CONSTRUCTION OF A RECYCLED BITUMINOUS PAVEMENT USING FOAMED ASPHALT

Adriaan van Wijk
Graduate Instructor in Research
School of Civil Engineering
Purdue University

Leonard E. Wood
Professor
School of Civil Engineering
Purdue University

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ABSTRACT

The recycling of pavement materials is a cost effective and energy efficient method of reconstruction. Good results can and have been obtained with recycling. Two types of recycling are available viz. cold and hot recycling.

Cold recycling usually has a lower cost, but also a lower strength than hot recycling. Various binders have been used in cold recycling. The most widely used are asphalt cement and asphalt emulsion. Another promising binder is foamed asphalt. The process of foaming asphalt was developed in the late 1950's and modified in the late 1960's. Since then it has been widely used as a binder for pavement materials. Foamed asphalt has the advantage over asphalt cement in that it can be used at lower temperatures and over emulsion in that it does not need the curing time.

Laboratory studies have demonstrated that foamed asphalt can be used with success as a binder in cold recycling.

During the summer of 1981 the Indiana Department of Highways constructed an experimental section of 7.0 km using foamed asphalt in a cold recycling project. The main purpose was to monitor and evaluate the construction procedures and the performance of such reconstruction.

The initial concept was to use in-place cold recycling. Due to mainly the inability of the milling machine to reduce the pavement to a full depth of 125 mm the construction procedure was changed. During actual construction the initial pavement was reduced in two 65 mm layers and the material stockpiled at a nearby central plant. Some additional aggregate was precoated with 4% foamed asphalt and mixed with an additional 1-1/2% of foamed asphalt in a ratio of 1 to 3 to form the final base course mixture. All the mixing was done by a twin shaft pugmill. The final mixture was placed in two layers with a total thickness of approximately 140 mm. This new base course was overlayed by a 38 mm hot asphalt mixture.

Tests were conducted prior, during and after construction to evaluate the properties of the mixture and the performance of the recycled layer.

The use of foamed asphalt caused no serious problems during construction. Conventional equipment could be used with only small modifications. The recycled pavement could be opened to traffic soon after compaction without any problems. It was therefore also possible to keep the road open to traffic throughout the construction.

Foamed asphalt seems to behave well as a binder in cold recycling. The initial performance is satisfactory.

INTRODUCTION

Recycling is widely accepted as a feasible alternative to most of the highway rehabilitation or reconstruction methods. This is shown by the wide interest in recycling at conferences such as these: the Transportation Research Board meetings, the Asphalt Paving Technologists Conferences, the International Conferences on Concrete Pavements, etc. Recycling has obvious advantages regarding the saving of construction materials, energy and valuable resources when compared to some conventional methods such as overlaying or reconstruction with new material.

McKinney indicated at the Purdue Road School in 1979 that 94% of all paved roads utilize bituminous surfaces in the United States. This varies from state to state and, of course, in Canada. For instance, the percentage of bituminous surfaced roads makes up approximately 83% of the total paved, hard-surface structures under the jurisdiction of the Indiana Department of Highways (12). Within any governmental agency the percentage of bituminous roads remains high. It is therefore obvious that the recycling of bituminous pavements will be an alternative to be considered in a large number of maintenance projects.

A very important aspect of recycling is the savings in energy, especially liquid fuel. The fuel and energy savings aspect was one of the characteristics that made recycling so promising after 1973. The emphasis in highway construction has changed to seriously consider energy conservation for the more effective use of limited funds during the past few years. Halstead indicated in 1979 that highway maintenance consumes a maximum of only 3% of the total energy used in the United States (8). Recycling alone will therefore not solve all the energy problems. Inferior construction practices may lead to excessive maintenance cost and energy usage. In other words although recycling has certain advantages over conventional maintenance methods or new construction, the performance of the pavement has also to be taken into consideration. This might create a problem for the designer since recycling of bituminous pavements has been used extensively for only the last few years. The performance of recycled mixtures has been studied in laboratories and has been reported to give very good results (5,6,7). The only way to verify this is by actual field application. The positive laboratory results have not been completely verified, due to the relatively few recycled pavements that have been constructed and their short time in actual use (19). This does not mean that laboratory studies are not important, on the contrary, they give the basic information regarding the composition, the performance and the possible application of new methods or mixtures at a relatively low cost. Less than 0.2 percent of highway dollars are spent on research by states and the federal government in the U.S. (10).

COLD RECYCLING WITH FOAMED ASPHALT

Recycling can be divided into two distinct areas based on the mixing procedure viz. cold and hot mixing. Cold recycling is used mainly to construct base courses. The binders traditionally used in the stabilizing of the cold recycled material were liquid asphalt cement and emulsified asphalt.

Another type of binder which shows promise as a stabilizer for virgin aggregates and recycled material is foamed asphalt. Foamed asphalt is the material obtained through the addition of a small amount of cold water (usually around 2% by weight of asphalt) to hot asphalt cement (usually at about 165 degrees C). This creates an asphalt foam. The expansion ratio is defined as the volume of the foamed asphalt compared to the volume of the asphalt cement. Unfortunately the asphalt cement does not stay in the foamed state for very long. The half life is defined as the elapsed time (in seconds) from maximum expansion to the time it takes the foam to be reduced from the maximum volume to one-half of the maximum volume. The idea of foaming asphalt was introduced by Prof. Csanyi of Iowa State University in the late 1950's (5). This method which produced foam by means of a steam generator was altered by Mobil of Australia in the late 1960's (8).

Foamed asphalt has been used with success to stabilize virgin aggregate and sands in base courses since the mid 1950's (1, 11,13). It was used in Canada at Nipawin in 1964 (20). The asphalt was foamed with a steam generator. To the authors' knowledge there is no reported use of foamed asphalt as a binder in cold recycling in actual application before 1980.

Laboratory research at Purdue University on foamed asphalt and recycling (3,15,16) showed that foamed asphalt can be used in recycling. Foamed asphalt has the advantage over asphalt cement in that it can be used at a lower mixing temperature and over emulsified asphalt in that it does not need extensive curing. The strength of the foamed asphalt mixture relies very heavily on the coating of the fines to form a mastic. Laboratory research provided the necessary information for the design of the foamed asphalt mixture.

