #1-Wet Process			
Asphalt-Rubber	170.00		
Alternate #2-Dry Process			
Asphalt		128.34	130.00
Rubber (Ultra-Fine)		900.00	840.00
Total Mix (Based on Contract Bid Quantities)	31.15	33.87	33.76

1 Metric Ton = 1.1 U.S. Ton

Table 13. Marshall Mix Design Parameters, I-135, McPherson County, No. 12-1994

Mix	Description		Binder Content	Marshall Parameters					
				Theo. Density	Density	VMA	Air Voids	VFA	Stability
			(%)	(Kg/M^3)	(Kg/M^3)	(%)	(%)	(%)	(N)
ARS	30% 60% 10%	Limestone Sandstone Sand	7.0* 8.0*	2386 2357	2218 2184	19.69 21.65	7.0 7.4	64.0 66.0	5089
ARB	55% 30% 15%	Limestone Sandstone Sand	7.0*	2383	2220	18.23	6.8	64.2	7353
ASPHALT SHOULDERS	50% 50%	Sandstone Sand	5.0 AC-10	2462	2347	14.82	4.7	68.5	4844
ASPHALT SURFACE COURSE	35% 40% 25%	Limestone Sandstone Sand	5.0 AC-10	2441	2338	13.86	4.2	69.7	8372
ASPHALT BASE COURSE	83% 17%	Limestone Sand	5.5 AC-10	2368	2233	14.52	5.7	60.8	6966
ASPHALT SHOULDERS	50% 50%	Limestone Sand	5.5 AC-10	2432	2323	14.65	4.5	69.46	5298

*13% Rubber / 87% AC-10
1 Kg/m^3 = 16.019 lb/ft^3
1 N = 0.225 lb

TABLE 14. TSRST Average Fracture Temperatures, I-135, McPherson County, No. 12-1994

NO	MIX	DESCRIPTION	ASPHALT CONTENT (%)	AVERAGE FRACTURE TEMPERATURE (C)
1	ARS (Field)	135-59 K-3450-01 (87% AC-10) (13% Type III Rubber)	7-8	-29
2	ARB (Field)	135-59 K-3450-01 (87% AC-10) (13% Type III Rubber)	7	-29
3	ARS (Lab)	Wet (82% AC-5) (18% Type II Rubber)	8.5-10	-29
4	ARS (Lab)	Dry (82% AC-5) (18% Ultra Fine Rubber)	8.5-10	-28
5	Surface Course (Lab)	AC-5	4-6	-29
6	Surface Course (Lab)	AC-10	4-6	-28
7	Surface Course (Lab)	AC-20	4-6	-24
8	Surface Course (Lab)	PG 64-34	4-6	-34

TABLE 15. Mix & Cost Data, I-135, McPherson County No. 12-1994

Description	Mix ($ / Metric Ton)
Asphalt Rubber Surface	39.40 (+56%)
Asphalt (Only) Surface	25.30
Asphalt Rubber Base	32.90 (+45%)
Asphalt (Only) Surface	25.30

TABLE 16. Actual Control and Test Section Cost, I-135, McPherson County, No. 12-1994

Description	Section ($/Km)
Control (Rubblized PCCP/Asphalt Only)	164,000
Test Section No. 1 (Lime Treated Subgrade)	317,000 (+93%)
Test Section No. 2 (Rubblized PCCP/Thin)	150,000 (-9%)
Test Section No. 3 (Rubblized PCCP/Thick)	208,000 (+27%)
( )	Percentage indicate the increase/decrease as compared to the Control Section

1 Km = 0.6 Mi

TABLE 17. Crack & Rut Survey, I-135, McPherson County, No. 12-1994

	TOTAL CRACKING (Meters)		
SURVEY DATE (Mo/Day/Yr)	TEST SECTION # 1 Reconstruction 40mm ARS 320mm ARB 150mm LTS	TEST SECTION # 2 Reduced Thickness 40mm ARS 140mm ARB Rubblized PCCP	TEST SECTION # 3 Full Thickness 40mm ARS 185mm ARB Rubblized PCCP
1994	0 (Construction) (Slurry Seal)	0 (Construction) (Slurry Seal)	0 (Construction) (Slurry Seal)
6 /12/1995	0	0	0
2 /18/1998	0	0	0
5 /12/1999	0	0	0
5 /12/2000	0	0	0
RUTTING DEPTH (As of 5/15/2000)	5.6 mm	2.3 mm	4.8 mm

TABLE 18. Test Section Elastic Modulus, I-135, McPherson County, No. 12-1994 After Overlay of Rubblized Layer

Elastic Modulus for Rubblized Layer (psi)

