TECHNICAL REPORT STANDARD TITLE PAGE

1. Report Number	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/TX-93/1272-1		

4. Title and Subtitle ROUTINE MAINTENANCE USES FOR MILLED RECLAIMED ASPHALT PAVEMENT (RAP)	5. Report Date December 1992 6. Performing Organization Code
7. Author(s) Cindy K. Estakhri and Joe W. Button	8. Performing Organization Report No. Research Report 1272-1
9. Performing Organization Name and Address Texas Transportation Institute The Texas A&M University College Station, Texas 77843-3135	10. Work Unit No. 11. Contract or Grant No. Study No. 2-18-90-1272
12. Sponsoring Agency Name and Address Texas Department of Transportation Transportation Planning Division P. O. Box 5051 Austin, Texas 78763	13. Type of Report and Period Covered Interim Report - Sept. 1987 to Oct. 1992 14. Sponsoring Agency Code

15. Supplementary Notes

Research performed in cooperation with the Texas Department of Transportation and the U.S. Transportation Federal Highway Administration.
Study Title - "Routine Maintenance Uses for Milled RAP"

16. Abstract

The overall objective of this study was to determine the most economical and effective routine maintenance uses for asphalt pavement millings. Specific objectives include (1) determine existing effective uses of milled RAP, (2) determine effectiveness of new, untried ideas and improvements on existing uses through field experimentation, and (3) provide the Department with a mode of implementation. Most of the uses addressed in this study refer to routine maintenance applications; although other uses were reviewed.

Districts were interviewed in Texas and other states to identify current methods for using RAP. The literature was also reviewed to identify new and innovative approaches.

RAP was collected in three locations throughout the state to characterize its laboratory properties. Cold mix designs were performed using different emulsified admixtures. The effects of these emulsions were then evaluated on the properties of the blended RAP mixtures.

Fourteen field projects were evaluated in this study. The objective of the field study was to identify and evaluate existing Departmental uses of RAP, investigate and assess the value of new uses for RAP, and to collect video footage of these activities for the production of videos to support their implementation by the Department.

Samples of the field-produced RAP maintenance mixes were obtained and tested in the laboratory. Laboratory properties of the treated RAP mixtures were characterized as well as corresponding control maintenance mixtures. These properties will later be correlated to pavement performance. The Department has an ongoing study to monitor the performance of the maintenance field projects for a period of two years.

17. Key Words	18. Distribution Statement
Reclaimed Asphalt Pavement, RAP, Millings, Recycling, Maintenance, Asphalt Concrete, Cold Mix, Rejuvenator.	No restrictions. This document is available to the public through the National Technical Information Service, 5285 Port Royal Road Springfield, Virginia 22161.

19. Security Classif.(of this report)	20. Security Classif.(of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	170	

Form DOT F 1700.7 (8-69)

"Routine Maintenance Uses for Milled Reclaimed Asphalt Pavement (RAP)"

by

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and

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Sponsored by the
Texas Department of Transportation
in cooperation with the
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December 1992

METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	2.54	centimeters	cm
ft	feet	0.3048	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	6.452	centimeters squared	cm^2
ft^2	square feet	0.0929	meters squared	m^2
yd^2	square yards	0.836	meters squared	m^2
mi^2	square miles	2.59	kilometers squared	km^2
ac	acres	0.395	hectares	ha
		MASS (weight)		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		VOLUME		
fl oz	fluid ounces	29.57	millimeters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.0328	meters cubed	m^3
yd^3	cubic yards	0.765	meters cubed	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

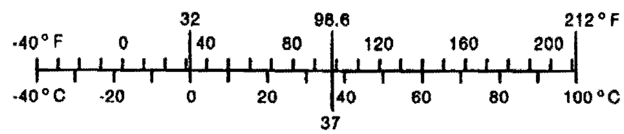
Note: Volumes greater than 1000 L shall be shown in m^3.

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
yd	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
yd^2	kilometers squared	0.39	square miles	mi^2
ha	hectares (10,000 m^2)	2.53	acres	ac
		MASS (weight)		
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1000 kg)	1.103	short tons	T
		VOLUME		
mL	millimeters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.308	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

These factors conform to the requirement of FHWA Order 5190.1A

*SI is the symbol for the International System of Measurements



IMPLEMENTATION STATEMENT

Due to the continuing public pressure on government agencies to utilize waste materials to the greatest extent possible, implementation of the findings of this research have national significance. The findings are capable of immediate implementation by the Texas DOT and all other highway agencies. With appropriate mixture design and modification techniques, milled RAP can alleviate the problem districts sometimes experience in procuring maintenance mixes of sufficient quantity to meet their needs.

Implementation of this research will be through the use of videos. One video will address maintenance crews, the other engineers. The video aimed at maintenance personnel will be instructional, explaining proper methods for working with RAP. The video for engineers will be more promotional in nature, documenting the various uses for RAP, its economical advantages over conventional techniques, and the environmental benefits inherent in a cold recycling process.

Findings of this study indicate that recent legislation associated with requiring the State of Texas to retain ownership of RAP may not be in the best interest of the taxpaying public. It is recommended that this be further studied.

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration or the Texas Department of Transportation. This report does not constitute a standard, specification or regulation. This is not intended for constriction, bidding, or permit purposes.

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INTRODUCTION

The first asphalt pavement was placed in the United States in 1870. By 1915, reuse of asphalt pavements in road structures was recognized as an important option for pavement rehabilitation. Nevertheless, use of asphalt to stabilize recycled asphalt pavement probably dates back only to the 1930s or 1940s.

Study Background and Objectives

Cold milling of asphalt pavements to correct surface irregularities, maintain curblines, or to remove a poor-quality layer is a common rehabilitation procedure used by the Department. Most often the material being milled was originally purchased as a high-quality paving material; therefore, it is obviously economical to find uses for these asphalt-pavement millings.

Guidelines for the use of high-quality, uniform RAP for hot recycling, cold recycling, and in-place recycling are fairly well established and are widely used by the Texas Department of Transportation and other highway agencies. (1, 2, 3, 4, 5) However, this type of recycling utilizes only a portion of what is removed from the pavements in Texas. This study was initiated to determine how to make the best use of available RAP or what methods could be used to improve the quality of the RAP such that a suitable paving or maintenance material for low-volume paved areas could be produced.

Texas has historically used RAP in both maintenance and construction activities. However, all RAP is not being consumed. Recent legislation (Articles 6673i and 6674i-2 of the Texas Civil Statutes) has mandated maximum use of RAP by the Department. The new law requires the Department to retain title to all RAP from the State Highway System with the authority to transfer to another governmental entity, to maximize the use of RAP, to keep inventory of RAP, and to annually report the use of RAP to the legislative audit committee.

Texas Department of Transportation (TxDOT) Directive No. 7-92 states that ".... TxDOT will use RAP when it is available and practical for the construction and maintenance of the State Transportation System." It further states, "The districts will have primary responsibility for maximizing the use of RAP. The appropriate divisions will guide and assist the districts in the handling and use of RAP." Although this study was begun before the new statutes were passed, it provides information useful to the districts and divisions in achieving these mandates.

The overall objective of this study as stated in the research contract was to determine the most economical and effective uses of milled RAP. More specific objectives were to: (1) determine existing effective uses of milled RAP currently used within the districts and in other states and countries; (2) determine effectiveness of new, untried ideas and improvements on existing uses through field experimentation, and (3) provide the Department with a mode of implementation of the research results.

Research Approach

The work plan for this study was developed through a series of meetings with the Study Advisory Committee. The initial course of this research was rather broad, aimed at covering the use of RAP in both construction and maintenance activities. However, the advisory committee felt that the primary focus should be on the use of RAP in routine maintenance activities. In fact, the title of the study was officially changed from "Utilization of Milled, Reclaimed-Asphalt Pavement" to "Routine Maintenance Uses for Milled, Reclaimed-Asphalt Pavement".

The first task in the work plan was to interview districts within the state of Texas and in other states to identify current methods for using RAP. The literature was also reviewed to identify new and innovative approaches for the utilization of RAP.

Secondly, RAP was collected in three locations throughout the state to characterize its laboratory properties. With these RAP samples, cold mixture designs were performed using three different emulsified admixtures. The effects of these emulsions were then evaluated on the properties of the blended RAP mixtures. The three RAP materials were also blended with limestone rock asphalt (LRA) to quantify changes in pertinent engineering properties. All work in this task focused on evaluating modified RAP and improving its quality as a maintenance mixture.

Thirdly, fourteen field projects were evaluated in the study: 12 of these were maintenance projects and the remainder were construction projects. The objective of the field study was to identify and evaluate existing Departmental uses of RAP, investigate and assess the value of new uses for RAP, and to collect video footage of these activities for the production of videos to support their implementation by the Department.

A fourth task in the work plan was to obtain samples of the field-produced RAP maintenance mixtures and perform the following:

(1) Characterize laboratory properties of treated RAP mixtures identified as performing successfully by Department personnel, and

(2) Correlate laboratory properties to field performance.

Results of these tasks are discussed herein. It should be noted that the Department has established an ongoing research study (Study 187-13) to monitor performance of the field maintenance projects constructed during this study.

Also resulting from this study is a field manual which contains guidelines for using RAP in maintenance activities (Report 1272-2F) and two video tapes. One video is aimed at maintenance personnel and is instructional, explaining proper methods for working with RAP. The second video is for engineers and is more promotional in nature, documenting the various uses for RAP, its economical advantages over conventional techniques, and the environmental benefits inherent in a cold recycling process.

RESULTS OF STATEWIDE SURVEY

At the beginning of this study, a questionnaire was distributed to all of the 24 districts in the state. The results of this questionnaire provided the background information necessary to assess the magnitude of the problem and to guide the research such that the Department's needs could best be met. Input from all the districts was also needed to complete, in part, the first study objective mentioned above. It should be noted that the survey results were obtained before the recent state laws (Article 6673i and 6674i-2 of the Texas Civil Statutes) became effective. Thus, under the requirements of the laws, there should be a significant change in the RAP quantities presented herein.

The questionnaire as shown in Figure 1 was sent to each district in the state. Since both maintenance and construction applications of asphalt millings were initially investigated in this study, pooled responses from the District Construction Engineer, Maintenance Engineer and Design Engineer were requested. District response was excellent, and all of the results presented herein reflect information provided by the districts in October of 1990. Most of the results obtained from the questionnaires are summarized in Figures 2 through 6 and Tables 1 and 2. Appendix A provides separate results for each district.

The amount of hot-mixed, cold-laid (HMCL), asphalt concrete used by each district annually for maintenance purposes is exhibited in Figure 2. Also included in this figure is the portion of the HMCL used in locations other than the main lanes (i.e., shoulders, driveways, etc.). This information was requested to determine the extent to which the use of asphalt-pavement millings or RAP as a maintenance mix could reduce the quantity of new HMCL purchased annually. Due to the general quality of RAP, most of the uses explored in this study for RAP were outside the main travel lanes. The combined total quantity of HMCL used by all the districts is 686,100 cubic yards, and 19 percent of this material (approximately 130,000 cubic yards) is used in locations other than main lanes. Statewide totals are shown in Figure 6.

Figure 3 presents the estimated quantities of asphalt-pavement millings produced annually as compared with the total amount of HMCL used. On a statewide-total basis, as shown in Figure 6, about 412,500 cubic yards of asphalt-pavement millings are produced each year, and 686,100 cubic yards of HMCL

QUESTIONNAIRE FOR RESEARCH STUDY 1272
UTILIZATION OF MILLED RECLAIMED ASPHALT PAVEMENT (RAP)

The objective of Research Study 1272 is to determine the most economical and effective uses of milled asphalt pavement whether it be in construction or maintenance operations. Cold milling of asphalt pavements to correct surface irregularities, maintain curblines, or to remove a poor quality layer has become common practice. As a result, large stockpiles of milled asphalt paving material have accumulated and are continuing to accumulate in many areas of Texas. In this questionnaire, this milled asphalt material that is salvaged for reuse will be referred to as Reclaimed Asphalt Pavement (RAP). After completion of the following questionnaire, please return to:

John Bohuslav
State Department of Highways
and Public Transportation
D-18 Maintenance
125 East 11th Street
Austin, Texas 78701-2483

If you would like to elaborate on any of these questions, please do so on a separate page. If you have any questions please call Cindy Estakhri at TTI (409) 845-9551 or Texas 857-9551.

(1) In what district are you located? ______ Please provide your name and title?

(2) a. What is the estimated amount in cubic yards of hot mixed cold laid asphalt concrete used for maintenance in your district per year?____

b. Of this amount, what percent is used for maintenance work in locations other than the main lanes? _________

(3) What is the total quantity in cubic yards of milled asphalt pavement currently owned by and stockpiled in your district?

___0 to 10,000 ___10,000 to 25,000 ___25,000 to 50,000

___50,000 to 75,000 ___75,000 to 125,000 ___Over 125,000

If over 125,000 cy, please give approximate amount. _________

(4) What is the estimated amount (cy) of asphalt paving material milled in your district per year? Please estimate total amount including that which the contractor must dispose of plus that of which the State retains ownership?

___0 to 10,000 ___10,000 to 25,000 ___25,000 to 50,000

___50,000 to 75,000 ___75,000 to 125,000 ___Over 125,000

If over 125,000 cy, please give approximate amount. _________

(5) Of this total quantity indicated in question (4), what percent will be owned by the contractor?

______0 to 10 ______10 to 30 ______30 to 60 ______60 to 90 ______90 to 100

(6) Of this total quantity indicated in question (4), what percent do you believe could be reusable?

______0 to 10 ______10 to 30 ______30 to 60 ______60 to 90 ______90 to 100

(7) What is the average top-size particle of the RAP? ____ What percent of the RAP is larger than 1 1/2 inches?____ What percent is larger than 3 inches? _____ What percent is larger than 6 inches?_____

(8) What is the most common type of asphalt pavement which is milled? i.e. Type D, Type C, asphalt stabilized base, etc.

(9) a. What are some uses your district has found for RAP in both construction and maintenance applications?

b. Of these uses, which have been successful for at least one year? Describe on a separate page what additives were used and how the material was mixed, stockpiled, and handled.

(10) Would your district be willing to participate in field trials involving the evaluation of RAP in either construction or maintenance operations?

(11) Please provide the name and phone number of a person to contact for further information if needed.

Figure 1. Questionnaire as Submitted to Each District.

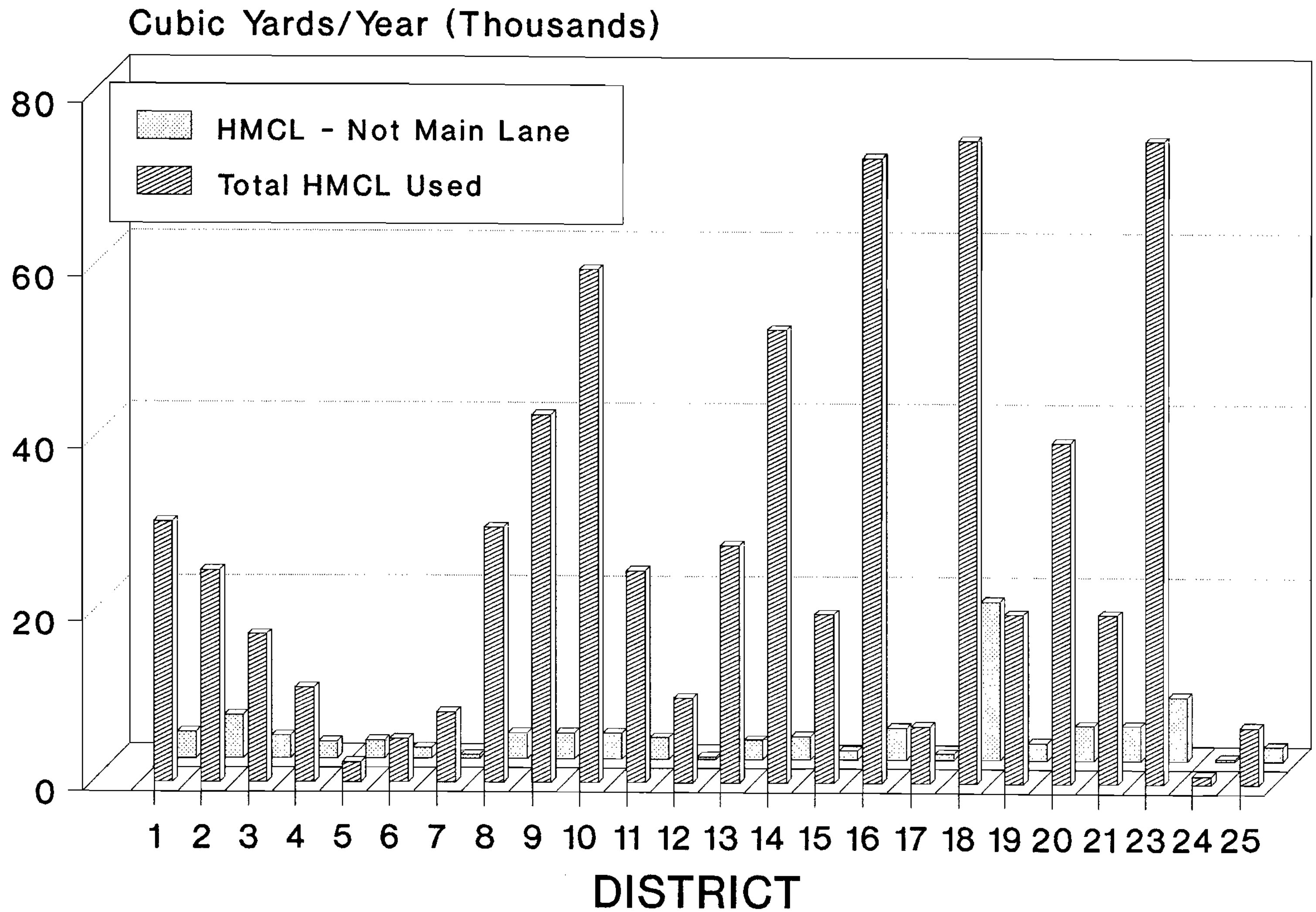

Figure 2. Total Hot-Mixed, Cold-Laid, Asphalt Concrete Used Annually in Texas and the Amount Used in Locations Other than Main Lanes.

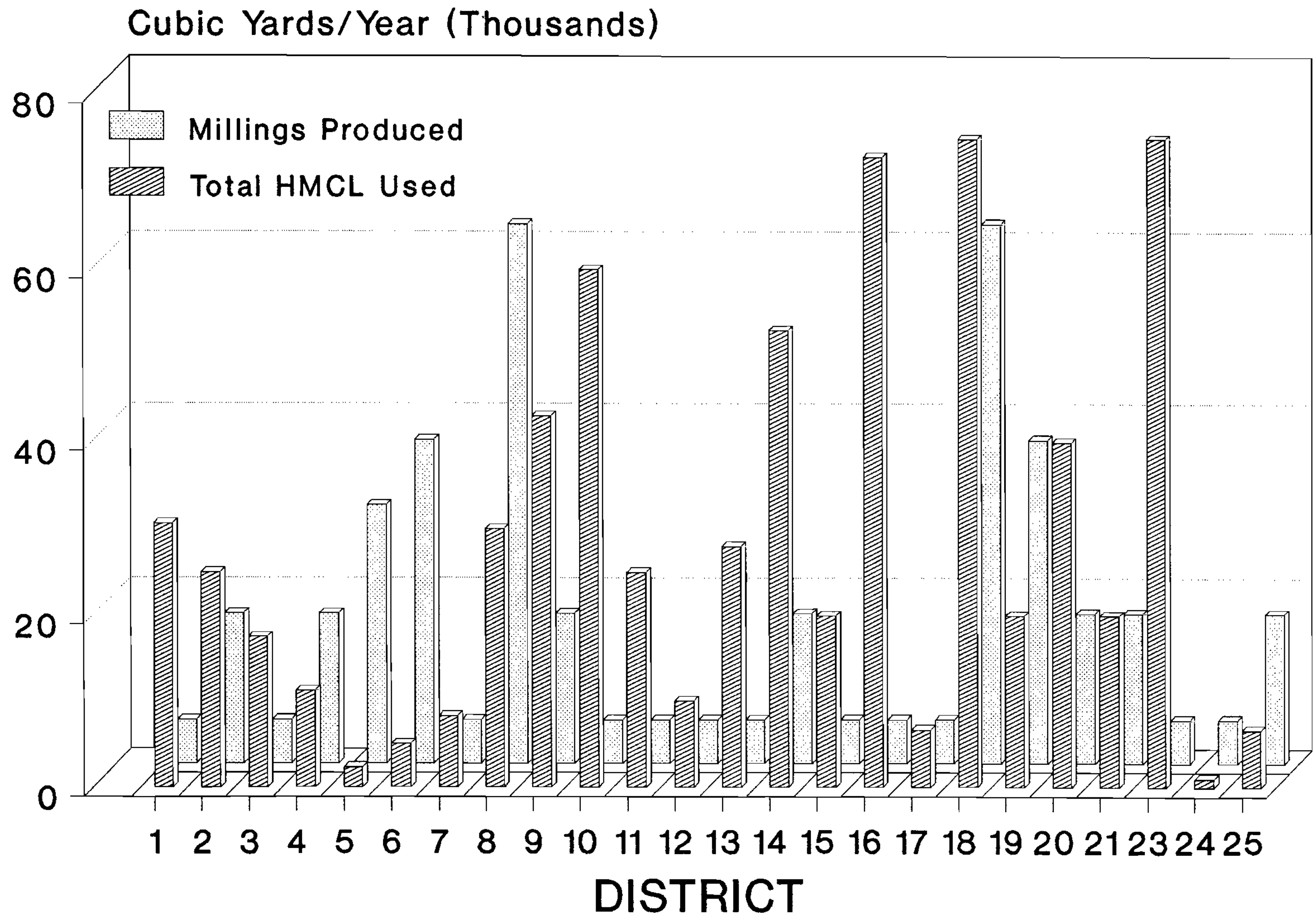

Figure 3. Total Hot-Mixed, Cold-Laid, Asphalt Concrete Used Annually in Texas Compared to the Amount of Asphalt-Pavement Millings Produced Annually.

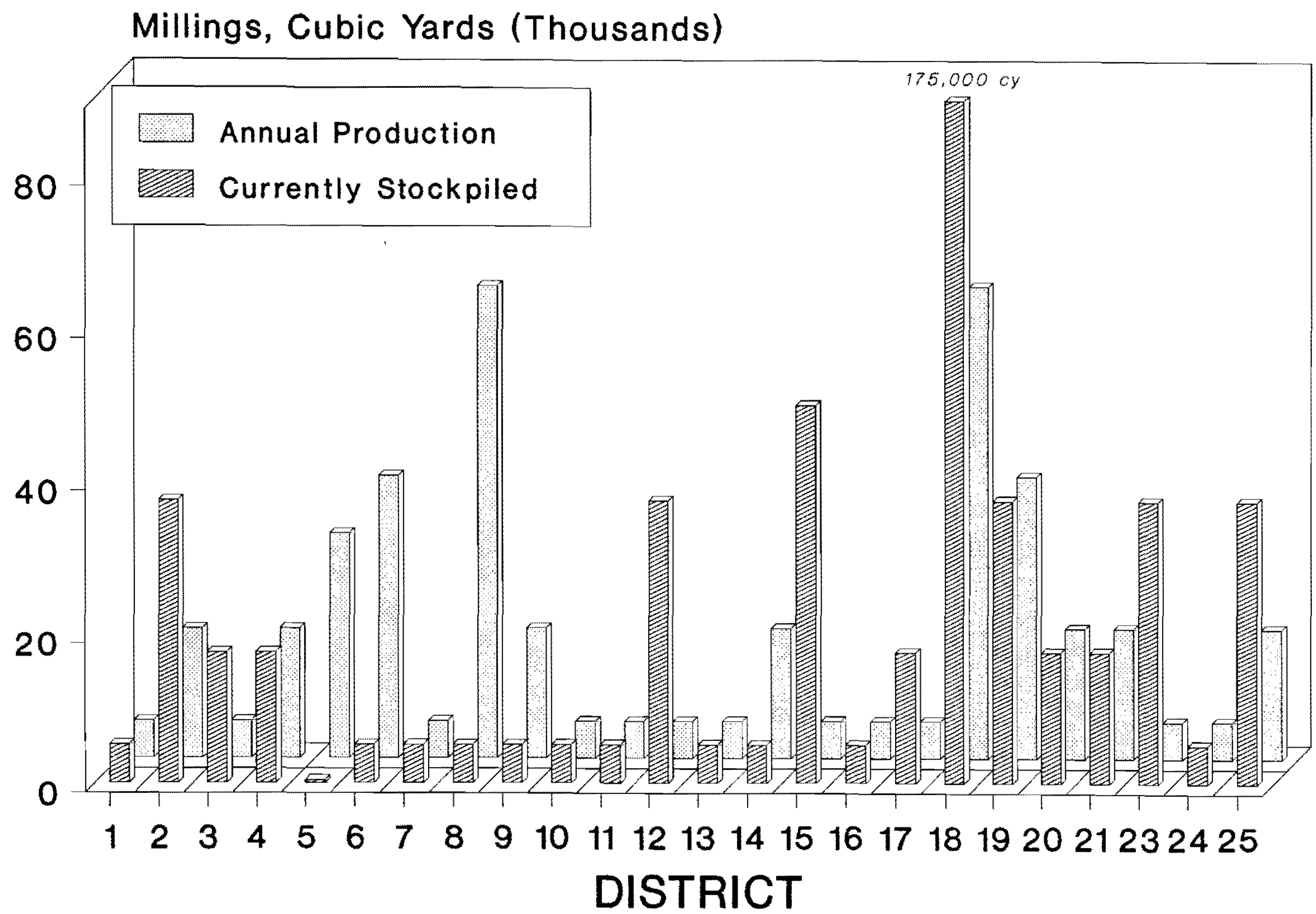

Figure 4. Annual Production of Asphalt-Pavement Millings Compared with Quantity of Millings Currently Stockpiled.