As indicated earlier, research can provide information up to a point. Only field application can evaluate the construction procedure and the performance under actual traffic loads and environmental conditions.

The balance of this paper will discuss the construction of a recycled layer using foamed asphalt with the cold process in Indiana.

THE CONSTRUCTION OF THE RECYCLED PAVEMENT USING FOAMED ASPHALT

During 1980 the decision was made by the Indiana Department of Highways to construct an experimental section using foamed asphalt and emulsion as binders in cold recycling. The road selected for this purpose was a 14 km. segment of SR 16 from the junction with SR 231 to the Jasper-White county line. It was a road which was to be resurfaced during the same year. Figure 1 shows the location of the road. This segment was divided into two approximately equal segments, one utilizing foamed asphalt as the binder and one using emulsion. The main objectives of this experimental section were (9):

1. To determine the feasibility and suitability of the use of cold recycling.
2. To monitor the performance of such a pavement under actual conditions of traffic and weather.
3. To determine the cost and time required for the project.
4. To determine the interest and ingenuity of the contractors in this project.
5. To gain experience in the use of foamed asphalt and emulsion in recycling.

This was especially true for the construction of the foamed asphalt section, since foamed asphalt had not been used previously in Indiana. Conventional construction equipment had to be modified to be able to produce and mix foamed asphalt. As mentioned earlier the rest of the discussion will center around the construction of the foamed asphalt section.

The Conditions of the Initial Pavement

The initial pavement was 5.5 meters wide. It showed a few longitudinal cracks, some rutting, some consolidation and extensive flushing. The longitudinal cracks appeared mostly along the wheelpath closest to the centerline. These cracks could have been caused by the lack of internal friction in the sandy subgrade (17) and/or excessive bending stresses in the wheelpath (18). None of these pavement defects caused serious performance problems. The flushing created an unsafe roadway in wet weather. The road also needed an improved cross section. The traffic volume as determined in 1978 consisted of approximately 550 vpd in both directions with 18% trucks.

Original Construction Concept

The plan was to reconstruct the pavement using the pulverized in place pavement material mixed with additional aggregate and foamed asphalt as a base course. It was felt that cold inplace recycling could provide a low cost simple construction procedure.

Tests were conducted on cores obtained from the initial pavement in order to design the recycled mixture and to determine the thickness. Approximately 100 125 mm cores were taken over the 14 km. section.

Initially, twenty-four core samples from six sites were analyzed to determine the aggregate grading and the asphalt content. The results are given in Table 1. In a second investigation eight cores from 4 different locations were analyzed to determine the penetration and the kinematic viscosity of the asphalt in the initial pavement. The results are given in Table 2. The average asphalt penetration was 41 pen. and the average kinematic viscosity 460 cSt. Both the penetration and the viscosity values had large variances. The average asphalt content was 6.1 percent, with a small variance.

Ten extra 100 mm cores were analyzed to determine the effect of temperature on the resilient modulus (Mr). Mr values were also determined on specimens from the top and the bottom 65 mm. There was no significant difference (at alpha = 0.05) between the Mr-values obtained from the top and the bottom 65 mm. The average total thickness was 170 mm. Visual inspection seemed to indicate that the top half had more asphalt than the bottom half. This was not verified through testing. The insitu CBR-values were also determined through Dynamic cone penetrometer (DCP) tests at 28 locations at the center of the lanes. The average CBR of the sandy silt subgrade was approximately 12, with a standard deviation of 4.3. The subgrade was overlaid by an average, 120 mm thick granular layer with a CBR of 30 (standard deviation of 11).

Information obtained from the above tests, results from research at Purdue and practical experience were used to establish the material and construction requirements. The requirements are summarized in Table 3.

The plan was to reconstruct the road to a width of 6.7 meter by increasing the width by 0.6 meters on each side. Excavations had to be made to a depth of 125 mm. to extend the 125 mm.

base course. The excavated material was to be used on the shoulders. Some additional aggregate had to be added to maintain the 125 mm. thickness of the base course. Figure 2 shows a cross section of proposed final pavement.

A thickness of 125 mm. of recycled base course and a 32 mm. hot mix asphalt concrete surface seemed to be sufficient to carry the traffic on this road. No structural coefficients were available to be used in the design. The selection of the thickness of the stabilized base was made strictly from a practical viewpoint.

Cold in-place recycling was specified in the construction proposal. The initial pavement had to be ripped, milled, scarified or pulverized to a depth of 125 mm. to such an extent that 100% of the material passed the 75 mm. sieve and 90 to 100% the 38 mm. sieve. After the excavations on the sides were made, the additional aggregate had to be placed on top of the reduced and shaped material at a rate of approximately 87 kilograms per square meter. The additional aggregate could be crushed stone, crushed blast furnace slag, natural or blast furnace slag, sand or a combination of these materials meeting a standard specification. A material complying to the specifications of the Indiana Department of Highways for a #53 crushed stone would be acceptable, as shown in Figure 3.

The first application of foamed asphalt had to be applied directly to the additional aggregate at a rate of approximately 3.5 liters per square meter (4% by weight of aggregate) and simultaneously shallow mixed to a depth of not more than 13 mm. below the additional aggregate layer. A second application of foamed asphalt had then to be applied at 5 liters per square meter (1.5% by weight of material) and mixed to full depth. The hot mix surface at a rate of 11 kg. per square meter had to be placed on top of the recycled base (the specifications are summarized in Table 3).

The bid was made on the basis of in-place recycling (9). The unit prices were $0.40 for the shallow mixing, $1.00 for full depth mixing and $0.25 for the spreading and compaction of the recycled base. The successful low bidder was A. Metz Inc. The contractor was given 60 working days to finish the 14 km. section. Adjustments to the proportions of the materials could be, and were, made.

Actual Construction

The construction of the foamed asphalt section started in August 1981. It was the first experience with foamed asphalt for the contractor.

