Report No. CDOT-DTD-R-95-12

Using Ground Tire Rubber in Hot Mix Asphalt Pavements

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Construction Report
June 1995

Prepared in cooperation with the
U.S. Department of Transportation
Federal Highway Administration

Acknowledgements

The authors would like to thank the research study panel for providing many excellent comments and suggestions for this study. The panel included Tim Aschenbrener (CDOT), Steve Horton (CDOT), Gerry Peterson (CDOT), and Richard Zamora (FHWA).

The authors would like to thank the Region 6 Personnel who were instrumental in helping maintain the continuity of this research through construction.

Special thanks to Richard Wade (CDOT Region 6 Materials) and Kevin Hsu (CDOT Region 6 Construction) for the added effort they put forth to obtain and provide the required data for evaluation.

REPORT DOCUMENTATION PAGE

FORM APPROVED
OMB NO. 0704-0188

1. AGENCY USE ONLY (Leave Blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	July 1995	Construction Report

4. TITLE AND SUBTITLE
Using Ground Tire Rubber in Hot Mix Asphalt Pavements

5. FUNDING NUMBERS

6. AUTHORS(S)
Donna Harmelink and Robert LaForce

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(S)
Colorado Department of Transportation
4201 E. Arkansas Ave.
Denver, Colorado 80222

8. PERFORMING ORGANIZATION REPORT NUMBER
CDOT-DTD-R-95-12

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(S)
Colorado Department of Transportation
4201 E. Arkansas Ave.
Denver, Colorado 80222

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
Prepared in Cooperation with the U.S. Department of Transportation, Federal Highway Administration

12a. DISTRIBUTION/AVAILABILITY STATEMENT
No Restrictions: This report is available to the public through the National Technical Information Service. Springfield, VA 22161

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)
This report documents the development of CDOT's crumb rubber mixes and the construction of the project containing these crumb rubber mixes. This project contained 4 different mix designs. Approximately 9000 tons of HBP containing crumb rubber was placed on on this project. Of this 9000 tons of HBP, 500 tons contained 1% (20 lbs/ton) crumb rubber and 500 ton contained 3 lbs/ton of crumb rubber. The remaining 8000 tons contained 1 lb/ton. In addition 500 tons of HBP containing no rubber was placed.

This project will be evaluated for 3 years. In the Fall of 1997 a final report documenting the performance of the different mixes will be written.

14. SUBJECT TERMS
Hot Mix Asphalt (HMA), crumb rubber, tire rubber, dry process, ISTEA Section 1038(d)

15. NUMBER OF PAGES
50

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

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In Hot Mix Asphalt

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1.0 Introduction

1.1 Background

A large number of used tires are discarded each year in the United States, approximately 285 million.(1) This averages out to one tire per person per year. For Colorado this figure calculates to approximately 3.5 million tires per year. In addition, it is estimated that there are more than 30 million scrap tires in Colorado that have not been properly disposed of or recycled.(2) Throughout the United States the management of these scrap tires has become a major concern. Whole tires are very difficult to dispose of and consequently landfills are full of tires. The Scrap Tire Management Council estimates that there are over 800 million tires in stockpiles and uncontrolled tire dumps across the country.(2) These scrap tire stockpiles impose health, environmental and aesthetic problems.

Out of the 285 million scrap tires generated in 1990, approximately 33 million were retreaded and 10 million were reused. The EPA does not count retreaded and reused tires in their waste tire inventory. Less than 7 percent of the remaining 242 million tires discarded in the United States during 1990 were recycled into new products and about 11 percent were converted into energy. Over 77 percent, or about 188 million tires in 1990 were landfilled, stockpiled, or illegally dumped, and the remaining 5 percent were exported.(3)

To help combat and reduce the number of scrap tires being generated each year, Congress enacted Section 1038(d) of the ISTEA legislation. See Appendix A.

1.2 Legislation

1.2.1 Intermodal Surface Transportation Efficiency Act of 1991

In December 1991, the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) was signed into law. Section 1038(d) of this legislation requires states to use crumb rubber from recycled tires in a minimum percentage of asphalt surfacing placed each year. Noncompliance with this legislation would result in severe Federal funding reduction. The ISTEA legislation minimum utilization requirement for asphalt pavement containing recycled rubber from scrap tires was as follows:

1994 5% utilization
1995 10% utilization
1996 15% utilization
1997 20% utilization
and 20% utilization each year there after.

Colorado's crumb rubber utilization requirements are based on the amount of Federal aid asphalt mix tonnage. Based on 1992 figures, (1,000,000 tons of Hot Bituminous Pavement) the amount of crumb rubber Colorado would be required to put into their pavement at 5% would be 452,488 kgs (1,000,000 lbs).

In October of 1993 the House and Senate agreed to impose a one-year moratorium on Section 1038(d) of the Intermodal Surface Transportation Efficiency Act. FHWA advised the department that in effect, this moratorium deleted the 5% utilization requirement for 1994; however, beginning in 1995 the department would be required to meet the 10% utilization mandate.

In September of 1994 the House and Senate passed the FY95 Department of Transportation Appropriations Bill (HR 4556). This bill extended for another year the moratorium on the Federal Highway Administration's enforcement of the crumb rubber minimum utilization requirements in Section 1038(d) of ISTEA. It has not yet been determined what the requirements for 1996 will be.

The two year delay in implementation has allowed the department to evaluate alternate design criteria for incorporation of crumb rubber into hot mix asphalt.

1.2.2 Colorado House Bill 93-1318

To promote recycling Colorado House Bill 93-1318 was passed and went into effect in June 12, 1993. Beginning January 1, 1994, Section 25-17-202 C.R.S. (created by H.B. 93-1318) required a $1.00 "Recycling Development Fee" be collected by the retailer from the purchaser for each old tire collected when purchasing new tire replacement. Revenues generated from this assessment fee are available for loan under the Recycling Economic Development Loan Program administered by the Colorado Housing And Finance Authority (CHFA). Any Colorado business can apply for these funds as long as recycling or waste diversion is a component in their business. However, there is no limitation on the type of material the business recycles.

To date, five loans have been approved to borrow funds from this program, however, none of the loans have been to tire recycling companies.

1.3 Colorado's History Using Crumb Rubber

Crumb rubber can be incorporated into the Hot Bituminous Pavement in two ways. In the first method the crumb rubber is blended into an asphalt binder prior to the addition of the heated aggregates. This process is commonly referred to as the "wet" method. In the second method the crumb rubber is added directly to the heated aggregates. This process is commonly referred to as the "dry" method.

Colorado's experience with crumb rubber is limited. The state's first use of crumb rubber started in the late 1970's with crumb rubber crack fillers and crumb rubber stress absorbing membrane interlayers (SAMI) and stress absorbing membranes (SAM) or chip seal coats.

Five SAMI projects and four SAM projects were constructed and evaluated by the Research Branch with the results that neither treatment was found to be cost effective compared to available standard treatments.(4 & 5)

SAMI's were more expensive than reflection cracking fabric interlayers with comparable results. Additionally, the chips required as part of these treatments caused numerous problems with broken windshields on high speed, high volume roads. These chips also caused problems in urban areas when traffic threw them up on the sidewalks.

Chip seal coats (SAM's) using crumb rubber modified asphalt did not perform any better than seal coats with standard binders (RC-800 rubberized). The cost of the crumb rubber modified binder was approximately three times the cost of the standard binders. Additionally this binder was quite susceptible to snow plow damage on highways where packed snow and ice are routine. These seals were not recommended in the mountains.(6 & 7)

In the winter of 1985-1986, the CDOT Flexible Pavement Unit performed a mix design using a patented dry process (Plus Ride) with local asphalts and aggregates. This design was performed using the Hveem design method. The Plus Ride system determines optimum asphalt content at 2% voids while with the Hveem system an optimum asphalt content is selected near 4% void content providing other properties such as stability and moisture resistance are met. The Plus Ride design using the Hveem Method appeared to have a very low stability and strength coefficient. The design performed yielded what appeared to be a very unstable mix. The Immersion/Compression (AASHTO T165) test for moisture resistance had passing strength ratios, but the compressive strengths were extremely low, approximately one-half of the standard mix from the same aggregate source. This data coupled with the variable performance of crumb rubber pavements in our area resulted in CDOT not building a dry process crumb rubber project.(8)

Projects in Arvada and Aurora as well as a project in New Mexico showed early distress in the form of ravelling from the surface down into the mat while a project at the Lamar Airport has performed well. Except for crumb rubber modified crack fillers, the CDOT has not used any crumb rubber in asphalt pavements since 1981.

In 1994 Colorado initiated a research project to incorporate crumb rubber into their pavements to identify construction, environmental and other problems which may be encountered. Colorado chose to begin first with the "dry" process because with this process it is easier to control the mixing and less complicated for the contractor. The purpose of this report is to document the construction and provide a guideline for future crumb rubber projects.

2.0 Colorado Crumb Rubber Project

Colorado paved its first crumb rubber project in 1994. This project is located on Platte Canyon (SH 75) from Bowles to C470 in the Denver Metropolitan area. The location of this project can be seen in Figure 1.

2.1 Development of Mixes

Prior to the selection of the project mixes, mixes containing varying amounts of crumb rubber were designed in the Staff Materials Laboratory.

In the laboratory, four "dribble" mixes were designed with no changes to the gradation of the aggregate, and no special treatment during mixing and compaction. A "dribble" mix is a small amount of crumb rubber uniformly added to a mix. The idea of a "dribble" mix is that a large amount of crumb rubber could be used without special mix designs or special handling. The crumb rubber was added to the original mix design and then lab testing proceeded in the normal manner. Sinclair AC-10 was used in this design.

Following is a summary of the test results from using the "dribble" mix at varying rubber contents.

Table 1. Crumb Rubber Mix Designs

	TEXAS GYRATORY COMPACTIVE EFFORT					
	20-50-2500			30-100-2500		
% CRUMB RUBBER	Hveem Stab.	Opt. % AC	Cohes.	Stab.	Opt. % AC	Cohes.
0%	38	5.4	137	38	4.9	149
0.05% (1 lb/ton)	36	5.3	142	36	4.9	169
0.15% (3 lbs/ton)	32	5.6	98	36	5.4	110
0.25% (5 lbs/ton)	30	5.7	95	34	5.5	104

Table 1 shows that the addition of crumb rubber at the 1 lb/ton rate had very little effect on the original mix. Additions of crumb rubber above the 1 lb/ton rate had a tendency to increase the asphalt demand and lower the stability. At the 5 lbs/ton rate these changes would not be acceptable without taking the volume of crumb rubber into consideration in the gradation.

In order to make room for the rubber in the mix, the gradation of the aggregate was changed by eliminating 3% of the minus #4 sieve fraction for each 1% crumb rubber added. The mix was then treated like an absorptive mix. After mixing the rubber and aggregate with the asphalt cement, the mix was aged for four hours at compaction temperature to give the asphalt and rubber a chance to react.

An additional change in the design was that a five pound weight was placed on the top of the molded samples until they cooled. Once they cooled the samples were removed from the molds and tested for Hveem stability, bulk specific gravity, etc. The five pound weight is recommended to control swell of the crumb rubber mix. This technique accomplishes the control of swell in the same way that rolling in the field is continued until the mat cools to 60°C (140°F).

The Lottman (AASHTO T283) samples from this mix were also tested after cooling with a 5 pound weight on the molds. The Tensile Strength Retained (TSR) results for the mix containing 1% crumb rubber was 89%.

The addition of 1% crumb rubber dramatically increased the asphalt demand and as noted in the manual from the crumb rubber modified workshop, the Hveem stabilities are about half of normal.(9)

2.2 Selection of Crumb Rubber Mix

Upon completion of the testing by the Staff Materials Laboratory, it was decided that on the first construction project, three different percentages of crumb rubber would be evaluated. The design mixes would Included 1 lb/ton, 3 lbs/ton, and a 1% (20 lbs/ton) mixture. The design mixes can be found in Appendix B. In addition to these mixes a mix containing no crumb rubber would be placed on the project for evaluation purposes. The specifications for this project can be found in Appendix C.

2.3 Additional Costs With Crumb Rubber

The contractor's bid for the crumb rubber mixes is shown in Table 2 along with the standard mix bid price.