Section	Description	1994	1995	1996	1997	1998	1999
1	1.5" ARS + 12.5" ARB + 6" LTSG	N/A	N/A	N/A	N/A	N/A	N/A
2	1.5" ARS + 5.5" ARB + 9" Rubblized PCCP	944,902	418,132	378,798	363,660	332,158	282,427
3	1.5" ARS + 7.5" ARB + 9" Rubblized PCCP	2,032,622	814,423	550,311	505,313	390,254	405,536
4	1" BM-1T + 8" BM-2C + 9" Rubblized PCCP	354,418	395,776	1,044,755	1,747,792	2,113,850	2,938,597

Elastic Modulus for Asphalt Layer (psi)

Section	Description	1994	1995	1996	1997	1998	1999
1	1.5" ARS + 12.5" ARB + 6" LTSG	472,173	194,028	125,346	125,938	145,823	121,830
2	1.5" ARS + 5.5" ARB + 9" Rubblized PCCP	657,879	268,861	501,418	555,920	378,010	533,638
3	1.5" ARS + 7.5" ARB + 9" Rubblized PCCP	672,968	264,579	506,689	555,920	395,331	511,998
4	1" BM-1T + 8" BM-2C + 9" Rubblized PCCP	604,105	186,698	407,086	490,997	361,274	398,865

A slurry seal was placed in 1995 after the 1995 FWD testing was completed

TABLE 19. Summary of Projects

PROJECT	FORMAL CRACK SURVEYS	TEST SECTIONS OR FULL PROJECT	CURRENT STATUS	RATING High=4 Low =0
NO. 1 -1990/US-75/Osage	Yes	Test Sections Only Change Order	Overlaid in 1996	1
NO. 2 -1990/K-2/Sedgwick	Yes	Test Sections Only Change Order	Overlaid in 1996	1
NO. 3 -1991/US-24/Jefferson	Yes	Test Sections & Full Project & Competitive Bidding	Overlaid in 1996	4
NO. 4 -1991/US-24/Mitchell	Yes	Test Sections Only Change Order	Overlaid in 1998	1
NO. 5 -1991/US-59/Allen	Yes	Test Sections Only Change Order	Overlaid in 1998	1
NO. 6 -1992/US-54/Kingman	No	No Test Sections Full Project & Competitive Bidding	Overlaid in 1995	0
NO. 7 -1992/K-16/Jackson	No	Test Sections Only Change Order	Overlaid in 1998	3
NO. 8 -1992/I-70	No	No Test Sections Change Order	ACR used for temporary patching only	2
NO. 9 -1994/US-54/Kiowa	No	Test Sections Only Change Order	Emergency Maintenance Patch in 1996	0
NO. 10-1994/US-56/Johnson	No	No Test Sections Full Project & Competitive Bidding	**(In Active Service)**	3
NO. 11-1994/K-32/Douglas	No	No Test Sections Full Project & Competitive Bidding	**(In Active Service)**	2
NO. 12-1994/I-135/Mcpherson	Yes	Test Sections & Full Project & Competitive Bidding	**(In Active Service)**	2
NO. 13-1995/US-75/Brown	No	No Test Sections Full Project & Competitive Bidding	Emergency Double Seal in 1995	0
AVERAGE RATING				**1.53 (Low Average)**

ASPHALT RUBBER PROJECTS

(1990 - 1995)