The contractor requested permission to mix the milled material and the additional aggregate at a central plant instead of in place. The main reasons for this were:

1. the contractor had a mixing plant available approximately 8 to 16 km. from the construction site.
2. the milling machine had difficulty milling to a depth of 125 mm. in one pass. The twin shafted pugmill the contractor originally intended to use was no longer available.
3. the mixing control would be better at a central plant.

During trial runs at the central plant the proportion of the additional aggregate to be added was changed from 29% to approximately 33% by weight of reduced material or 25% by total weight of material. This small change did not seem to influence the quality of the mixture. #53 crushed stone was to be used as additional aggregate as it was readily available to the contractor.

The centerline of the initial pavement was used as reference height. This meant that the transverse slope was measured from the centerline. The depth of the intended excavation of 125 mm. on the sides of the pavement therefore varied since the initial pavement did not have a constant transverse slope.

The construction procedure was changed from cold in-place recycling to cold recycling at a central plant. Figure 4 displays a flow diagram of the actual construction procedure. The specifications given in Table 3 were still valid.

Description of the Actual Construction Procedure

In order to keep the road open to traffic during non-work periods the milling was done in two layers. A CMI rotomill was used. The milling was done by a subcontractor. The pavement also had to be safe for traffic during nonwork periods and no dropoffs were allowed overnight. First a layer of 65 mm. was removed. The remaining 65 mm. of initial pavement was sufficient to sustain traffic during construction. Approximately, 2400 to 3000 linear meters of milling of this 2.75 meter wide and 65 mm. thick pavement layer could be done in a day. The milling was done to the lane width of 2.75 meters at a time. It was found that the milling was faster and fewer pieces larger than 75 mm. were created during cooler weather. The milling was therefore done mainly from early morning (6:30 a.m.) to just after noon (2:30 p.m.). The milled material was hauled to the central plant and stockpiled.

During the first milling operation the additional aggregate (#53B) was mixed with 4 percent foamed asphalt (by weight of aggregate) and stockpiled. The mixing was done at the central plant with a modified twin-shaft pugmill. Figure 5 shows the process schematically. An old Barber-Greene twinshaft pugmill was modified to be able to mix the foamed asphalt. Four large nozzles were installed to spray the foamed asphalt into the mixing chamber. The water was stored in a tank on the ground and pumped under pressure to the nozzles. The asphalt cement came directly from an asphalt tanker and was at approximately 165 degrees C. The asphalt was also pumped to the expansion section where it came into contact with the water. The foam was produced with this contact between the water and the hot asphalt cement. The mixing time was approximately 45 seconds. This modified pugmill can produce up to 120 tons of a foamed asphalt mixture per hour. The foamed asphalt coated the fines better than the coarse aggregate, as expected, since foaming relies on the mastic properties of the fines. The premixed stockpile had the color of wet aggregate and not asphalt coated aggregate.

The second milling operation followed the first one and removed an additional 65 mm. of initial pavement. An average thickness of 25 mm., of initial pavement was left on top of the underlaying layers. This protected the subgrade and avoided problems with heavy construction equipment on places where very soft subgrades appeared.

The second milling operation was followed closely, at approximately 300 meters, with the placement of the first 75 mm. of the intended 140 mm. of recycled base course. The placement to a width of 3.35 meters, which was the lane width was done by a conventional asphalt paver. The 600 mm. on the sides was cleared by a motor grader. Since the centerline height was taken as reference height and transverse slope had to be 1-1/2% no excavations (as originally specified) were made. The paver completed the portion that had been milled previously by the end of the construction day. This provided a graded, compacted and safe roadway during non work periods. Care was taken, through the milling of a few centimeters at the side of the placed recycled material, to provide a good bond between the recycled material to be placed in the opposite lane and the recycled layer which had already been placed.

The mixture used in the paving operation was mixed in the twin-shaft pugmill at the central plant. The reduced material was mixed with the premixed additional aggregate in the ratio of three to one. The percentage of foamed asphalt added was 1-1/2% of the total mixture.

The compaction was started immediately after the placement of the first lift by two passes of a steel wheel roller. This was followed by two passes of a rubber wheel roller after a few hours and another two passes of the same roller at the end of the day. Nuclear density tests showed that six passes gave adequate compaction. Since the road was opened to traffic after a few hours, traffic and especially the heavy construction trucks travelling to and from the central plant caused extra compaction.

The placement of the second lift of 65 mm. to establish a base thickness of 140 mm. followed the first lift. It was placed and compacted in the same way as the first lift. An uncompacted layer of 100 mm. compacted to a thickness of approximately 65 mm. This is completely different from hot asphalt mixes.

Material from the first and second milling operations were stockpiled in separated piles. Material from both these stockpiles were used simultaneously in the mixing process to minimize the effect of possible unequal asphalt contents of the top and bottom of the initial bituminous pavement. The mixed material was generally transported directly from the pugmill to the paver. Only in a few cases, when some additional aggregate had to be coated was the recycled mixture stored for a few days.

The placement of the second lift (top) of base course was followed after about three days with an AE-T tack coat of 0.25 liters per square meter and the hot asphalt surface of 65 kg. per square meter. A shoulder, using one size material obtained as a by-product from the production of crushed stone, completed the construction. The construction of the foamed asphalt section took between 20 and 25 days, including the milling of the initial pavement.

Control of the Foamed Asphalt Mixture

The properties of the foamed asphalt were checked before construction and it was found that a reasonable coating could be obtained by using a half-life of only 12 seconds and an expansion ratio of 10. These properties were checked frequently during construction.

It was never necessary to adjust the free moisture content of the material, since it was between 2.5 and 3.5 percent for most of the time.

Only a small amount of material larger than 75 mm. was obtained through the milling operation. No effort was made to remove these pieces, since it was assumed that they would be broken down during the mixing.

Construction Problems

No serious problems occurred during construction. One of the minor problems was that milling during high pavement temperatures caused the milled material to stick together. Another minor problem was that the larger pieces of reduced material were dragged along by the paver and the scars had to be corrected manually.