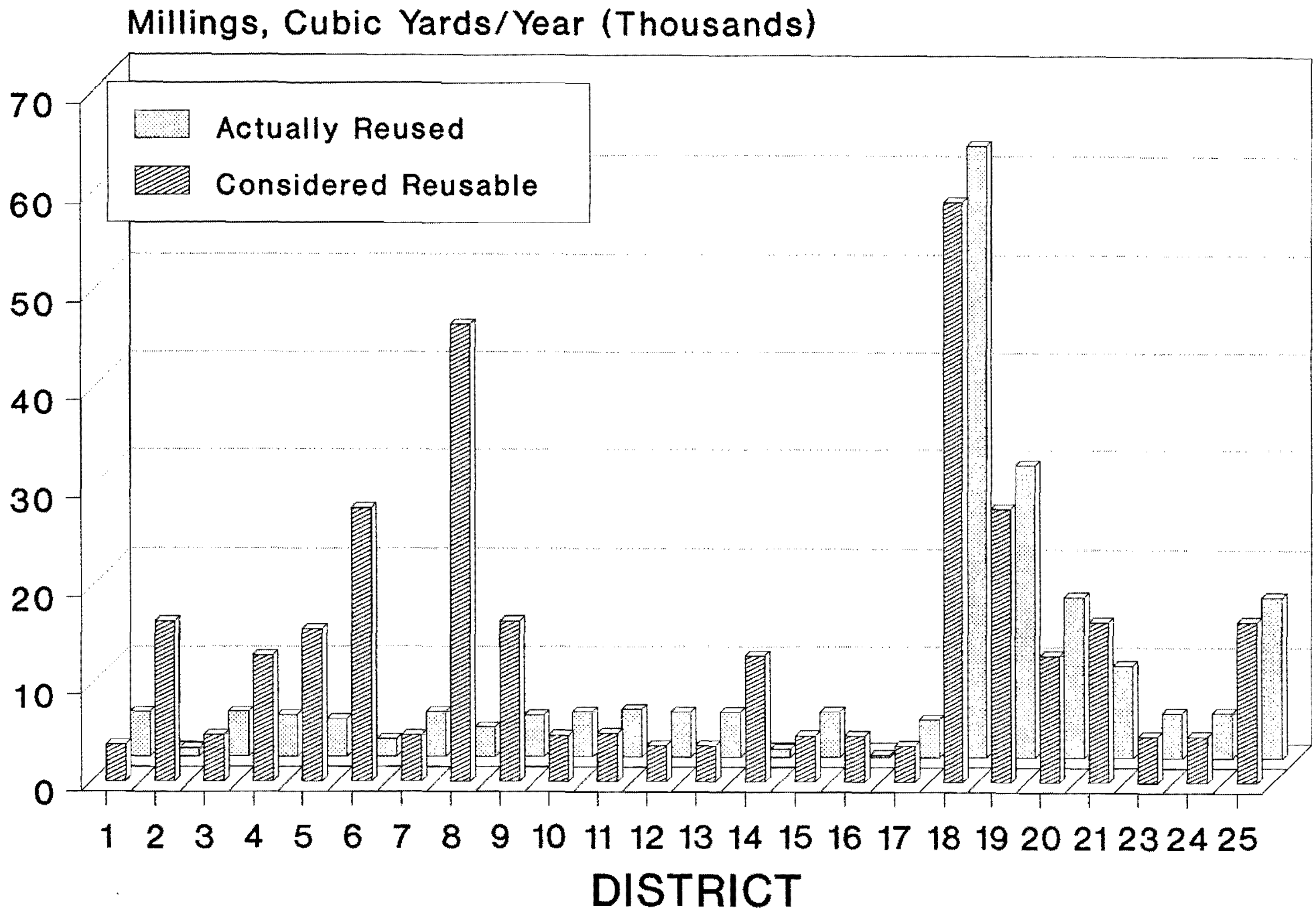

Figure 5. Annual Use of Asphalt-Pavement Millings Compared with Quantity of Millings Considered Reuseable.

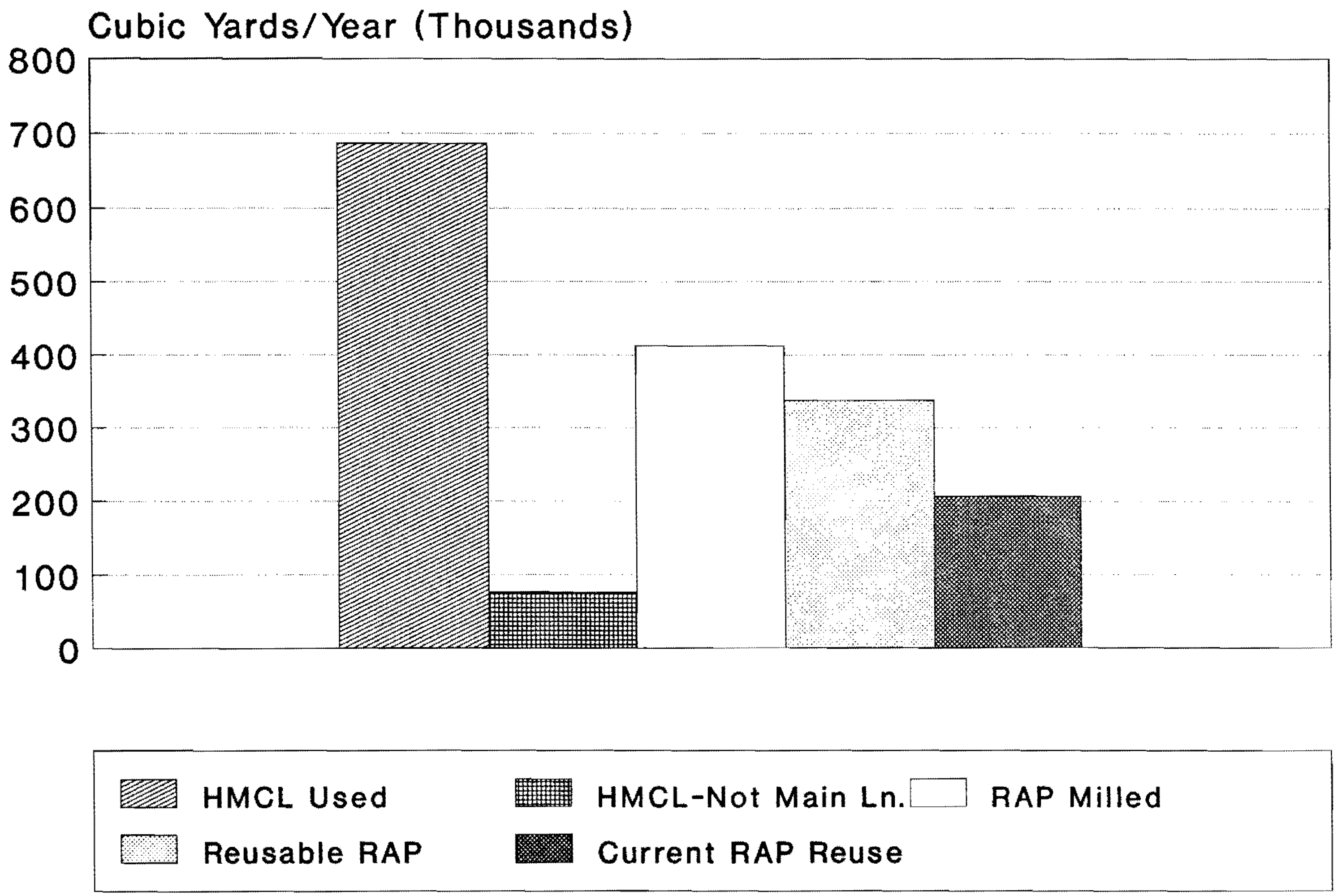

Figure 6. Statewide Questionnaire Results.

Table 1. RAP Average Particle Size.

District	Average Top-Size Particle of RAP, inches	Percentage of RAP Larger than 1½ inches	Percentage of RAP Larger than 3 inches	Percentage of RAP Larger than 6 inches
1	1½	*	*	*
2	1	0	0	0
3	¾	20	3	0
4	¾	2	1	0
5	¾	*	*	40
6	1 to 2	30	10	minimal
7	1	0	0	0
8	2	50	10	1
9	4	50	10	0
10	1	0	0	0
11	¾	5	0	0
12	1½	15	10	10
13	1	5	0	0
14	½	5	0	0
15	1½	0	0	0
16	1	*	*	*
17	5	8	5	0
18	3	5	1	<1
19	1½	5	<1	0
20	½	0	0	0
21	8	20	10	5
23	1	25	5	5
24	⅝	0	0	0
25	2	0 to 10	0	0

* No Response.

Table 2. Successful District Uses for RAP in Both Maintenance and Construction Activities.

District	Successful Uses for Milled RAP
1	Repairing driveways and mailbox turnouts (no additives).
2	Base Course: Used in HMAC as an aggregate with no additives. Backfilling edge of pavement (no additives). Surfacing driveways (no additives). Pothole patching: added CMS-1 emulsion and rejuvenating agent in pug mill.
3	Used as flex base to build service road (no additives). Used as shoulder material and for mailbox turnouts (no additives).
4	Base for pavement repairs (no additives). Driveways and mailbox turnouts, shoulder dropoffs (no additives).
5	Driveway repair, crossovers, and mailbox turnouts (no additives).
6	Mailbox turnouts, litter barrel turnouts, and paving material for maintenance yards (material was blade mixed with an emulsion). Parking lot (no additives).
7	Mailbox turnouts (no additives). On one occasion, material was sprayed with emulsion after it was laid.
8	RAP used in Item 246, Foundation Course in rehabilitation of F.M. highways and frontage roads. RAP was dumped on the existing foundation course and the two materials were mixed with a Bomag and maintainer on the roadway. Water was the only additive. Good results. Used for private driveways and mailbox turnouts. RAP was mixed with MS-1 emulsion by maintainer in the maintenance yard and hauled to the job site. The material was used immediately after being mixed. A maintainer and pneumatic roller were used to place material at the job site. Good results. District has used approximately 50,000 tons this way. Used extensively as a part of Item 292, Asphalt Stabilized Base, full depth recycle project. Used more than 1 million tons this way and consider it to be better than virgin mix. Performed successful cold recycling experiment whereby the old asphaltic-concrete pavement was broken down, pulverized in place, and remixed with additional asphalt without the use of heating equipment. Conclusions resulting from the experiment were that this method of cold recycling of asphaltic-concrete pavement is feasible and, in many cases, highly practical.

9	No successful uses.
10	RAP was mixed in a pug mill with AES-300 emulsion and used for base repair in both main lanes and paved shoulders. Used for construction and reconstruction of public road and street entrances and for edge and driveway repair.
11	Driveway surfacing and pavement edge repairs. Sometimes the RAP is used without additives. RAP has been mixed with AES-300R using a portable Kolberg Mixing Plant, stockpiled for approximately 30 days and then bladed on.
12	Used for shoulder dropoffs, mailbox turnouts, park-and-ride lot, and as a base for full depth concrete repairs. RAP was mixed with AES-300R in a recycling plant that heated the material and mixed with the emulsion. It was mixed and stockpiled with a front-end loader at the same location. It was then handled like a hot-mixed, cold-laid material.
13	Used for edge repair, mail box turnouts, minimum level-up, and pipe end stabilization. Recently used as a flexible base. RAP was hauled to roadbed, dumped and spread. Approximately 10% binder and 1 to 1.3% dry bulk lime was spread over millings, mixed and laid with maintainers and rollers.
14	Used on driveways and pavement edge dropoffs (no additives).
15	Some of the uses have been edge/shoulder repair, level-up, erosion backfill, mailbox turnouts, ditch liner, hot recycled ACP and substitution for Flex Base in reconstruction of a low volume roadway or repairing base failures. Main-lane usage was usually sealed. Additives have consisted of MS-1, cement and in the case of the hot-recycled ACP, some rejuvenator and virgin AC was used. Most RAP has been stockpiled at a convenient location. Prior to its use, the additive is introduced and mixing is done with a blade. Future plans are to use AES-300RP and mix it with the RAP through the use of a pulver-mixer. A two to three month supply will be stockpiled and used as needed.
16	Used for edge protection, driveways, pot holes, mailbox turnouts, blade-on level-up, and patches. Mixed with emulsion for blade-on.
17	Used for driveways, mailbox turnouts and pavement edge repair. Two mixing processes have been used: 1. RAP was mixed with 5-6% AES-300R through a pug mill. 2. RAP was mixed with a blade and mixer in windrow with 5-6% AES-300R. After mixing, material was stockpiled and used as needed.

18	RAP has been used on low edges, driveways and section yards with no additives for a number of years. District has also been successful mixing binders (RC-250, emulsions, etc.) in small quantities for low edges and patching shoulders for a number of years. In 1989, mixed AES-300RP with RAP in pugmill at two locations. Some of this material was used to construct shoulders on an F.M. road which was very successful. The other material was used for low edges, shoulder repair and driveways. District recently completed a contract to mix AES-300RP with RAP in five sections (approximately 60,000 cubic yards). RAP has been used successfully as a percentage of the material for an asphalt base on a large project. A project on IH 45 began construction in 1991 using 90 to 100% RAP for asphalt-concrete surface.
19	RAP has been mixed with both cracked fuel oil and AES-300, and used successfully on low edges, driveways, mailbox turnouts, base repairs and heavy level ups. Has been recycled in Item 292.
20	Untreated RAP has been used in maintenance as a base material, for driveways, turnouts, and shoulder repairs. Untreated RAP has been used also in construction as a base material.
21	RAP has been mixed with rejuvenator and used mostly in edge repair. RAP is also recycled back in new hot mix at a RAP content of approximately 35%.
23	Used as a blade level-up. RAP material is windrowed along highway, then MS-2 is applied and mixed with maintainer working it back and forth until satisfactory mix is obtained. Used for driveways, turnouts and edge treatment. Tack coat of MS-2 is applied, RAP is spread with maintainer, rolled with pneumatic or flat-wheel roller and finished with application of MS-2, if needed. Recently mixed RAP with AES-300RP in a pugmill and stockpiled.
24	In construction, RAP has been used as a subbase: Material was hauled from stockpile to roadway, dumped, spread, and grid-rolled to break up-consolidated material. Material was then windrowed and placed in a similar manner to a base material. It was then sprinkled lightly with water and compacted. Used approximately 13,000 cubic yards. In maintenance, RAP has been used as a subbase in patches and has also been used to pave small areas. It has also been used as a slope stabilizer along roadways and as a support material behind curbs. Material was sprinkled lightly with emulsion, placed and compacted. In some instances, it was heated in a heating drum and used as a hot-mix patch. Used approximately 1,000 cubic yards.

25	In maintenance, RAP has been mixed 50/50 with fresh hot-mixed, cold-laid asphalt concrete pavement for use in blade patches. In construction, pavement has been milled full depth and mixed in-place with existing flexible base material.

are purchase annually.

When this study first began, there was a concern that there were large stockpiles of milled, asphalt pavement across the state. At the time of this questionnaire response, there was a total of approximately 555,400 cubic yards of stockpiled RAP in the state. When comparing the millings produced annually with the amount currently stockpiled for each district (Figure 4), there did not appear to be an excess of stockpiled millings, and indications from the districts were that much of this stockpiled material would be reused.

While the majority of the districts retain most of the asphalt-pavement millings, at the time of this survey, several districts required the contractor to assume ownership of the material after milling it from the pavement. It was assumed that if the contractor did not acquire the material, then the district retained ownership and reused the material. The assumed annual use of asphalt-pavement millings is shown in Figure 5. The annual quantity of RAP believed to be reused by the districts is about 49% of the total annual millings (203,750 cubic yards per year) as shown in Figure 6. Also shown in Figures 5 and 6 are the quantity of millings or RAP produced annually considered to be reusable. Over 80 percent of the millings being produced were considered to be of a reusable quality.

Table 1 provides an indication of the quality and reusability of the asphalt-pavement millings. Table 1 shows the average top-size particle of the millings across the state. This is important information in terms of cost-effectiveness. The larger the particle size, the more processing required to break it down into a size that can be reused. This, of course, will increase the cost. However, as shown in Table 1, it appears that the top particle size of most of the millings being produced is 1 ½ inches or smaller. Therefore, it seems that very little or no further crushing would be necessary.

Table 2 summarizes some of the successful and innovative uses the districts have found for milled, asphalt pavement in both maintenance and construction activities. A vast amount of important information has been collected and conveniently summarized in this table. Preliminary findings indicate that the most common uses appear to be for driveways, mailbox turnouts and shoulder repairs. Some districts use the millings with no further processing and others blade-mix it or mix it in a pugmill with an emulsified asphalt. Millings have also been mixed 50/50 with fresh hot-mixed, cold-laid, asphalt concrete.

Asphalt-pavement millings have been used for paving maintenance yards, constructing shoulders, pothole patching, base repairs, erosion backfill, pipe-end stabilization, and as a drainage-ditch liner. It has been used in the following TxDOT Specification items: Item 246, Foundation Course; Item 292, Asphalt-Stabilized Base; Item 249, Flexible Base (delivered); Item 340, Hot-Mixed, Asphalt-Concrete Pavement; and as a level-up course on low-volume roads. (6)

Summary

There is a significant quantity of asphalt-pavement millings being produced annually in the state and of a quality that can be reused with minimal processing and handling. At the time of this survey (1990), the Department was reusing about half of these millings. There are many innovative ways asphalt-pavement millings are currently being used in the state. The more successful were examined in this research study.

Although the survey was intended to address construction and maintenance uses, it appears that most of the responses only discussed routine maintenance uses. For more information on other uses of RAP in the Department, refer to Departmental Research Report DHT-26.

Use of RAP After Legislation

As a result of the recent legislation (Articles 6673i and 6674i-2 of the Texas Civil Statutes) concerning RAP, the Department is required to keep inventory of RAP and to report on the use of RAP to the Legislative Audit Committee. The following is a summary on the use of RAP by TxDOT for fiscal year 1992 prepared by the Division of Maintenance and Operations - Maintenance Section (October 1992).

In accordance with Senate Bills 352 and 1340 (Article 6673i and Article 6674i-2 of the Texas Civil Statutes) as passed by the 72nd Legislature, TxDOT implemented requirements and procedures concerning Reclaimed Asphalt Pavement (RAP) beginning in September 1991. Initial requirements and procedures were distributed to All Districts by a draft Administrative Circular dated September 20, 1991. The Department issued TxDOT Directive No. 7-92 and Administrative Circular No. 16-92 which set forth the specific requirements concerning RAP.

As shown in Figure 7 for FY 1992, "RAP Received, Used, and Transferred", TxDOT:

* *Received almost 1,000,000 cubic yards of RAP,*
* *Used over 500,000 cubic yards of RAP, and*
* *Transferred less than 50,000 cubic yards to other governments.*

In summary, approximately 60% of the RAP received was used or transferred for use. This may be considered a significant accomplishment for the first year under the new statute; however, it appears TxDOT must substantially increase the use of RAP in order to keep the inventory as low as possible. Recently adopted Standard Specifications which allow the use of RAP in hot mix-hot laid ACP and asphalt stabilized base should provide an increase in TxDOT RAP use if and when the RAP is available and practical for use.

As shown in Figure 8 for FY 1992, "Use of RAP", TxDOT used RAP in construction and maintenance for the following purposes:

* *56.2% (302,738 CY) for flexible base admixture,*
* *7.0% (37,813 CY) for HM-HL ACP surface course,*
* *5.7% (30,714 CY) for HM-HL ACP or ASB (not surface course),*
* *6.3% (33,813 CY) for cold stabilized base,*
* *24.8% (133,585 CY) for routine maintenance and other uses*

Total 100.0% (538,663 CY) for construction and maintenance.

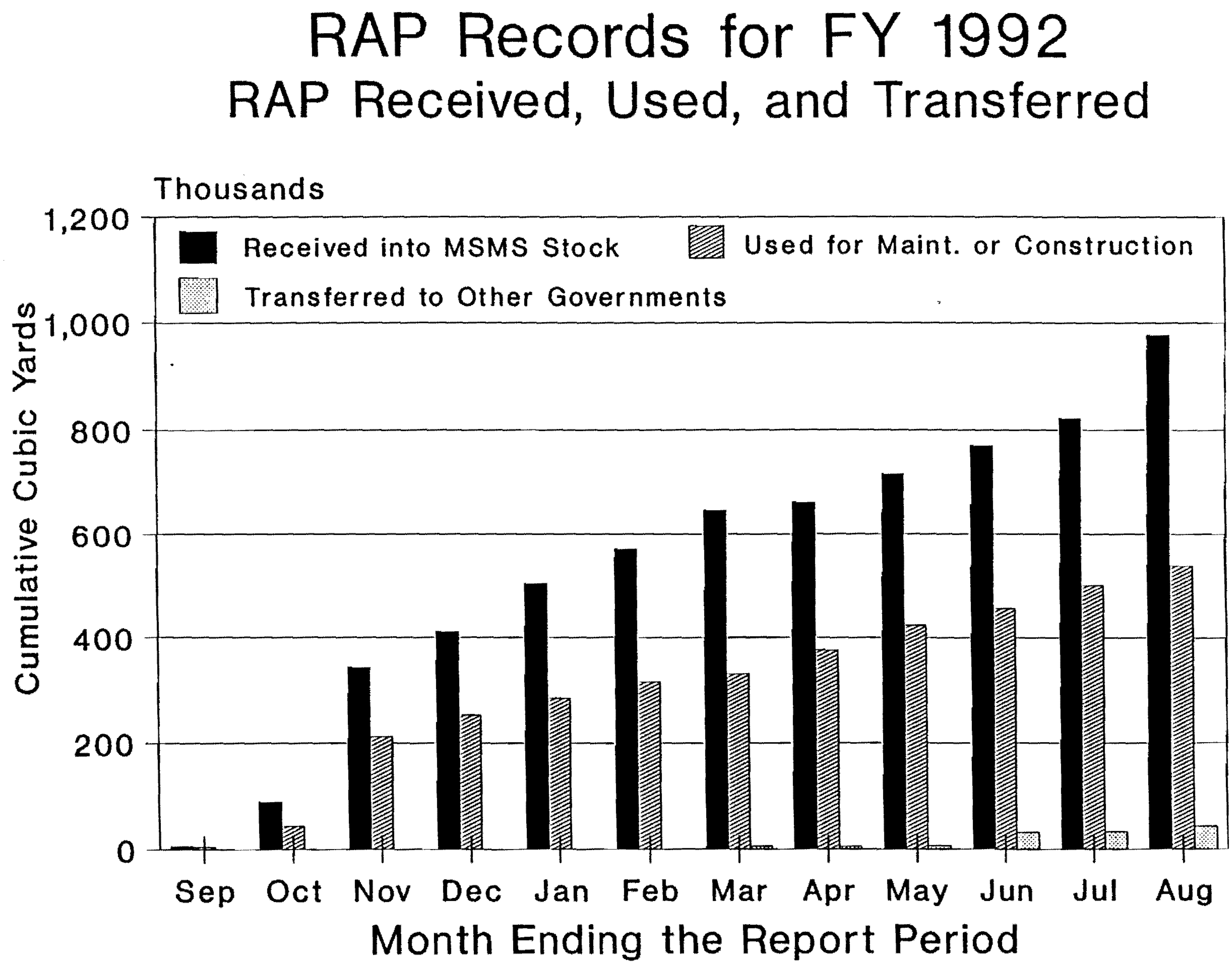

Figure 7. RAP Received, Used, and Transferred by TxDOT for Fiscal Year 1992. (Prepared by the Division of Maintenance and Operations - Maintenance Section , October, 1992).