Table 2. Bid Costs of Crumb Rubber and Hot Mix Asphalt Mixes

TYPE OF MIX	CONTRACTOR'S BID
Grading C (1 lb/ton)* 8575 tons	$30.00
Grading C (20 lbs/ton) 500 tons	$35.00
Grading C No Rubber 500 tons	$29.00

* Because the quantity of crumb rubber in the 1 lb/ton and the 3 lbs/ton mix was small the contractor did not bid them separately and the 8575 tons includes both mixes.

The difference in the contractor's bid between the Grading C without rubber and the Grading C with the 1% (20 lbs/ton) was $6.00 per ton of Hot Bituminous Pavement (HBP). The rubber in this project increased the total cost of the HBP by 4%.

At this time it is very difficult to predict what the cost increase will be in the future. With the small amount of rubber incorporated into this project it was expected that there would be a significant increase. Not only was the contractor unfamiliar with the rubber, they had to adapt their plant to incorporate the rubber. The contractor was also limited to suppliers of the material. Although the addition of the crumb rubber only increased the total HBP cost by 4% the amount of crumb rubber used on this project was very insignificant compared to the amount that Colorado Department of Transportation needs to use to meet the ISTEA requirement. The crumb rubber in the 20 lbs/ton mix increased the cost per ton of the mix by 21% which would be a significant cost increase if mixes containing higher percentages of this crumb rubber are used on a project. One can only predict that as the demand for the rubber increases, a decrease in cost will be noticed.

The cost to the contractor for the equipment to properly add the material will be realized initially; however, if there becomes a demand for the crumb rubber material it is anticipated that the market will be very competitive. The cost of crumb rubber will probably not be the major deciding factor, it will be long term performance.

2.4 Crumb Rubber Supplier

At the time this project was constructed, Colorado did not have a crumb rubber supplier. The crumb rubber used on this project came from a supplier in Dayton, Ohio. Colorado now has crumb rubber suppliers.

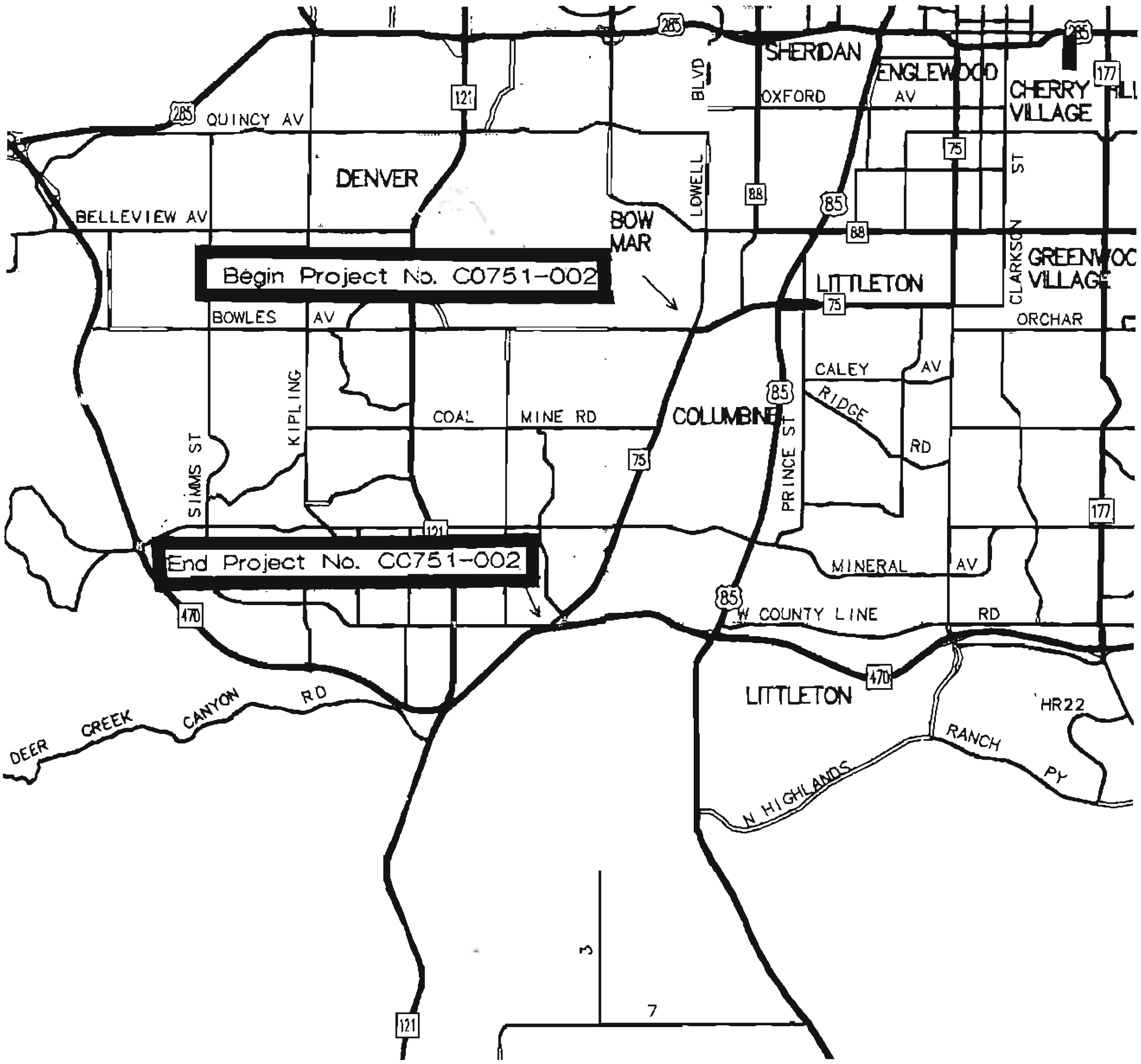

Figure 1. Location of Project

3.0 Construction

3.1 Project Description

Project No. C 0751-002, selected for evaluation, is located in Region 6 (Denver area) on SH 75 (Platte Canyon Road) between West Bowles Avenue to C470. The 1993 average daily traffic between Ken Caryl Avenue and Bowles Avenue ranged from 8,500 to 14,600 vehicles with 2% trucks. The project was designed using 10 year 18K ESAL of 332,000. The project contained 4 different mix designs. Approximately 9000 tons of Hot Bituminous Pavement containing crumb rubber was placed on this project. Of this 9000 tons of HBP, 500 tons contained 1% (20 lbs/ton) crumb rubber and 500 tons contained 3 lbs/ton of crumb rubber. The remaining 8000 tons contained 1 lb/ton. In addition 500 tons of HBP containing no rubber was placed. The location of the placement of the specific crumb rubber mixes is shown in Figure 2.

3.2 Project Plans

The original plans called for a 2" HBP overlay. Prior to the overlay the entire length of the project was to be planed and paving fabric installed as directed by the Engineer. However upon inspection of the project it was determined that in some areas the depth of the existing pavement was only 2 to 3 inches thick which was too shallow to plane. Planing was eliminated except in areas which contained curb and gutter.

Construction plans were then changed to include paving fabric the entire length of the project and the depth of the HBP was increased from 2" to 2-1/2".

3.3 Evaluation Sections

Prior to construction, four 1000 foot evaluation sections were established. One evaluation section was established for each of the mixes containing crumb rubber plus one in the section containing no crumb rubber. These sections are located in the northbound lane between Ken Caryl and Bowles. Figure 2 shows the location of the evaluation sections.

3.4 Pre-Construction Evaluation

A pre-construction evaluation was performed on these sections. This evaluation included crack mapping, rut depth measurements, photographs and a visual inspection.

The existing pavement was severely distressed. Block and alligator cracking was found throughout the evaluation sections. The cracks had not been filled and averaged about 25 mm (1 inch) wide. There were several areas in the evaluation sections that had ravelled out creating large holes in the mat. The rut depth measurements throughout the project averaged 12 mm (.5 inch). The pre-construction condition of the pavement can be seen in Figure 3.

3.5 Plant Description

The drum mixer plant was located 2 miles from the south end of the project. The mix discharge temperature was between 140°C (285°F) and 149°C (300°F). A baghouse was used for emission control. During production the baghouse was checked for crumb rubber particles. No crumb rubber was found in the baghouse. The mix was delivered to the site by tandems and end dumps. The mix temperature behind the paver ranged from 127°C (260°F) to 135°C (275°F).

Although, stack emissions at the plant during production were not measured it appeared that the 1 lb/ton or the 3 lbs/ton did not make a significant difference in the smoke stack opacity. The quantity of the 1% crumb rubber mix produced was quite small and any effect that this percentage of crumb rubber had on the emission was difficult to determine. It is recommended that on future projects the emissions of the plant during production of the crumb rubber mixes be monitored to better determine if there is an emissions problem during the production of these mixes.

The crumb rubber was conveyed through a grain auger and added at the recycled asphalt pavement (RAP) collar. The amount of crumb rubber being added was controlled by the speed of the auger. The addition of the rubber was not monitored by the Colorado Department of Transportation (CDOT). Although the contractor did not have problems adding the crumb rubber, they thought the 2000 b bags were difficult to handle. However, if the addition of crumb rubber becomes a standard practice, the plant could be equipped to handle this more efficiently. Because the diameter of the grain auger was only 6" the production at the plant was slowed down to accommodate the 1% mix. This resulted in a higher production temperature. If using crumb rubber becomes a standard practice a more precise method for the adding the crumb rubber will need to be developed.

Photographs showing the addition of the crumb rubber at the plant are shown in Figures 4, 5, 6 and 7

3.6 Laydown Operation

Because of the possible pick up by pneumatic rollers on mats containing rubber, the specifications did not allow pneumatic rollers on rubber mixes unless directed by the engineer. The pneumatic roller was not permitted the first day of paving. The 1 lb/ton was placed on the first day. As a result of the mix being tender the mat placed on the first day developed hair line cracks. A pneumatic roller was used after the first day to seal these tiny cracks. The hair line cracks were eliminated and the use of the pneumatic roller was continued with minor pick up.

Three rollers were used for the majority of the paving. A Hyster 350D was used for breakdown. A Hyster C530A pneumatic roller was used as the intermediate roller. A Hyster C766B was used for the finish roller. Density was easily obtained in all the mixes containing crumb rubber and in the section containing the standard mix. The final density in the evaluation sections ranged from 92.3% in the 3 lbs/ton mix to 94.5% in the 1% crumb rubber mix.

Hours for paving on this project were limited. The contractor was not allowed to start placing pavement until 9:00 am and was required to be off the roadway by 3:30 pm. Because traffic is not normally allowed on the paved section until the mat temperature is 65^{o}C (150^{o}F) or below, a water truck was used to spray the mat on several occasions to drop the mat temperature. Because the crumb rubber specification requires the contractor to continue rolling the mat until the surface temperature is 60^{o}C (140^{o}F), a time restriction for opening a section of roadway to traffic became more critical. The restricted time element needs be considered if the entire project is under the 60^{o}C (140^{o}F) rolling specification because it will limit the contractor on the amount of pavement that can be placed daily.