The biggest problem was ravelling. This was fortunately a problem only during the first few days of placement. It usually appeared on the outside few feet of the pavement. It occurred soon after placement and was initiated by the wheels of the heavy construction vehicles. The reasons for the ravelling appear to have been a too low binder content, inadequate compaction for heavy vehicular use as well as a very soft or improperly prepared subgrade. The existence of some organic material, e.g. grass could have prevented proper compaction. The ravelling was compacted by the traffic to a distress pattern similar to rutting and was corrected by the placement of either the second lift of base course material or the surface. It was not necessary to remove these sections.

SOME IMPORTANT TEST RESULTS

The main thrust of the research at Purdue University on this project was to determine the structural coefficients of the foamed asphalt recycled layer. The material properties that were important in such a study were the resilient modulus, the Poisson's ratio and the tensile strength.

Samples of the mix were taken during construction and compacted in the laboratory at room temperature using the California kneading compaction method. Samples were taken at six different positions and at least six specimens prepared at each position. All six specimens were cured for 10 days in laboratory conditions (approximately 21 degrees C). Three specimens were subjected to one hour vacuum saturation and left under water for twenty-four hours. The resilient modulus, Hveem-R value, Marshall stability and flow values were then determined at approximately 21 degrees C for all six specimens using standard testing procedures. The resilient moduli were also determined for the three unsaturated specimens at 1 and 40 degrees C.

Hundred (100) mm. cores were also taken after construction at 18 different positions. Several additional cores were taken at each location to obtain a total of 35. It was very difficult to get full size cores. They tended to crumble or break at the bond of the two lifts. The cores were cut into three segments; two 65 mm. specimens representing the first and second lift and one 32 mm. specimen representing the surface. These specimens were tested in the same manner as those prepared from the samples of the mix obtained in the field, except that only four were tested using vacuum saturation.

The resilient modulus (Mr) and Marshall stability values showed no statistical difference at alpha = 0.05 between the two lifts and the position on the pavements for both the laboratory samples and the cores. There is a difference between the Mr of the laboratory compacted samples and the cores, as shown in Figure 6. This is also true of the Marshall stability. The main reason for this is the difference between the densities of the laboratory samples and the cores. The average density of the laboratory samples was 2.36 gr/cc with a range from 2.29 to 2.39 and of the field cores 2.22 gr/cc with a range from 2.12 to 2.40 gr/cc. The cores are expected to have lower densities since the Hveem compaction method simulates the pavement densities after approximately one year in use. The cores were taken approximately four to six weeks after construction and tested four weeks thereafter. A few cores taken 250 days after construction had a density of 2.29 gr/cc on the average. It was also observed that the Mr (stiffness) decreases with an increase in temperature.

Figures 7 and 8 depict the influence of water on the resilient modulus and the Marshall stability respectively. The resilient modulus is reduced significantly (at alpha = 0.05) with the introduction of water. The effect is less pronounced on the Marshall stability of the mixture, but still present. It is therefore important to keep water out of the foamed asphalt recycled layer through proper side drainage and surface protection.

Another very important factor in the stability of the mixture is the compaction moisture content. A definite optimum compaction moisture content exists. The effect of compaction moisture content on the Marshall stability for the laboratory compacted samples is displayed in Figure 9 where the optimum moisture content is 2.4%.

Curing time and method have a marked influence on the Mr (stiffness) and the tensile strength of the foamed asphalt recycled material as shown in Figures 10 and 11. Maximum curing is supposed to represent the condition of the pavement after some time in use under favorable conditions. This was simulated by air curing for 10 days and curing for 50 hours at 60 degrees C. The 10 days air curing represents the condition of the pavement after a few weeks in use and the 1 day air curing represented the condition of the pavement immediately after construction. The results displayed in these figures were obtained by testing an extra eighteen specimens compacted from a mixture sample taken during construction.

Deflection measurements were taken with a Dynaflect before, during and twice after construction. The first set of deflection measurements was taken only twelve days after construction and the second approximately 250 days thereafter. Figure 12 shows the Dynaflect maximum deflections before construction and during construction (on the foamed asphalt base course). The values have been adjusted for temperature (14). There was no statistical significant differences among the average deflections, but the newly constructed pavement had a higher average deflection than the initial pavement. The initial pavement was structurally sound and based on the maximum deflections the newly constructed pavement also. The laboratory study on the effect of the curing on the stiffness (Mr) indicates that the stiffness will increase and the deflections will therefore decrease over time. This was what happened during the first 250 days after construction (Figure 13). The deflections decreased and were essentially the same as those before construction. It is not possible at this stage to predict how long this situation will continue.

CONCLUSIONS

Foamed asphalt seems to be an acceptable binder in cold recycling. No major equipment changes had to be made during construction to accommodate the foamed asphalt. Conventional equipment could be used with only minor modifications. The construction procedure could also be kept simple and progress maintained at an acceptable rate. The construction crew adjusted well to the placement of the new material although they said that it was easier to place hot asphalt concrete.

The pavement could be opened to traffic soon after construction and it performed well. Even the heavy construction vehicles had no detrimental effect on the recycled layer.

The importance of the correct moisture content during compaction and the detrimental effect of water on the recycled material must be kept in mind in design and construction.

The initial and short term performance of this foamed asphalt recycled layer seems to be satisfactory. Results from tests show that the long term performance of the recycled layer seems to be satisfactory. The pavement was still in good condition after eight months. The surface layer showed some thin cracks at the centerline of the lanes. These cracks appear to be in the surface layer only and not caused by the recycled layer. Results from tests indicate that there is reason to believe that the pavement will behave well in the future, but, as mentioned in the introduction, this can only be verified through monitoring the future and ultimate performance of the pavement in actual use.