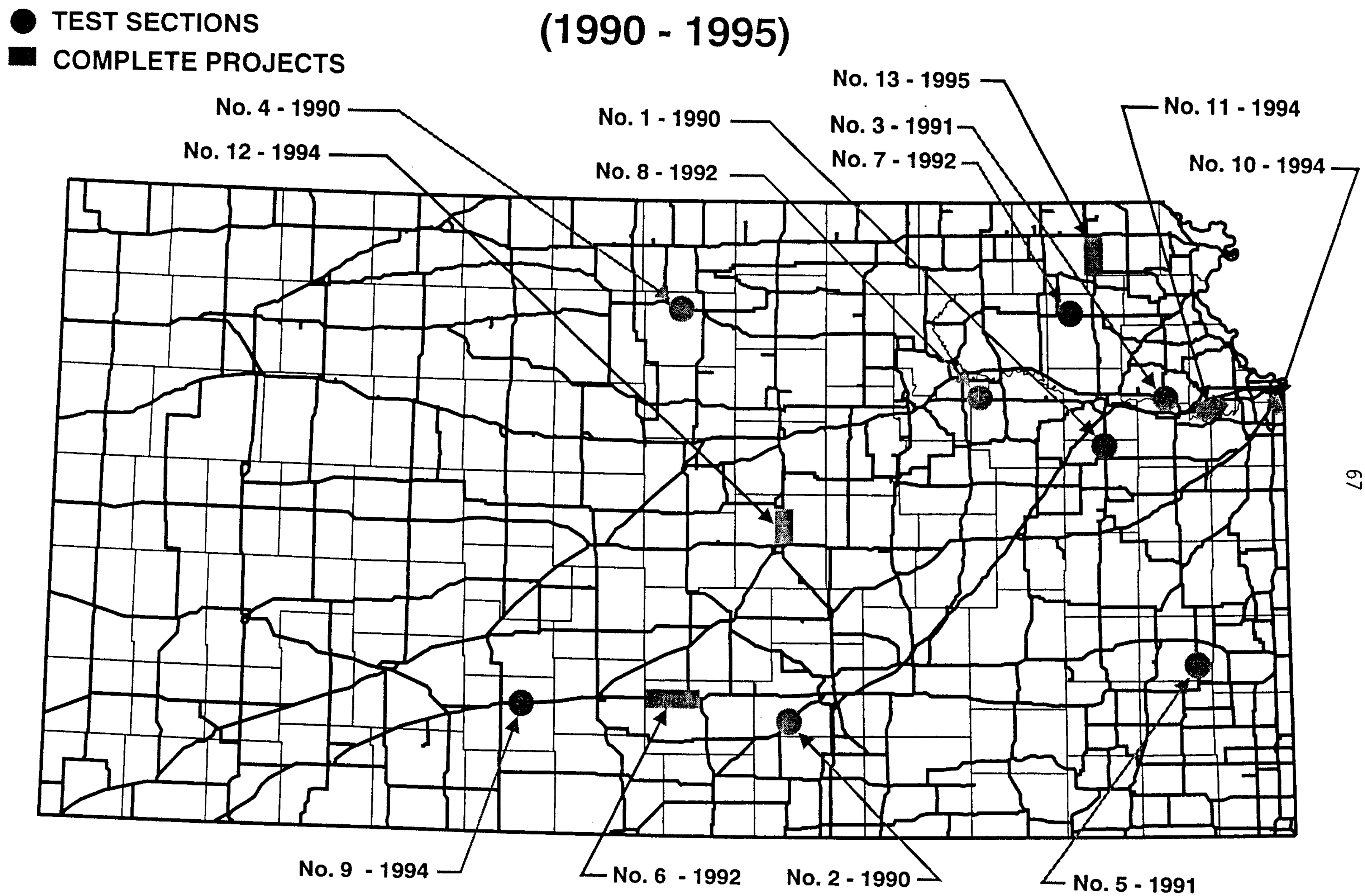


FIGURE 1 / Asphalt Rubber locations

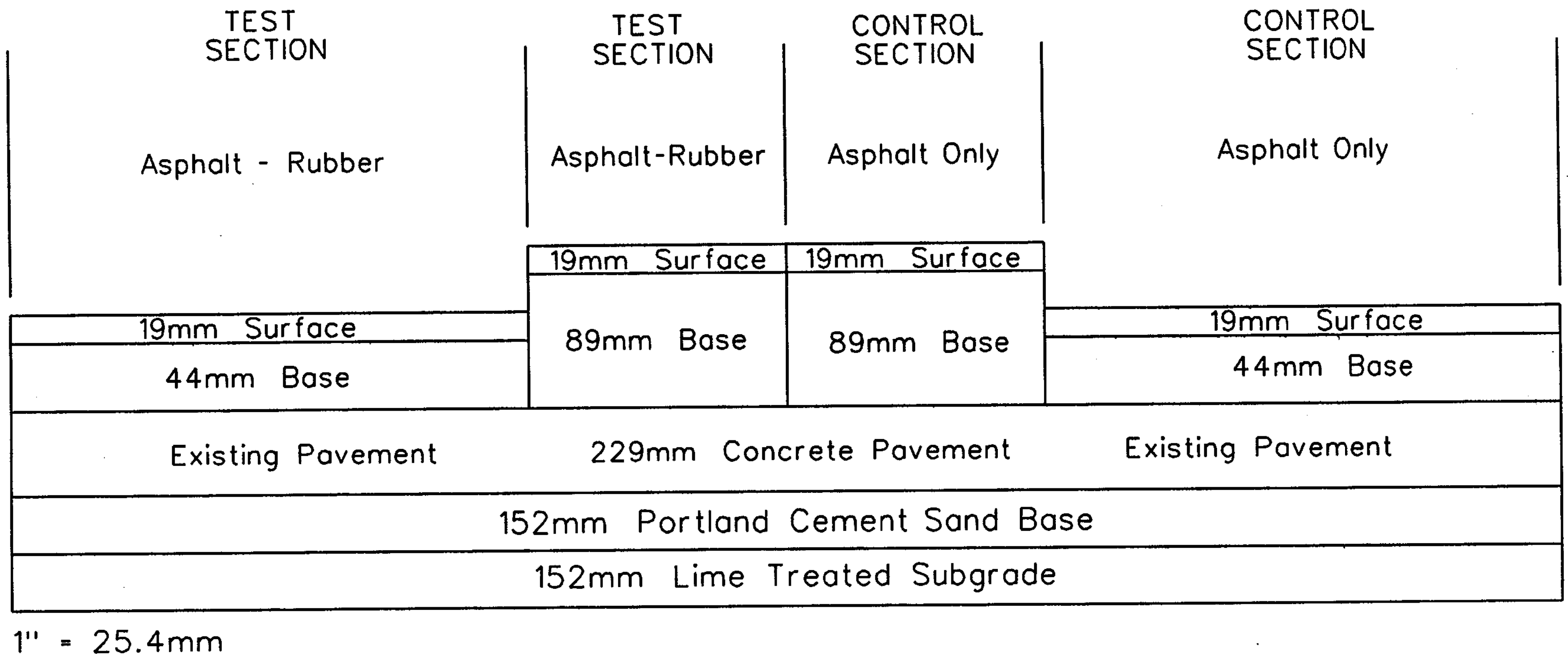