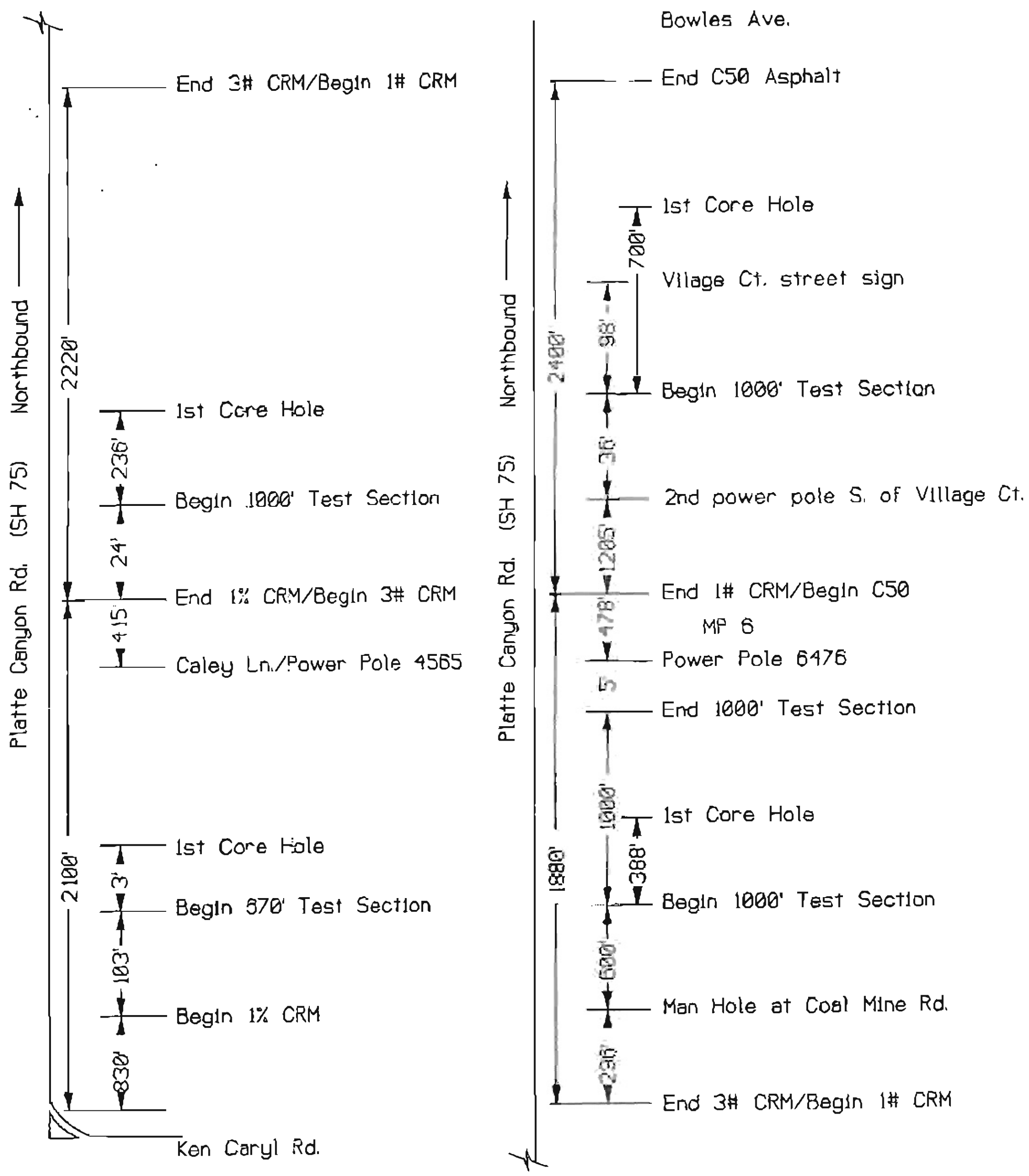

Figure 2. Location of Crumb Rubber Sections

Figure 3. Typical distress found in existing pavement

Figure 4. Crumb Rubber was supplied in 2000 lb bags

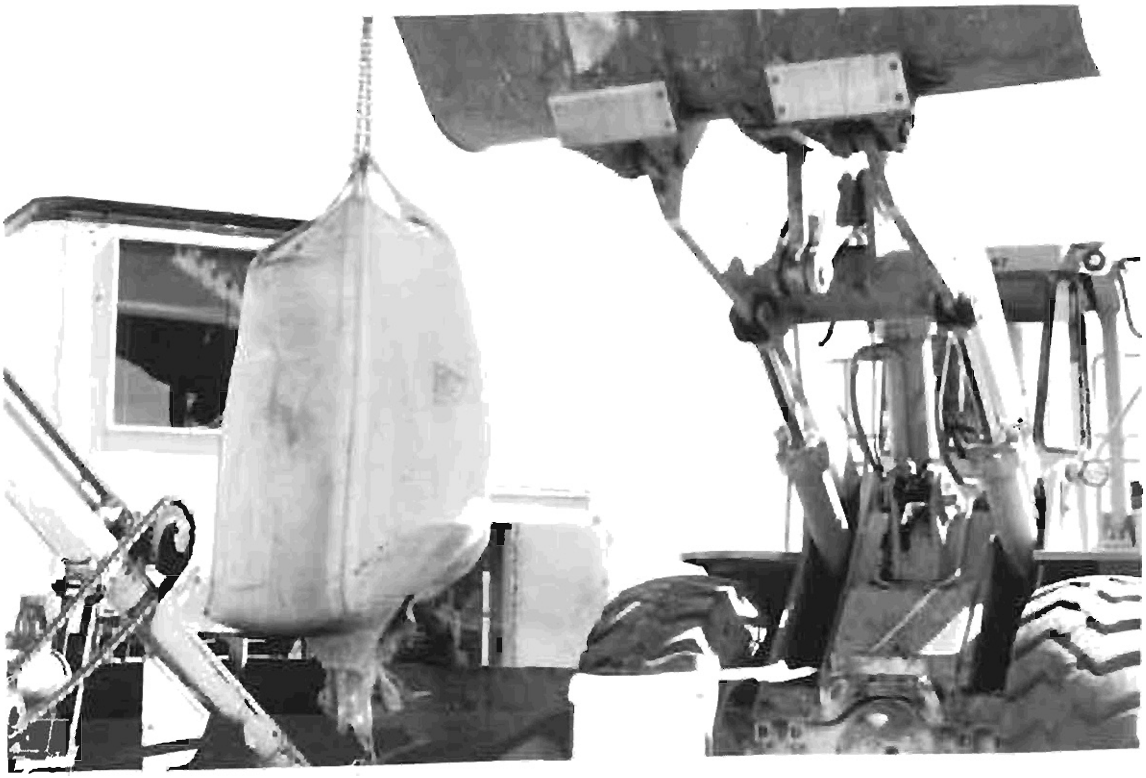

Figure 5. The crumb rubber bags were emptied into a storage bin

Figure 6. An auger was used to transport the crumb rubber to the RAP collar

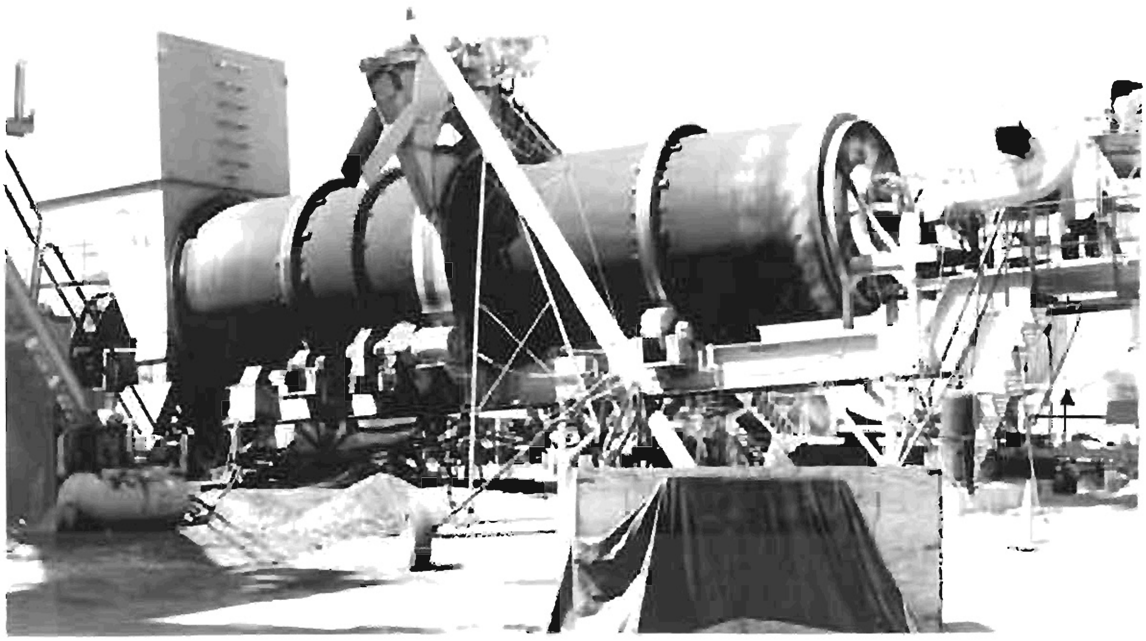

Figure 7. An overview of the crumb rubber system

4.0 Field Verification Test Result

4.1 Crumb Rubber Gradation

Only one crumb rubber gradation sample was verified during the paving of this project. The gradation specification and the gradation results for the project are shown in Table 3.

Table 3. Crumb Rubber Gradation Results

SIEVE SIZE	PERCENT BY WEIGHT PASSING SQUARE MESH SIEVES	
	Specification	Test Results
4.75 mm (No. 4)	100	
2.36 mm (No. 8)	80 - 100	100
1.18 mm (No. 16)	40 - 70	71
600 µm (No. 30)	0 - 20	1.1
300 µm (No. 50)		.4
150 µm (No. 100)		.3
75 µm (No. 200)		0.1

Note -- Gradation was tested in accordance with ASTM C 136 using a 50 gram sample.

All crumb rubber modifier retained on the 2.36 mm (No. 8) sieve shall be cubical in shape and individual particles shall have a flatness or elongation ratio no greater than 2:1.

The gradation results shows that the crumb rubber used on this project was slightly finer on the 2.36 mm sieve than the specification allows. At this time it is difficult to predict if this will have any effect on the performance of the pavement.

4.2 Asphalt Content, Stability, Field Compaction and Volumetrics

Table 4. Asphalt Content, Stability, Field Compaction and Volumetrics Test Results

% CRUMB RUBBER	% ASPHALT CONTENT	HVEEM STABILITY	% OF MAXIMUM DENSITY	% VOIDS	TSR	VMA %
0% No Crumb rubber	4.9 (4.9)	36 (37)	93.2 (92.0)	2.4 (3.88)	99 (*)	13.2
0.05% 1 lb/ton	4.8 (4.9) 4.8 (4.9)	38 (39) 37 (39)	93.4 (92.0)	2.4 (4.02) 3.6 (4.02)	101 (98) 106 (98)	13.1 13.9
0.15% 3 lbs/ton	5.0 (4.9)	34 (36)	92.3 (92.0)	3.4 (4.25)	99 (100)	14.6
1.0% 20 lbs/ton	5.4 (6.1)	31 (24)	94.5 (92.0)	1.5 (3.89)	92 (93)	13.9

( ) These denote values at optimum AC content for each specified percentage of crumb rubber.
* Data unavailable

Only one sample was taken from each evaluation section. The voids in the field mix were significantly lower in all the sections. There was only one gradation sample taken and it was slightly finer on the 2.36 mm sieve than the specification allowed. Future testing with cores will determine the void content in each design and how they change with time. This will ultimately determine the performance of the crumb rubber mixes.

4.3 Cores

Cores were taken between the wheel paths in the evaluation sections immediately following construction. These cores were used to determine the as constructed air voids.
Table 5 shows the as constructed air voids in each of the evaluation sections.

Table 5. As Constructed Air Voids

TYPE OF MIX	PERCENT AIR VOIDS
Grading C No Rubber	4.27 *
Grading C (1 lb/ton)	3.25
Grading C (3 lbs/ton)	5.93
Grading C (20 lbs/ton)	2.52

* This value is suspect and will be verified when cores are taken next year.

The performance of the pavement over the evaluation period will determine how the air voids affect the performance of the crumb rubber mixes.

4.4 Testing in French Rutting Tester

Normally, for the Denver area, a mix would be tested on the French rut tester at 45°C or 50°C (10), however, this project is located on a roadway with relatively low traffic loading, and hence a low compactive effort mix design was used.

The testing on the French rut tester was performed at 45°C. In order to determine if there was a difference in the rutting potential between the standard mix and the same mix containing various percentages of crumb rubber.

The specification for rutting is a maximum of 10% rut depth after 30,000 passes. As can be seen in Table 6, at a temperature of 45°C. The mix containing no crumb rubber and 1 lb/ton passed the rutting test, the mix containing 3 lbs/ton barely failed the requirement, and the mix with 1% crumb rubber also failed.

The mixes with no crumb rubber, 1 lb/ton, and 3 lbs/ton all were constructed at the same asphalt content, (4.9% AC). From the rutting data, the rubber which is an aggregate substitute in the dry process, does not appear to have provided any aggregate interlock so the more crumb rubber added, the greater the rutting potential. With the small amounts added, 1 lb/ton and 3 lbs/ton, the effect was minor and the rutting results were similar.

In the case of the 1% crumb rubber mix, the design asphalt content was 6.1% and the RAP was removed in order to provide room for the crumb rubber. This mix was rich in asphalt cement and did not provide the rut resistance needed under these traffic and environmental conditions.

The field evaluation should provide valuable data on how these mixes perform under actual traffic conditions.