REFERENCES

1. Abel, F. and Hines, C. R. Base stabilization with foamed asphalt. Colorado Highway Department. Interim report (June 1979).
2. Bowering, R. H. and Martin, C. L. Foamed Bitumin: Production and Application of Mixtures. Evaluation and Performance of Pavements. Proc. AAPT Vol. 45 (1976).
3. Brennen, M., Tia, M., Altschaeffl, A. and Wood, L. A laboratory investigation on the use of foamed asphalt for recycled bituminous pavements. Proc. TRB-meeting 1981.
4. Castedo, H. and Shofstall, R. L. Stabilization of three typical Indiana aggregates using foamed asphalt. JHRP Interim report.
5. Csanyi, L. H. Foamed asphalt in bituminous paving mixtures. TRR #160, pp. 108-122.
6. Epps, J. A. State-of-the-Art Cold Recycling. TRR #780, p. 68.
7. Epps, J. A., Little, D. N., Holmgreen, R. J., Terrel, R. L., Ledbetter, W. B. Guidelines for recycled pavement materials. NCHRP #24.
8. Halstead, W. J. Energy concerns relating to highway construction and maintenance. Proc. Purdue Road School, 1979, p. 1.
9. Kercher, K. J. Cold recycling on SR-16. Project B: Emulsified Asphalt. Interim Report. Indiana Department of Highways. May 1982, p. 2.

10. Larson, T. D. Need for continued Transportation research. Transportation Research News no. 99. March-April 1982, p. 9.

11. McComb, R. W. Pueblo West, Colorado. Foamix experience. Proc. TRB-meeting 1982.

12. McKinney, J. L. Recycling of bituminous pavements. Proc. Purdue Road School, 1979, p. 12.

13. Mosey, J. and Welke, R. A. Use of in-situ foamed asphalt in Michigan. Proc. TRB-meeting, 1982.

14. Tia, M., Wood, L. and Hancher, D. The effect of added virgin binders on the properties of cold mix recycled asphalt paving mixtures. Proc. AAPT Vol. 50, 1981.

15. Sharpe, G. W., Southgate, H. F. and Deen, R. C. Pavement evaluation by using dynamic deflections. TRR #700, pp. 34-36.

16. Yoder, E. J. and Witczak, M. Principles of Pavement Design, p. 631.

17. --------. A pavement rating system for low-volume roads. Asphalt Institute Information Series No. 169 (IS-169).

18. --------. International aspects of recycling. Rural and Urban Roads, July 1981, p. 22.

19. --------. Plant set-up for Foamed asphalt. Construction Canada, July 1964, pp. 20-23.

TABLE 1: RESULTS OF TESTS ON TWENTY-FOUR CORE SAMPLES

		Ave.	S.D.	Range
% Asphalt		6.10	0.40	5.06- 6.79
% Passing Sieve	17.25 mm.	0.83	1.21	0 - 4.18
	12.5 mm.	8.56	2.89	4.19-14.72
	9.5 mm.	16.90	2.75	11.46-21.50
	4.75 mm.	34.50	2.74	27.39-39.14
	3.55 mm.	9.12	0.89	7.67-11.14
	0.075 mm.	25.11	4.09	18.93-37.10
	<0.075 mm.	4.39	0.81	2.39- 5.76

TABLE 2: RESULTS OF TESTS ON EIGHT CORE SAMPLES

		Ave.	S.D.	Range
Penetration (in pens)		41	12.18	28-63
Kinematic viscosity (cSt)		459.9	155.5	195.2-651.4
% Passing Sieve	2.36 mm.	28.3	2.43	25.8-33.3
	0.60 mm.	15.1	1.41	13.4-17.9
	0.45 mm.	13.4	1.09	11.9-15.0
	0.30 mm.	11.9	1.07	10.1-12.5
	0.15 mm.	8.6	0.79	7.3- 9.5
	0.075 mm.	5.5	0.41	4.6- 5.9

TABLE 3: CONSTRUCTION AND MATERIAL REQUIREMENTS

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1. Foamed Asphalt:

Asphalt: AC-5
Mixing temperature: 165 ± 5 degrees C
Amount of water: 2% by weight of asphalt
Expansion ratio = (volume of foam)/(volume of original asphalt cement)
Half life = 20 seconds = time it takes the volume of foam to reduce from its maximum volume to one-half of the maximum volume
Temperature during processing > 50 degrees C
during non-work periods and it had to be graded and compacted

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2. Milled Material:

Maximum size: 75 mm.
90 to 100 percent less than 38 mm.
Free moisture during mixing = 2.5 - 3.5%

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3. Additional Aggregate:

The construction section had to be open to two-way traffic.

Grading: meeting section 903 of IDOH standard specifications
Coarse aggregate: meet requirements of Class C aggregate
Free moisture during mixing: 2.5 - 3.5%

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4. Geometry of the Pavement:

Minimum thickness of the recycled base: 125 mm.

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5. Construction:

The construction section had to be open to two-way traffic during non-work periods and it had to be graded and compacted.