Figure 2. Test & Control Sections, US-75, No. 1-1990

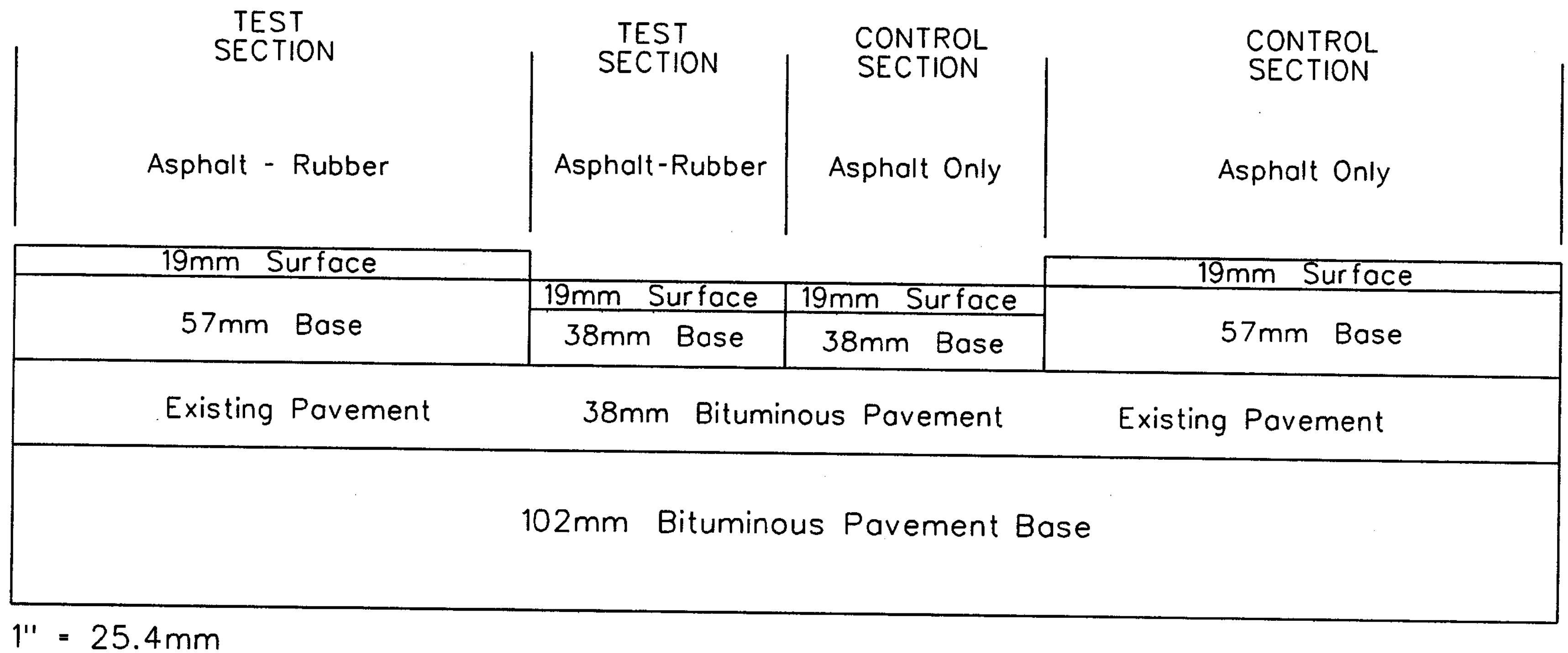
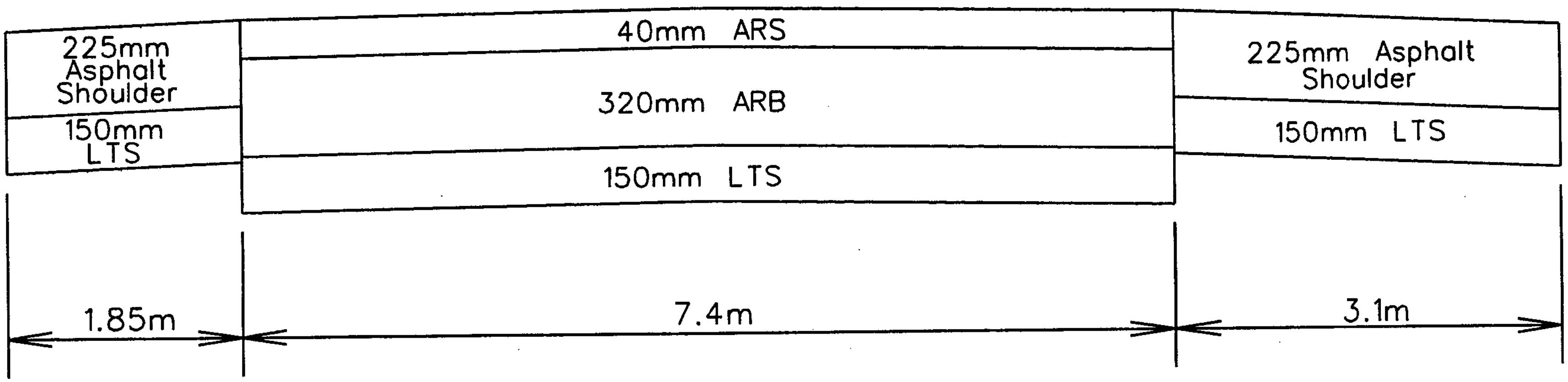