Table 6. French Rutter Results

TEMPERATURE	NO CRUMB RUBBER	1 LB CRUMB RUBBER	3 LBS CRUMB RUBBER	1% (20 LBS) CRUMB RUBBER
40°C	----	----	3.6%	6.6%
45°C	6.3%	8.4%	10.8%	16.5%
50°C	13.6%	----	----	----

---- samples were not tested

4.5 Project Summary

If the Colorado Department of Transportation would have been required to meet the 1994 ISTEA utilization requirement of 5%, they would have had to use 1,000,000 lbs of crumb rubber. This equates to approximately 83,333 tires based on one tire producing 12 lbs of useable material. The project that was constructed in 1994 on Platte Canyon used approximately 19,000 lbs of crumb rubber or 1600 tires. Fifty projects of this magnitude would be needed in 1994 to meet Colorado's obligation of 5%.

5.0 First Post-Construction Evaluation

The first evaluation following construction was performed on May 1, 1995. This evaluation was approximately nine months following construction.

The evaluation included crack mapping, rut depth measurements, deflection measurements, smoothness measurements, skid testing and a visual observation. Signs were also placed to mark the beginning and end of each section.

5.1 Cracking

No cracking was found in any of the test sections.

5.2 Rutting

Rutting was measured with a six foot straight edge and was measured in both wheel paths. No measurable rutting was noted.

5.3 Deflection

The Falling Weight Deflectometer was used to measure deflection. The existing structural number will be calculated for each evaluation section. These values will be used as the base line and compared to the measurements taken at the conclusion of the study.

5.4 Smoothnesss

The Ames profilograph was used to determine smoothness. Typically in urban areas smoothness is measured on percent improvement. However, this project did not include a smoothness specification so no data was obtained on the original surface but was collected after the completion of the project. The measurements which were taken in both wheel paths in each evaluation section are shown in Table 7. The values shown in Table 7 were derived using a 1/10 inch blanking band.

Smoothness data will be collected again at the conclusion of the study. These values will be compared to the data in Table 7 to determine if crumb rubber has any effect on the smoothness of the hot bituminous pavement as compared to the standard mix used on this project.

CDOT's smoothness specification can be found in Appendix D.

Table 7. 1995 Profilograph Data

% Rubber	Left Wheel Path mm/km	Right Wheel Path mm/km
0%	495	462
0.05% (1 lb/ton)	204	416
0.15% (3 lbs/ton)	342	425
1% (20 lbs/ton)	241	287

5.5 Skid Testing

Skid testing was performed on all the evaluation sections. The results indicated that the crumb rubber does not change the skid resistance of the pavement. Skid testing will be taken again at the conclusion of the study.

5.6 Visual Observation

Crumb rubber particles are visible on the surface of all the sections. Photographs taken of the surface during this evaluation are shown in Figures 8 and 9.

5.7 Future Evaluations

The next evaluation is planned for Fall 1995. At this time, cores will be drilled and ruts will be measured.

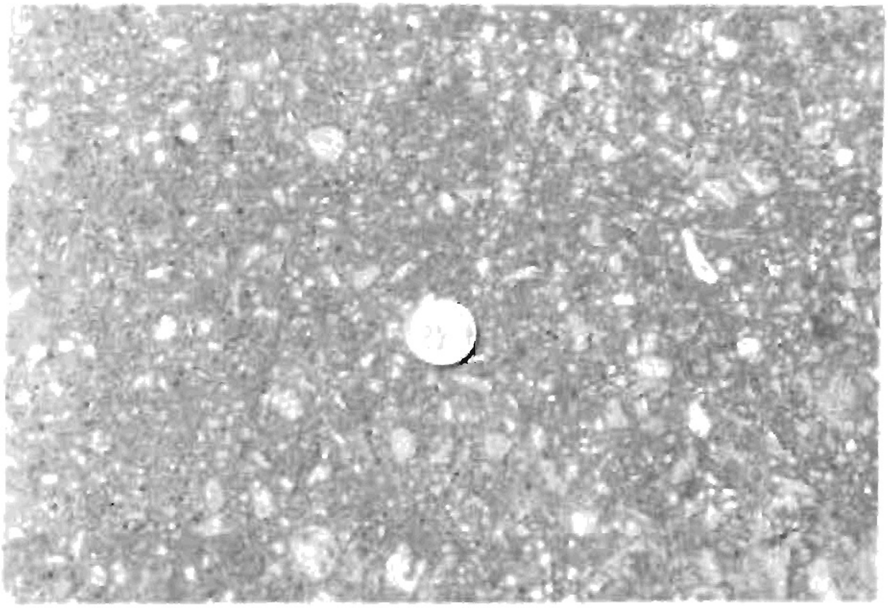

Figure 8. Surface of the 1 lb/ton. Notice the rubber particles on the surface.

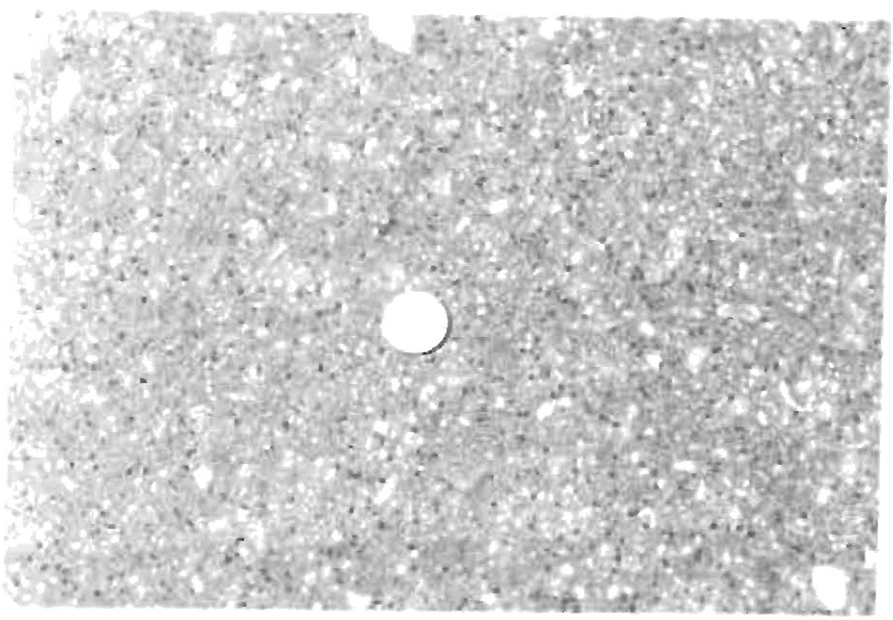

Figure 9. Surface of the 20 lb/ton. Notice the rubber particles on the surface.

6.0 Conclusions

There were no apparent constructibility problems on the Platte Canyon project. The contractor did not experience any problems at the plant other than when the production was reduced during the addition of the 1% (20 lbs/ton) crumb rubber. This problem was project specific and could be corrected with equipment that could accommodate larger percentages of crumb rubber.

After construction there was no apparent difference in the appearance or performance of the pavement containing crumb rubber as compared to the standard section (no crumb rubber).

7.0 Future Plans

7.1 Post-Construction Evaluations

The Platte Canyon project will be evaluated in the spring and fall of each year for 3 years. The evaluation in the spring will include rut depth measurements taken with a 6-foot straight edge, crack mapping, skid testing and smoothness evaluation. In the fall rutting depth measurement and cores will be taken. The cores will be taken to determine if and how the voids are changing. During each evaluation visual inspections will be made of the entire projects. Short field notes will be written documenting the evaluation and the findings.

Defection measurements, taken with the Falling Weight, smoothness values and skid measurement will be taken again during the last field evaluation.

At the end of the three-year evaluation a final report documenting the performance will be written and made available for distribution.

7.2 Future Crumb Rubber Projects in Hot Bituminous Pavement

The Colorado Department of Transportation anticipates constructing another project containing crumb rubber. This project will contain 3 evaluation sections and one control. The percentage of crumb rubber in the test sections will be 1% (20 lbs/ton), 2% (40 lbs/ton), and 3% (60 lbs/ton). The control section will not contain any crumb rubber. The evaluation on this project will be the same as that on the Platte Canyon project. The project selected for evaluation will be in a different environmental area than the Platte Canyon project. This will give CDOT an opportunity to look at the performance of crumb rubber under different environmental conditions.

7.3 Testing Schedule on Future Projects

Based on the Platte Canyon project, testing schedules on future crumb rubber projects will be more comprehensive.

On future crumb rubber projects, the crumb rubber will be sampled according to the Department of Transportation's schedule for minimum materials sampling of gradation. The current procedure of materials sampling is 1 test per 1000 tons of mix produced.

Samples of the mix from future projects will be taken from the beginning of the test section, from the middle of the test section and from the end of the test section. Six random locations in each section will be selected to determine densities in each section.

7.4 Future Use of Crumb Rubber Other than in Hot Bituminous Pavement

The Colorado Department of Transportation will continue to place and evaluate projects containing crumb rubber. Since current legislation does not allow a state to take credit for any recycled tire used in any process other than hot asphalt pavement, other methods for disposing of Colorado's used tire supply should be pursued. This will include using tires as fuel, embankment materials, fills etc. However, if a state can eliminate all the recyclable tires in their state, they will be exempt from the ISTEA requirement of Section 1038(d).

8.0 References

1. Heitzman, Michael A. (1992), "State of the Practice -- Design and Construction of Asphalt Paving Materials with Crumb Rubber Modifier", FHWA-SA-92-022, FHWA Office of Engineering/Office of Technology Application, Washington, D.C., 118 pages.

2. Scrap Tire Management Council, Scrap Tire Use/Disposal Study, February 1995, Executive Summary.

3. Environmental Protection Agency, "Markets for Scrap Tires", EPA/530-SW-90-074A, October 1991.

4. Donnelly, Denis E., LaForce, Robert F. and Swanson, Herbert N. (1980) "Reflection Cracking Evaluation, Kannah Creek, Colorado Project FC 050-1(8)" Colorado Department of Transportation, CDH-DTP-R-80-10, 42 pages.

5. Donnelly, Denis E., LaForce, Robert F. and Swanson, Herbert N. (1980) "Reflective-Cracking Treatments -- Alameda Avenue, Project MU 0026(2)," Colorado Department of Transportation, CDH-DTP-R-80-11.

6. LaForce, Robert F. (1983) "Squeegee Seal and Crumb Rubber Chip Seal Sapinero - East", Colorado Department of Transportation, CDH-DTP-R-83-13, 31 pages.

7. LaForce, Robert F. (1986) "Crumb Rubber Chip Seal East of Punkin Center", Colorado Department of Transportation, CDOH-DTP-R-86-3, 26 pages.

8. LaForce, Robert F. (1987) "Rubber Modified Asphalt Concrete", Colorado Department of Transportation, CDOH-SMB-R-87-15, 16 pages.

9. Crumb Rubber Modifier Workshop Design Procedures and Construction Practices, March 1 - 2, 1993 Stouffer Concourse Hotel Denver, Colorado.

10. Aschenbrener, Timothy (October 1992) " Comparison of Results Obtained from the French Rutting Tester with Pavements of Known Field Performance", Colorado Department Transportation, CDOT-DTD-R-92-11, 73 pages.

APPENDIX A

Section 1038(d) of the ISTEA Legislation

for nonrail purposes; and

''(ii) will not use any funds or assets from high-speed rail operations for purposes other than high-speed rail purposes,''; and

(B) by inserting ''or high-speed rail services'' after ''provide rail services''; and

(4) by adding at the end the following new subsection:

''(n) Definitions.-As used in this section, the term 'high-speed rail' means all forms of nonhighway ground transportation that run on rails providing transportation service which is-

''(1) reasonably expected to reach sustained speeds of more than 125 miles per hour; and

''(2) made available to members of the general public as passengers.

Such term does not include rapid transit operations within an urban area that are not connected to the general rail system of transportation.''.

(f) General Accounting Office Study.-The Comptroller General, within 2 years after the date of the enactment of this Act, and annually thereafter, shall analyze the effectiveness of the application of section 511 of the Railroad Revitalization and Regulatory Reform Act of 1976 to high-speed rail facilities and equipment, and report the results of such analysis to the Committee on Energy and Commerce of the House of Representatives and the Committee on Commerce, Science, and Transportation of the Senate.

SEC. 1037. RAILROAD RELOCATION DEMONSTRATION PROGRAM.