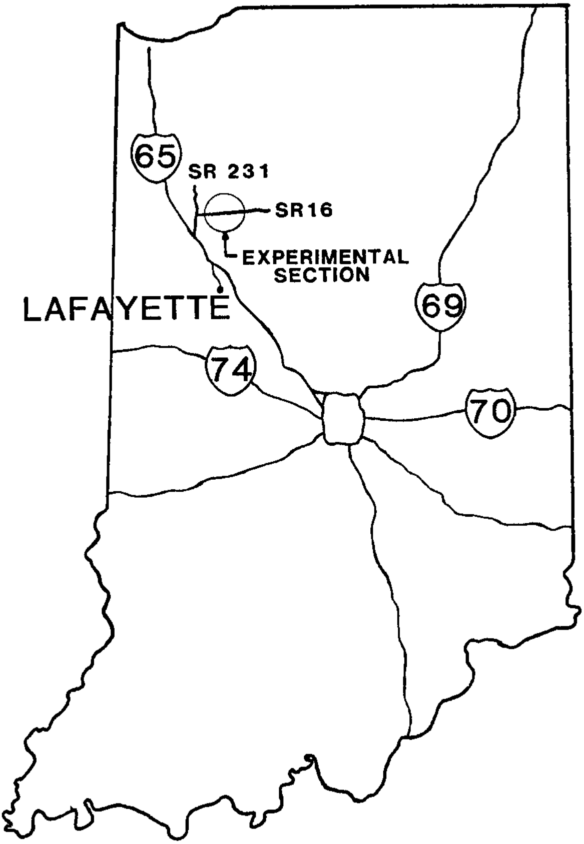

Fig. 1 Location of the Test Road

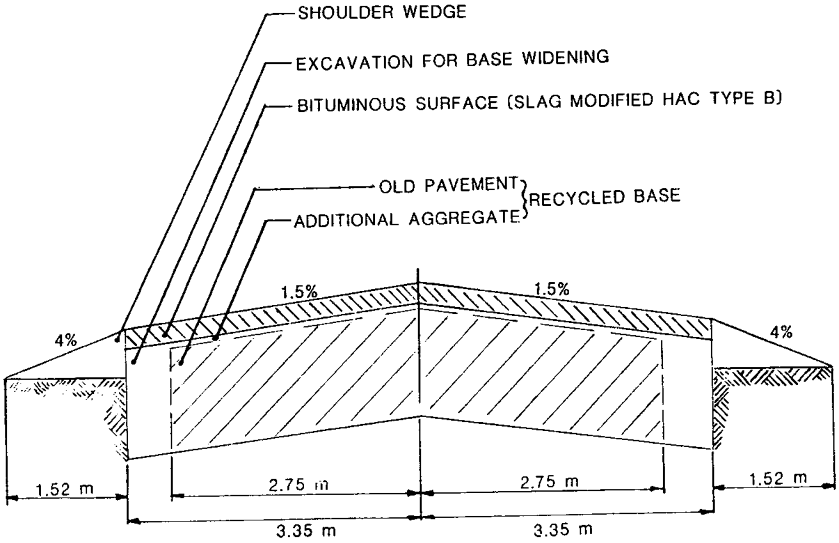

Fig. 2 Cross Section of Proposed Final Pavement

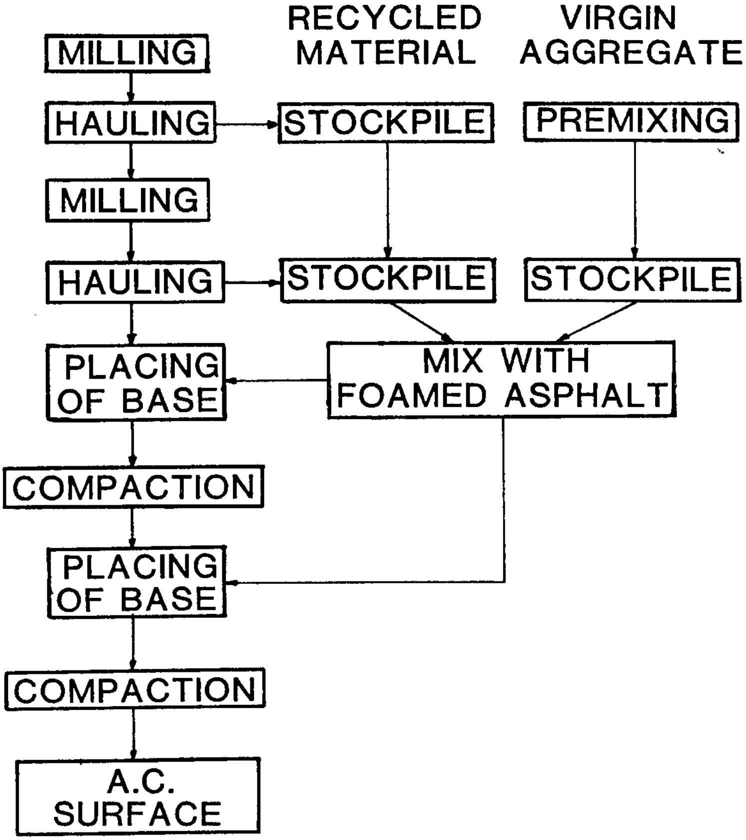

Fig. 3 Grading Analysis of the Actual Construction

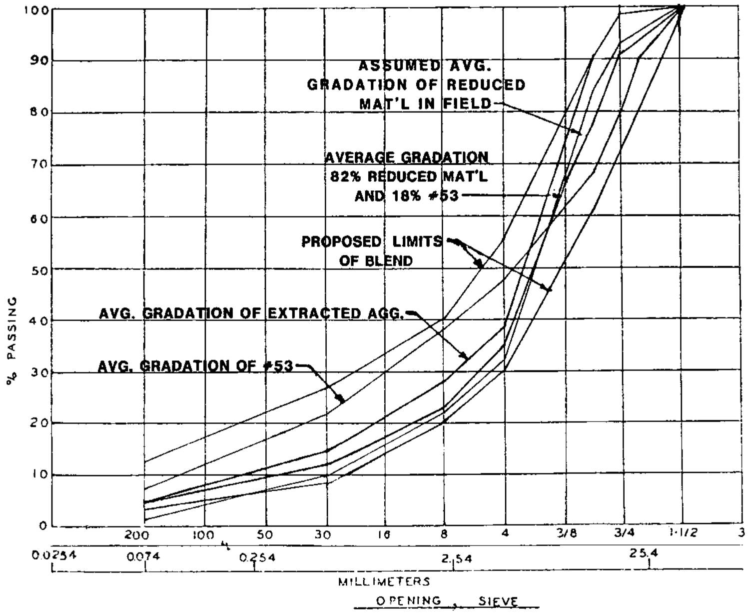

Fig. 4 Flow Diagram of Actual Construction

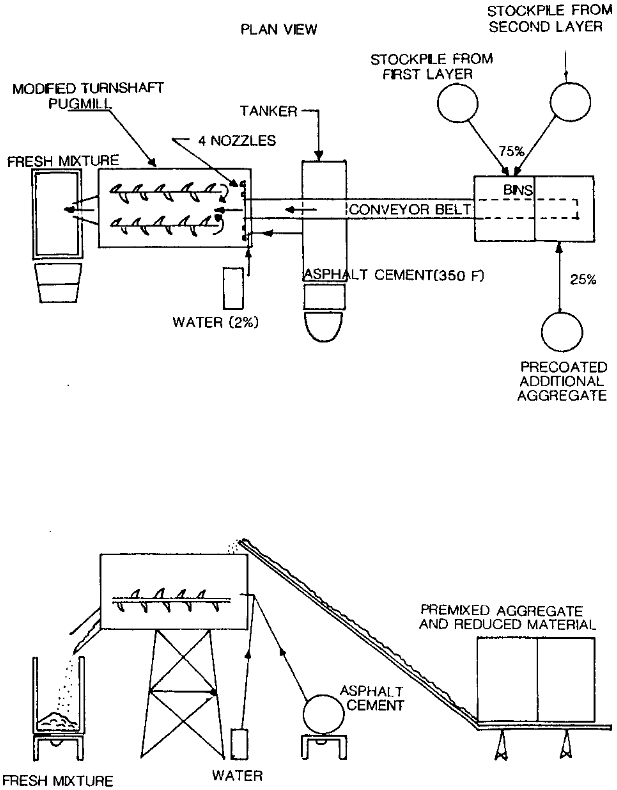

Fig. 5 Mixing Process