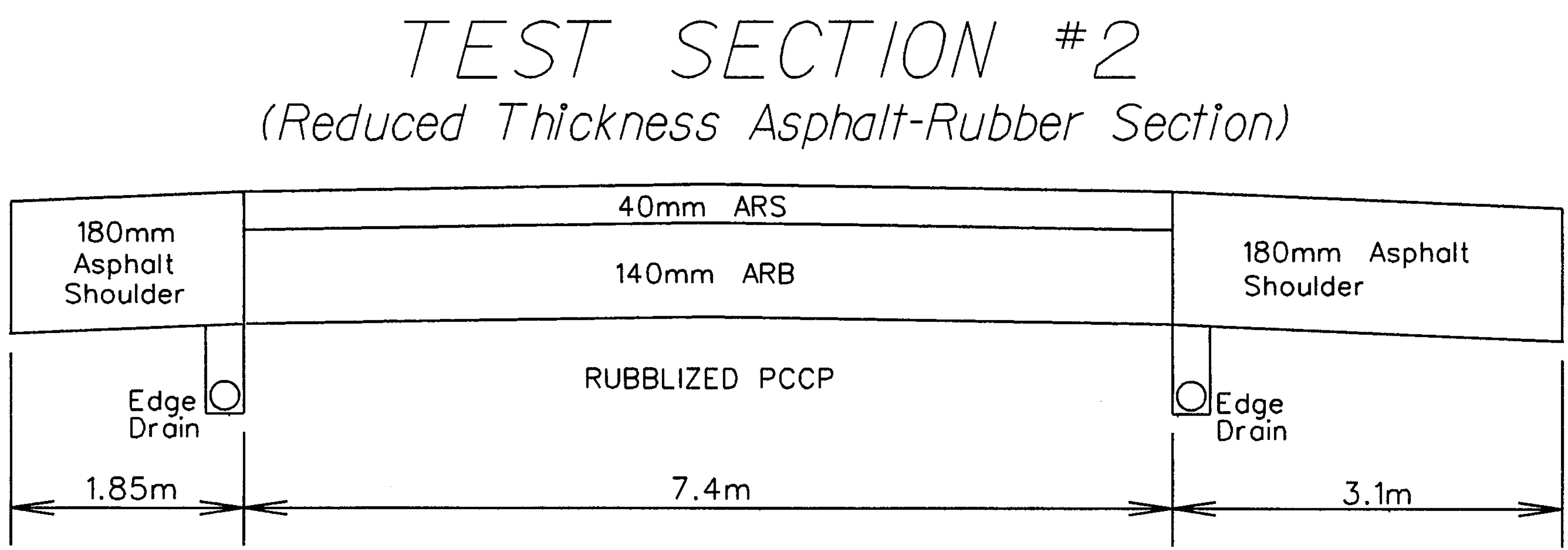
Figure 3. Test & Control Sections, K-2, No. 2-1990

TEST SECTION #1
(Reconstruction Section)



LTS - Lime Treated Subgrade
ARB - Asphalt Rubber Base
ARS - Asphalt Rubber Surface