Section 163(p) of the Federal-Aid Highway Act of 1973 (23 U.S.C. 130 note) is amended by striking ''and 1991,'' and inserting ''1991, 1992, 1993, and 1994,''.

SEC. 1038. USE OF RECYCLED PAVING MATERIAL.

(a) Asphalt Pavement Containing Recycled Rubber Demonstration Program.-Notwithstanding any other provision of title 23, United States Code, or regulation or policy of the Department of Transportation, the Secretary (or a State acting as the Department's agent) may not disapprove a highway project under chapter 1 of title 23, United States Code, on the ground that the project includes the use of asphalt pavement containing recycled rubber. Under this subsection, a patented application process for recycled rubber shall be eligible for approval under the same conditions that an unpatented process is eligible for approval.

(b) Studies.-

(1) In general.-The Secretary and the Administrator of the Environmental Protection Agency shall coordinate and conduct, in cooperation with the States, a study to determine-

(A) the threat to human health and the environment associated with the production and use of asphalt pavement containing recycled rubber;

(B) the degree to which asphalt pavement containing recycled rubber can be recycled; and

(C) the performance of the asphalt pavement containing recycled rubber under various climate and use conditions.

(2) Division of responsibilities.-The Administrator shall conduct the part of the study relating to paragraph (1)(A) and the Secretary shall conduct the part of the study relating to paragraph (1)(C). The Administrator and the Secretary shall jointly conduct the study relating to paragraph (1)(B).

(3) Additional study.-The Secretary and the Administrator, in cooperation with the States, shall jointly conduct a study to determine the economic savings, technical performance qualities, threats to human health and the environment, and environmental benefits of using recycled materials in highway devices and appurtenances and highway projects, including asphalt containing over 80 percent reclaimed asphalt, asphalt containing recycled glass, and asphalt containing recycled plastic.

(4) Additional elements.-In conducting the study under paragraph (3), the Secretary and the Administrator shall examine utilization of various technologies by States and shall examine the current practices of all States relating to the reuse and disposal of materials used in federally assisted highway projects.

(5) Report.-Not later than 18 months after the date of the enactment of this Act, the Secretary and the Administrator shall transmit to Congress a report on the results of the studies conducted under this subsection, including a detailed analysis of the economic savings and technical performance qualities of using such recycled materials in federally assisted highway projects and the environmental benefits of using such recycled materials in such highway projects in terms of reducing air emissions, conserving natural resources, and reducing disposal of the materials in landfills.

(c) DOT Guidance.-

(1) Information gathering and distribution.-The Secretary shall gather information and recommendations concerning the use of asphalt containing recycled rubber in highway projects from those States that have extensively evaluated and experimented with the use of such asphalt and implemented such projects and shall make available such information and recommendations on the use of such

asphalt to those States which indicate an interest in the use of such asphalt.

(2) Encouragement of use.-The Secretary should encourage the use of recycled materials determined to be appropriate by the studies pursuant to subsection (b) in federally assisted highway projects. Procuring agencies shall comply with all applicable guidelines or regulations issued by the Administrator of the Environmental Protection Agency.

(d) Use of Asphalt Pavement Containing Recycled Rubber.-

(1) State certification.-Beginning on January 1, 1995, and annually thereafter, each State shall certify to the Secretary that such State has satisfied the minimum utilization requirement for asphalt pavement containing recycled rubber established by this section. The minimum utilization requirement for asphalt pavement containing recycled rubber as a percentage of the total tons of asphalt laid in such State and financed in whole or part by any assistance pursuant to title 23, United States Code, shall be-

(A) 5 percent for the year 1994;

(B) 10 percent for the year 1995;

(C) 15 percent for the year 1996; and

(D) 20 percent for the year 1997 and each year thereafter.

(2) Other materials.-Any recycled material or materials determined to be appropriate by the studies under subsection (b) may be substituted for recycled rubber under the minimum utilization requirement of paragraph (1) up to 5 percent.

(3) Increase.-The Secretary may increase the minimum utilization requirement of paragraph (1) for asphalt pavement containing recycled rubber to be used in federally assisted highway projects to the extent it is technologically and economically feasible to do so and if an increase is appropriate to assure markets for the reuse and recycling of scrap tires. The minimum utilization requirement for asphalt pavement containing recycled rubber may not be met by any use or technique found to be unsuitable for use in highway projects by the studies under subsection (b).

(4) Penalty.-The Secretary shall withhold from any State that fails to make a certification under paragraph (1) for any fiscal year, a percentage of the apportionments under section 104 (other than subsection (b)(5)(A)) of title 23, United States Code, that would otherwise be apportioned to such State for such fiscal year under such section equal to the percentage utilization requirement established by paragraph (1) for such fiscal year.

(5) Secretarial waiver.-The Secretary may set aside the provisions of this subsection for any 3-year period on a determination, made

in concurrence with the Administrator of the Environmental Protection Agency with respect to subparagraphs (A) and (B) of this paragraph, that there is reliable evidence indicating-

(A) that manufacture, application, or use of asphalt pavement containing recycled rubber substantially increases the threat to human health or the environment as compared to the threats associated with conventional pavement;

(B) that asphalt pavement containing recycled rubber cannot be recycled to substantially the same degree as conventional pavement; or

(C) that asphalt pavement containing recycled rubber does not perform adequately as a material for the construction or surfacing of highways and roads.

The Secretary shall consider the results of the study under subsection (b)(1) in determining whether a 3-year set-aside is appropriate.

(6) Renewal of waiver.-Any determination made to set aside the requirements of this section may be renewed for an additional 3-year period by the Secretary, with the concurrence of the Administrator with respect to the determinations made under paragraphs (5)(A) and (5)(B). Any determination made with respect to paragraph (5)(C) may be made for specific States or regions considering climate, geography, and other factors that may be unique to the State or region and that would prevent the adequate performance of asphalt pavement containing recycled rubber.

(7) Individual state reduction.-The Secretary shall establish a minimum utilization requirement for asphalt pavement containing recycled rubber less than the minimum utilization requirement otherwise required by paragraph (1) in a particular State, upon the request of such State and if the Secretary, with the concurrence of the Administrator of the Environmental Protection Agency, determines that there is not a sufficient quantity of scrap tires available in the State prior to disposal to meet the minimum utilization requirement established under paragraph (1) as the result of recycling and processing uses (in that State or another State), including retreading or energy recovery.

(e) Definitions.-For purpose of this section-

(1) the term ''asphalt pavement containing recycled rubber'' means any hot mix or spray applied binder in asphalt paving mixture that contains rubber from whole scrap tires which is used for asphalt pavement base, surface course or interlayer, or other road and highway related uses and-

(A) is a mixture of not less than 20 pounds of recycled rubber per ton of hot mix or 300 pounds of recycled rubber per ton of spray applied binder; or

(B) is any mixture of asphalt pavement and recycled rubber that is certified by a State and is approved by the Secretary, provided that the total amount of recycled rubber from whole scrap tires utilized in any year in such State shall be not less than the amount that would be utilized if all asphalt pavement containing recycled rubber laid in such State met the specifications of subparagraph (A) and subsection (d)(1); and

(2) the term ''recycled rubber'' is any crumb rubber derived from processing whole scrap tires or shredded tire material taken from automobiles, trucks, or other equipment owned and operated in the United States.

SEC. 1039. HIGHWAY TIMBER BRIDGE RESEARCH AND DEMONSTRATION PROGRAM.

(a) Research Grants.-The Secretary may make grants to other Federal agencies, universities, private businesses, nonprofit organizations, and any research or engineering entity to carry out research on 1 or more of the following:

(1) Development of new, economical highway timber bridge systems.

(2) Development of engineering design criteria for structural wood products for use in highway bridges in order to improve methods for characterizing lumber design properties.

(3) Preservative systems for use in highway timber bridges which demonstrate new alternatives and current treatment processes and procedures and which are environmentally sound with respect to application, use, and disposal of treated wood.

(4) Alternative transportation system timber structures which demonstrate the development of applications for railing, sign, and lighting supports, sound barriers, culverts, and retaining walls in highway applications.

(5) Rehabilitation measures which demonstrate effective, safe, and reliable methods for rehabilitating existing highway timber structures.

(b) Technology and Information Transfer.-The Secretary shall take such action as may be necessary to ensure that the information and technology resulting from research conducted under subsection (a) is made available to State and local transportation departments and other interested persons.

(c) Construction Grants.-

(1) Authority.-The Secretary shall make grants to States for construction of highway timber bridges on rural Federal-aid highways.

(2) Applications.-A State interested in receiving a grant under

APPENDIX B

Project Design Mixes

Division of Transportation
State of Colorado
Form DOH 429 Flex 2.00

Date Received 06/22/94

Project No: C 0751-002
Location: SH 75,Bowles to C470
District # 6 Subaccount: 10154
Lab # 496x-500x
Field Sample # 64227 (combination 3)

LABORATORY DESIGN for HOT BITUMINOUS PAVEMENT - CONSTRUCTION

Item 403 Grading C Sinclair AC-10, 20-50-2500
Pit name: KWC Contractor/Supplier: Kiewit

SIEVE ANALYSIS: T11 & T27, sampled by CP30

Test No.->	496x	497x	498x	499x	500x	Hyd	As Used		Job Mix
% used-->	18.0	15.0	41.0	10.0	15.0	1.0			
1 1/2	100	100	100	100	100	100	100	1 1/2	
1	100	100	100	100	100	100	100	1	
3/4	99	100	100	100	100	100	100	3/4	100
5/8	40	100	100	100	100	100	89	5/8	
1/2	19	98	100	100	98	100	85	1/2	85
3/8	4	60	100	100	93	100	76	3/8	76
4	2	4	98	100	71	100	63	4	63
8	2	3	72	100	53	100	49	8	49
16	2	2	48	71	39	100	34	16	
30	2	2	32	39	29	100	23	30	30
50	2	2	20	12	21	100	14	50	
100	1	1	13	3	14	98	9	100	
200	1.2	1.1	9.5	2.5	9.8	97.0	6.9	200	6.9
%AC in aggr.	0.00	0.00	0.00	0.00	5.86	0.00	0.88		

Combined Aggregate: Bulk SpG: 2.608 Sand Equivalency:

TEST RESULTS

Percent bitumen	4.5	5.0	5.5	6.0
Max Sp. Gr. T209	2.461	2.442	2.423	2.404
Bulk Sp. Gr. T166	2.339	2.354	2.359	2.364
% Voids CPL 5105	5.0	3.6	2.6	1.7
Stability CPL 5105	39	36	34	23
Modulus CPL 5110				
Strength coefficient	0.44	0.44	0.44	0.44
VMA (effective)	15.3	15.2	15.3	15.6
VMA (bulk)	14.4	14.3	14.5	14.8
% of bulk VMA filled	65	74	82	88
Dust / AC ratio	1.48	1.32	1.20	1.09

IMMERSION-COMPRESSION CPL 5104
% bitumen
PSI Wet
PSI Dry
% Absorption
% Swell
% Ret. Strength
% Additive used
Asphalt additive type

LOTTMAN CPL 5109
% bitumen
Wet D.T.St
Dry D.T.St
% Voids
% Saturation
% T.S.Ret.
% Additive

Optimum asphalt content 4.9
Stability at Optimum A.C. 37
Asphalt film thickness at Optimum A.C.: 7.7 microns

Lab Max. SpG at Optimum 2.446
% Voids at Optimum A.C. 3.88

"C" w/o Rubber

Date Reported 8/2/94

Robert LaForce 757-9724
Flexible Pavement Engineer

Division of Transportation
State of Colorado
Form DOH 429 Flex 2.00

Date Received 06/22/94

Project No: C 0751-002
Location: SH 75,Bowles to C470
District # 6 Subaccount: 10154
Lab # 496x-500x
Field Sample # 64227 (combination 1)

LABORATORY DESIGN for HOT BITUMINOUS PAVEMENT - CONSTRUCTION

Item 403 Grading C 1lb/Ton Crumb Rubber, 20-50-2500
Pit name: KWC Contractor/Supplier: Kiewit