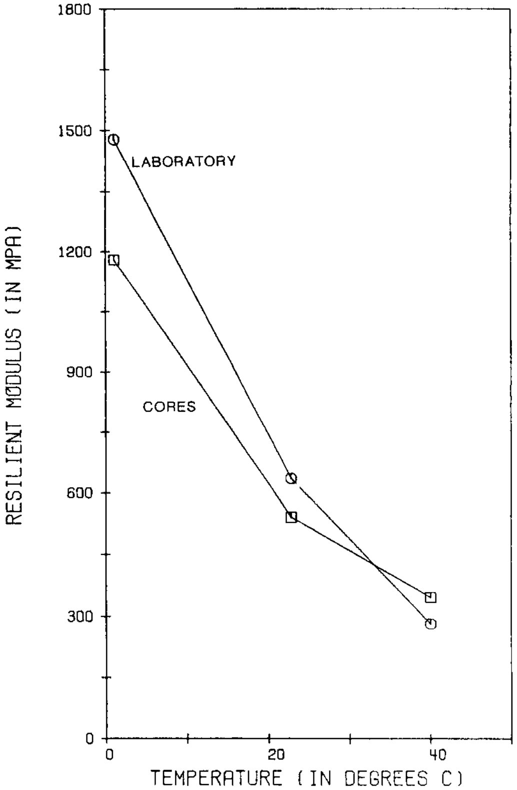

Fig. 6 Effect of Temperature on Resilient Modulus

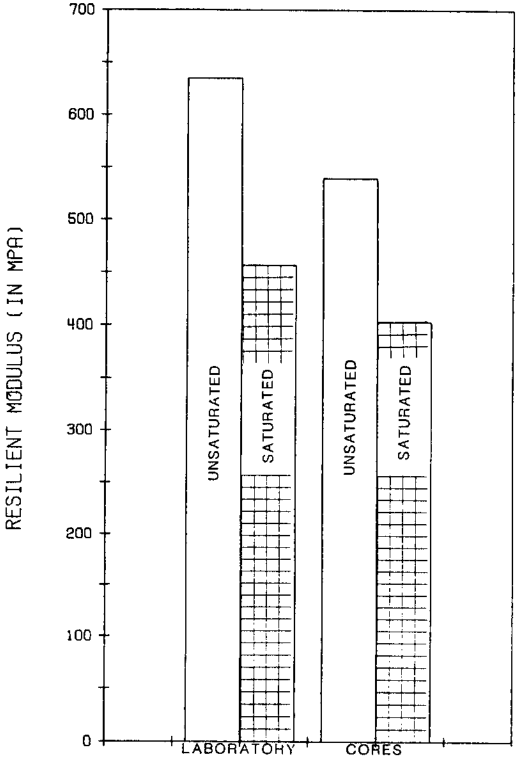

Fig. 7 Influence of Water on the Resilient Modulus

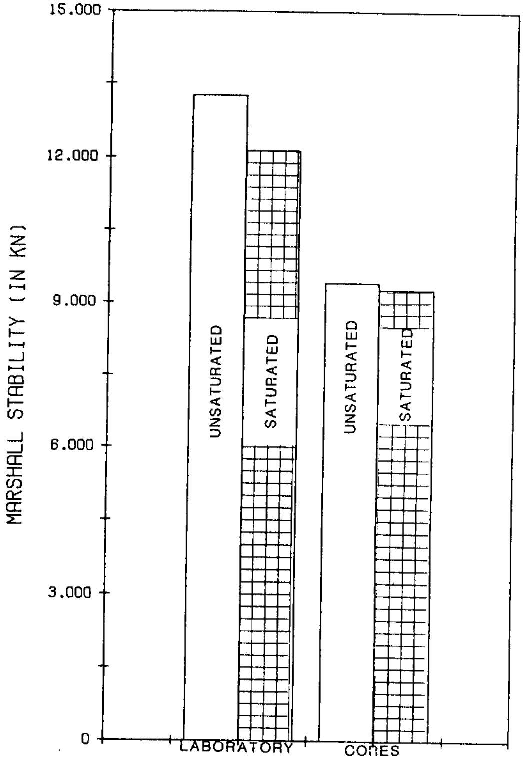

Fig. 8 Influence of Water on the Marshall Stability

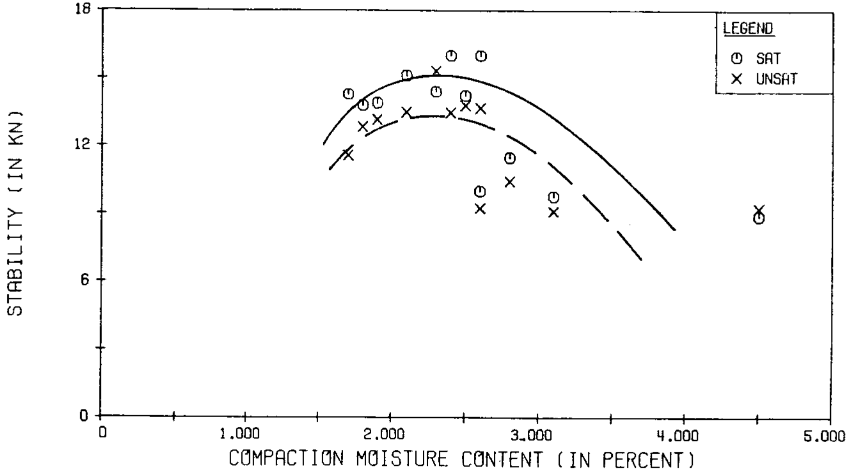

Fig. 9 Effect of Compaction Moisture Content on Marshall Stability