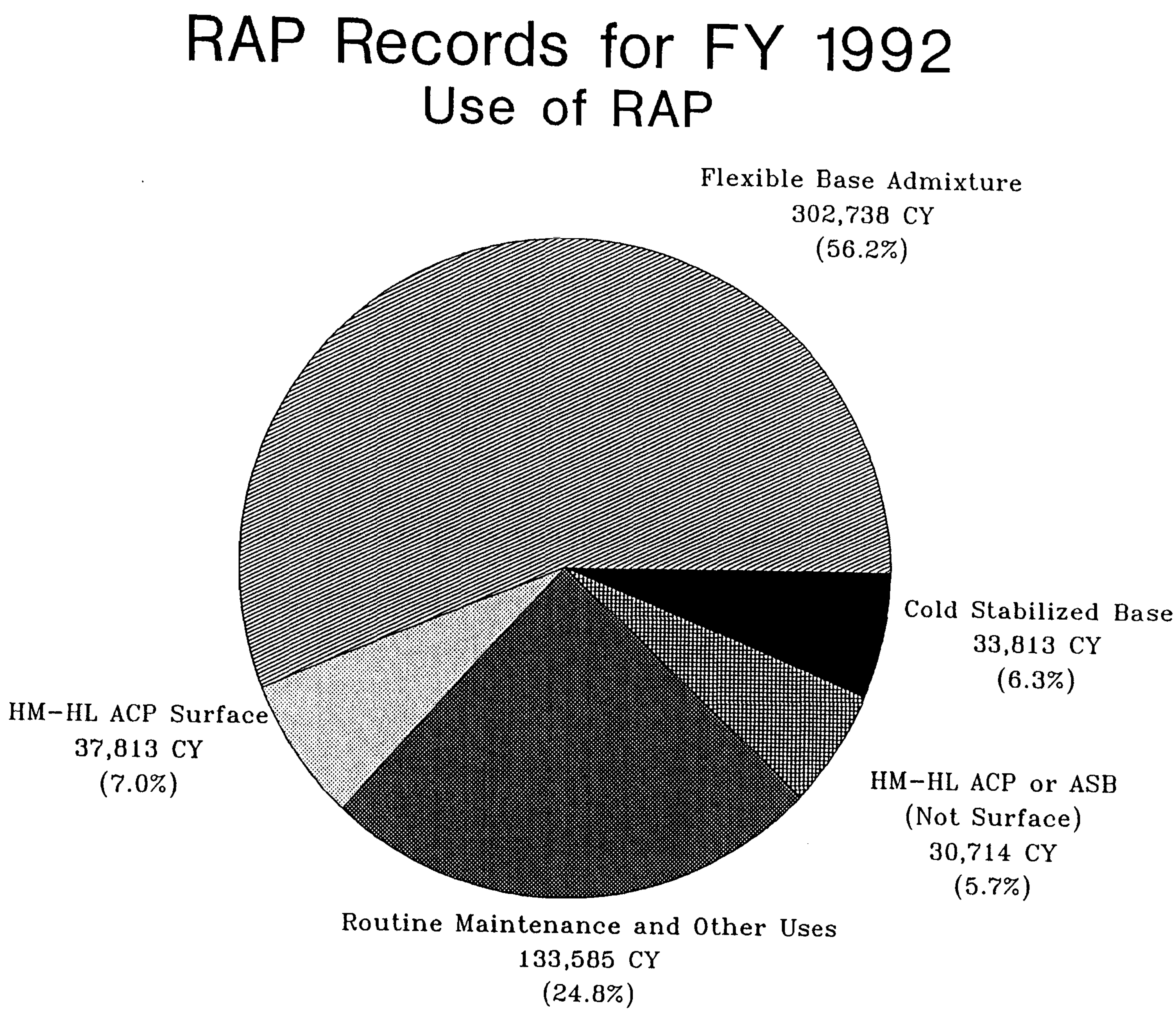

Figure 8. Use of RAP by TxDOT in Fiscal Year 1992. (Prepared by Division of Maintenance and Operations - Maintenance Section, October, 1992)

Summary of Findings

In the search for effective methods for using milled RAP, one source considered to possess much valuable information was the other 49 state DOTs. Representatives of many of these DOTs were contacted in a telephone survey conducted as a part of this study to obtain information on recycling policy and usage of RAP. Information from the remaining DOTs was gleaned from the literature. Data collected in this portion of the work and pertinent to this study or to the Department in general is summarized in Table 3.

It appears that most RAP is used in hot recycled mixtures. Most well-thought-out specifications have been developed for hot mixtures. Many states allow the use of higher percentages of RAP in mixes produced by drum plants than by batch plants. Allowable percentages of RAP in hot mix range from zero to 70 percent. Often, less RAP is allowed in surface mixtures than in mixtures for base or binder courses.

A few states do not use RAP in maintenance operations, while others make extensive use of RAP in maintenance. Both plant mixing with stockpiling and mixing in place were reported in pavement surface, base, binder course, and shoulder construction in maintenance operations. Some DOTs stabilize the RAP with emulsion or cutback asphalt, while others use no additional binder. A few states reported they used only water to aid in compaction.

No innovative concepts for consumption of large quantities of RAP were identified as a part of this task. However, two points that may have particular application to TxDOT are (1) retention of RAP ownership and (2) routine use of small quantities of RAP in hot mix. These points will be explored in more detail in the following subsections.

Ownership of RAP

Texas Civil Statutes Articles 6673i and 6674i-2 state that TxDOT is to:

- retain title to all RAP from the state highway system, with authority to transfer title to another governmental entity,
- maximize the use of RAP when feasible,
- keep a public record of the location and amount of department-owned RAP, and
- report annually to the Legislative Audit Committee on the department's use of RAP.

Table 3. Summary of Milled RAP Use by Other State DOTs.

STATE	Successful Uses for Milled RAP
ALABAMA	Requires that recycled mixture has properties similar to a new mixture. Uses asphalt cement as recycling agent. Allows maximum of 40% RAP with batch plants and 50% with drum plants.
ALASKA	Has no standard specifications. They are using RAP only in developmental projects at the present time.
ARIZONA	They try to anticipate when they are going to mill and perform a hot recycling mixture design. If RAP is not used immediately in hot recycling, the districts are asked if they want the RAP. If RAP is not useable on the pavement shoulders, RAP ownership is retained by the contractor. Arizona is experimenting with deep recycling of RAP by using in base layers. They allow up to 40% RAP in HMA for all ACP layers.
ARKANSAS	Allows up to 70% RAP in HMA for all ACP layers. They are using RAP material for shoulder construction, usually without adding any new asphalt binder. Have done some research on addition of emulsion to RAP in field trials in about 1987.
CALIFORNIA	Uses RAP in both hot and cold recycling in construction. Some millings are used for maintenance operations on shoulders. Use of cold mix is restrained in the state because of volatiles. Some research has been performed on use of RAP for base repair.
COLORADO	Experimentation with hot recycling methods was performed around the 1980s. Contractors can use up to 30% RAP in ACP. Typically use 15% in most urban areas. RAP has been used as a base material, if it meets R-value requirements. Maintenance forces have used RAP mixed with MC-70 or MC-800 as a cold mix. The material is primarily used on shoulders, turnouts, and as base material. RAP has also been used for vegetation control on shoulders up to 8 feet away from the roadway. Typically have 3 to 4 reconstruction jobs per year using cold recycling in-place with milling trains.
CONNECTICUT	Allows a maximum of 40% in all ACP layers. Up to 15% RAP may be used routinely in ACP after notifying the DOT.
DELAWARE	Delaware allows 10% RAP to be incorporated into ACP surface materials. No RAP is allowed in open-graded friction courses. RAP is allowed to be incorporated into base course and sub-base in cold applications. Maintenance forces use RAP for shoulders and driveways without the addition of asphalt emulsions or cutbacks. Allows up to 30% RAP in batch plants and 50% in drum plants.

Table 3. Continued.

FLORIDA	Specifications for hot, plant mixed material permit 50% maximum because of the high dust content of the milled RAP. Florida decided early to allow contractor ownership of the RAP expecting savings to come from more competitive ACP prices. Maintenance forces use RAP to repair raveling pavement edges. Cold in-place operations have been successfully used. Problems arise from the large dust content of the millings and the formation of a dusty layer that induces slippage at the pavement-base interface. Microwave methods have been used successfully. Hot in-place recycling methods of various types have proven acceptable.
GEORGIA	Specifications allow use of contractor-owned RAP. RAP must be approved by the DOT. Allows up to 25% in batch plants and 40% in drum plants.
HAWAII	RAP is limited to base construction only. Allows up to 30% RAP in batch plants and 40% in drum plants.
IDAHO	Has policy of using all RAP possible in hot recycling. They typically use up to 55% RAP in recycled mix. One reason for the high percentage of RAP is the fine-graded nature of their virgin ACP mixes in the 1970's. The state uses both cold, and hot in-place recycling methods to reconstruct roadways. The cold methods typically involve milling trains and have been used on a wide variety of roads including interstates. They will place RAP produced from an interstate milling operation onto a frontage road. Counties in the state use excess RAP to produce a cold patching mixture for maintenance and construction of low volume roadways. The material is produced through a pugmill, or blade mixed using emulsified asphalt.
ILLINOIS	RAP becomes property of the contractor. Allows use of RAP in all ACP layers except the riding surface. The exact percentage of RAP used in ACP depends on ability to meet specifications. Illinois does not use RAP for maintenance operations.
INDIANA	Allows RAP to be used in ACP products included in the standard specifications on a contract by contract basis. Some contracts set aside the RAP for maintenance uses. Maintenance forces use raw RAP to build/repair shoulders. No emulsion or cut back products are used in the RAP in these applications. Compacted shoulder is covered with a chip seal.
IOWA	RAP from a project becomes the property of the contractor. Standard mixes allow up to 30% RAP. Mixes containing RAP must meet same specifications as mixes with no RAP. Virgin AC must be at least 70% of the total AC contained in the mix. Allows contractors to use RAP from other projects as long as gradation remains constant. When using a stockpile of RAP from several locations, they allow 10% maximum to be incorporated in hot mix. Iowa does not do much in-place recycling. Pavement design requires a 25 year life.

Table 3. Continued.

KANSAS	Ten percent RAP may be routinely used in ACP. One hundred percent must pass the 2¼-inch scalping screen.
KENTUCKY	RAP used in open-graded mix or other surface mixtures requiring polish-resistant aggregate must meet requirements of virgin material. When RAP is not salvaged from DOT projects, RAP percentage is limited to 20%.
LOUISIANA	Primary recycle method is to allow contractors to recycle up to 20% RAP into ACP. Allowable RAP percentage is controlled by the stiffness of the aged asphalt.
MAINE	Up to 20% RAP is allowed in all base and binder mixtures on all projects. Up to 40% RAP is allowed in specific projects only. No RAP is allowed in wearing surfaces. They use highest percentage of RAP hot mixes on low volume roads. They have calculated a savings of between 6 and 7 dollars per ton by using RAP in their hot mix specifications ($18.00 per Ton vs. $25.00 per Ton). They have used RAP with no emulsion (to reduce the probability of rutting) to construct bases on several roadways. The roadway is then resurfaced with 3 to 6 inches of hot mixed asphalt. They use RAP as an improved sub-base/base course material to reduce dust.
MARYLAND	Uses only hot recycling. Most recycling is done using a 50/50 blend of RAP and virgin aggregates. Recycled ACP is used in all overlays. Some hot in-place recycling is also used. They use no cold recycling nor RAP in maintenance procedures.
MASSACHUSETTS	Uses RAP in quantities up to 50% in binder courses, and up to 10% in surface courses. Recycled material must meet original virgin ACP specifications. In-place recycling is not used routinely. Allows up to 20 percent RAP in batch plants and 40% in drum plants.
MICHIGAN	Fifteen percent RAP is allowed without designing a special mixture formula.
MINNESOTA	Maximum top size of RAP restricted to one half paving lift thickness up to 2-inch maximum top size. Will allow 3/4-inch top size in a 1-inch leveling course.
MISSISSIPPI	Largest use of RAP is in hot recycling. A maximum of 30% RAP can be used in ACP. RAP is not allowed in the surface course. All RAP becomes the property of the contractor. They appear to like hot in-place recycling.
MISSOURI	RAP is commonly recycled in hot mixed ACP. Up to 50% RAP is permitted. Recycled mixtures are not allowed on the interstates or high volume roadways in urban areas. They have applied a cold recycling method whereby the roadway is cold milled using a special machine that adds emulsion directly into a mixing chamber. This stabilized material is then hauled to a low volume roadway where it is spread and compacted. They have not explored the use of RAP in maintenance.

Table 3. Continued.

MONTANA	Typically, hot recycled mix must meet the same specifications as virgin HMA. No RAP is allowed in surface courses. However, specifications are tailored to each project. Montana is investigating hot in-place recycling and cold in-place recycling using milling trains. Montana plans to incorporate more RAP into the roadway in the future. RAP has been used in maintenance to widen shoulders for frontage roads and build guard rail pads.
NEBRASKA	Uses all of the RAP material that the DOT produces. Most is hot recycled back into the pavement structure in a 50/50 mix with virgin materials. Typically, the material is utilized as a base course, shoulder, or surfacing. They have done very little cold recycling. Some RAP has been mixed with HFE-300 emulsion to produce a patching material, quantity has been limited due to the lack of available material.
NEVADA	RAP is used in both cold and hot recycling. Contractors have the option of using up to 15% RAP in new HMA. They have experimented with hot in-place methods. DOT has used cold recycled RAP as an alternative subbase material and for building shoulders. Cold in-place recycling is used extensively. Modifier is required when RAP percentage is between 35-50.
NEW HAMPSHIRE	RAP used in HMA up to 35% in batch plants and 45% in drum plants. RAP is allowed in all ACP except the top course. One cold mix project has been completed on a low volume section of interstate. This project hauled the millings to a portable pugmill where they were mixed with approximately 0.8% HFMS emulsion. The mix was placed back onto the roadway with a conventional paver, and rolled with a 35-ton roller. The roadway was then resurfaced with 3 inches of ACP. DOT has not used RAP in maintenance operations.
NEW JERSEY	Specifications are for RAP to be used on the project where it originated, otherwise, from blended stockpile. Allows 10% in surface and 20% in base and binder courses.
NEW MEXICO	RAP must be screened, placed in separate stockpiles of 3/8 inch to 2 inches and minus 3/8 inch. Primarily use cold in-place recycling; between 2 and 8 projects done yearly. Unless demonstrated economically beneficial, DOT does not use hot recycling.
NEW YORK	Maximum RAP content is linked to RAP moisture content. Allows maximum of 50% RAP for batch plants (and 70% for drum plants) in base and binder courses and none in surface mixes.
NORTH CAROLINA	AC-20 may be allowed with 15% or less RAP in hot mix. Will permit use of up to 60% RAP in HMA for all ACP layers.

Table 3. Continued.

NORTH DAKOTA	Uses primarily hot recycling. They allow up to 50% RAP in HMA for all ACP layers. They do not like to use in-place recycling methods; they have had problems with compaction of the material. When RAP is used in a base material it is mixed 50/50 with crushed aggregate. They feel that RAP alone does not constitute a high quality construction material.
OHIO	When RAP percentage is less than 10%, special mixture design is not required. DOT allows maximum of 50% in hot mixed base and binder courses and 30% in surface courses.
OKLAHOMA	Specifications allow up to 25% RAP in HMA for base and binder courses; for surface courses, 25% is allowed on roadways with less than 1000 ADT, all others, no RAP allowed. Typically, AC-20 is used as binder. Up to 50% RAP has been tried but results not considered successful. In maintenance operations, RAP is used in raw form to build/repair shoulders, driveways, and mailbox turnouts.
OREGON	Allows up to 20% RAP in all pavement courses including shoulders. Normally, RAP becomes the property of the contractor. Contractor can use RAP from any source as long as the recycled ACP meets state specifications. In cold recycling, Oregon mainly uses the recycling trains. They have had great success with cold recycling in the hot, dry eastern side of the state but not in the cool, wet western side. Primarily use CRS-2 emulsion in cold recycling. Has tried several hot in-place recycling methods. RAP is not used much in maintenance because of the value placed on it by contractors and the large usage of RAP in plant and in-place recycling.
PENNSYLVANIA	Does not have a limitation on the maximum amount of RAP allowed in hot mix asphalt concrete; however, no more than 35% is typically used. All mixtures containing RAP must meet the same criteria as virgin mixtures. If a surface mix is to contain 15% RAP or more, then documentation must be provided regarding the frictional characteristics of the RAP.
RHODE ISLAND	Allows 35% RAP in HMA for base and binder mixes for batch plants (50% for drum mix plants) and no RAP in surface mixes.
SOUTH CAROLINA	Allows 20% RAP in base courses, 15% in binder courses, and 10% in surface courses.

Table 3. Continued.

SOUTH DAKOTA	Allows maximum of 50% RAP in all HMA. Typically, 40% RAP is used in plant recycling methods. Cold in-place recycle trains are frequently used. Extensive lab testing is performed on the prospective pavement using Marshall mix design procedure and California Bearing Ratio (CBR). Typically, 1% HFE-200 emulsion gives them the highest strengths. Marginal RAP is often recycled into the base course on reconstruction projects. Maintenance forces typically use RAP left over from hot recycling projects for shoulder and base repair. HFE-200 material is sometimes used to improve the RAP, typically at a concentration of 1%. Maximum particle size for RAP is 3/4 inch.
TENNESSEE	Their recycling specifications are fairly open. At least 65% of asphalt cement in final mix shall be new material. Up to 20% RAP allowed without analysis of RAP and stockpile.
TEXAS	TxDOT allows use of RAP in hot-mix asphalt concrete and in asphalt-stabilized base as long as the produced mixture meets the requirement of the specification item and the same criteria for virgin mixes. There is no limitation on the maximum allowable RAP content in a mix. RAP is used in routine maintenance for driveways, mailbox turnouts and shoulder repairs. As discussed in this report, RAP is blended with recycling agents or with other maintenance mixtures to improve the characteristics of the RAP for use in maintenance operations. TxDOT has used more than 3 million tons of RAP in the past 20 years. A recent state law mandates that TxDOT maximize the use of RAP: TxDOT is required to retain title to the RAP (with authority to transfer to another governmental entity), to maximize the use of RAP, to keep inventory of RAP, and to annually report the use of RAP to the legislative audit committee.
UTAH	Allows up to 70% RAP in all HMA mixes. Recovered asphalt cement and aggregate gradations, after recycling, must meet same requirements as new material.
VERMONT	All recycled mixtures must meet standard specifications.
VIRGINIA	Allows a maximum of 25% RAP in all HMA mixtures unless otherwise approved by the engineer.
WASHINGTON	Milled RAP becomes property of the contractor. DOT allows up to 15% RAP without mixture design modifications. They have allowed up to 80% RAP in a specially designed mix. All RAP-modified HMA must meet standard state specifications. They have done a few in-place recycling projects. They scarified and windrowed the road surface then added emulsion and blade mixed the product then spread and compacted; success rate was minimal. In maintenance applications, work by state forces is limited by state statute. State forces do not own or use much RAP in maintenance applications.

Table 3. Continued.

W. VIRGINIA	Recycling specification is open except that penetration of asphalt extracted from recycled mixture shall not be less than 60.
WISCONSIN	Primarily uses hot recycling. Presently, they recycle one million tons of RAP per year, or between 25-35% of the total ACP produced. They have not had good results in using RAP surface courses and have disallowed the use. Due to cold climate, they have not had much success with cold in-place methods using emulsions. They have had success in using RAP as a base course. RAP is mixed with water and compacted to achieve specified density. The State mills approximately 100 lane-miles per year where the RAP millings are placed directly onto the shoulders.
WYOMING	DOT emphasizes use of RAP. They are recycling on 50% of all state ACP projects. These projects allow between 10 and 50 percent RAP to be used in all layers of the road surface with DOT approval. They do not normally perform in-place recycling. Maintenance forces use RAP where ever a crushed gravel might normally be used. RAP is typically used without an emulsion binder.

ACP - asphalt concrete pavement
HMA - hot mixed asphalt

Any Texan conscientious about recycling would certainly consider the above to be worthy objectives, but their accomplishment places a huge burden on TxDOT. Land has to be available for stockpiling the RAP. Double stockpiling will be necessary when the contractor is selected for a given construction project and he has to move the RAP to his plant site. The cost of stockpiling will always be borne directly or indirectly by TxDOT. Paperwork has to be generated and maintained to retain ownership of the RAP, transfer it to another governmental entity, keep a current inventory of the RAP, and report annually to the Legislative Audit Committee.

The alternative is to transfer ownership of the RAP to the contractor when the milling is performed. The majority of state DOTs permit the contractor to retain ownership of RAP. About 15 percent of state DOTs are known to retain ownership of milled RAP. The official position of the Texas Hot Mix Asphalt Pavement Association and the National Asphalt Pavement Association (whose memberships are composed of paving contractors) is that the contractor should retain ownership of RAP because they believe it is most economical. This ostensibly gives innovative contractors flexibility and a competitive edge which should be seen in lower bid prices which, in turn, should save the State money.

In 1980, a Minnesota DOT engineer (7) stated that the entity (contractor) responsible for producing the recycled mixture should be responsible for the removal, processing and recycling of these materials. This ensures a vested interest in maintaining the inherent quality of the pavement removed and stockpiled. He continues, the user agency (DOT) should not retain ownership of salvaged materials unless it is willing to protect its quality. Ownership should go to the person controlling the end use of the material. The user agency (DOT) should allow the contractor to incorporate these potentially valuable materials into recycled mixtures for payment equal to conventional mixtures.

In order to make this system (contractor ownership of RAP) function properly, it may also be necessary to ensure incentives for using the RAP in roads and other public works. Incentives for asphalt pavement recycling are stronger in some countries than in the United States. This is primarily because of their relatively higher population density which has forced more emphasis on land and resource management. As an example, in The Netherlands, two million tons of reclaimed asphalt pavement (RAP) are available annually as compared to seven million tons of new hot mix asphalt produced in the same time period. All this RAP will be reused because (1) a shortage of mineral aggregate exists in several European countries, including The Netherlands, (2) disposing of RAP in a Dutch waste dump costs more than purchasing virgin hot mix asphalt, and (3) European environmental laws prohibit the unregulated dumping of RAP.

In 1989, in a study for Georgia DOT, the National Center for Asphalt Technology (8) concluded that contracts should be written so that RAP removed from state projects becomes property of the contractor. They reasoned that by placing this in the contract the state will get a reasonable price for the RAP and will not be required to stockpile the material for possible use later.

This is a very complex and controversial problem which was not a major part of this study. A clear and definitive solution to this problem was certainly beyond the scope of this study. The subject of RAP ownership deserves a systematic examination and analysis in which all facets of the problem are considered.

Use of Small Quantities of RAP in Hot Mix

One work element in this study was to investigate the use of small quantities of RAP (say five to fifteen percent) in most any hot mix paving operation. The concept is that the incorporation of a small quantity of RAP does not adversely affect the overall quality of the paving mixture.

This too was a rather minor part of the overall study, therefore, this portion of the investigation was not exhaustive. However, it was found that several state highway agencies follow different variations of this practice. Table 3 shows that at least 14 state DOTs (Connecticut, Delaware, Georgia, Indiana, Iowa, Kansas, Louisiana, Michigan, Nevada, Ohio, Oregon, Pennsylvania, Washington, and Wisconsin) allow the routine use of small quantities of RAP in HMAC. This table was developed based on information obtained through telephone surveys and from Reference 9. Of course, each of these state DOTs has its own unique specification. In most cases, small quantities of RAP can be incorporated in a mixture without altering the mixture design. Some DOTs permit the use of small quantities of RAP only in base courses and binder courses and prohibit the use in surface courses except by special permission. Others prohibit the use of RAP on Interstate highways without special mixture designs to accommodate the RAP. Still others allow the use of RAP (even non-uniform RAP) if the resulting asphalt concrete meets the specifications for the material stipulated.

Based on conversations with representatives of several of these state DOTs, the use of small quantities of RAP without modifying the mixture design is being performed successfully. However, no specific data or published literature was found to verify the successful application of this practice. A materials engineer from Pennsylvania DOT stated that they found that the addition of 10 percent RAP had a negligible effect on the selection of asphalt grade; that is, the normal paving grade asphalt can be used in the mixture and no recycling agent is needed to rejuvenate the RAP. Another engineer pointed out that small percentages of RAP are not a significant factor in plant emissions.

As a final thought, ample consideration should be given to selecting the RAP content in recycled hot mix. A past tendency has been to operate at as high a RAP content as possible, much to the disadvantage of plant productivity, the plant equipment, the environment, and hot mix quality. The higher the intended RAP content to be used in the hot mix asphalt, the greater the requirement that RAP be extremely consistent in quality, and thus the more stringent the quality control must be during the entire RAP handling procedure. The practice of using high RAP contents has been more prevalent in situations where the highway agency retained ownership of the RAP. Contractor ownership of RAP permits recycling at levels most practicable for each individual situation.(10)

In 1988, TxDOT began a major task of upgrading their 1982 Standard Specifications. As part of this task, Specification Item 340, "Hot Mixed Asphalt Concrete Pavement" and Item 292, "Asphalt Stabilized Base" were substantially revised and reissued in 1992. The new specifications allow use of RAP on any project as long as the produced mixture meets the requirement of the specification item.

FIELD STUDY

The objective of the field study was to (1) identify and evaluate existing Departmental uses of RAP, (2) to evaluate new uses of RAP, and (3) to collect video footage of these uses for the production of implementation videos.