Figure 4. Test Section No. 1, I-135, No. 12-1994



ARB - Asphalt Rubber Base
ARS - Asphalt Rubber Surface

Figure 5. Test Section No. 2, I-135, No. 12-1994

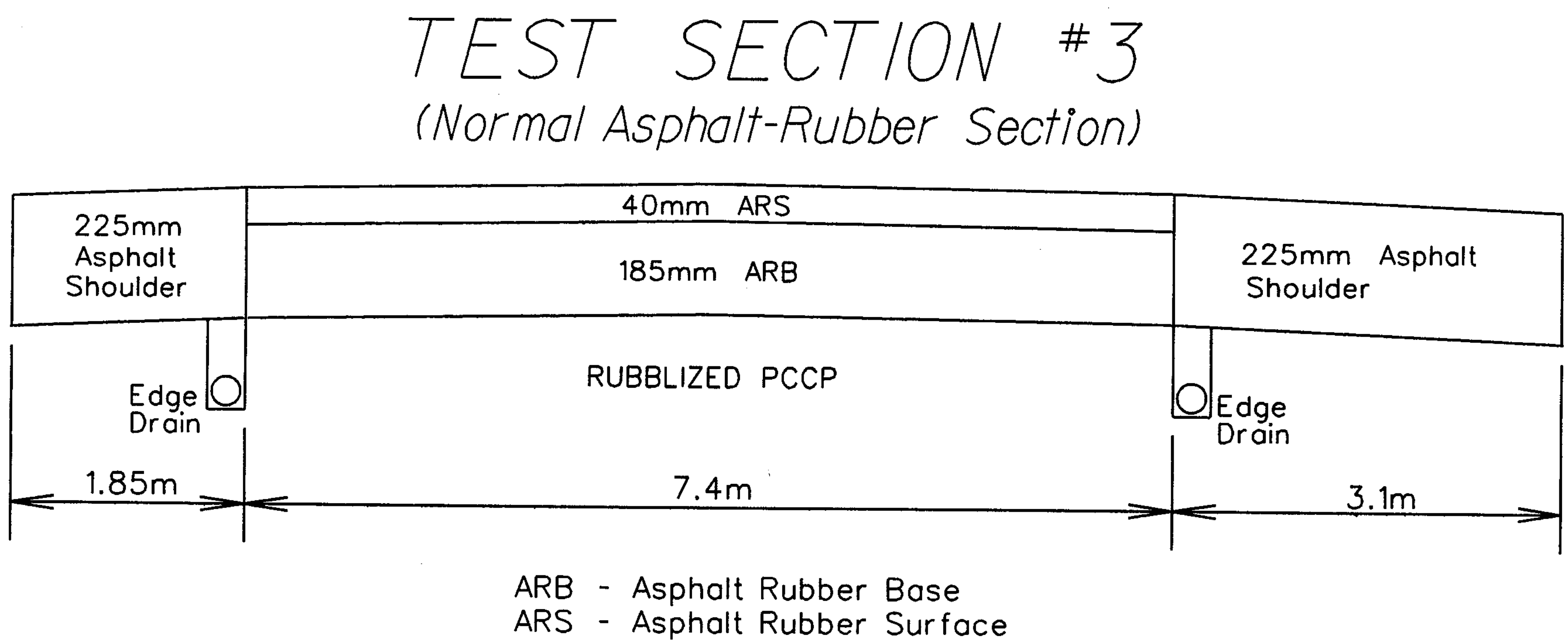