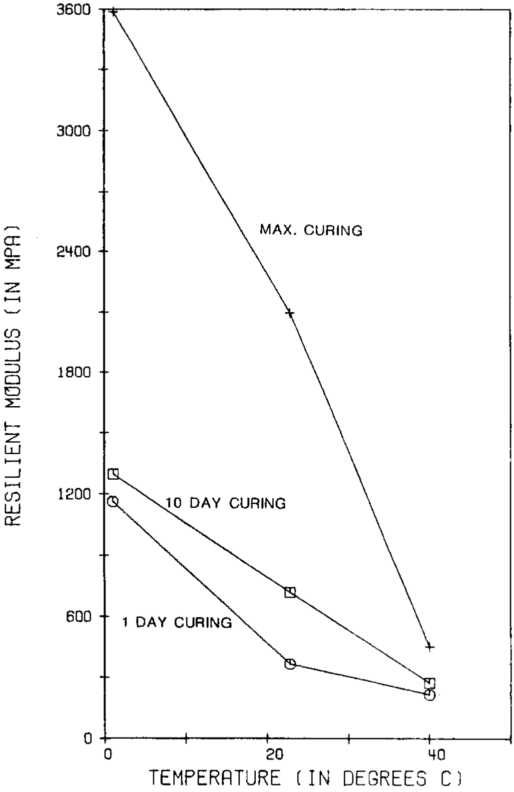

Fig. 10 Effect of Curing Time on Resilient Modulus

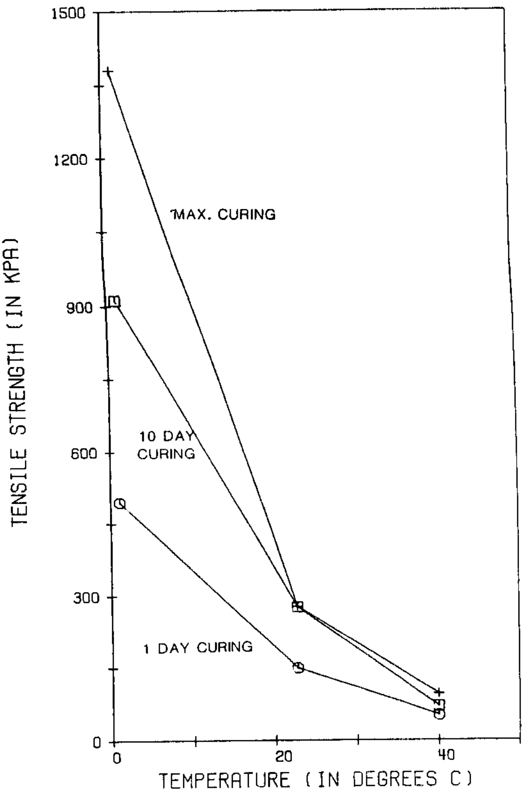

Fig. 11 Effect of Curing Time on Tensile Strength

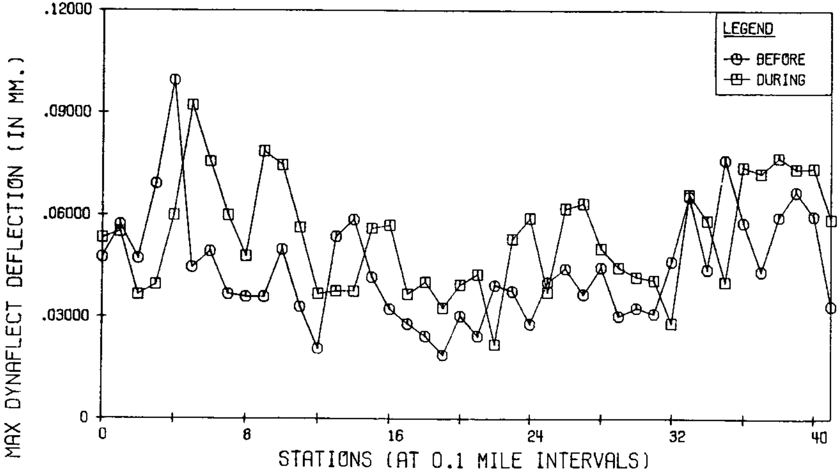

Fig. 12 Dynaflect Deflections: Before and During Construction

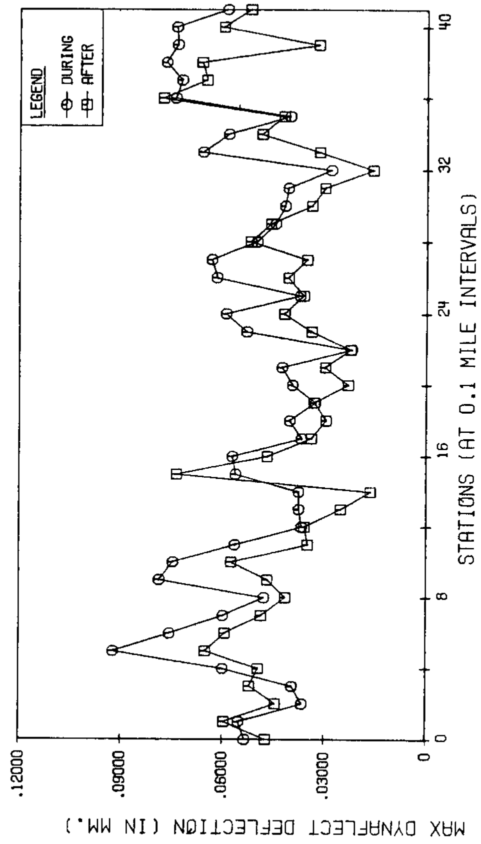

Fig. 13 Dynaflect Deflections: During and 250 Days After Construction