Fourteen projects were evaluated in the study: two projects were construction projects and the remainder were maintenance projects. Table 4 provides a summary describing the different field projects evaluated in this study. A discussion of these individual projects follows.

USE OF RAP AS A MAINTENANCE MIX

RAP has been used as is (without improvement) by maintenance personnel in the Department for several years as a temporary maintenance treatment where minimal traffic is expected such as on driveways, mailbox turnouts, and pavement edge repairs. However, with minimal processing, RAP can be greatly improved in terms of performance, life, workability and appearance. When properly blended with recycling emulsions, it can be stockpiled and used as any other maintenance mix with some limitations. The RAP maintenance mixes produced in the field projects mentioned above were sampled and tested by TTI to determine some simple methods for improving the RAP for routine maintenance. These laboratory results are discussed later in this report.

COLD MIXING PROCESS

Two processes for cold-mixing RAP with a recycling emulsion were evaluated in this study: (1) pugmill mixing, and (2) blade/pulver-mixing. These are described below.

Pugmill Mixing Process - Dallas District (McKinney)

The Dallas district routinely blends RAP with a recycling emulsion called AES-300RP using a pugmill. AES-300RP is a high-float, anionic, medium-setting recycling emulsion. TxDOT specifications used for AES-300RP are shown in Appendix B. In September of 1990, TTI observed a mixing operation in the Dallas district in McKinney, Texas. On this job, the contractor provided the emulsion and the pugmill, operated the pugmill, and provided guidance in determining the quantity of emulsion to be added to the RAP.

Table 4. Summary of Field Projects Evaluated in This Study.

Project Type	District	Materials Used	Cost of Finished Mixture	Project Description
Maintenance	Dallas	RAP treated with 2½ to 3½% AES-300RP (by weight of total mix)	$11.56/cy	<u>Mixing Process.</u> RAP was blended in a pugmill with AES-300RP by contractor.
Maintenance	San Antonio	RAP treated with 2% AES-300RP	$11.11/cy	<u>Mixing Process.</u> RAP was mixed using a blade and pulver-mixer with AES-300RP by maintenance personnel.
Maintenance	Childress	RAP with 2½% AES-300RP RAP with 3 to 3½% CRR-60 RAP with 3 to 3½% ARE-68 RAP with 3 to 3½% MS-1	$15.21/cy $24.27/cy $24.82/cy $17.10/cy	<u>Research Test Sections.</u> RAP was blended in a pugmill with four different emulsions. Thin overlays of the four different blends were placed in early fall of 1992 and spring of 1993.
Maintenance	Dallas	LRA / Treated RAP (50/50) LRA / Untreated RAP (60/40) LRA (Control) HMCL / Treated RAP (50/50) HMCL /Untreated RAP (60/40) HMCL (Control)	$22.00/cy $19.00/cy $30.00/cy $15.00/cy $10.60/cy $16.00/cy	<u>Research Test Sections.</u> Untreated RAP and RAP which had been previously blended in a pugmill with AES-300RP (treated RAP) were mixed with conventional maintenance mixes (limestone rock asphalt -LRA and hot mixed, cold laid ACP). Six test sections were placed end-to-end in March 1992 as thin overlays using the materials shown.

Table 4. Continued.

Project Type	District	Materials Used	Cost of Finished Mixture	Project Description
Maintenance	Ft. Worth	LRA / Treated RAP (50/50) LRA (Control) HMCL / Treated RAP (50/50) HMCL /Untreated RAP (70/30) HMCL (Control)	Not Available	<u>Research Test Sections.</u> Five overlay test sections were placed in April 1992 using the materials shown. The "treated" RAP for this project consists of RAP which was blade mixed with MS-1 by maintenance forces.
Maintenance	San Antonio	LRA / Untreated RAP (60/40) Treated RAP HMCL	Not Available	<u>Research Test Sections.</u> Three overlay test sections were placed in September 1992 using the materials shown. The "treated" RAP for this consists of RAP which was blade/pulver mixed with AES-300RP by maintenance forces.
Maintenance	Tyler	HMCL (Control) RAP treated with AES-300RP	\$13.00/cy	<u>Research Test Sections.</u> Two overlay test sections were placed in June 1992 using the materials shown.
Maintenance	Brownwood	RAP treated with AES-300RP	\$15.36/cy	<u>Routine Maintenance.</u> RAP which had been previously blended in a pugmill with AES-300RP was used as a maintenance mix in three routine maintenance applications in November of 1990: a level-up course, a county road turnout, and base repair.

Table 4. Continued.

Project Type	District	Materials Used	Cost of Finished Mixture	Project Description
Maintenance	Dallas	RAP treated with AES-300RP	$12.15	Routine Maintenance. RAP which had been previously blended in a pugmill with AES-300RP was used to repave a section of a shoulder on Interstate 35 in June of 1992.
Maintenance	Bryan	Untreated RAP	Not Available	Routine Maintenance - Base Repair. A base failure was repaired using untreated RAP by pulverizing and blending through the use of a pulver-mixer.
Maintenance	Yoakum	Cement stabilized RAP	$2.83/sy (total in-place cost)	Routine Maintenance - Base Repair. Asphalt pavement surface was pulverized and blended in place with existing base and stabilized with lime in July 1992.
Maintenance	Houston	Cement stabilized RAP	$18.66/cy (in-place cost)	Parking Lot Construction. Stockpiled RAP was blade-mixed with cement and water. This stabilized material was placed 8 inches thick as a base for a new parking lot at the district office in October 1992.

Table 4. Continued.

Project Type	**District**	**Materials Used**	**Cost of Finished Mixture**	**Project Description**
Construction	Dallas	Plant Recycled RAP	$23.00/ton in-place	<u>Recycled Hot Mix.</u> Surface of IH 35 was milled, and recycled with 10 percent new aggregate and a rejuvenator in a plant using the "Cyclean" process and replaced as a surface course.
Construction	Paris	Cement Stabilized RAP/Base	Not Available	<u>Base Reconstruction.</u> Asphalt concrete surface was pulverized, mixed in place with existing base material and stabilized with cement.

Mixing Operation. The district supplied two people at the mixing site: one to operate a front-end loader and another to serve as inspector for the operation. The pugmill was set up next to the RAP stockpile and the front-end loader was used to load the RAP material into the pugmill bin. The bin was equipped with a screen to scalp off any material larger than 1½-inches.

Emulsion was metered into the pugmill at 130°F, and the mixing time was 25 seconds. The blended material was deposited from the pugmill onto the ground. The front-end loader was then used to stockpile the final mixture nearby. This pugmill was capable of mixing about 700 cubic yards of material daily.

As recommended by the emulsion supplier, the final mix was allowed to cure in the stockpile for at least 30 days before use. This is required for the rejuvenator in the emulsion to soften the aged asphalt cement in the RAP.

Determination of Emulsion Quantity. Determination of the quantity of emulsion needed to transform RAP into a suitable maintenance mix is sometimes difficult. This is primarily due to the material variability in a typical RAP stockpile. On this job, the contractor reported that he sampled the RAP stockpile and extracted the asphalt cement from the samples. He then determined the quantity of emulsion needed to lower the penetration value of the asphalt cement to between 35 and 45.

District personnel reported that, generally, adjustments needed to be made throughout the mixing process based on visual evaluations of the mix. The quantity of emulsion added to the RAP varied between 2½ and 3½ percent by weight of the total mix. This quantity was "agreed upon" by the contractor and inspector based only on visual inspection of the blended material. According to experienced district personnel, the mixture should have just enough emulsion so that the mix bonds together in a cohesive mass when squeezed by hand for two seconds and released.

Project Outcome. This RAP was mixed at a cost of $11.56 per cubic yard. This included the cost of mixing the stockpiled RAP and restockpiling at the same location. It did not include the cost of transporting the raw RAP to the stockpile location.

The mix produced in this operation was considered by district personnel to be of good quality and was used successfully in routine maintenance operations.

Comments of District Personnel. Several important observations were noted by district personnel experienced with RAP, treated RAP and this mixing process:

* "It is important to keep material handling to a minimum in order to keep

the cost of the treated RAP significantly below that of conventional maintenance mixes like hot-mixed, cold-laid (HMCL) asphalt concrete pavement. Once RAP millings are stockpiled, the pugmill should be brought to the stockpile location, material should then be processed and restockpiled in the same location and remain there until ready for use. It is quite feasible to contract a job such that the pugmill is transported to different RAP stockpiles throughout the district."

* "In order for the pugmill mixing operation to be cost-effective and lucrative enough for a contractor to bid a job, you should have at least 5000 cubic yards of RAP material to process."
* "It is very important to allow the treated RAP to cure in the stockpile at least 30 days."
* "The emulsion manufacturer should be consulted to determine stockpile life of treated RAP. We have found that RAP treated with AES-300RP should be used within six months to one year after mixing. If not used within this time, material can set-up and stockpile will be immovable. Optimum time to use material seems to be three to four months after mixing."
* "Untreated RAP should be used or processed within one year of stockpiling to prevent RAP stockpile from setting up."
* "We have experimented mixing RAP with other emulsions (such as MS-1) but do not get the performance and stockpile life that we get with the AES-300RP."
* "Because of the type of emulsion used in the treated RAP, it can be used quite effectively as a cold-weather maintenance mix."
* "We have used untreated RAP for several years to pave driveways, mailbox turnouts and repair shoulder edges. However, the treated RAP used in these same applications will last about twice as long."

Blade/Pulver-Mixing Process - San Antonio District (Floresville)

In June of 1991, the San Antonio district's maintenance forces blended RAP with AES-300RP. Equipment used on this job included the following:

* One Motor Grader,
* Two Dump Trucks,
* One Front-End Loader,
* One Pulver-Mixer, and
* One Distributor.

Mixing Process. The maintenance forces from the Floresville Maintenance Office mixed AES-300RP with 600 cubic yards of RAP in a right-of-way area location. The RAP material was windrowed and emulsion was sprayed with a distributor onto the RAP. Mixing was accomplished with the pulver-mixer and a motor grader.

It would seem, that with this method, it would be more difficult to get a uniform mix than with the pugmill; however, based on appearance, the mixture was quite uniform. Using this method of mixing, the maintenance supervisor reported that 150 cubic yards of RAP could be mixed in one day.

Determination of Emulsion Quantity. The maintenance personnel interviewed at the jobsite reported that when mixing RAP with AES-300RP, they typically add two percent emulsion by weight of total mix. They have also mixed RAP with MS-1 but must use four percent MS-1 by weight of mix to get a satisfactory mix.

Project Outcome. The maintenance mix produced from this RAP was used to overlay a portion of FM 539. It is performing well at this time. The cost of treating the stockpiled RAP as described here was $11.11 per cubic yard. This includes the cost of labor, equipment, and materials.

RESEARCH TEST SECTIONS

Test sections were placed in five locations across the state. These test sections were placed as thin overlays on the main travel lanes. The research committee for this research study advised against the use of RAP as a surface material on the main travel lanes except for research purposes.

Laboratory tests were performed on the different materials placed in these test sections, and these results are presented later. These test sections will be monitored and their performance documented for the next two years.

Childress District

Using the pugmill-blending process, RAP was mixed with four different emulsions in August of 1992: AES-300RP, CRR-60, ARE-68, and MS-1. TxDOT specifications for AES-300RP and manufacturer's specifications for CRR-60 and ARE-68 are included in Appendix B. Specifications for MS-1 are in the 1982 TxDOT Standard Specifications, Item 300 (6). As described previously, AES-300RP is a high-float, anionic recycling emulsion for use with RAP which is to be stockpiled. CRR-60 is a cationic recycling emulsion which can be mixed with RAP and stockpiled for long-term use (6 to 12 months). ARE-68 is also a cationic recycling emulsion that can be blended with RAP, but for short-term use. It provides a stockpile life of approximately 90 days.

A total of 6500 cubic yards of RAP were recycled in this project. The average cost of recycling this entire quantity of RAP was $18.57 per cubic yard. Approximate quantities and costs for the different recycled materials used on this job are listed below.

Type Emulsion Used	Quantity of Emulsion, % by wt. of RAP	Quantity of RAP Recycled	Cost (per yd^3) of Recycled Material
AES-300RP	2½%	2935 yd^3	$15.21
CRR-60	3 - 3½%	1115 yd^3	$24.27
ARE-68	3 - 3½%	1115 yd^3	$24.82
MS-1	3 - 3½%	1335 yd^3	$17.10

The manufacturer of the ARE-68 recommended that the blended material be used within two to 90 days after mixing; therefore, this material was placed soon after mixing. The RAP treated with ARE-68 was placed in the northbound lanes of US 287 between Estelline and Memphis in Hall County. It was placed in one lift approximately two inches thick, and district personnel report that it is exhibiting some slight rutting. This rutting is attributed to inadequate density achieved in the compacted mixture. The other three materials were placed in the spring of 1993.

Comments of District Personnel. One of the problems in the mixing process noted by district personnel was in controlling the quantity of emulsion mixed with the RAP. The target quantity was estimated based on the amount of emulsion being metered into the pugmill (gallons per minute) and by knowing the amount of time needed to fill up a truck with the recycled material. District personnel report that, in the future, a belt scale at the plant will be specified. This will provide more accurate control of the emulsion quantity.

Maintenance forces reported that the AES-300RP blend appeared to provide the best maintenance mix. Only 2½ percent AES-300RP was needed to achieve the desired mix, while 3 to 3½ percent of the other three materials was required.

Dallas District (McKinney)

Beginning on March 26, 1992, the Dallas district participated in an experiment to evaluate the performance of RAP and treated RAP blended with other commonly used maintenance mixes. The following materials were used in this experiment:

* RAP (untreated),
* Treated RAP (RAP which had been blended in a pugmill with AES-300RP three months prior to this experiment),
* HMCL (hot-mixed, cold-laid asphalt concrete pavement - TxDOT Specifications for Item 350, Type D),
* LRA (Limestone rock asphalt - TxDOT Specifications for Item 330, Type C).

Six overlay test sections were constructed using these materials and combinations of these materials on FM 1461 in Collin County near McKinney, Texas. These six test sections were constructed end-to-end across both lanes of FM 1461. Each test section was 700 feet in length and about one to 1½-inches thick. The test sections were constructed as follows:

1. HMCL,
2. HMCL blended with untreated RAP (started with a 45/55 blend of RAP and HMCL, increased it to 55 percent HMCL and 45 percent RAP and finally to 70 percent HMCL and 30 percent RAP),
3. HMCL blended with treated RAP (50/50 blend),
4. LRA blended with untreated RAP (60 percent LRA and 40 percent RAP),
5. LRA blended with treated RAP (50/50 blend), and
6. LRA.

Construction of Test Sections. Prior to construction of the test sections, the surface of FM 1461 was observed to be a seal coat which was moderately ravelled. There was also slight to moderate rutting on the existing pavement. Air temperature during construction ranged from 50 to 65°F.

The HMCL used for the construction of these test sections was freshly mixed and hauled directly from the plant to the jobsite where it was placed while still warm. The temperature of the mix at the time of placement was approximately 170°F. This provided for a better-than-average maintenance mix and may not be a fair comparison to a hot mix-cold laid mixture which has been stockpiled for several months and placed at ambient temperature. A tack coat consisting of about 0.1 gallons per square yard of RC-250 was sprayed prior to the placement of each test section. The first material blend applied was HMCL mixed with untreated RAP. Trucks dumped HMCL onto the westbound lane of FM 1461 for a length of 400 feet. Untreated RAP was then dumped on top of the HMCL. The two materials were then blade-mixed in the westbound lane while traffic was diverted into the eastbound lane. This blend was about 45 percent HMCL and 55 percent RAP.

District personnel thought the blend looked too dry and the surface appeared too rough. Therefore the remainder of the test section in the westbound lane (300 feet) was constructed with about 55 percent HMCL and 45 percent RAP. Maintenance personnel were still not pleased with the appearance of this blend and constructed the eastbound lane of the test section with 70 percent HMCL and 30 percent RAP.

The finished surface of all three HMCL/RAP blends was somewhat rough due to large clumps of material present in the RAP. While most of these larger clumps can be removed by the motor grader operator, it is impossible to remove all of them.

Project Outcome. A moderate amount of ravelling occurred in the westbound lane during the first 24 hours it was under traffic. Maintenance personnel believed this entire westbound section overlay would come off the road; however, no additional ravelling occurred in 17 months of service.

The remaining test sections of material blends are performing well after 18 months of service. All of the test sections which had RAP (both treated and untreated) have a more coarse surface texture and provide for a bit rougher ride than the HMCL and LRA control sections. However, no material loss appears to have occurred on any of these sections.

Blade-mixing two materials on the pavement proved very time consuming. Therefore, beginning with test section 4, preliminary blending was accomplished at the stockpile location using a front-end loader. The loader operator piled one material on top of another in the desired proportions. Mixing was accomplished by scooping material from the bottom of the pile to the top until a uniform blend was achieved. Final mixing was accomplished with a motor grader at the pavement site. This method provided a uniform blend of material and reduced the time of construction activity on the road.

Comments of District Personnel. District 18 has a significant amount of experience using treated RAP as a maintenance mix; however, they had not blended

RAP with conventional mixes before this experiment. Based on this field experiment, district personnel reported that they were most pleased with the HMCL/treated RAP blend. They felt in terms of initial appearance and cost, this was the most attractive blend, and they intend to use it more.

Fort Worth District (Cleburne)

On April 29, 1992, the Fort Worth District began construction of five research test sections to evaluate RAP. The following materials were used in the experiment:

* RAP (untreated),
* Treated RAP (RAP blended with one percent MS-1),
* HMCL (Hot-mixed, cold-laid ACP - TxDOT Specifications for Item 350, Type FF),
* LRA (Limestone rock asphalt - TxDOT Specifications for Item 330, Type CC).

Five overlay test sections were constructed using these materials on FM 1902 in Johnson County near Joshua, Texas. These test sections were constructed end-to-end across both lanes of FM 1902. Each test section was 500 feet in length and the material was placed about one inch thick. The test sections were constructed as follows:

1. HMCL,
2. HMCL blended with untreated RAP (70 percent HMCL and 30 percent RAP),
3. HMCL blended with treated RAP (50/50 blend),
4. LRA, and
5. LRA blended with treated RAP (50/50 blend).

Construction of Test Sections. Prior to construction of the test sections, the surface of FM 1902 was observed to be a plant mix seal which was badly ravelled in places and with some large patches. Air temperature during construction ranged from 60 to 85°F.

The treated RAP was blade mixed at the stockpile with one percent MS-1 the day it was placed on the pavement. Combinations of mixtures were blended at the stockpile using a front-end loader and then hauled to the jobsite for placement. The material was spread and placed using a motor grader and then compacted with a steel-wheel roller.

Project Outcome. All sections performed well within the first 24 hours except the HMCL/treated RAP section which began to ravel. The test sections are still performing adequately after 18 months of service.

San Antonio District (Pleasanton)

Beginning September 1, 1992 the San Antonio District constructed the following test sections:

* Treated RAP,
* LRA/RAP blend,
* HMCL.

Three overlay test sections were constructed using these materials on SH 97 near Pleasanton, Texas in Atascosa County.

The treated RAP was blended with AES-300RP using the same equipment and mixing process as used in the Floresville job as previously described. These test sections have been in service for twelve months and are performing well.

Tyler District

In June of 1992, the Tyler district contracted to have several stockpiles of RAP pugmill-blended with AES-300RP. These stockpiles were located throughout the district and the pugmill was transported to each location. Approximately two percent, by weight, AES-300RP was blended with the RAP at an average cost of $13.00 per cubic yard.

Test sections were constructed using this material in September of 1992. A 500-foot test section of the treated RAP was placed on FM 2011 in Rusk County. A 500-foot control test section was also placed here consisting of Item 350, Type DD HMCL asphalt-concrete pavement.

Project Outcome. After 14 months of service, the treated RAP section is exhibiting permanent deformation with rutting depths as great as one inch. The control section is performing well.

Brownwood District

In November of 1990, the Brownwood District blended RAP with AES-300RP using a pugmill. Approximately 8000 cubic yards of RAP was blended with three percent AES-300RP. The emulsion and pugmill were provided by the contractor and district personnel operated the pugmill. It should be noted that district personnel reported that, due to their lack of experience in operating the pugmill, they recommend that the contractor also should provide an operator for the pugmill on future projects such as this.

The cost of purchasing the AES-300RP, renting the pugmill, and mixing the RAP was $15.36 per cubic yard for the mixed RAP. New HMCL cost about $21 per cubic yard at the time of this project.

In July of 1991, TTI observed the construction of three routine maintenance operations using this treated RAP: the approach to a county road turnout, a level-up to correct a pavement dip, and a base repair. District personnel felt the treated RAP contained excessive asphalt binder; therefore, for the base repair, the treated RAP was blended with one-third untreated RAP prior to placement.

These test sections are reported as performing satisfactorily after 32 months of service.

Dallas District (Denton)

On June 16, 1992, maintenance forces used treated RAP to repave 500 feet of an interstate shoulder. This job was located in Denton, Texas on Interstate 35W between FM 2449 and FM 407. The main travel lanes of this interstate are continuously reinforced concrete pavement; however, the shoulders are of a "sandwich" design. The shoulders are constructed of six inches of hot mix, eight inches of flexible base, and surfaced with a chip seal.

Maintenance personnel had reported numerous failures on these shoulders which they attribute to moisture trapped in the flexible base layer. This particular section of shoulder exhibited cracking, ravelling and shoving at the time of repair.

Construction. The existing shoulder was removed down to the hot-mix layer. Eight inches of treated RAP was placed on the shoulder in one lift and compacted with a pneumatic roller.

The RAP material had been blended in a pugmill in January of 1992 with 2½ percent AES-300RP. The treated RAP appeared to contain excessive binder and exhibited tenderness under the weight of the roller.

Project Outcome. Even though the mixture appeared to have excessive binder, it was believed that it may perform suitably on the inside shoulder with little traffic. However, excessive rutting and shoving occurred in the mix and it was removed from the pavement.

Bryan District

State forces in the Bryan district used untreated RAP to repair a base failure on FM 980 at Riverside, Texas 10 miles east of Huntsville in May of 1992. The total length of the project was two miles. There are two limestone quarries serviced by FM 980 which likely contributed to this base failure.

The existing pavement appeared to be a series of chip seals over a thin base. The objective of the project was to scarify and pulverize the existing pavement structure and mix in some additional RAP to increase the bearing capacity and provide a more moisture resistant base material. The pavement section was then primed and surfaced with a chip seal.

The following equipment was used in the project:

* Pulver-mixer,
* (2) Motor graders,
* 8,000 to 10,000 pound pneumatic roller,
* Water truck, and
* Self-propelled broom.

Construction. The existing pavement was initially broken up using the rippers on the motor grader. The pulver-mixer worked the broken pavement for several passes to reduce the maximum particle size and to mix the existing base with the pulverized surface. Motor graders were then used to windrow the mix.

Untreated RAP was hauled to the job from a stockpile location and mixed into the existing material at the rate of one truckload of RAP per 100 feet (12 foot-lane). Water was added to the mix as needed to enhance compaction. Care was taken to insure the RAP material was uniformly distributed along the entire length of pavement.

Project Outcome. This base repair is performing well after one year of service.

Yoakum District

On July 6, 1992, maintenance personnel in the Yoakum District repaired a base failure on FM 609 in Fayette County. The cross section of pavement repaired was as follows:

3½ inches of Hot-Mix ACP
6 inches of crushed stone base
2½ inches of ACP

A pavement recycler was used to repair this base failure. This equipment is capable of pulverizing the asphalt concrete pavement and mixing the pulverized RAP with the existing base material. The recycler went down the full 12 inches to get both layers of hot-mix. Some new base material was also added so that a more gradual slope could be provided at the edge of the pavement for better side support. Lime was used to stabilize the pulverized mixture. A seal coat was constructed over the compacted base repair.

The cost for this repair is tabulated below.

Labor		
Fayette County Labor - 7 men x 4 hours @ 16.52 per hr	=	$462.56
District Labor - 1 man x 4 hours @ 16.71 per hr	=	$ 66.84
		$529.40
Equipment		
Recycling Equipment - 4 hours at $85.00 per hour	=	$340.00
Other Equipment -	=	$346.85
		$686.85
Material		
Lime - 155 sacks at $2.16 per sack	=	$334.80
Base Material - 30 cubic yards at $1.75 per cy	=	$ 52.50
		$387.30
TOTAL		**$1603.55**
Base Repair Area = 567.11 square yards		
TOTAL UNIT COST		**$2.83/sy**

The statewide average for fiscal year 1992 base repair is as follows:

Base Removal and Replacement	$5.23/sy (State Forces)
	$7.84/sy (Contract)
Base In-place Repair	$1.79/sy (State Forces)
	$5.68/sy (Contract)

The base repair is performing well after one year of service.

Houston District

On October 12, 1992, the Houston District used RAP to construct the base of a parking lot at the district office. The RAP material was stockpiled near the district office where it was blade mixed by maintenance personnel with Type II cement. Cement was added at the rate of 1½ sacks per cubic yard of RAP and approximately 10 to 12 gallons of water per cubic yard were added. About 80 cubic yards of material could be mixed at one time.