Figure 6. Test Section No. 3, I-135, No. 12-1994

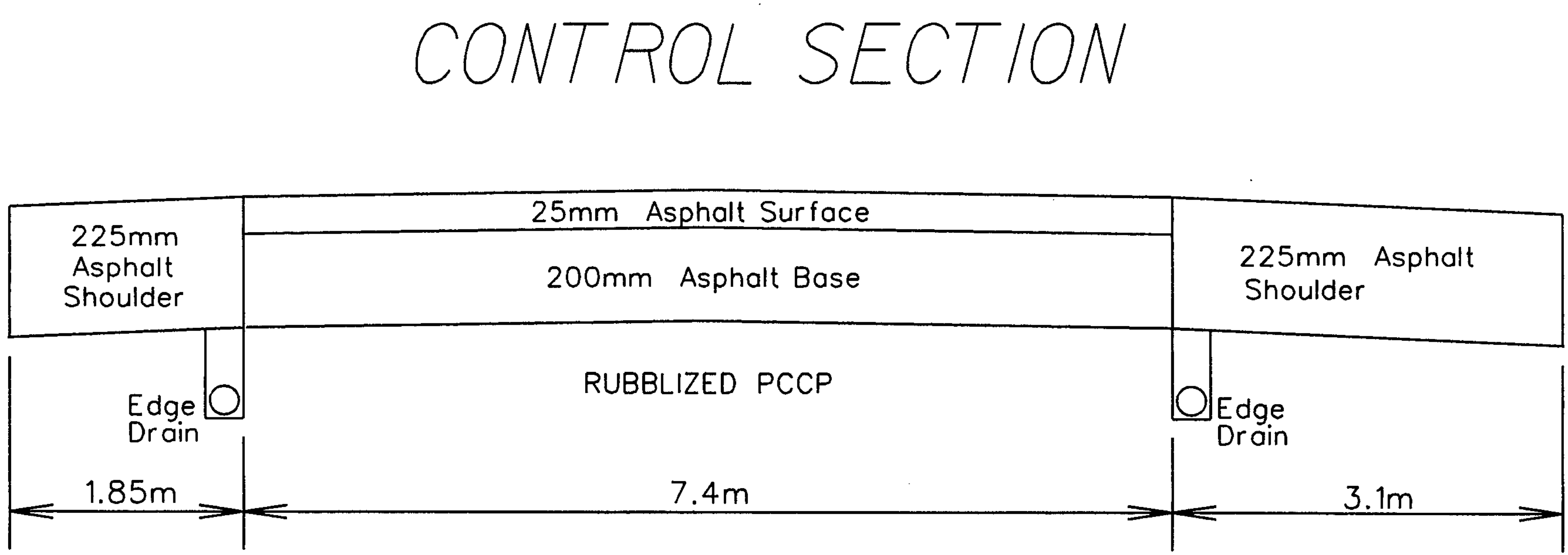


Figure 7. Control Section, I-135, No. 12-1994

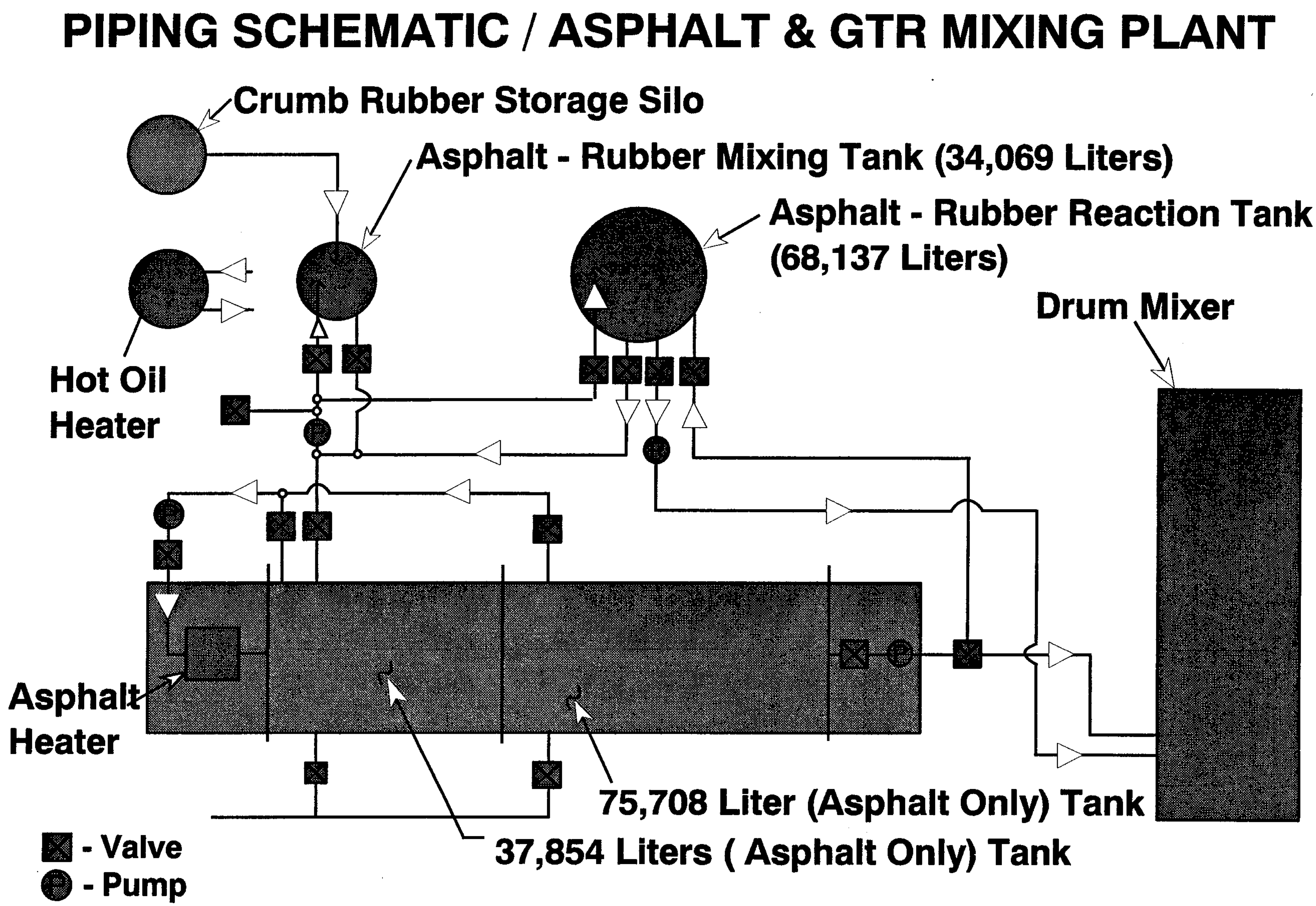