SIEVE ANALYSIS: T11 & T27, sampled by CP30

Test No.->	496x	497x	498x	499x	500x	Hyd	As Used		Job Mix
% used-->	18.0	15.0	41.0	10.0	15.0	1.0			
1 1/2	100	100	100	100	100	100	100	1 1/2	
1	100	100	100	100	100	100	100	1	
3/4	99	100	100	100	100	100	100	3/4	100
5/8	40	100	100	100	100	100	89	5/8	
1/2	19	98	100	100	98	100	85	1/2	85
3/8	4	60	100	100	93	100	76	3/8	76
4	2	4	98	100	71	100	63	4	63
8	2	3	72	100	53	100	49	8	49
16	2	2	48	71	39	100	34	16	
30	2	2	32	39	29	100	23	30	23
50	2	2	20	12	21	100	14	50	
100	1	1	13	3	14	98	9	100	
200	1.2	1.1	9.5	2.5	9.8	97.0	6.9	200	6.9
%AC in aggr.	0.00	0.00	0.00	0.00	5.86	0.00	0.88		

Combined Aggregate: Bulk SpG: 2.608 Sand Equivalency:

TEST RESULTS

Percent bitumen	5.5	6.0	6.5	7.0	4.5	5.0
Max Sp. Gr. T209	2.422	2.403	2.384	2.365	2.460	2.441
Bulk Sp. Gr. T166	2.370	2.370	2.366	2.359	2.319	2.354
% Voids CPL 5105	2.1	1.4	0.8	0.3	5.7	3.6
Stability CPL 5105	46	23	21	10	38	40
Modulus CPL 5110	713	534	359	264	549	775
Strength coefficient	0.44	0.44	0.40	0.25	0.44	0.44
VMA (effective)	14.9	15.3	15.8	16.5	16.0	15.1
VMA (bulk)	14.1	14.6	15.2	15.9	15.1	14.3
% of bulk VMA filled	85	90	95	98	62	75
Dust / AC ratio	1.20	1.09	1.00	0.93	1.48	1.32
Cohesiometer	225.1	228.8	221.0	199.3	259.7	223.6

IMMERSION-COMPRESSION CPL 5104		LOTTMAN CPL 5109	
% bitumen		4.9	% bitumen
PSI Wet		58	Wet D.T.St
PSI Dry		59	Dry D.T.St
% Absorption		6.89	% Voids
% Swell		69	% Saturation
% Ret. Strength		98	% T.S.Ret.
% Additive used		0.0	% Additive
Asphalt additive type			

Optimum asphalt content 4.9
Stability at Optimum A.C. 39
Asphalt film thickness at Optimum A.C.: 7.7 microns

Lab Max. SpG at Optimum 2.445
% Voids at Optimum A.C. 4.02

Date Reported 8/2/94

Robert LaForce 757-9724
Flexible Pavement Engineer

Division of Transportation Project No: C 0751-002

Division of Transportation
State of Colorado
Form DOH 429 Flex 2.00

Project No: C 0751-002
Location: SH 75,Bowles to C470
District # 6 Subaccount: 10154
Lab # 496x-500x

Date Received 06/22/94

Field Sample # 64227 (combination 2)

LABORATORY DESIGN for HOT BITUMINOUS PAVEMENT - CONSTRUCTION

Item 403 Grading C 3lb/Ton Crumb Rubber, 20-50-2500
Pit name: KWC Contractor/Supplier: Kiewit

SIEVE ANALYSIS: T11 & T27, sampled by CP30

Test No.->	496x	497x	498x	499x	500x	Hyd	As Used		Job Mix
% used-->	18.0	15.0	41.0	10.0	15.0	1.0			
1 1/2	100	100	100	100	100	100	100	1 1/2	
1	100	100	100	100	100	100	100	1	
3/4	99	100	100	100	100	100	100	3/4	100
5/8	40	100	100	100	100	100	89	5/8	
1/2	19	98	100	100	98	100	85	1/2	85
3/8	4	60	100	100	93	100	76	3/8	76
4	2	4	98	100	71	100	63	4	63
8	2	3	72	100	53	100	49	8	49
16	2	2	48	71	39	100	34	16	
30	2	2	32	39	29	100	23	30	23
50	2	2	20	12	21	100	14	50	
100	1	1	13	3	14	98	9	100	
200	1.2	1.1	9.5	2.5	9.8	97.0	6.9	200	6.9
%AC in aggr.	0.00	0.00	0.00	0.00	5.86	0.00	0.88		

Combined Aggregate: Bulk SpG: 2.608 Sand Equivalency:

TEST RESULTS						
Percent bitumen	5.5	6.0	6.5	7.0	4.5	5.0
Max Sp. Gr. T209	2.424	2.405	2.386	2.367	2.462	2.443
Bulk Sp. Gr. T166	2.358	2.371	2.363	2.356	2.306	2.348
% Voids CPL 5105	2.7	1.4	1.0	0.5	6.3	3.9
Stability CPL 5105	38	27	16	12	33	37
Modulus CPL 5110	723	534	352	268	818	710
Strength coefficient	0.44	0.44	0.35	0.26	0.44	0.44
VMA (effective)	15.4	15.3	16.0	16.6	16.5	15.4
VMA (bulk)	14.6	14.5	15.3	16.0	15.6	14.5
% of bulk VMA filled	81	90	93	97	59	73
Dust / AC ratio	1.20	1.09	1.00	0.93	1.48	1.32
Cohesiometer	262.5	257.9	235.2	215.4	162.6	208.4

IMMERSION-COMPRESSION CPL 5104		LOTTMAN CPL 5109	
% bitumen		4.9	% bitumen
PSI Wet		55	Wet D.T.St
PSI Dry		55	Dry D.T.St
% Absorption		7.18	% Voids
% Swell		62	% Saturation
% Ret. Strength		100	% T.S.Ret.
% Additive used		0.0	% Additive
Asphalt additive type			

Optimum asphalt content 4.9 Lab Max. SpG at Optimum 2.447
Stability at Optimum A.C. 36 % Voids at Optimum A.C. 4.25
Asphalt film thickness at Optimum A.C.: 7.7 microns

Robert LaForce 757-9724
Flexible Pavement Engineer

Division of Transportation
State of Colorado
Form DOH 429   Flex 2.00

Date Received 06/22/94

Project No: C 0751-002
Location: SH 75,Bowles to C470
District # 6   Subaccount: 10154
Lab # 496x-499x
Field Sample # 64226

LABORATORY DESIGN for HOT BITUMINOUS PAVEMENT - CONSTRUCTION

Item 403   Grading C   1% Crumb Rubber, 20-50-2500, Sinclair AC-10
Pit name: KWC   Contractor/Supplier: Kiewit

SIEVE ANALYSIS: T11 & T27, sampled by CP30

Test No.->	496x	497x	498x	499x	Cr.Ru	Hyd	As Used		Job Mix
% used-->	20.0	20.0	48.0	10.0	1.0	1.0			
1 1/2	100	100	100	100	100	100	100	1 1/2	
1	100	100	100	100	100	100	100	1	
3/4	99	100	100	100	100	100	100	3/4	100
5/8	40	100	100	100	100	100	88	5/8	
1/2	19	98	100	100	100	100	83	1/2	83
3/8	4	60	100	100	100	100	73	3/8	73
4	2	4	98	100	100	100	60	4	60
8	2	3	72	100	100	100	48	8	48
16	2	2	48	71	61	100	33	16	
30	2	2	32	39	1	100	21	30	21
50	2	2	20	12	1	100	13	50	
100	1	1	13	3	1	98	8	100	
200	1.2	1.1	9.5	2.5	0.0	97.0	6.2	200	6.2

%AC in aggr.
Combined Aggregate: Bulk SpG: 2.569   Sand Equivalency:

TEST RESULTS				
Percent bitumen	5.5	6.0	6.5	7.0
Max Sp. Gr. T209	2.397	2.379	2.361	2.342
Bulk Sp. Gr. T166	2.264	2.281	2.291	2.307
% Voids CPL 5105	5.6	4.1	3.0	1.5
Stability CPL 5105	29	24	22	12
Modulus CPL 5110	257	233	228	195
Strength coefficient	0.44	0.44	0.40	0.25
VMA (effective)	17.8	17.5	17.6	17.3
VMA (bulk)	16.7	16.6	16.6	16.5
% of bulk VMA filled	66	75	82	91
Dust / AC ratio	1.08	0.98	0.90	0.83
COHESIOMETER	99.67	108.62	134.49	153.41

IMMERSION-COMPRESSION CPL 5104		LOTTMAN	CPL 5109
% bitumen		6.1	% bitumen
PSI Wet		30	Wet D.T.St
PSI Dry		33	Dry D.T.St
% Absorption		8.25	% Voids
% Swell		59	% Saturation
% Ret. Strength		93	% T.S.Ret.
% Additive used		0.0	% Additive
Asphalt additive type			

Optimum asphalt content 6.1   Lab Max. SpG at Optimum 2.375
Stability at Optimum A.C. 24   % Voids at Optimum A.C. 3.89
Asphalt film thickness at Optimum A.C.: 10.7 microns

Date Reported 7/25/94

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Flexible Pavement Engineer

APPENDIX C

Project Specifications

REVISION OF SECTION 403
HOT BITUMINOUS PAVEMENT

Section 403 of the Standard Specifications is hereby revised for this project as follows:

Subsection 403.01 shall include the following:

This work includes construction of test sections with one or more courses of HBP, Hot Bituminous Pavement (Rubber Modified Asphalt Concrete), HBP (RUMAC), on a prepared base in accordance with these specifications, and in conformity with the lines, grades, thicknesses, and typical cross sections shown on the plans or established.

The test sections shall be as follows:

1. 1-500 Ton test section of HBP (Gr. C) (Asphalt)
2. 1-500 Ton test section of HBP (Gr. C) (Asphalt)(RUMAC) at 3 lbs./ton CRM
3. 1-500 Ton test section of HBP (Gr. C) (Asphalt)(RUMAC)(1% CRM) at 1% CRM by weight of total mix.

The balance of the bituminous pavement on the project shall be HBP (Gr. C) (Asphalt)(RUMAC) at 1 lb./ton CRM.

The test sections shall be placed at locations designated by the Engineer.

The HBP (RUMAC) shall be composed of a mixture of aggregate, crumb rubber modifier (CRM), filler if required, and bituminous material.

HBP (RUMAC) may be covered by patent numbers 4,086,291 and 4,548,962 or others. Any use of this technology should include a determination of the validity of the patent rights and risk of infringement.

Subsection 403.02 shall include the following:

The design mix for hot bituminous pavement shall conform to the following:

TABLE 403-1

PROPERTY	TEST METHOD	VALUE FOR GRADING	
		C(C50)	PATCHING
Air Voids, percent	CPL 5105	3-5	3-5
Stability, minimum	CPL 5105	33	33
Lab Compaction (End Point Stress, psi)	CPL 5105	50	50
Aggregate retained on the No. 4 sieve with at least 2 mechanically induced fractured faces, % minimum	CP 45	70	70
Accelerated Moisture Susceptibility Tensile Strength Ratio (Lottman), minimum	CPL 5109	80	80
Minimum dry split tensile strength, psi	CPL 5109	30	30
Grade of Asphalt Cement		AC-10	AC-10
Voids in the mineral aggregate (VMA), % minimum	CP 48	See Table 403-2	
Voids filled with asphalt (VFA), %	AI MS-2	65-80	65-80

AI MS-2 = Asphalt Institute Manual Series 2

REVISION OF SECTION 403
HOT BITUMINOUS PAVEMENT

Note: The current version of CPL 5105 is available from the Region Materials Engineer.

Note: Design criteria for Grading C and Grading CX mixes should be approached with caution to avoid mixes that produce a maximum density plot. As a minimum, contractors are advised to develop mixes 2-3% above or below the maximum density line.

Note: Based on limited lab testing it is anticipated that to use crumb rubber at the one percent or higher rate, a number of changes will be required in the mix.

Approximately 3 percent of the fine aggregate will need to be eliminated to make room for each 1% crumb rubber.

Crumb rubber acts like an absorptive aggregate, and it is anticipated that the asphalt content for a mix containing 1% crumb rubber will increase approximately 0.5% to 1.0%.

TABLE 403-2

Minimum Voids in the Mineral Aggregate (VMA)			
Nominal Maximum Size* Inches (mm)	Design Air Voids**		
	3.0%	4.0%	5.0%
1 1/2 (37.5)	10.0	11.0	12.0
1 (25.0)	11.0	12.0	13.0
3/4 (19.0)	12.0	13.0	14.0
1/2 (12.5)	13.0	14.0	15.0
3/8 (9.5)	14.0	15.0	16.0

* The Nominal Maximum Size is defined as one sieve larger than the first sieve to retain more than 10%.