The cement stabilized RAP was then hauled to the parking lot jobsite where it was placed and compacted in three lifts for a total thickness of eight inches. It was then surfaced with Item 340, Type D, hot-mix asphalt concrete pavement.

The maintenance supervisor reported that if the base had not been constructed with the RAP, the material of choice would have been Item 292, asphalt-stabilized base. The cost of labor, equipment and materials for construction of the RAP base was $9,330 ($18.66 per cubic yard). The estimated cost of labor, equipment and materials to construct the parking lot base using Item 292 was $11,644 ($23.29 per cubic yard). The parking lot is performing well after one year of service.

LABORATORY INVESTIGATION OF RAP AND TREATED RAP

Based on the survey conducted throughout the state, the maintenance uses for RAP which were considered more successful by Department personnel generally involved blending the RAP with an asphalt emulsion, a recycling emulsion, or another maintenance mix. An asphalt emulsion which is commonly available in most maintenance yards is MS-1. It has been blended with RAP to improve the qualities of RAP. According to experienced Districts, the most successfully produced RAP cold mixes consist of a blend of the RAP with a recycling emulsion (AES-300RP) specifically designed for this purpose. Another successful method consists of blending the RAP 50/50 with Limestone Rock Asphalt (LRA) (6) which is a maintenance mix commonly used in the State.

Using this information, a laboratory investigation was conducted in the first year of this study with the following objectives in mind:

(1) Obtain samples of milled RAP from three locations in the state and determine properties.

(2) With selected RAP samples, perform cold mix designs using MS-1 and AES-300RP mixture additives.

(3) Evaluate the effects of MS-1 and AES-300RP on the three different RAP materials.

(4) Evaluate the effects of the three RAPs blended with LRA.

All laboratory work in this study focused on evaluating RAP and improving its quality as a maintenance mix.

Selection of RAP Samples

Samples of RAP were collected for this laboratory investigation from three districts: Brownwood, Dallas, and Houston.

The Brownwood RAP was observed to be composed of the following aggregate materials: local limestone aggregate, lightweight aggregate (from seal coats), and field sand. This RAP was collected from various locations and stockpiled in the Cisco area.

The Dallas RAP contained limestone and field sand aggregates. The RAP was recovered from SH 75 at McKinney and was originally paved as Item 340, Type D (6) hot mix asphalt concrete pavement. A small percentage of Portland cement concrete was also evident in the stockpile.

The Houston RAP consisted predominantly of a limestone aggregate of unknown origin and field sand. This material was collected from various locations and stockpiled under a bridge on I-10 near the district office.

Properties of RAP

Two dry sieve analyses were performed on representative samples of each of the three RAP materials. Asphalt was extracted from the RAP samples and washed sieve analyses were performed on the extracted aggregates. Average values for these results are shown in Figure 9 for each RAP. The gradation from the dry sieve analysis on each RAP is significantly coarser than the washed analysis of the extracted aggregate. As expected, this indicates that much of the aggregate in the milled RAP remained agglomerated together with asphalt.

The washed sieve analyses from the extracted aggregates reveals that degradation of the aggregate occurs in the milling process. The original gradation of the material prior to milling is indeterminate; however, these gradations are finer than Item 340, Type D (6) hot mix as shown in Figure 10. Type D has a nominal maximum size of 3/8 inch and is the most commonly used fine-graded hot mix ACP placed by TxDOT.

Extraction and recovery of the asphaltic material from the RAP was performed to evaluate the properties of the recovered asphalt. Properties of the recovered asphalt are shown in Table 5 below. These values represent the average of three samples.

Table 5. Properties of Asphalt Recovered from RAP.

RAP Sample	Asphalt Content of RAP, percent	Viscosity of Recovered Asphalt at 140°F, poise	Penetration of Recovered Asphalt at 77°F
Brownwood	6.1	85,000	4
Dallas	5.7	47,000	27
Houston	4.7	18,000	14

The stiffest paving grade asphalt cement typically used in Texas is an AC-20 which has a maximum viscosity of 2400 poises and a minimum penetration value of 55. After thin-film oven testing (which simulates the hardening of the asphalt that occurs in the mixing plant), an AC-20 must have a viscosity of no more than 6000 poises. It is, therefore, obvious from the results in Table 5 that significant age-hardening of the asphalt had occurred, particularly in the Brownwood RAP.

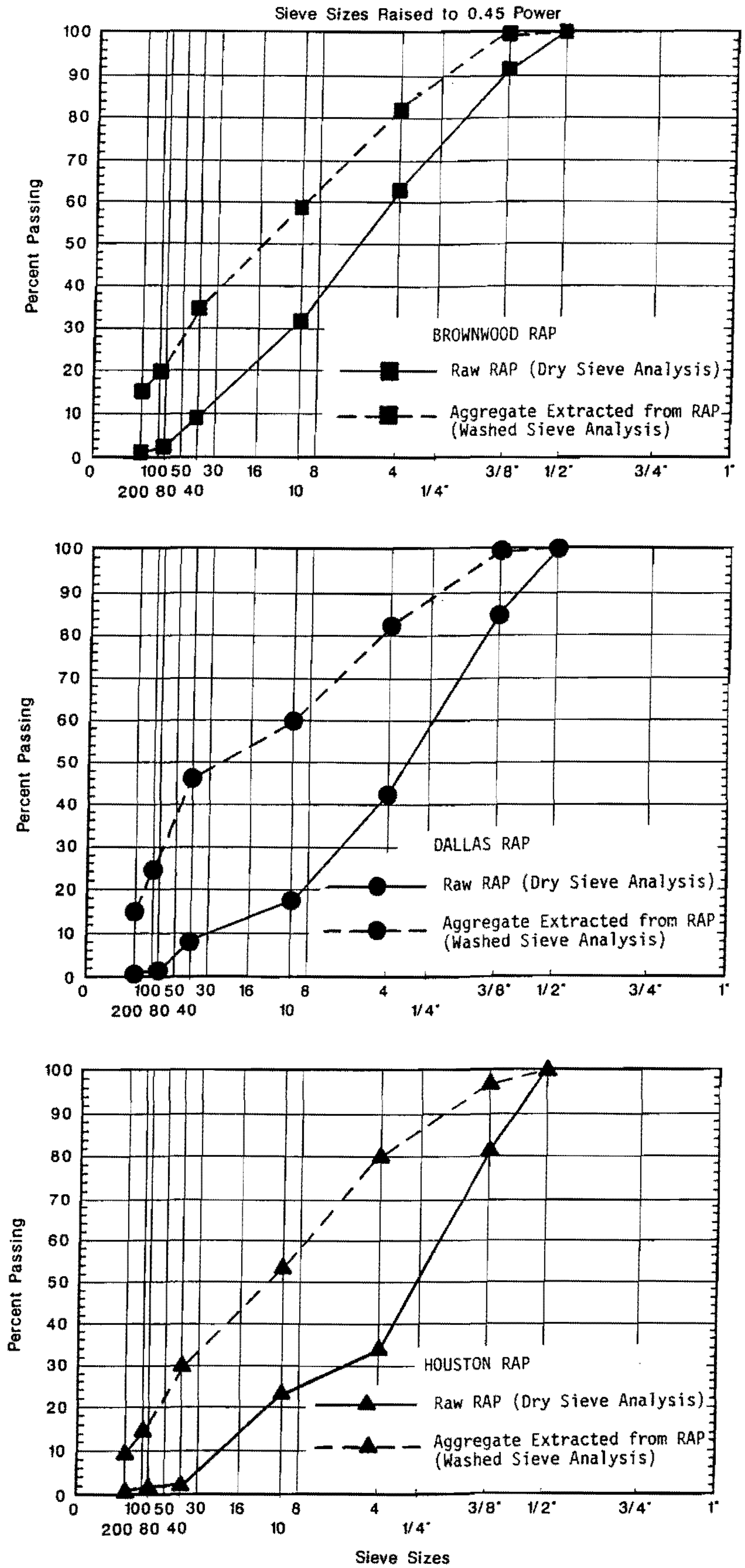

Figure 9. Sieve Analyses Results for Raw RAP Compared to Aggregate Extracted from RAP.

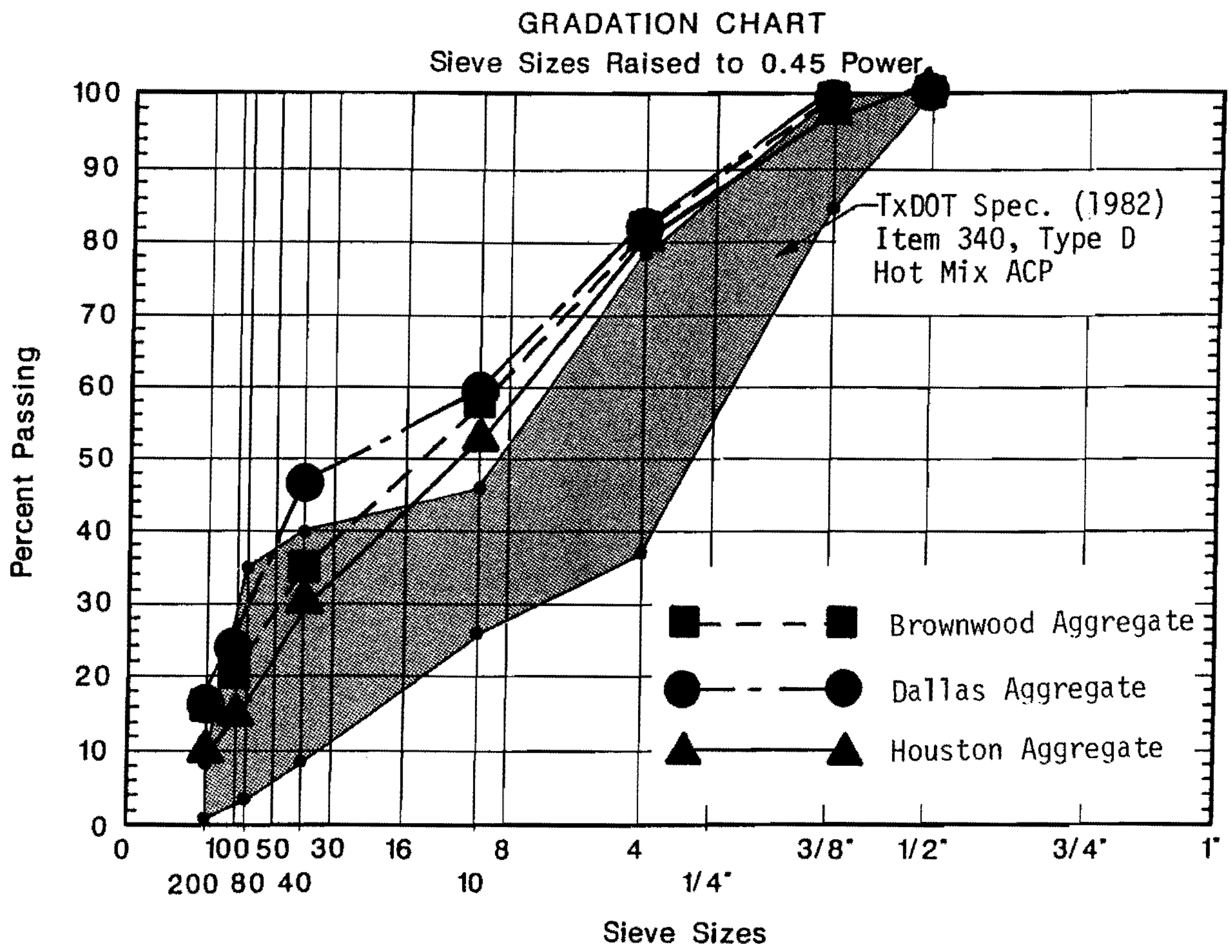

Figure 10. Sieve Analyses for Aggregates Extracted from Brownwood, Dallas and Houston RAPs.

Mixture Designs

The RAP materials were blended in the laboratory with different amounts of two types of emulsions: MS-1 and AES-300RP. A mixing method was adapted for these RAP cold mixes using the Basic Emulsion Manual from the Asphalt Institute Manual 19 and TxDOT cold mix procedures (11). The emulsion was heated to 140°F and added to the RAP material which was at room temperature. Additional moisture was added as needed to facilitate mixing and compaction

Samples were molded at room temperature to simulate field conditions and to produce air void contents similar to those obtained in the field. Three samples were molded at each of the following emulsion contents: 0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, and 3.5 percent by total weight of the mix. Samples were cured for two weeks at room temperature and then vacuum desiccated for three days. Tests which were performed on each of the samples after curing include the following:

- Hveem Stability,
- Resilient Modulus, and
- Indirect Tensile Strength.

Results of these tests are tabulated in Appendix C.

Hveem Stability. Hveem stability (Figures 11, 12, and 13) is largely dependent upon the interparticle friction of the aggregate and is also affected by asphalt content in the mix. The Hveem stability test is employed by TxDOT in standard mix design procedures. Stabilities for all three RAPs decreased with increasing levels of emulsion and the AES-300RP modified mixes generally had lower stabilities than the MS-1 mixes. These results indicate that conventional mix design procedures may not be applicable for designing cold mixes consisting of RAP only. It should also be noted that RAP is treated with an emulsion rejuvenator to improve its workability in the field, not to increase stability.

One must remember that RAP, which was originally placed as hot-mix ACP, was designed at optimum asphalt content. While the milling process causes a change in the aggregate gradation, the mix still may have sufficient asphalt to maintain its optimum stability. Any additional emulsion or binder may cause the stability to drop which is apparently what happened here. The AES-300RP generally produces a lower stability in the mix than the MS-1. This may indicate that more MS-1 than AES-300RP can be added to RAP. For example, in Figure 11, 1½ percent AES-300RP produces a mix with a stability of approximately 20; however, 3½ percent MS-1 can be added to the mix before the stability drops to 20. These data

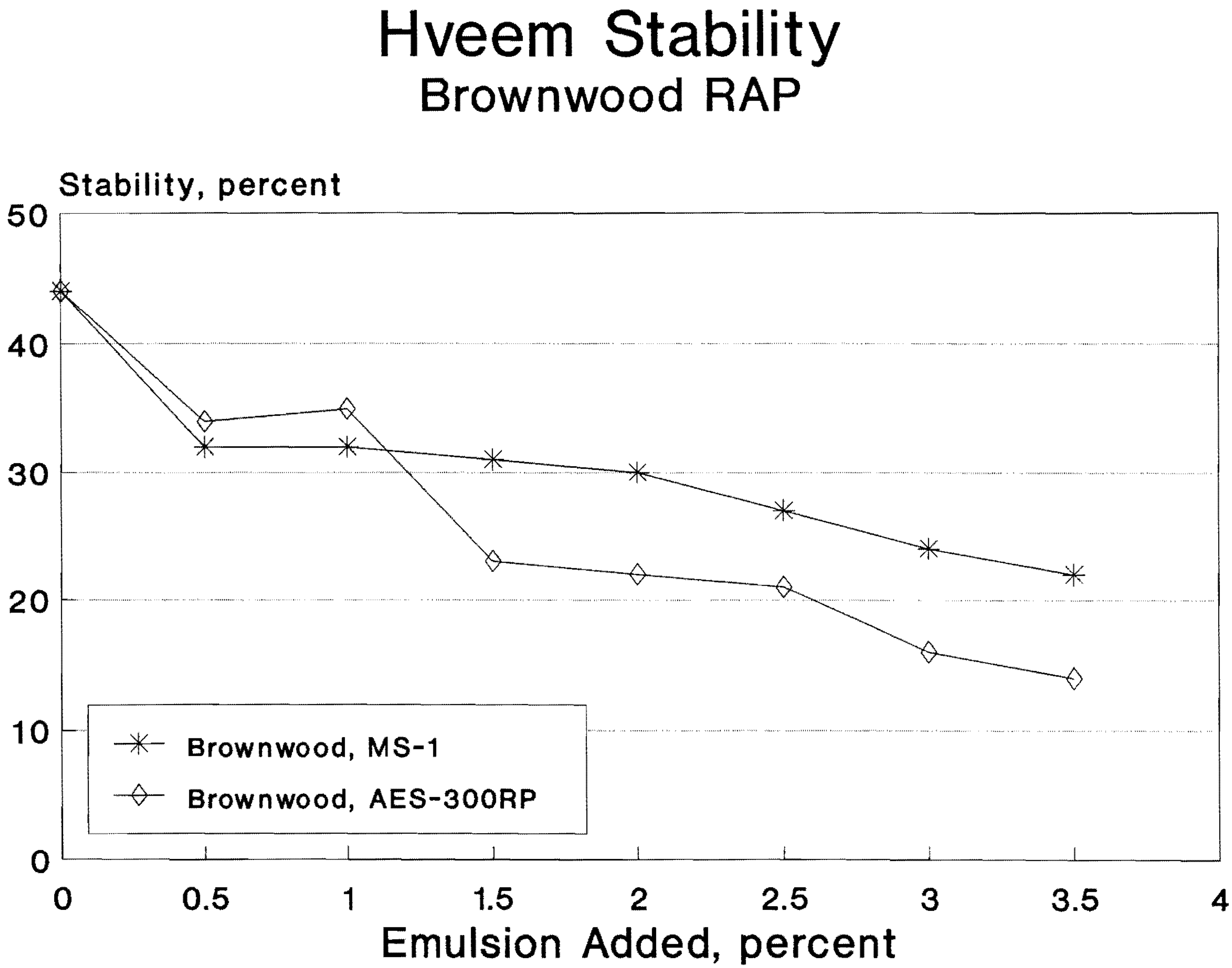

Figure 11. Hveem Stability Results for Brownwood RAP Blended with Increasing Levels of MS-1 and AES-300RP.

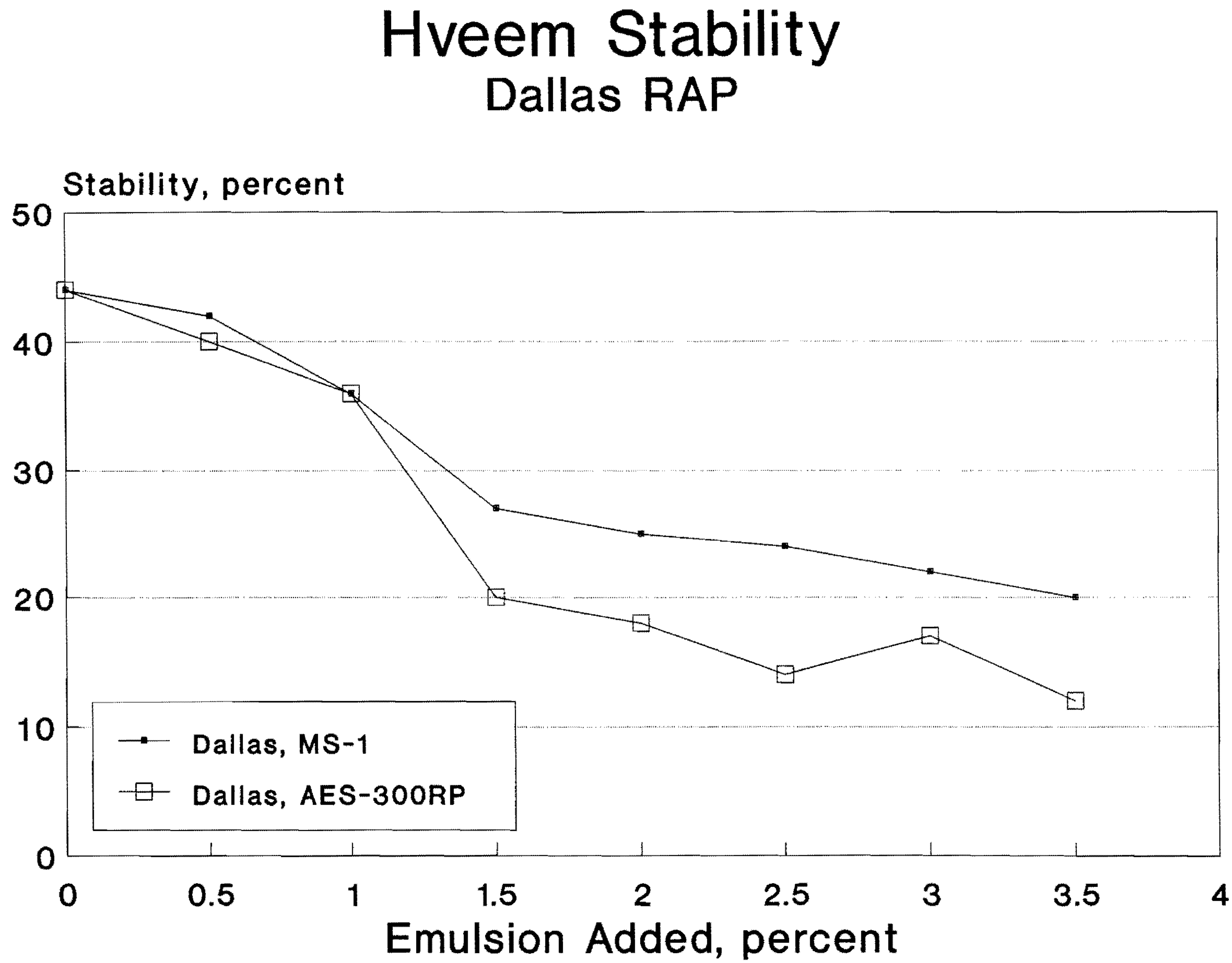

Figure 12. Hveem Stability Results for Dallas RAP Blended with Increasing Levels of MS-1 and AES-300RP.

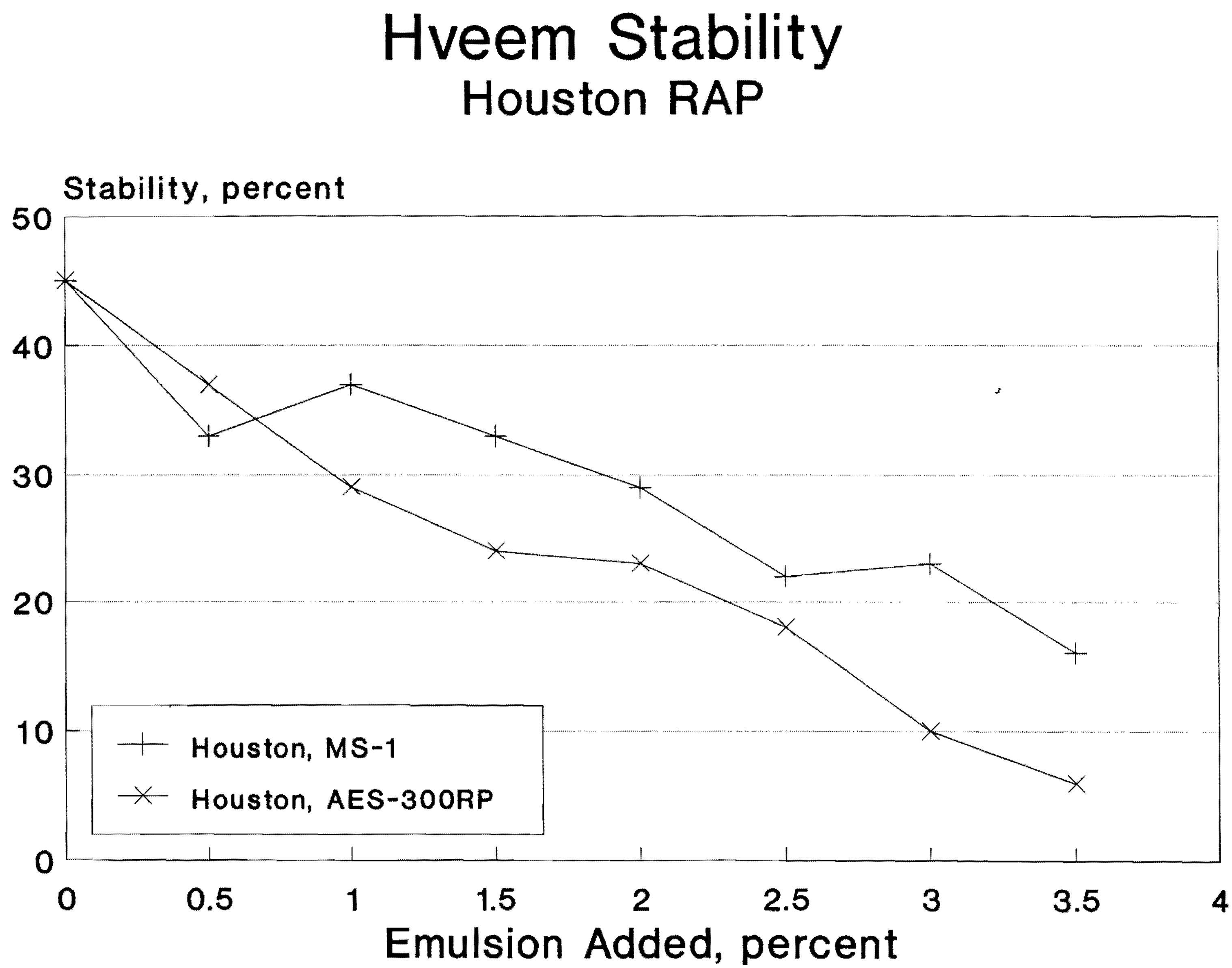

Figure 13. Hveem Stability Results for Houston RAP Blended with Increasing Levels of MS-1 and AES-300RP.

support information provided by field personnel. Some say, "To produce a maintenance mix from RAP using MS-1, you need twice the amount of MS-1 compared to AES-300RP."