Figure 8. Piping Schematic/Asphalt & GTR Mixing Plant, I-135, No. 12-1994

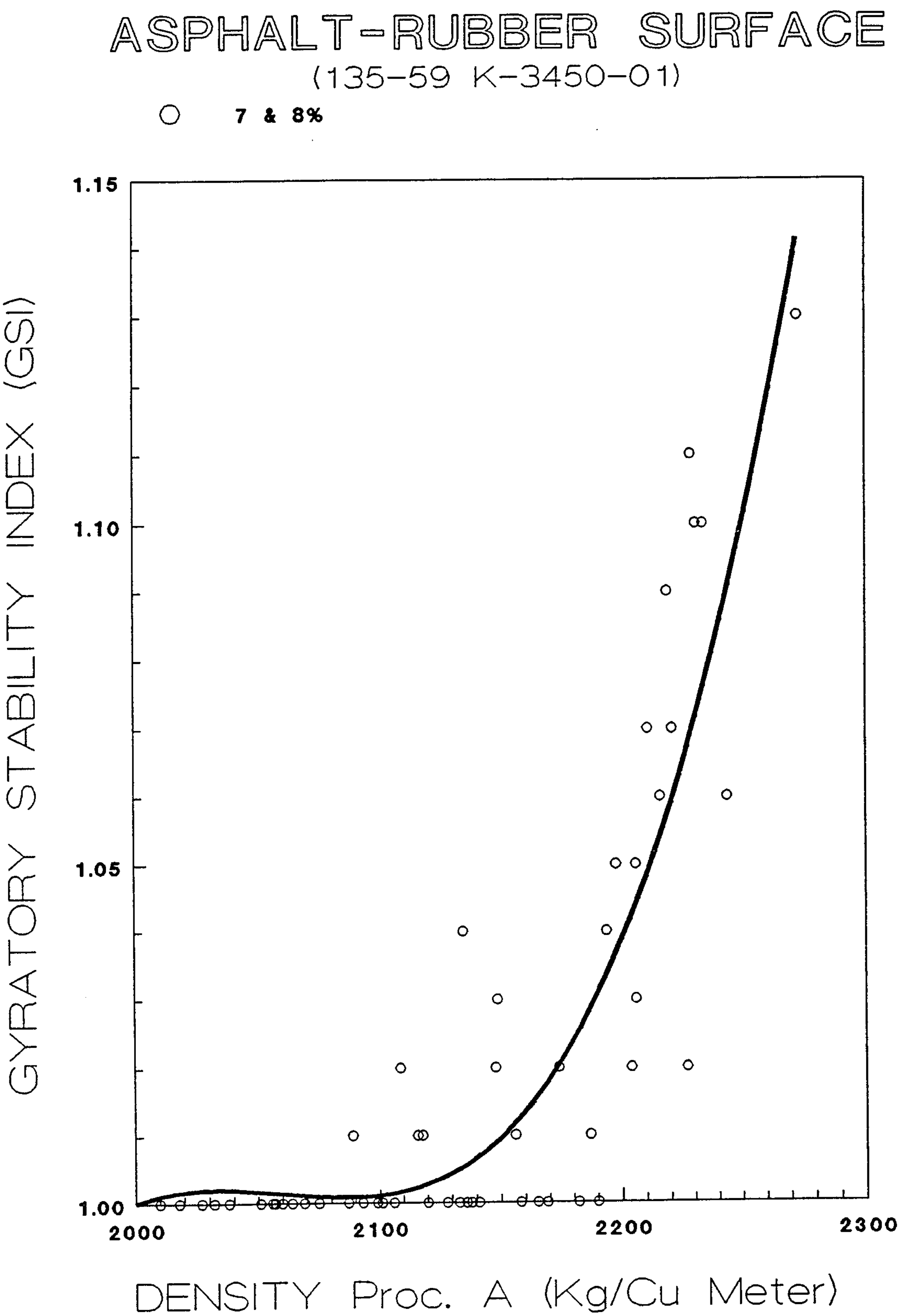


FIGURE 9. GSI vs. DENSITY, I-135,

No. 12-1994