** Interpolate specified VMA values for design air voids between those listed.

REVISION OF SECTION 403
HOT BITUMINOUS PAVEMENT

The Contractor shall prepare a quality control plan outlining the steps taken to minimize segregation of HBP. This plan shall be submitted to the Engineer and approved prior to beginning the paving operations. When the Engineer determines that segregation is unacceptable, the paving shall stop and the cause of segregation corrected before paving operations will be allowed to resume.

The hot bituminous pavement and HBP(RUMAC) shall not contain more than 15 percent reclaimed asphalt pavement. The HBP(RUMAC)(1% CRM) shall not contain recycled asphalt pavement.

Hot bituminous pavement for patching shall conform to the gradation requirements for Hot Bituminous Pavement (Grading C).

A minimum of one percent hydrated lime by weight of the combined aggregate shall be added to the aggregate for all hot bituminous pavement, HBP(RUMAC), and HBP(RUMAC)(1% CRM).

HBP(RUMAC) shall conform to the requirements for the specified grading and shall include 1 lb./ton, 3 lbs./ton and 1% CRM by weight of total mix, CRM in the mixture.

CRM shall meet the requirements of subsection 712.15. The selection of the CRM properties, including process method and gradation, shall be as recommended by the manufacturer/supplier. Gradation shall be either CRM-II or CRM-III as shown in subsection 712.15, Table 712-9.

The Contractor's proposed job mix formula (JMF) for HBP (RUMAC) shall be submitted in accordance with subsection 401.02 at least 30 days prior to beginning production. The Contractor shall submit with the JMF: the source, composition and proportion of CRM.

The following stability requirements apply to the HBP (Gr. C)(Asphalt)(RUMAC)(1% CRM) mix only:

(1) Stability tests will be performed for information only and the mixes will be designed at the normal void level.

(2) Mix design criteria for the appropriate grading shall apply to this item however, stability requirements will be determined prior to addition of the CRM.

(3) Stability of field produced material will be tested for information only.

REVISION OF SECTION 403
HOT BITUMINOUS PAVEMENT

The Contractor shall prepare a work plan detailing the method and sequence for adding CRM into the mixing process at a uniform rate of 1 lb./ton, 3 lbs./ton and 1% by weight of total mix. This plan shall be submitted to the Engineer and approved prior to beginning the paving operations. This plan shall provide for the addition of CRM so that it is not combined with the virgin aggregate prior to drying. Direct contact of the CRM with the burner flame shall not be allowed.

Subsection 403.03 shall include the following:

Areas to be patched shall be excavated and squared to a neat line, leaving the sides of the excavation vertical. Prior to placement of the patch the exposed sides of the existing pavement shall be thoroughly coated with Emulsified Asphalt (slow-setting). Hot bituminous pavement shall then be placed and compacted in succeeding layers not to exceed three inches in depth. Construction of the HBP(RUMAC) test sections shall conform to the following additional requirements:

(1) The hot mix asphalt mixing plant shall have automatic controls that coordinate the proportioning, timing and discharge of the mixture. The plant shall be capable of uniformly feeding and measuring the amount of the CRM placed into the mixing chamber.

(2) Drum mixing plants shall not add the CRM to the aggregates cold feed system The CRM must be added beyond the aggregate drying and heating section of the mixing chamber.

(3) When using a batch plant, the batch size and CRM bag size shall be adjusted to use whole bags of CRM. Adding partial bags of CRM into the mixing chamber will not be permitted.

(4) HBP (RUMAC) shall not be conveyed on rubber belts.

(5) Unless permitted by the Engineer pneumatic-tire rollers shall not be used to compact HBP (RUMAC).

(6) For the HBP (RUMAC)(1% CRM) rolling shall continue until the temperature of the mat is 140 degrees F.

Subsection 403.05 shall include the following:

Pay Item	Pay Unit
Hot Bituminous Pavement (Grading C)(Asphalt)(RUMAC)	Ton
Hot Bituminous Pavement (Grading C)(Asphalt)(RUMAC)(1% CRM)	Ton

REVISION OF SECTION 403
HOT BITUMINOUS PAVEMENT

Aggregate, asphalt cement, asphalt recycling agent, additives, hydrated lime, CRM, and all other work necessary to complete each hot bituminous pavement item will not be paid for separately but shall be included in the unit price bid.

Excavation, preparation, and tack coat of areas to be patched will not be measured and paid for separately, but shall be included in the work.

Mixtures containing either 1 lb./ton or 3 lbs./ton CRM will be paid for under the pay item Hot Bituminous Pavement (Grading_) (Asphalt) (RUMAC).

General Note: A compaction test section shall be established for each type of mix.

APPENDIX D

CDOT's Smoothness Specification

COLORADO PROCEDURE 70-93

OPERATION OF MULTI-WHEEL PROFILOGRAPH AND EVALUATION OF PROFILES (FOR HOT BITUMINOUS PAVEMENTS)

SCOPE

1.1 The operation of the Multi-Wheel Profilograph, the procedure used for determining the Profile Index from profilograms of pavements made with the Profilograph, and the procedure used to locate individual high points in excess of 0.3 inch are described in Parts I, II and III, respectively, in this test method.

PART I
OPERATION OF THE MULTI-WHEEL PROFILOGRAPH

APPARATUS

2.1 The Multi-Wheel Profilograph consists of a frame twenty-five feet in length supported on wheels at either end. The profile is recorded from the vertical movement of a wheel attached to the frame at midpoint and is in reference to the mean elevation of the points of contact with the road surface established by the support wheels (See Figure 3). The profilogram is recorded on a scale of one inch equal to twenty-five feet longitudinally and one inch equal to one inch, or full scale, vertically. Motive power may be provided manually or by the use of a propulsion unit powered with a gasoline engine attached to the center assembly.

OPERATION

3.1 The instruction for assembling the Profilograph are contained in a booklet accompanying each unit. Particular attention should be paid to the listed precautions.

3.2 In operation, the Profilograph should be moved at a speed no greater than a walk to eliminate as much bounce as possible. Too high a speed will result in a profilogram that is difficult to evaluate.

3.3 Calibration of the Profilograph should be checked periodically. The horizontal scale can be checked by running a known distance and scaling the result on the profilogram.

If the scale is off, the profile wheel should be changed to one of a proper diameter. The vertical scale is checked by putting a board of known thickness under the profile wheel and again scaling the result on the profilogram. If the scale is off, the cause of incorrect height should be determined and corrected.

PART II
DETERMINATION OF THE PROFILE INDEX

APPARATUS

4.1 To determine the Profile Index, use a plastic scale 1.70 inches wide and 21.12 inches long representing a pavement length of 528 feet or one-tenth of a mile at a scale of 1" = 25'. Near the center of the scale is an opaque band 0.1 inch wide extending the entire length of 21.12 inches. On either side of this band are scribed lines 0.1 inch apart, parallel to the opaque band. These lines serve as a convenient scale to measure deviations or excursions of the graph above or below the blanking bank. They are called "scallops".

METHOD OF COUNTING

5.1 Place the plastic scale over the profile to "blank-out" as much of the profile as possible. When this is done, scallops above and below the blanking band usually will be approximately balanced. (See Figure 1.)

5.2 When the specifications limit the amount of roughness in "any one-tenth mile section", the scale is moved along the profile and counts made at various locations to find those sections if any, that do not conform to specifications. The limits are then noted on the profile and can be later located on the pavement prior to correction.

5.3 The initial Profile Index shall be determined for the day's paving prior to any corrective work. When counting profiles, the day's paving shall include all transverse joints except for those at the end of lay-down passes (unconnected or abutted to existing pavement or bridge surfaces). The Contractor shall be responsible for smoothness, including joints, as part of daily profile indexes when he places the pavement on both sides of the joints. Joints not profiled at the end of lay-down passes shall be included in profiling for the day in which the joint is completed. When the Contractor places pavement on only one side of the joint, the daily profilogram count shall begin 25 linear feet from the joint. One-sided joints shall be tested by the profilograph only to determine conformance of the new work to the allowable 0.3 inch tolerance in 25 feet.

5.4 When averaging the Profile Index to obtain an average for a job, the average for each must be "weighted" according to its length. This is most easily done by totaling the counts for the 0.1 miles sections of a given line or lines and using the total length of the line in the computation for determining the Profile Index.

PART III
DETERMINATION OF HIGH POINTS IN EXCESS OF 0.3 INCH

APPARATUS

6.1 Use a plastic template having a line one inch long scribed on one face with a small hole or scribed mark at either end, and a slot 0.3 inch from and parallel to the scribed line. See Figure 2. (The one inch line corresponds to a horizontal distance of 25 feet on the horizontal scale of the profilogram).

6.2 To find high points in excess of 0.3 inch, locate each prominent peak or high point on the profile trace, place the template so that the small holes or scribe marks at each end of the scribed line intersect the profile trace to form a chord across the base of the peak or indicated bump. The line on the template need not be horizontal. With a sharp pencil draw a line using the narrow slot in the template as a guide. Any portion of the trace extending above this line will indicate the approximate length and height of the deviation in excess on 0.3 inch.

There may be instances where the distance between easily recognizable low points is less than one inch (25 feet). In such cases a shorter chord length shall be used in making the scribed line on the template tangent to the trace at the low points. It is the intent, however, of this requirement that the baseline for measuring the height of bumps will be as nearly 25 feet/inch as possible, but in no case to exceed this value. When the distance between prominent low points is greater than 25 feet/inch make the ends of the scribed line intersect the profile trace when the template is in a nearly horizontal position. A few examples of the proce-dure are shown in the lower portion of Figure 2.

The profile trace will move from a generally horizontal position when going around superelevated curves making it impossible to blank out the central portion of the trace without shifting the scale. When such conditions occur the profile should be broken into short sections and the blanking band repositioned on each section while counting as shown in the upper part of Figure 2.

Starting at the right end of the scale, measure and total the height of all the scallops appearing both above and below the blanking band, measuring each scallop to the nearest 0.05 inch (half a tenth). Write this total on the profile sheet near the left end of the scale together with a small mark to align the scale when moving to the next section. Short portions of the profile line may be visible outside the blanking band but unless they project 0.03 inch or more and extend longitudinally for two feet (0.08" on the profilogram) or more, they are not included in the count. (See Figure 1 for illustration of these special conditions.)

When scallops occurring in the first 0.1 mile are totaled, slide the scale to the left, aligning the right end of the scale with the small mark previously made, and proceed with the counting in the same manner. The last section counted may or may not be an even 0.1 mile. If not, its length should be scaled to determine its length in miles.

Example

SECTION LENGTH, MILES	COUNTS, TENTH OF AN INCH
0.10	5.0
0.10	4.0
0.10	3.5
400' = 0.076	2.0
Total 0.376	14.5

The Profile Index is determined as "inches per mile in excess of the 0.1-inch blanking band" but is simply called the Profile Index. The procedure for converting the counts of the Profile Index is as follows:

$$\text{Profile Index (PrI)} = \frac{1 \text{ mile}}{\text{lenght of profiles (miles)}} \times \text{total count in inches}$$

Example
Using the figures from the above example:

Length = 0.376 mile,
total count = 14.5 tenths of an inch

$$PrI = \frac{1}{0.376} \times \frac{14.5}{10} = 3.9$$

NOTE: The formula uses the count in inches rather than tenths of an inch and is obtained by dividing the count by ten.

The Profile Index is thus determined for the profile of any line called for in the specifications. Profile Indexes may be averaged for two or more profiles of the same section of road if the profiles are the same length.

Example:

	Section length Miles	COUNTS, TENTH OF AN INCH Wheel Track Left	Right
	0.10	5.0	4.5
	0.10	4.0	5.0
	0.10	3.5	3.0
400' =	0.076	2.0	1.5
Total	0.376	14.5	14.0
PrI (by formula)		3.9	3.7

$$PrI\ Average = \frac{3.9 + 3.7}{2} = 3.8$$

The specifications state which profiles to use when computing the average Profile Index for control of construction operations.