Resilient Modulus. Mixture stiffness was measured in accordance with ASTM D 4123-82 using the Mark III Resilient Modulus device. (See Figures 14, 15, and 16) Typically, a diametral load is applied for a duration of 0.1 seconds while monitoring the diametral deformation perpendicular to the loaded plane. These tests were performed at 77°F. As with the Hveem stability data, the resilient moduli decreased with increasing levels of emulsion except in the MS-1 modified Houston RAP. The reason for the initial increase in moduli with increasing levels of MS-1 (up to 1.5 percent emulsion) shown in Figure 16 cannot be explained. Typical resilient moduli values for hot-mix ACP range from 200,000 to 300,000 psi at 77°F.

Indirect Tension. The indirect tension test employs the indirect method of measuring mixture tensile properties. Two-inch high and four-inch diameter cylindrical specimens were loaded diametrally at a constant rate of deformation until complete failure occurred. The tests were performed at 77°F and at a deformation rate of two inches per minute. As shown in Figures 17, 18, and 19, tensile strength generally decreased with increasing levels of emulsion. All of the tensile strength values shown here are considered very low.

Extraction and Recovery of Binders. The binder was extracted from the samples molded using one percent emulsion and compared with the binder properties of the raw RAP. These results are shown in Figure 20 and 21. The MS-1 and AES-300RP both appear to have softening effects on the mixtures; however, the AES-300RP has a more significant effect as one would expect from a recycling emulsion. The data indicate that the AES-300RP has a more significant effect on some asphalts than on others. The AES-300RP more than tripled the penetration of the binder in the Dallas RAP - from 27 to 98. However, the Houston raw RAP which had a penetration comparable to the Dallas RAP of 14 exhibited little more than a two-fold increase in penetration to 34.

Laboratory Study of RAP Blended with LRA

Cold-mixed limestone rock asphalt (LRA) pavement consists of natural limestone rock asphalt mixed at ambient temperature with a prescribed flux oil and meets TxDOT specifications for Item 330 (6). Rock asphalt comes from an aggregate source in Texas where the limestone is naturally impregnated with

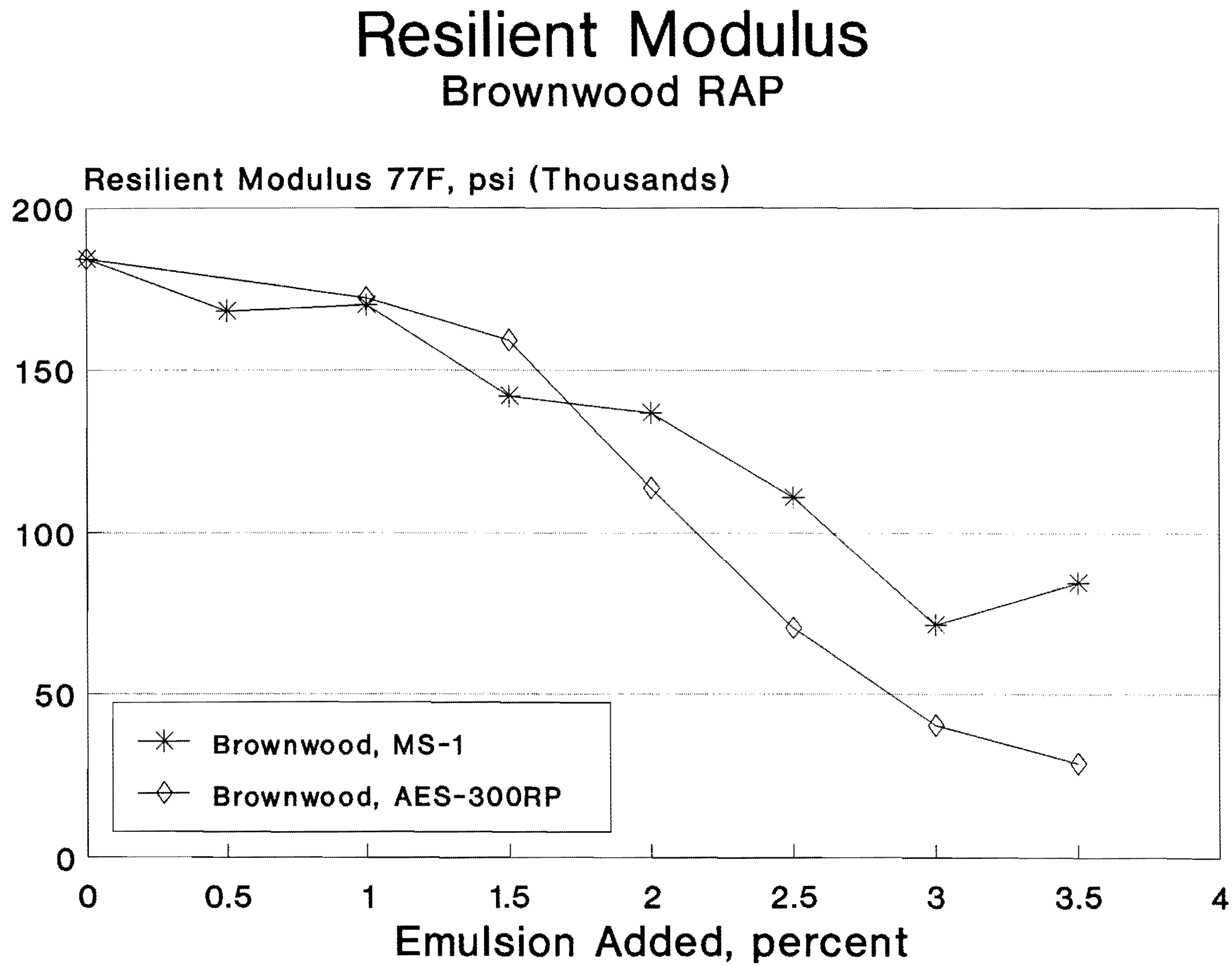

Figure 14. Resilient Modulus Results for Brownwood RAP Blended with Increasing Levels of MS-1 and AES-300RP Emulsions.

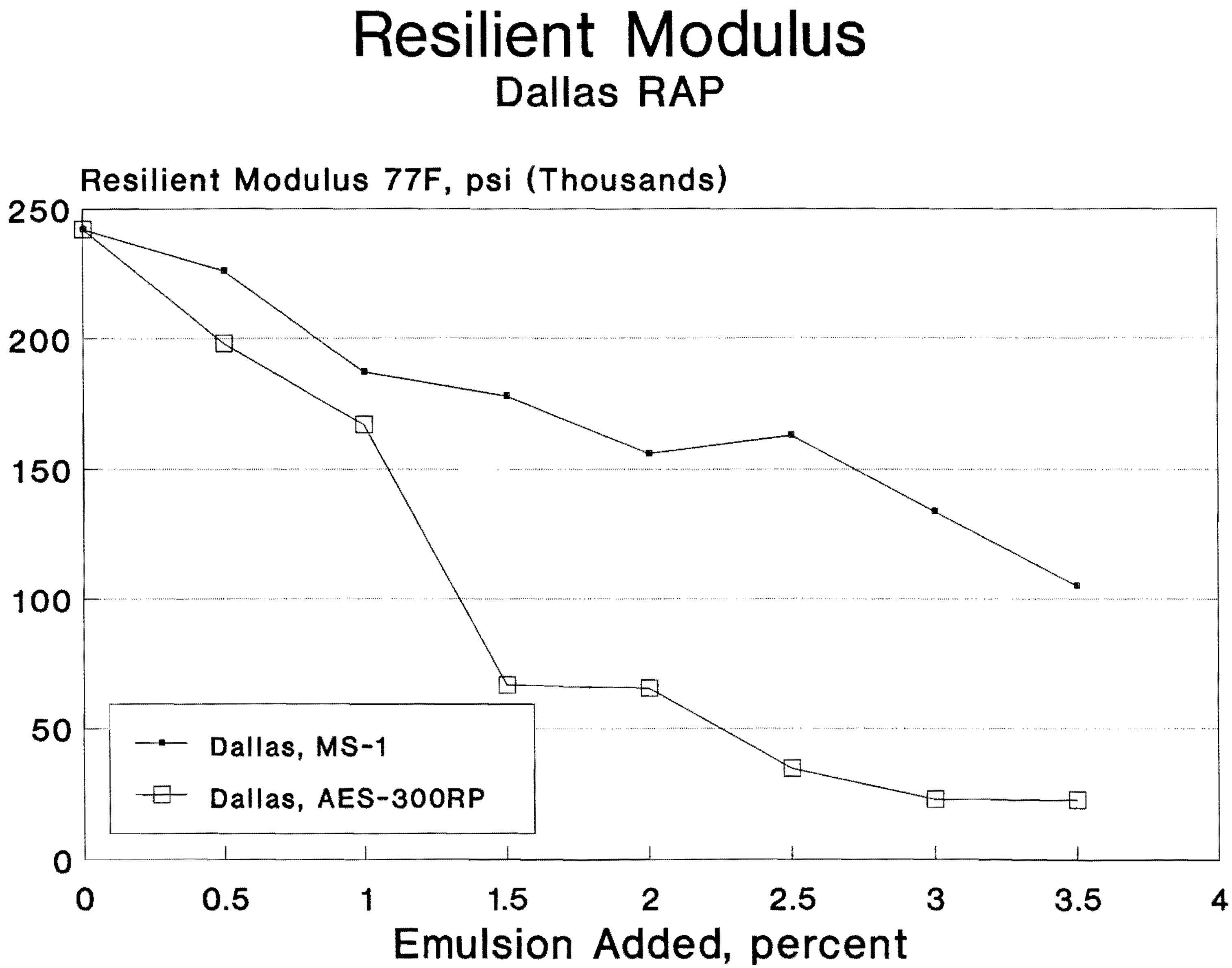

Figure 15. Resilient Modulus Results for Dallas RAP Blended with Increasing Levels of MS-1 and AES-300RP Emulsions.

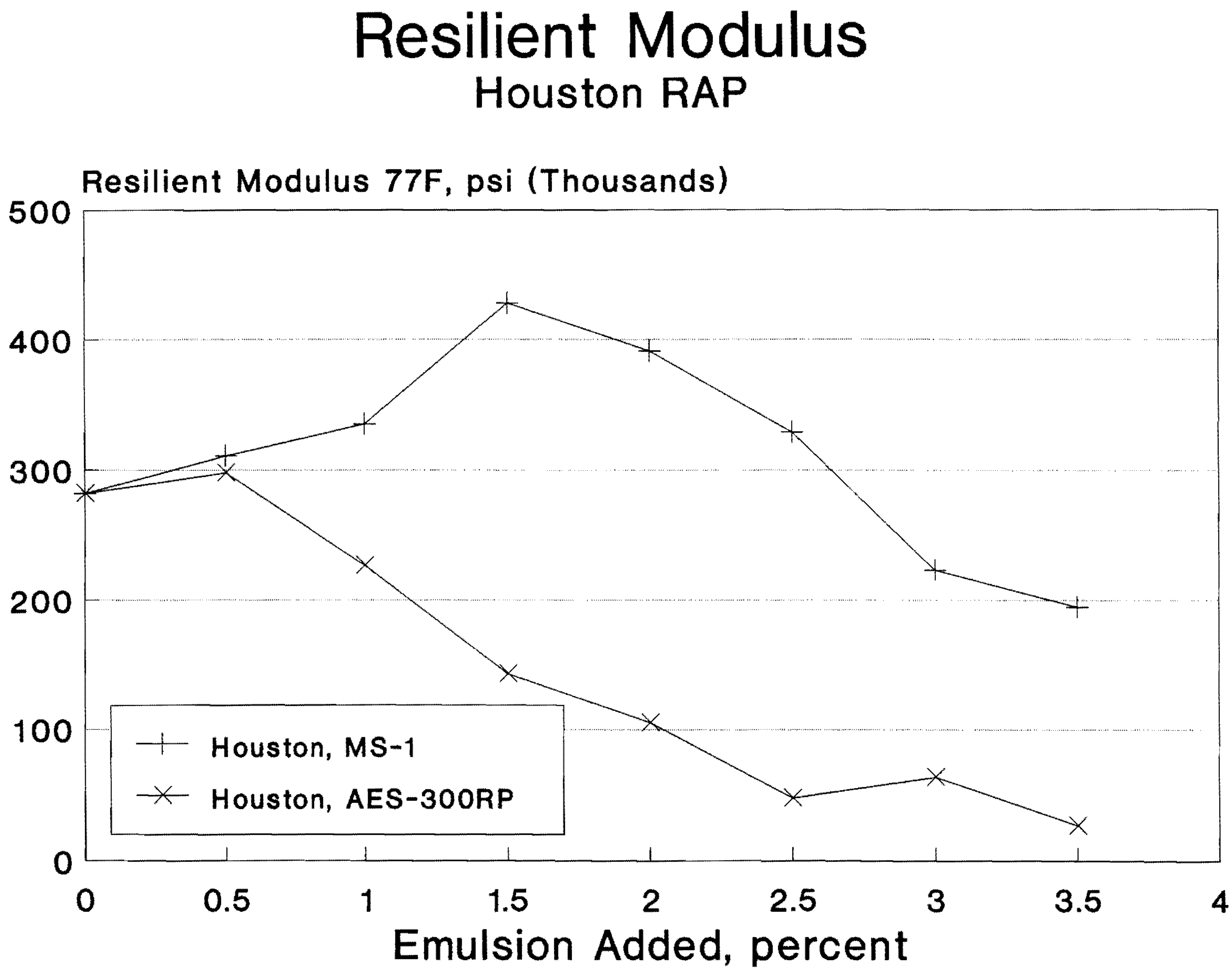

Figure 16. Resilient Modulus Results for Houston RAP Blended with Increasing Levels of MS-1 and AES-300RP Emulsions.

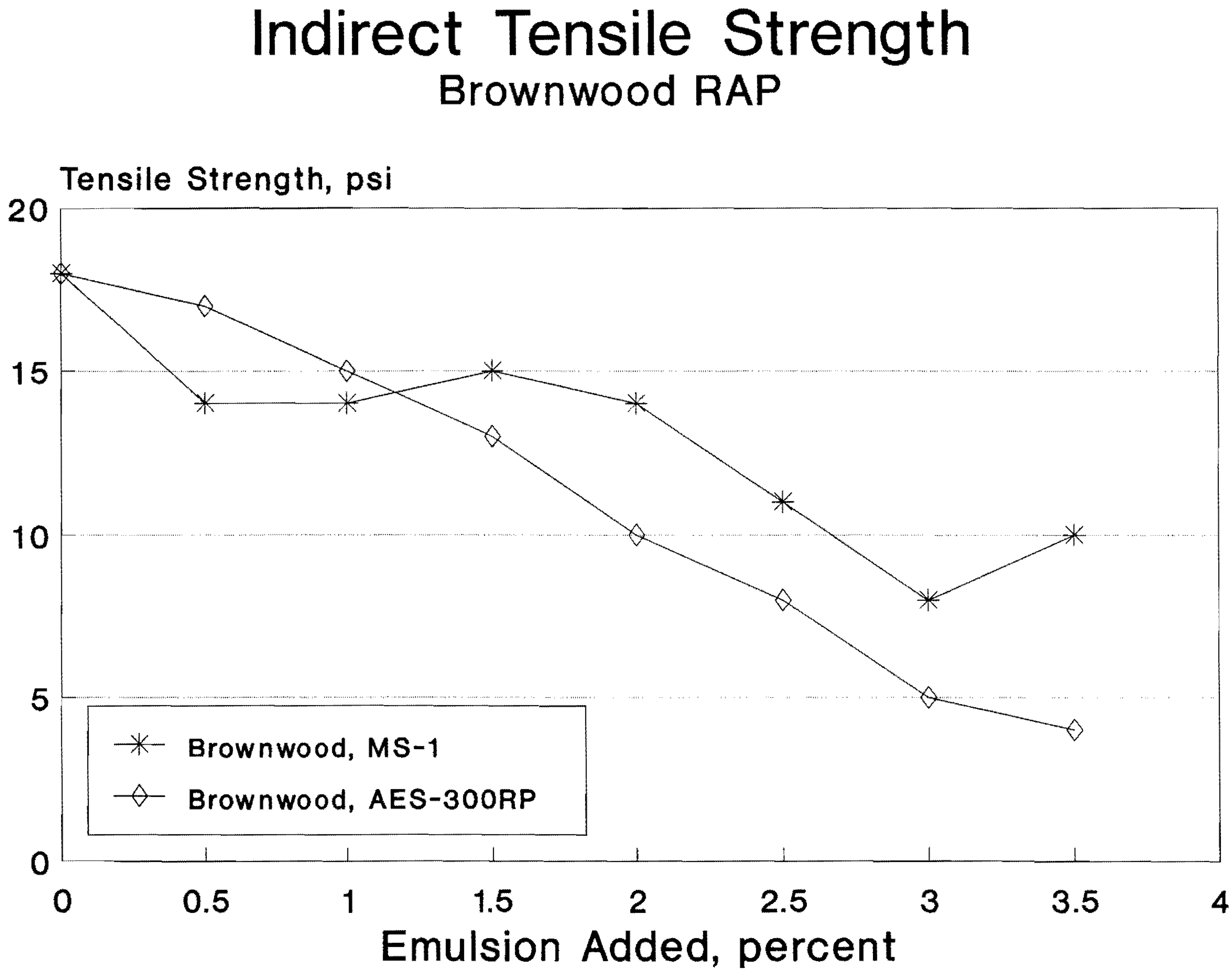

Figure 17. Tensile Strength of Brownwood RAP Blended with Increasing Levels of MS-1 and AES-300RP Emulsions.

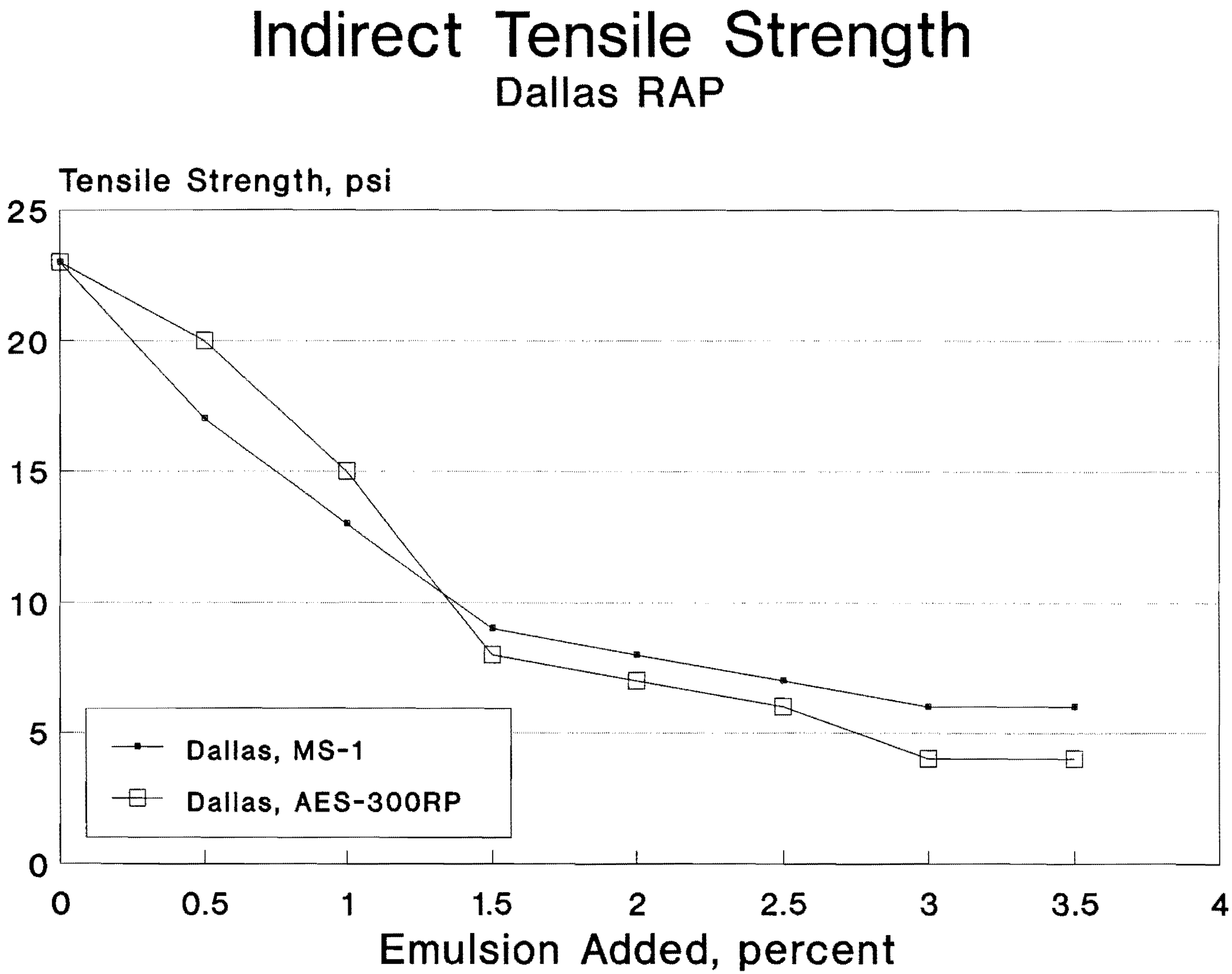

Figure 18. Tensile Strength of Dallas RAP Blended with Increasing Levels of MS-1 and AES-300RP Emulsions.

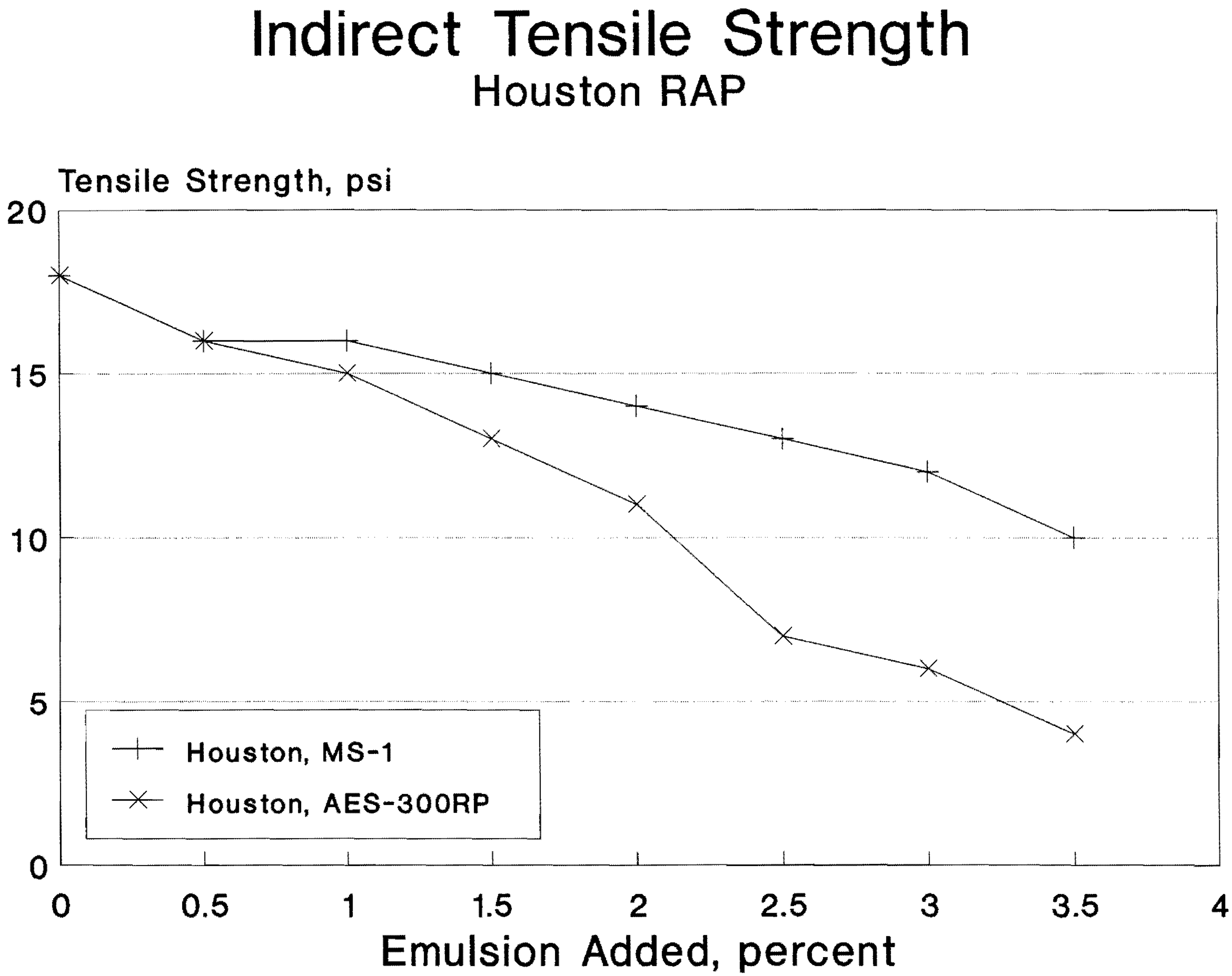

Figure 19. Tensile Strength of Houston RAP Blended with Increasing Levels of MS-1 and AES-300RP Emulsions.

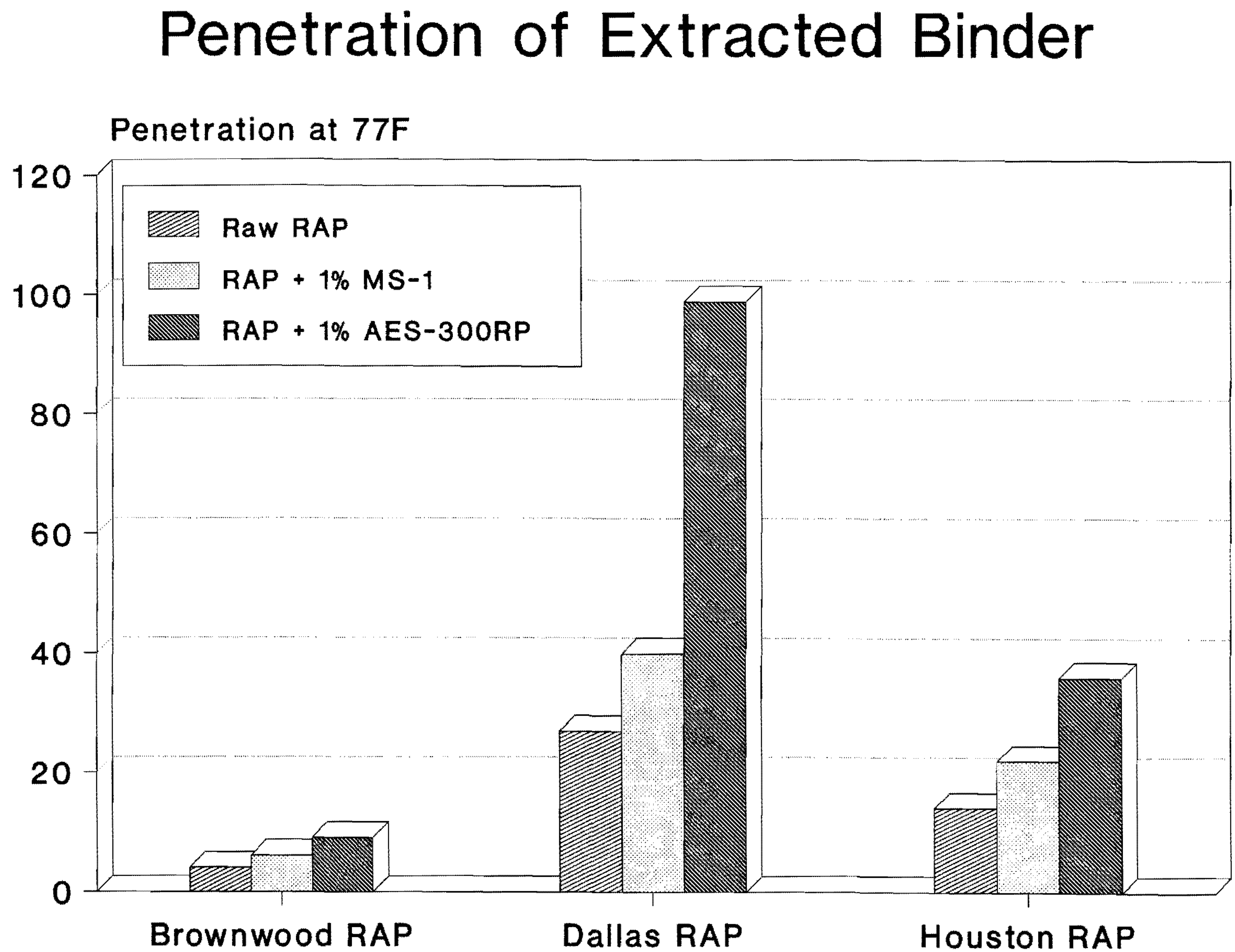

Figure 20. Penetration Values of Binders Extracted and Recovered from RAP and RAP Blended with MS-1 and AES-300RP.

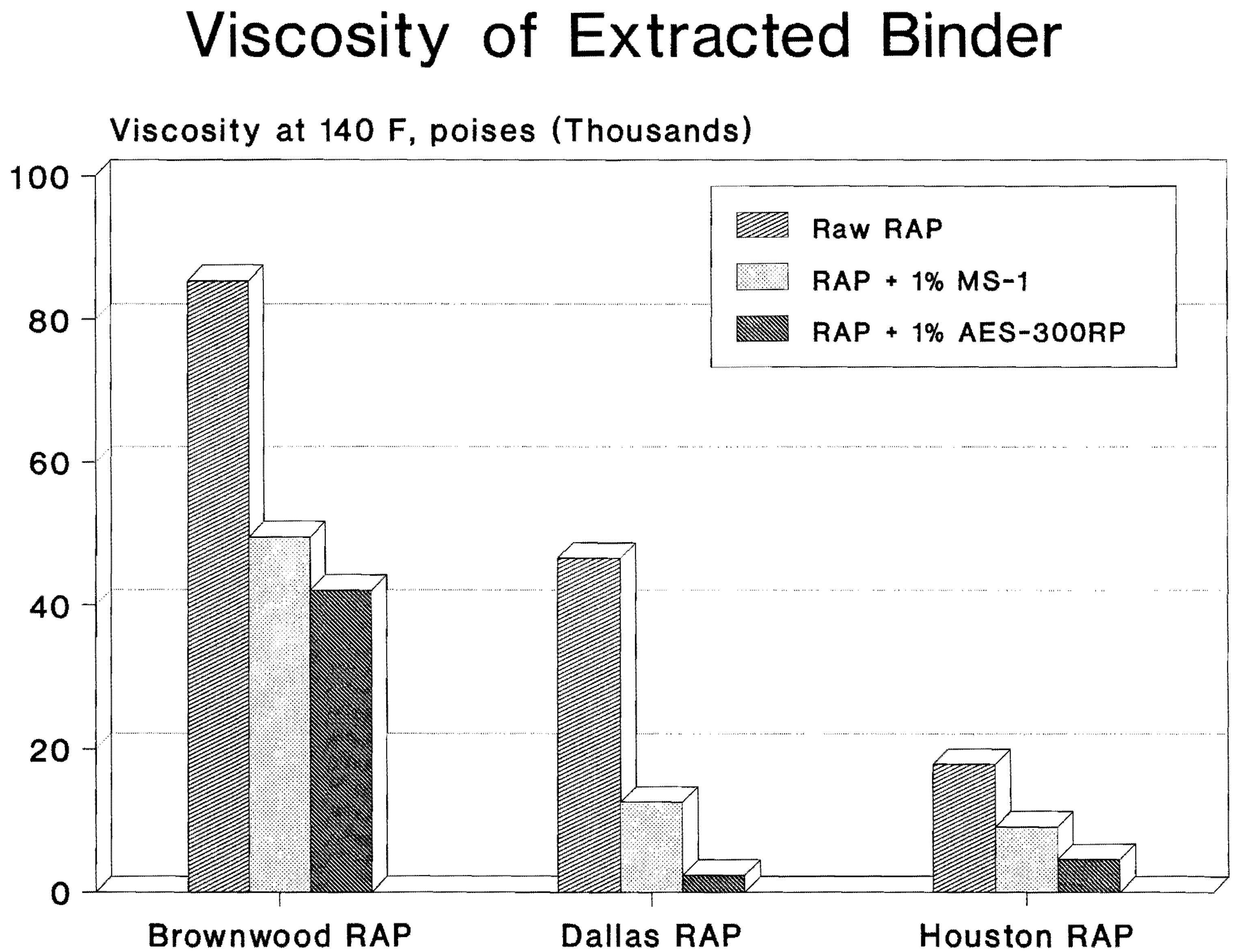

Figure 21. Viscosity Values of Binders Extracted and Recovered from RAP and RAP Blended with MS-1 and AES-300RP.

asphalt. The RAP materials used in the previous experiment were blended with LRA (Type C) in a 50/50 ratio (by weight). The samples were mixed and compacted at room temperature and no additional fluids were added. The samples were then cured in the same manner as in the previous experiment and subjected to Hveem stability, resilient modulus, and Marshall stability testing.

Results of the laboratory tests are shown in Figures 22 through 24. Hveem stability improved with the addition of Brownwood and Houston RAP to the LRA but remained the same with the Dallas RAP. The minimum required stability for LRA according to TxDOT specifications is 35. The stability value of 21 for the LRA does not meet specifications; however, the mixing and molding temperatures and curing procedures used in this experiment may have contributed to the lower stability. These results are similar to the results shown previously for the RAP materials blended with 1½ percent AES-300RP.

The LRA/RAP blends showed increases in resilient moduli and Marshall stability values over that of the LRA alone (Figures 23 and 24). The Marshall stability test is more sensitive to properties of the binder; whereas, Hveem stability is sensitive to aggregate properties.

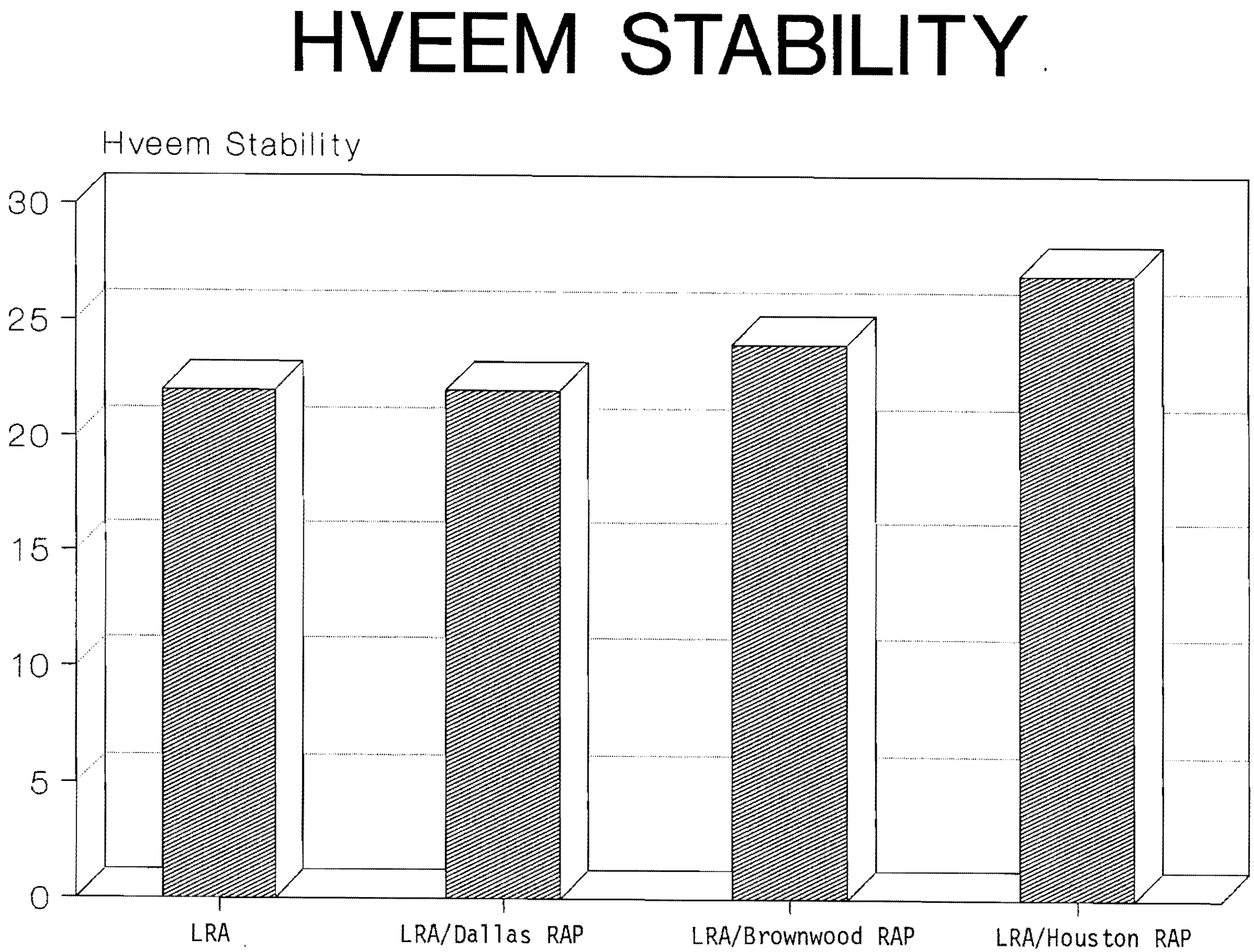

Figure 22. Hveem Stability Data for LRA and LRA Blended with RAP (50/50 Blend).

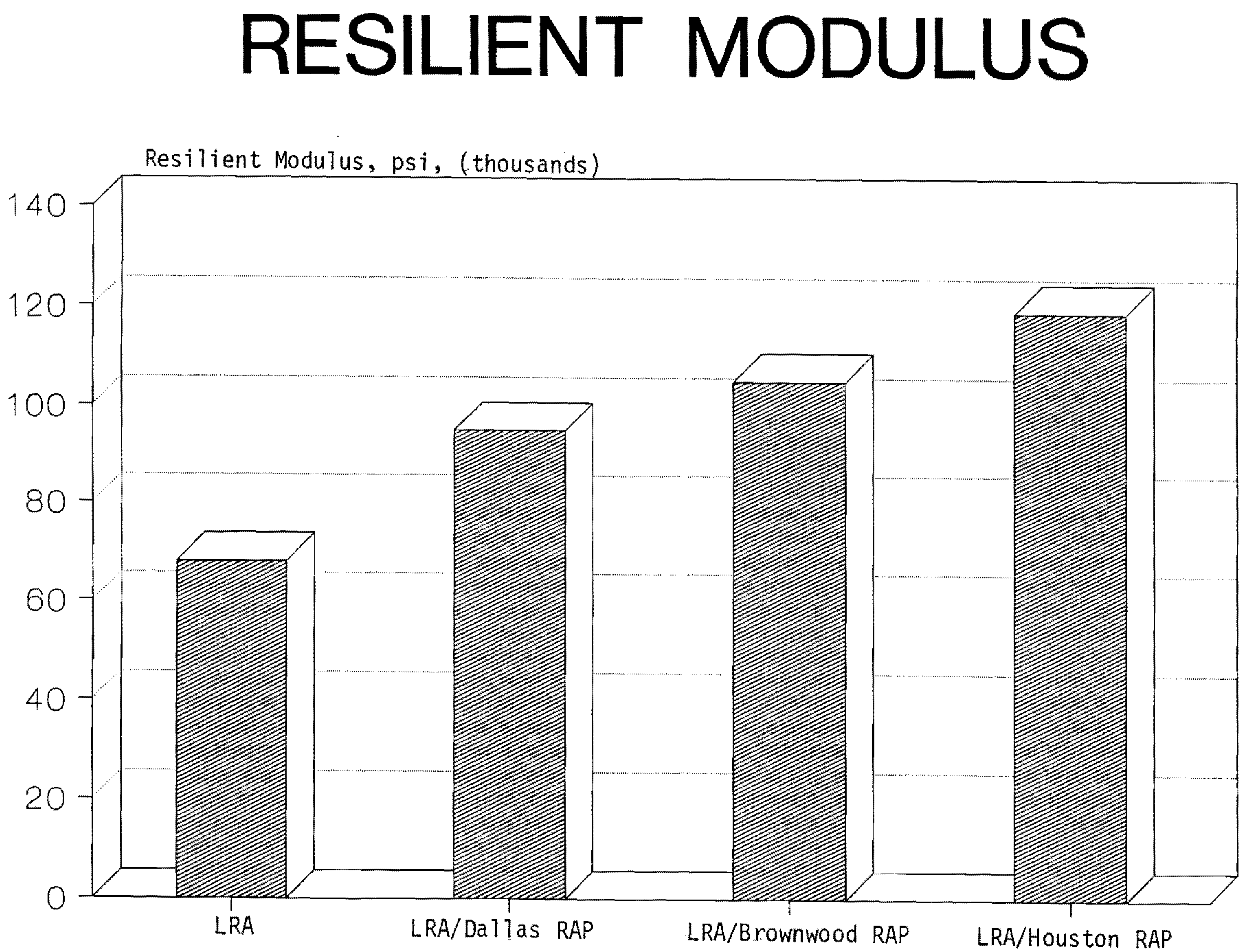

Figure 23. Resilient Modulus Data for LRA and LRA Blended with RAP (50/50 Blend).

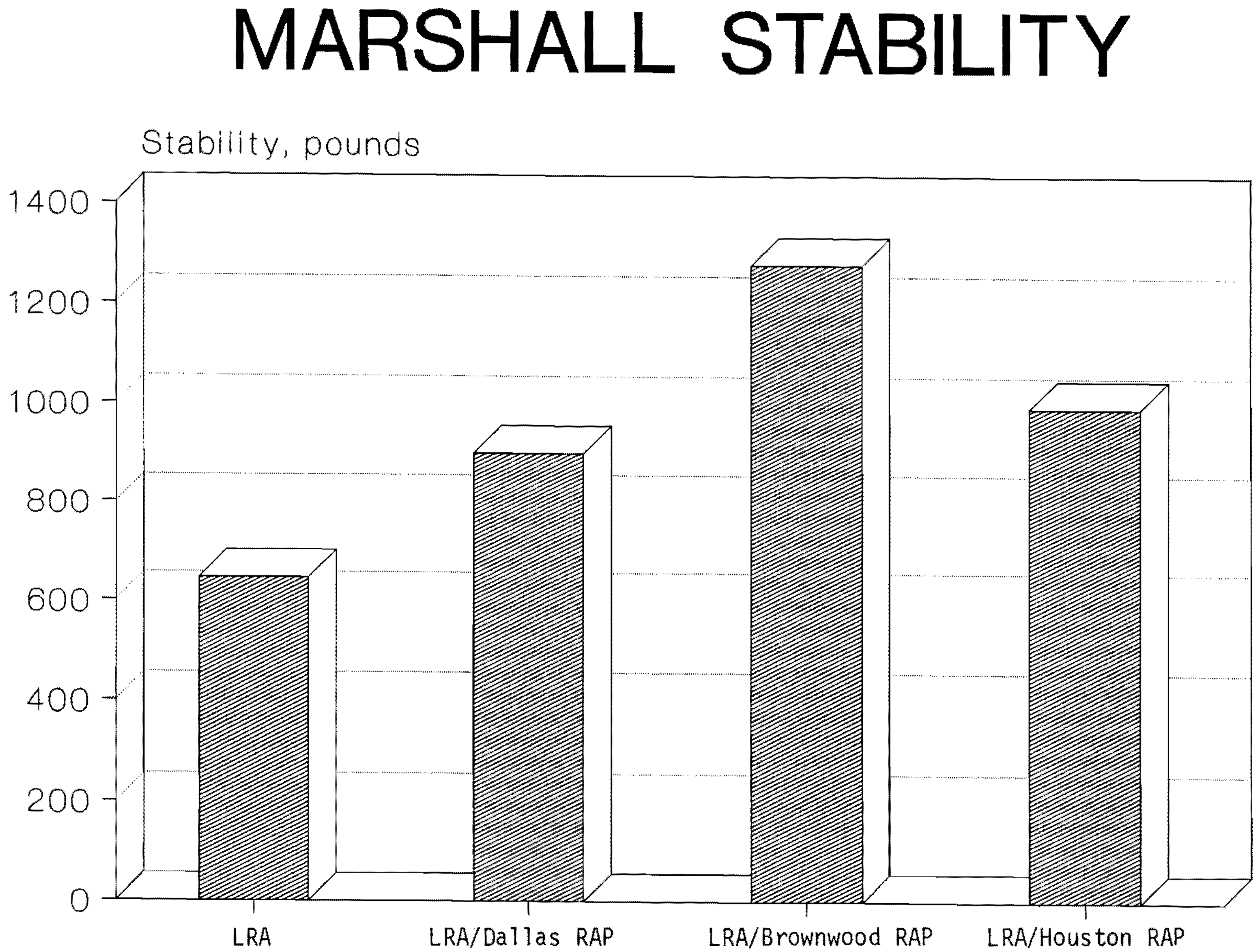

Figure 24. Marshall Stabilities for LRA and LRA Blended with RAP (50/50 Blend).

LABORATORY INVESTIGATION OF FIELD-PRODUCED RAP MAINTENANCE MIXES

Field maintenance projects were constructed throughout the state using RAP in maintenance mixes as described in the chapter entitled "Field Study". Material samples were obtained of the RAP maintenance mixes as well as control mixes which may have been used on these projects, such as hot-mixed, cold-laid (HMCL) ACP and limestone rock asphalt (LRA).

The objectives of this laboratory investigation were as follows:

(1) Characterize laboratory properties of treated RAP mixtures identified as performing successfully by Department personnel,

(2) Characterize laboratory properties of field tests sections built using treated RAP maintenance mixtures,

(3) Correlate laboratory properties to field performance.

Properties of RAP Field-Blended with AES-300RP

RAP was blended in the field with AES-300RP on seven different maintenance projects throughout the study. Blending was accomplished through a pugmill on five sites. The Floresville and Pleasanton materials were pulver/blade-mixed. Results of the laboratory mixture tests are tabulated in Appendix D and are presented graphically in Figures 25 through 29. Also shown in these figures are laboratory results from four conventional maintenance mixtures which contain no RAP (control samples). The RAP blends are compared with both hot-mixed, cold-laid (HMCL) asphalt concrete pavement and cold mix limestone rock asphalt (LRA) pavement. HMCL is the most commonly used maintenance mix by TxDOT and was, therefore, chosen as a control mix for RAP mixtures. LRA is also used quite routinely by the Department, mostly for winter use, and is also presented in this chapter as a control mix. The materials shown in Figures 25 through 29 are identified below.

HMCL 1	-	Item 350, Type D, Fine Graded Surface Course, sampled in Pleasanton
HMCL 2	-	Item 350, Type D, Fine Graded Surface Course, sampled in McKinney
HMCL 3	-	Item 350, Type FF, Fine Graded Surface Course, sampled in Cleburne
LRA 1	-	Item 330, Class A, Type D, sampled in McKinney
DEN	-	Denton RAP/AES-300RP Blend

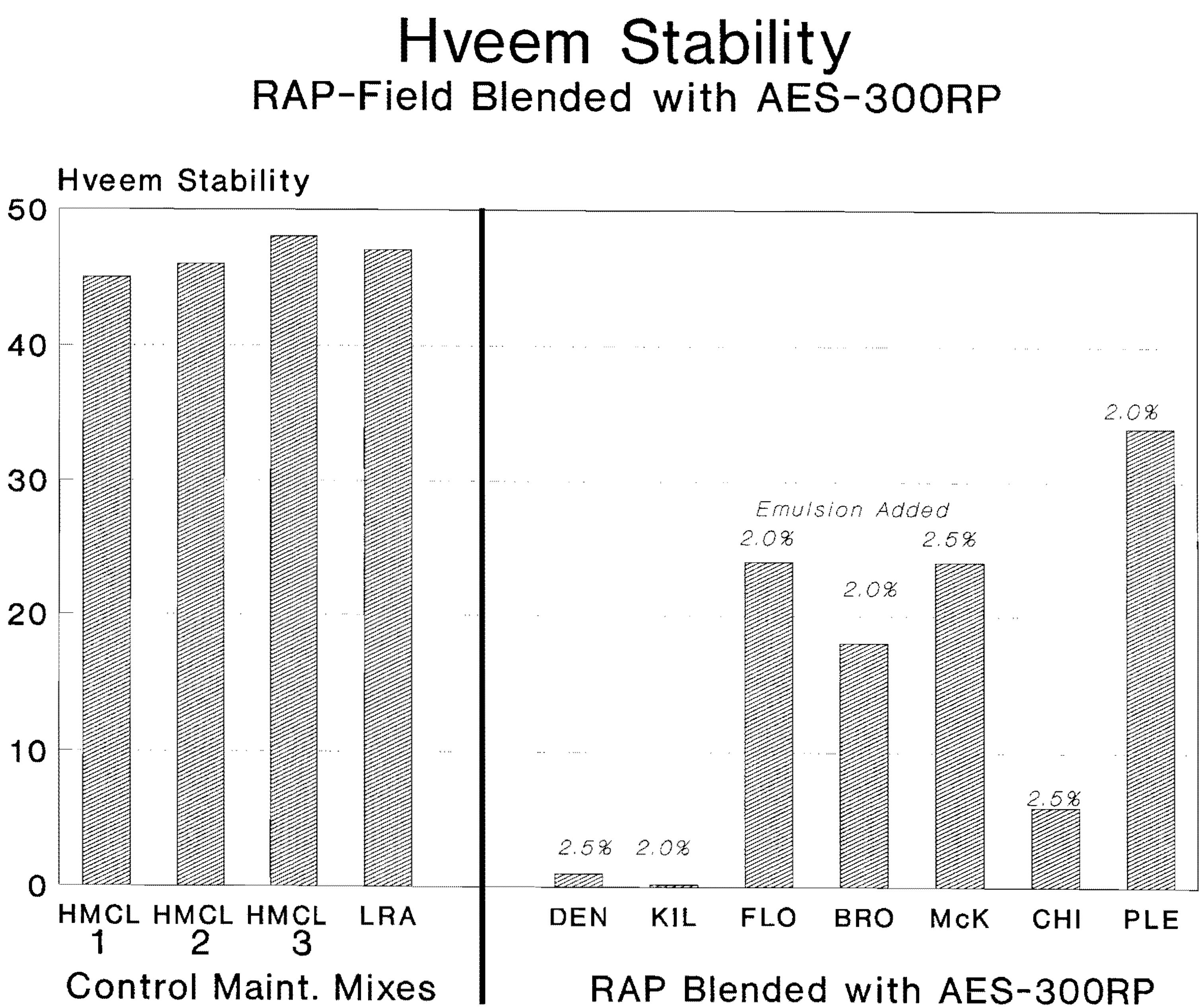

Figure 25. Hveem Stability Data for RAP Blended with AES-300RP and Control Mixes.