EXAMPLE SHOWING METHOD OF DERIVING PROFILE INDEX FROM PROFILOGRAMS

Fractional Numbers in Profilograph Trace Represent Tenths of Inches (i.e. $3\frac{1}{2}$ = 0.35 inches)

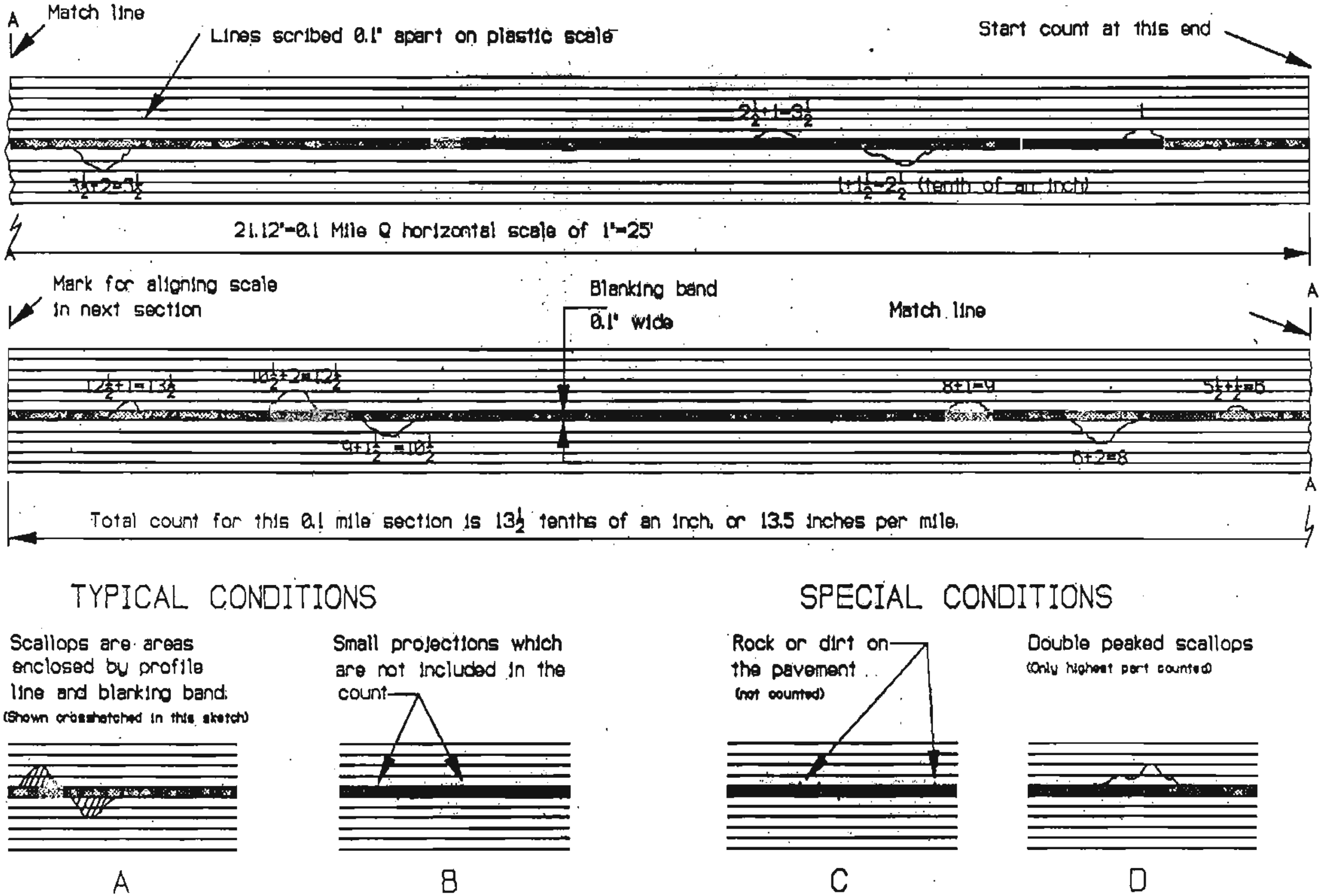
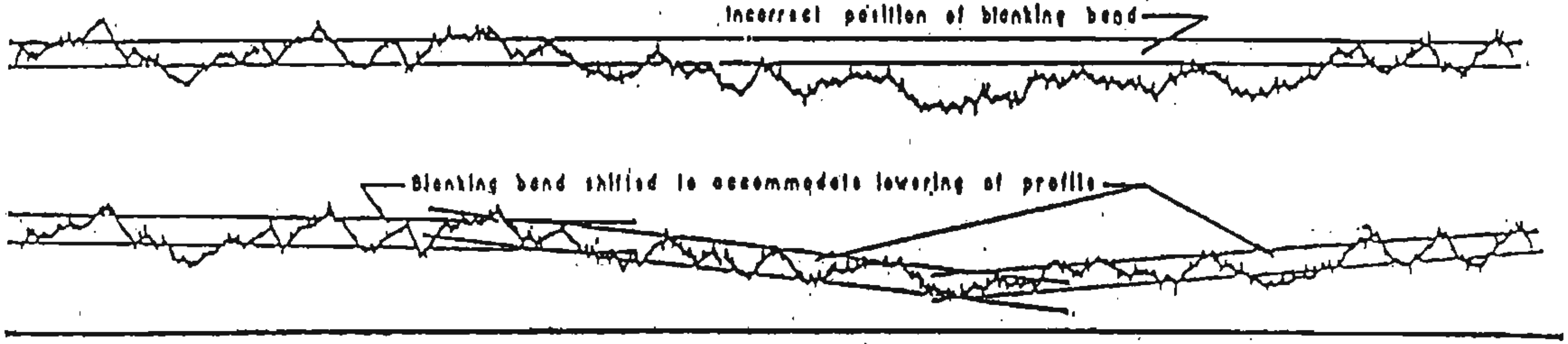
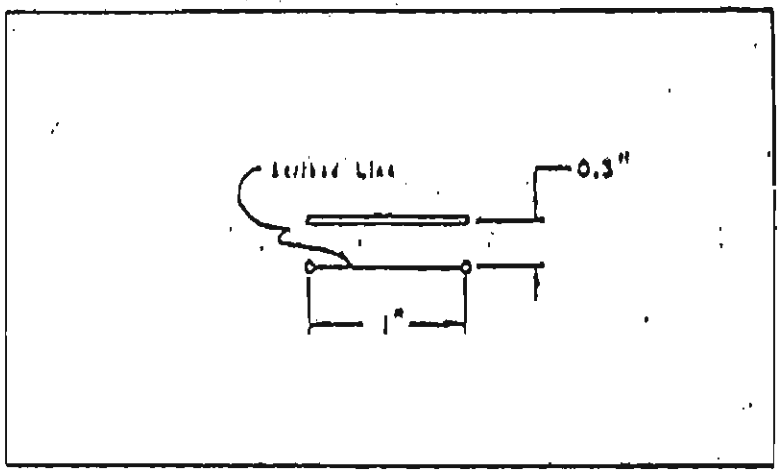


FIGURE 1

METHOD OF COUNTING WHEN POSITION OF PROFILE SHIFTS AS IT MAY WHEN ROUNDING SHORT RADIUS CURVES WITH SUPERELEVATION



METHOD OF PLACING TEMPLATE WHEN LOCATING BUMPS TO BE REDUCED



BUMP TEMPLATE

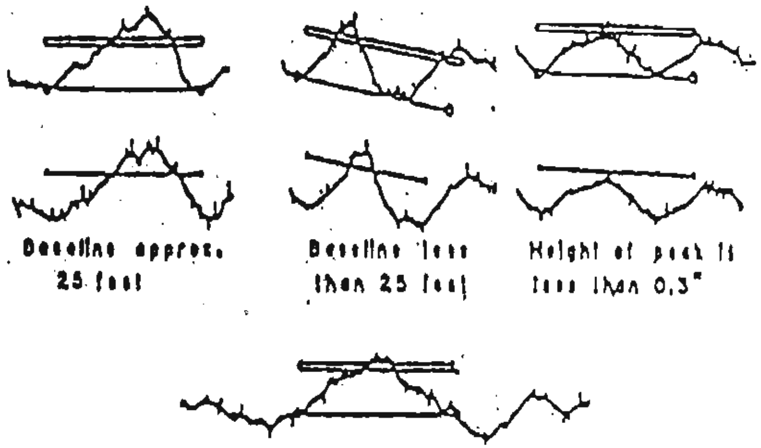


FIGURE 2

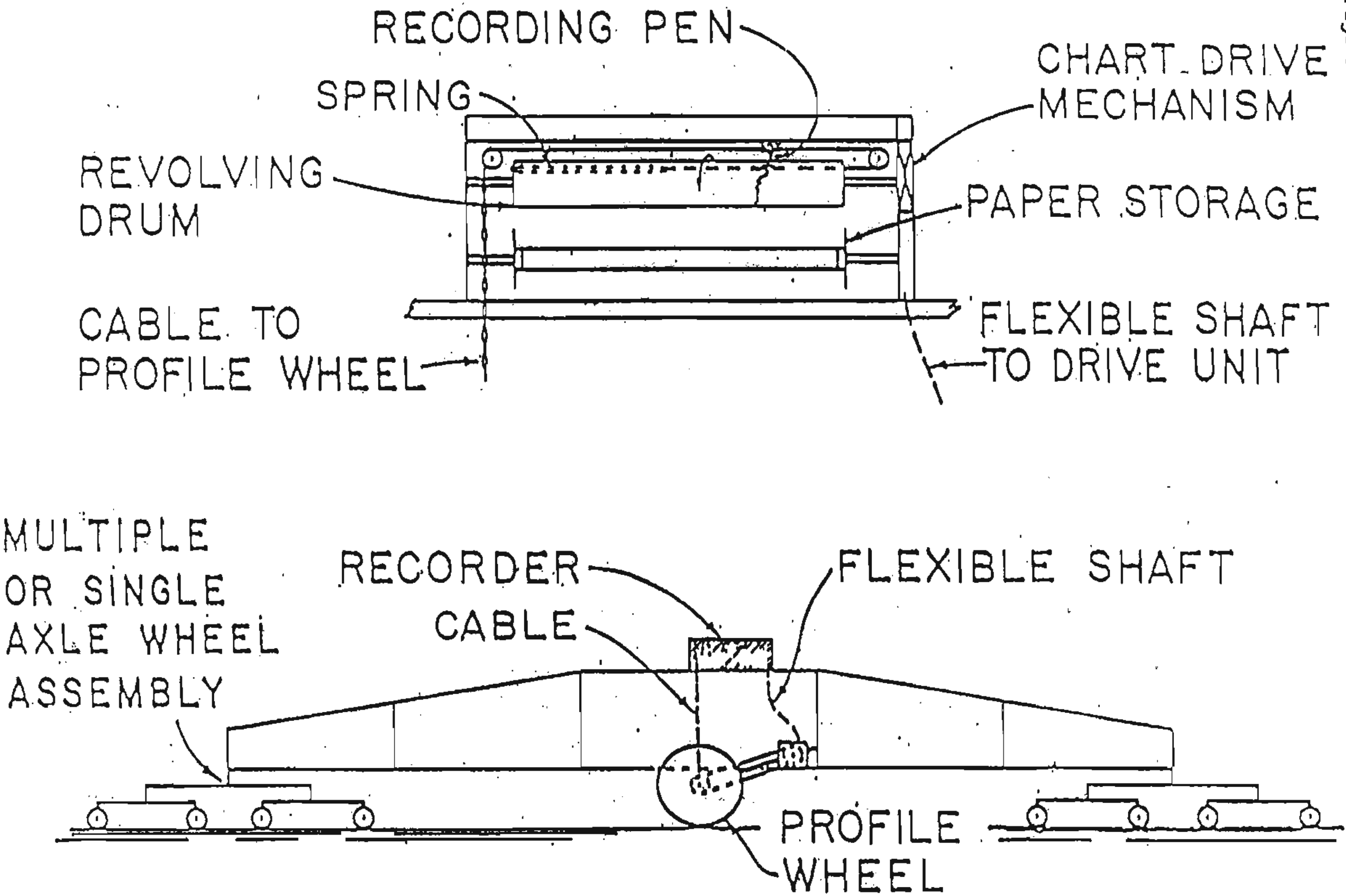

RECORDING PEN
SPRING
CHART DRIVE MECHANISM
REVOLVING DRUM
PAPER STORAGE
CABLE TO PROFILE WHEEL
FLEXIBLE SHAFT TO DRIVE UNIT
MULTIPLE OR SINGLE AXLE WHEEL ASSEMBLY
RECORDER
CABLE
FLEXIBLE SHAFT
PROFILE WHEEL

FIGURE 3