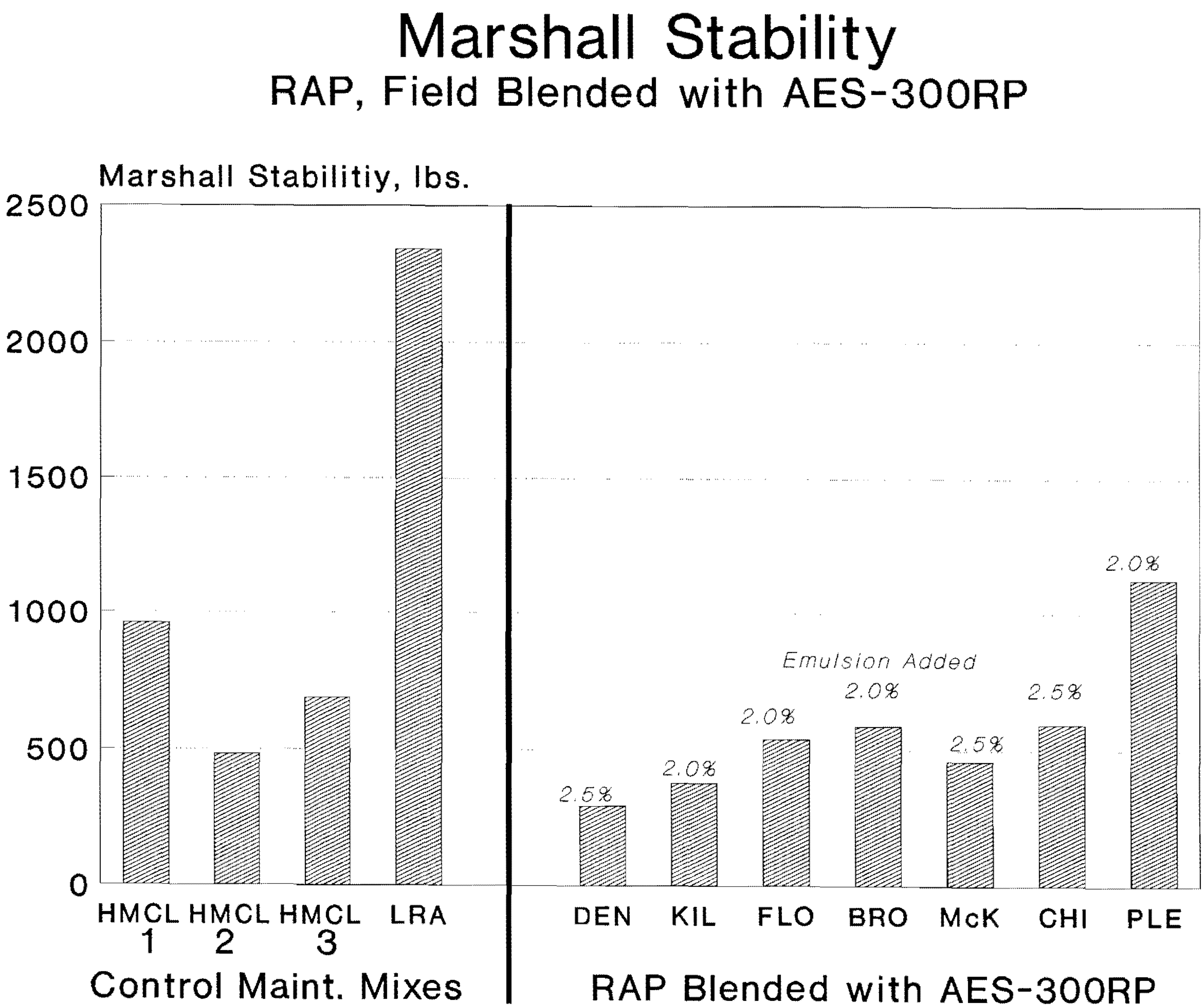

Figure 26. Marshall Stability Data for RAP Blended with AES-300RP and Control Mixes.

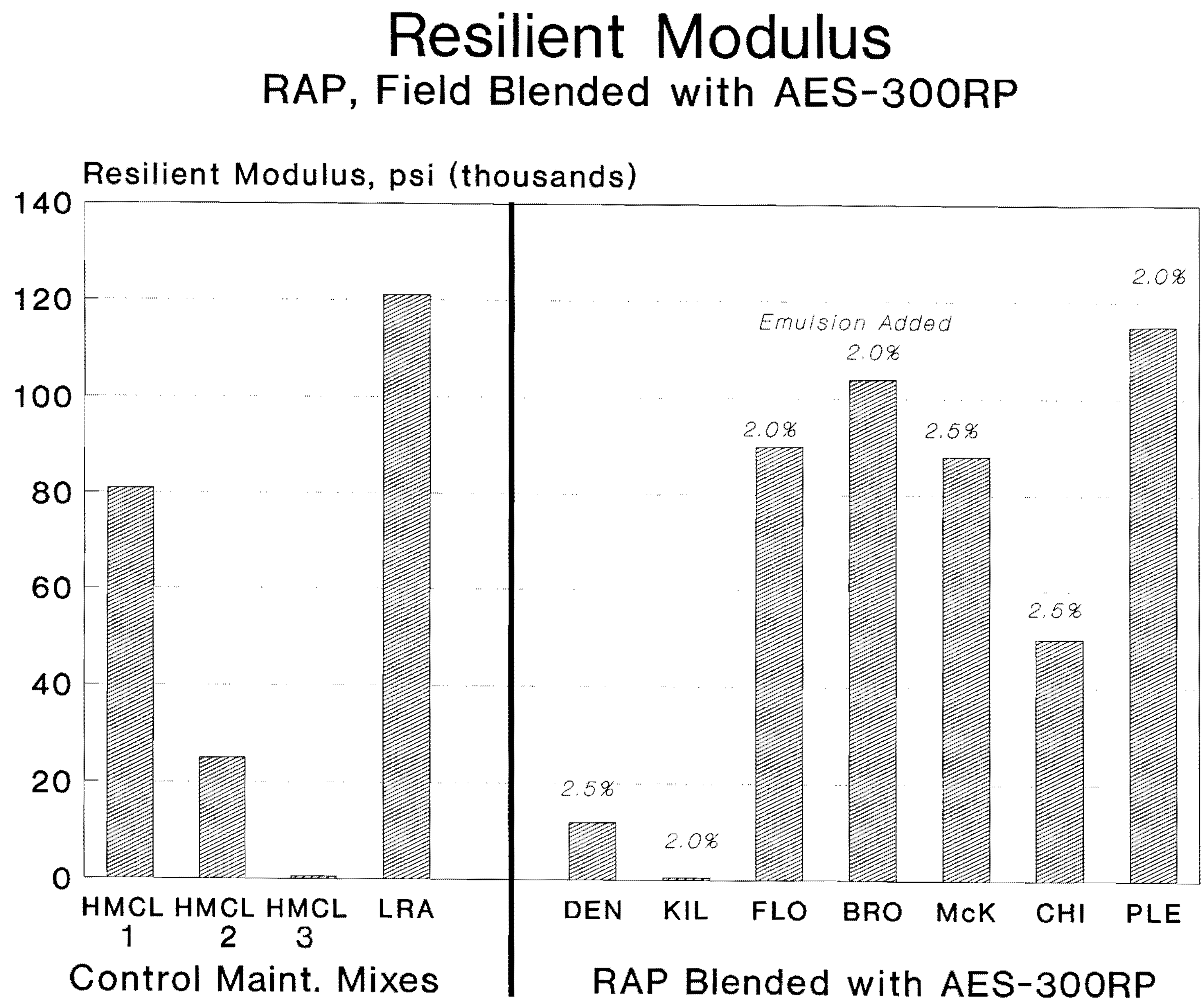

Figure 27. Resilient Modulus Data for RAP Blended with AES-300RP and Control Mixes.

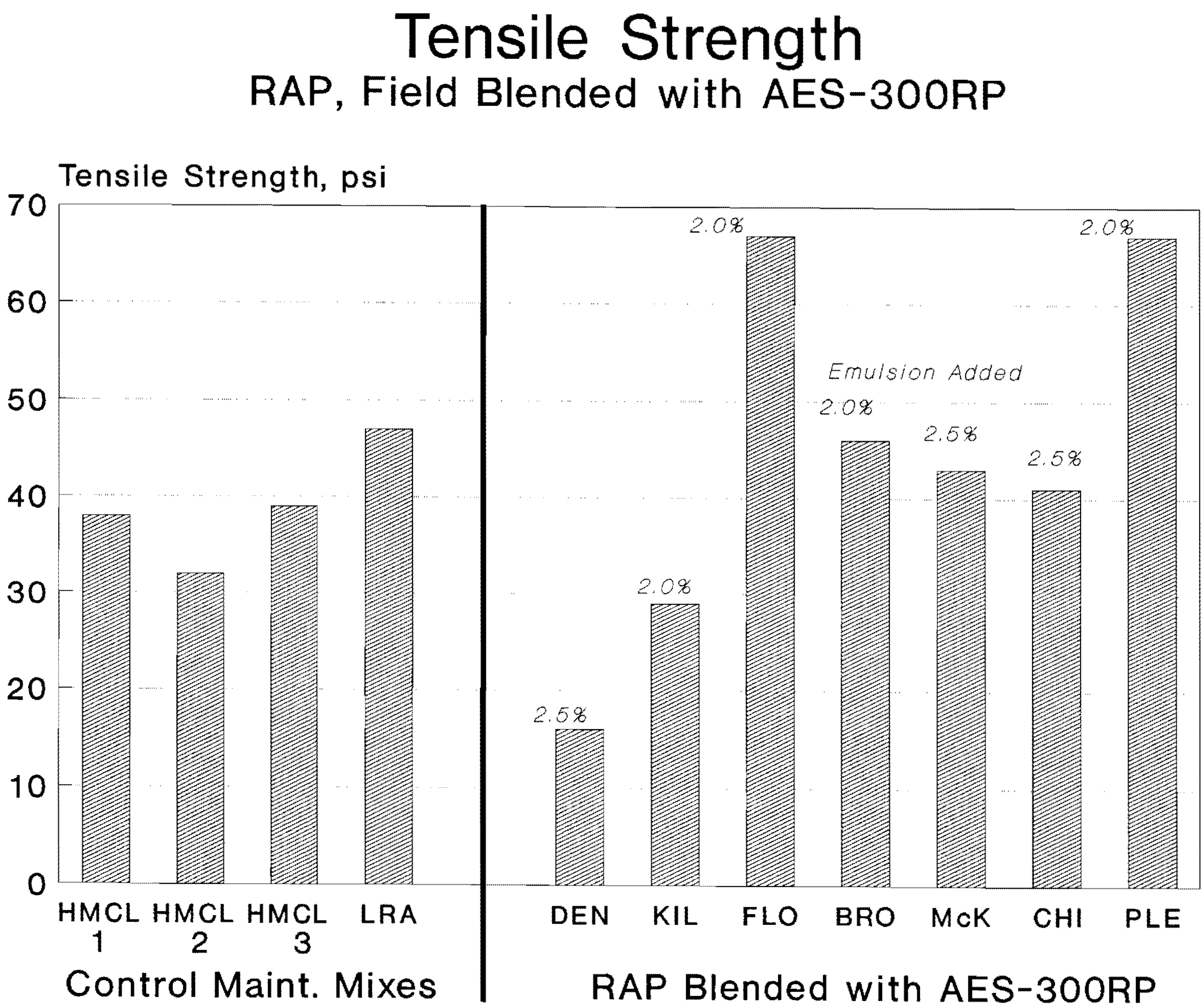

Figure 28. Tensile Strength Data for RAP Blended with AES-300RP and Control Mixes.

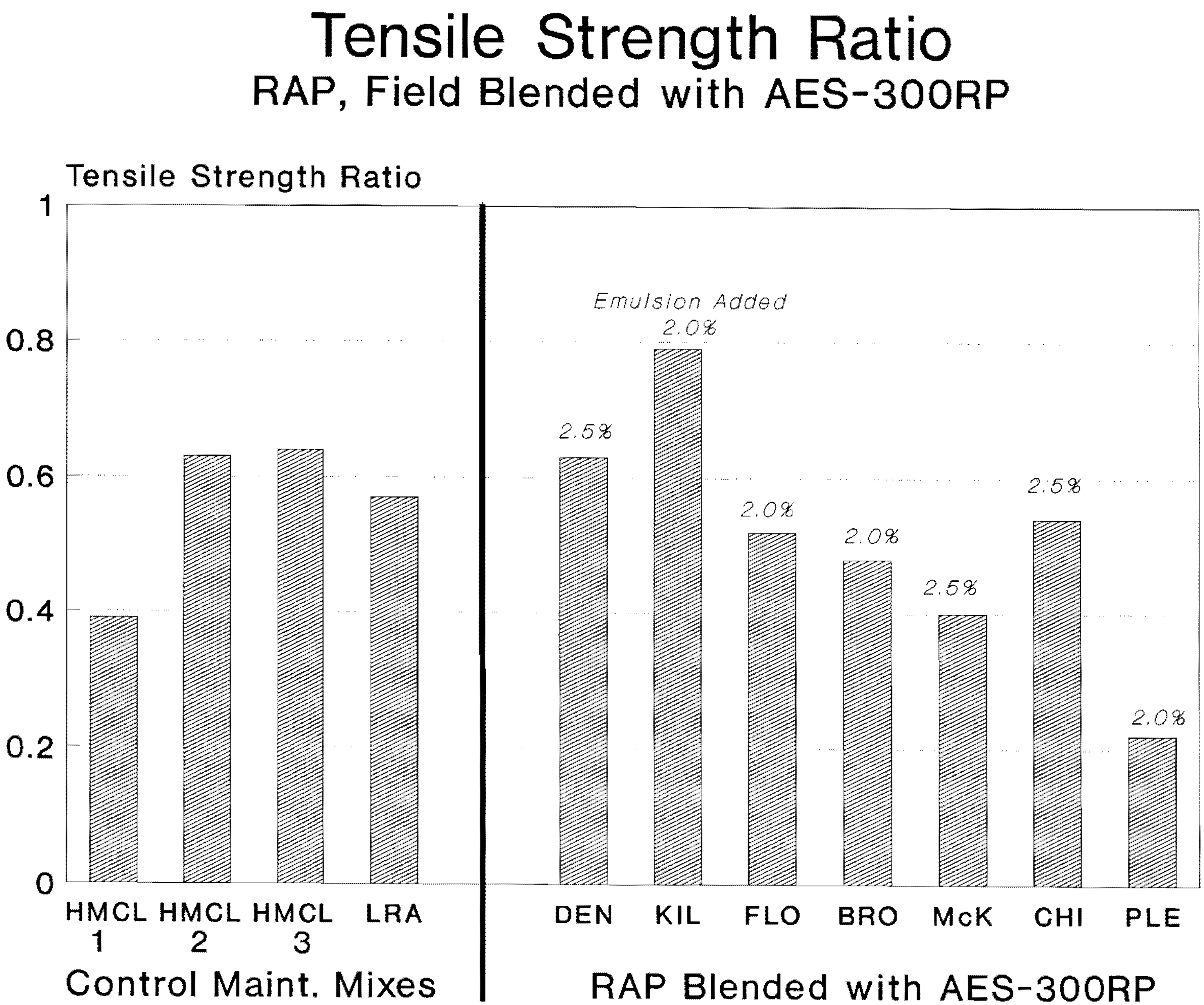

Figure 29. Tensile Strength Ratio for RAP Blended with AES-300RP and Control Mixes.

KIL - Kilgore RAP/AES-300RP Blend
FLO - Floresville RAP/AES-300RP Blend
BRO - Brownwood RAP/AES-300RP Blend
McK - McKinney RAP/AES-300RP Blend
CHI - Childress RAP/AES-300RP Blend
PLE - Pleasanton RAP/AES-300RP Blend

Hveem stability for the RAP blends (Figure 25) was significantly lower than the conventional (control) maintenance mixtures, with the exception of the Pleasanton blend. TxDOT specifications for HMCL require a minimum Hveem stability of 35. The Floresville and McKinney RAP blends had a Hveem stability of 24. However, these mixtures performed adequately in the field in the applications for which they were used.

The Brownwood RAP blend had a Hveem stability of 18. Based on the visual characteristics of the Brownwood RAP blend, it appeared to have excess binder. This material was used in the field experiments as a level-up course and a county-road turnout and has performed well to date. It was also used to repair a spot base failure; however, since it appeared to have excess asphalt, it was blended with one-third raw rap for the base repair and is performing well. The Kilgore and Childress RAP blends were only recently placed and it is too early to assess performance. The Kilgore RAP had a Hveem stability value of 0 and the Childress RAP had a stability of 6. Excess binder is attributed to these low stability values.

The Denton RAP blend had a Hveem stability of 1. Based on its visual characteristics, it also had too much binder. The material was used to reconstruct a shoulder on I-35 and was very tender under the weight of the pneumatic rollers. District personnel experienced with RAP blends did not consider it to be a good mix due to the excess asphalt.

Resilient modulus, tensile strength and to some extent Marshall stability are more strongly influenced by binder properties. The RAP mixes exhibited Marshall stabilities comparable to the HMCL control mixes. With the exception of the Denton and Kilgore RAP mixes, resilient moduli were also comparable to the control HMCL and LRA mixes. The resilient modulus test was performed at 77°F. The resilient modulus test is not commonly performed on bituminous maintenance mixtures; however, resilient modulus values for hot-mix ACP typically range from 200,000 to 300,000 psi at this temperature. All of the mixes, including HMCL and

LRA, are well below this range. However, the binder in these types of maintenance mixes will stiffen considerably with time. It is difficult to simulate field curing, which may span several months, in the laboratory.

Indirect tensile strength is shown in Figure 28. While there appears to be much variability between all of the mixes, the overall range is from 16 to 67 psi. This range of values is considered to be very low. Typical values for hot-mix ACP range from 100 to 250 psi. Denton and Kilgore RAP mixes had the lowest tensile strengths.

Indirect tension tests before and after exposure to moisture (Tex 531C) were used to evaluate the susceptibility of these mixtures to damage by moisture. Tensile strength ratios were calculated by dividing measurements after moisture treatment by those obtained on the untreated specimens. Test results are shown in Figure 29. The RAP and control mixes generally have ratios from 0.4 to 0.8, with the exception of the Pleasanton RAP mix which had a ratio of 0.22. A typical moisture resistant hot-mix asphalt concrete should have a tensile strength ratio of 0.7 or more. While these values are below 0.7, the RAP mixtures are comparable to the control maintenance mixtures.

After careful analysis of all of the data, it appears that Hveem stability most adequately characterizes the important mixture properties of RAP blends because it is sensitive to asphalt content and aggregate interlock in the mix. The other mixture tests are sensitive to binder properties and these properties in maintenance mixtures will change as the mixtures cure with time.

Properties of Childress RAP Field-Blended with Different Emulsions

As described in the "Field Study" section of this report, RAP was blended in a pugmill with four different emulsions: AES-300RP, ARE-68, CRR-60, and MS-1. Laboratory test results are presented in Figures 30 through 34. The AES-300RP-modified RAP had the lowest stabilities, resilient modulus, and tensile strength values. However, it had the highest tensile strength ratio indicating it is more resistant to moisture damage. In comparison with the other AES-300RP-modified RAPs, Hveem stability of the Childress RAP is very low. The MS-1-modified RAP had the highest stabilities, modulus and tensile strength values.

Properties of Pleasanton Test Sections

As described earlier, three test sections were placed in the San Antonio district near Pleasanton. These test sections consisted of HMCL, LRA blended

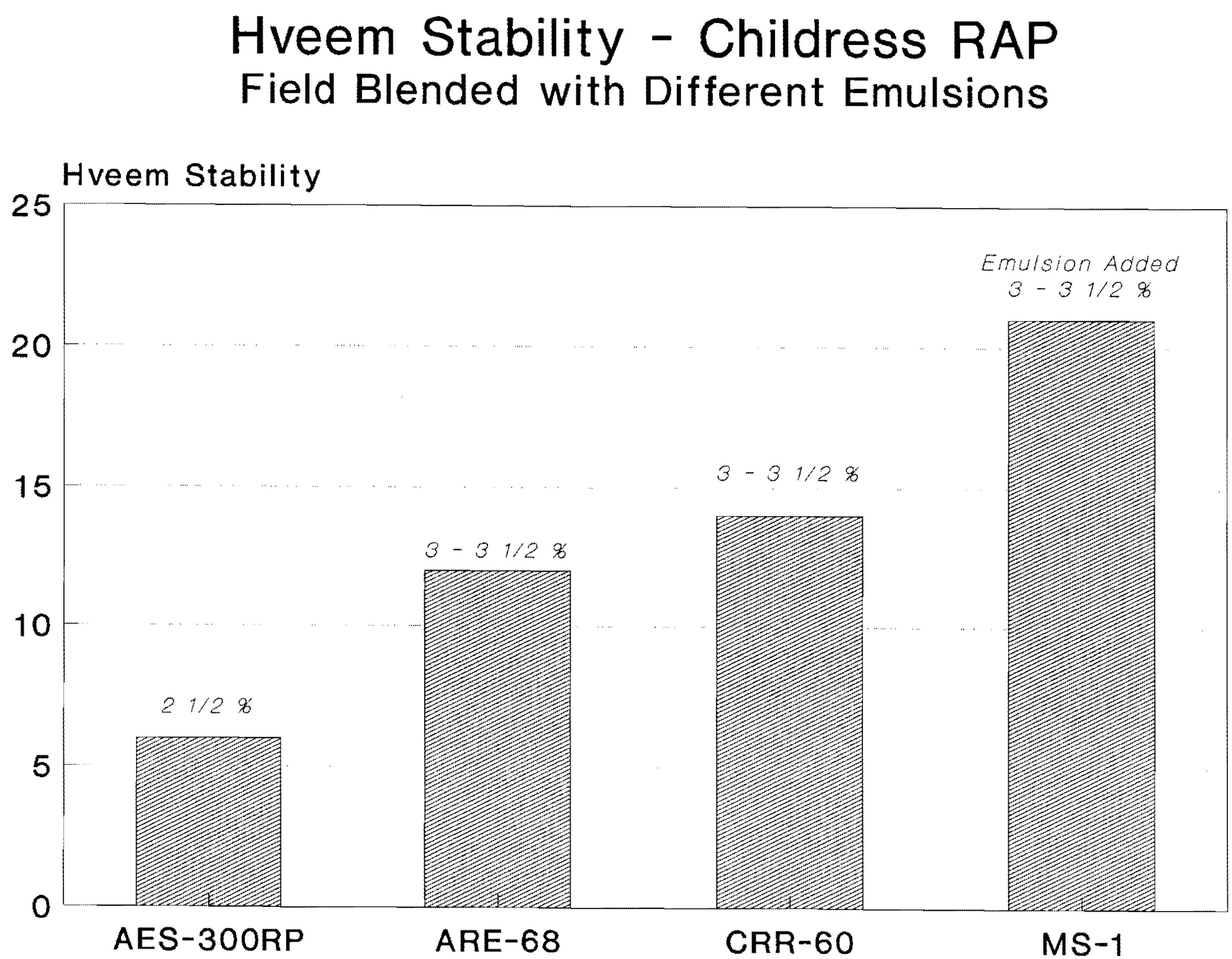

Figure 30. Hveem Stability Data for Childress Test Sections.

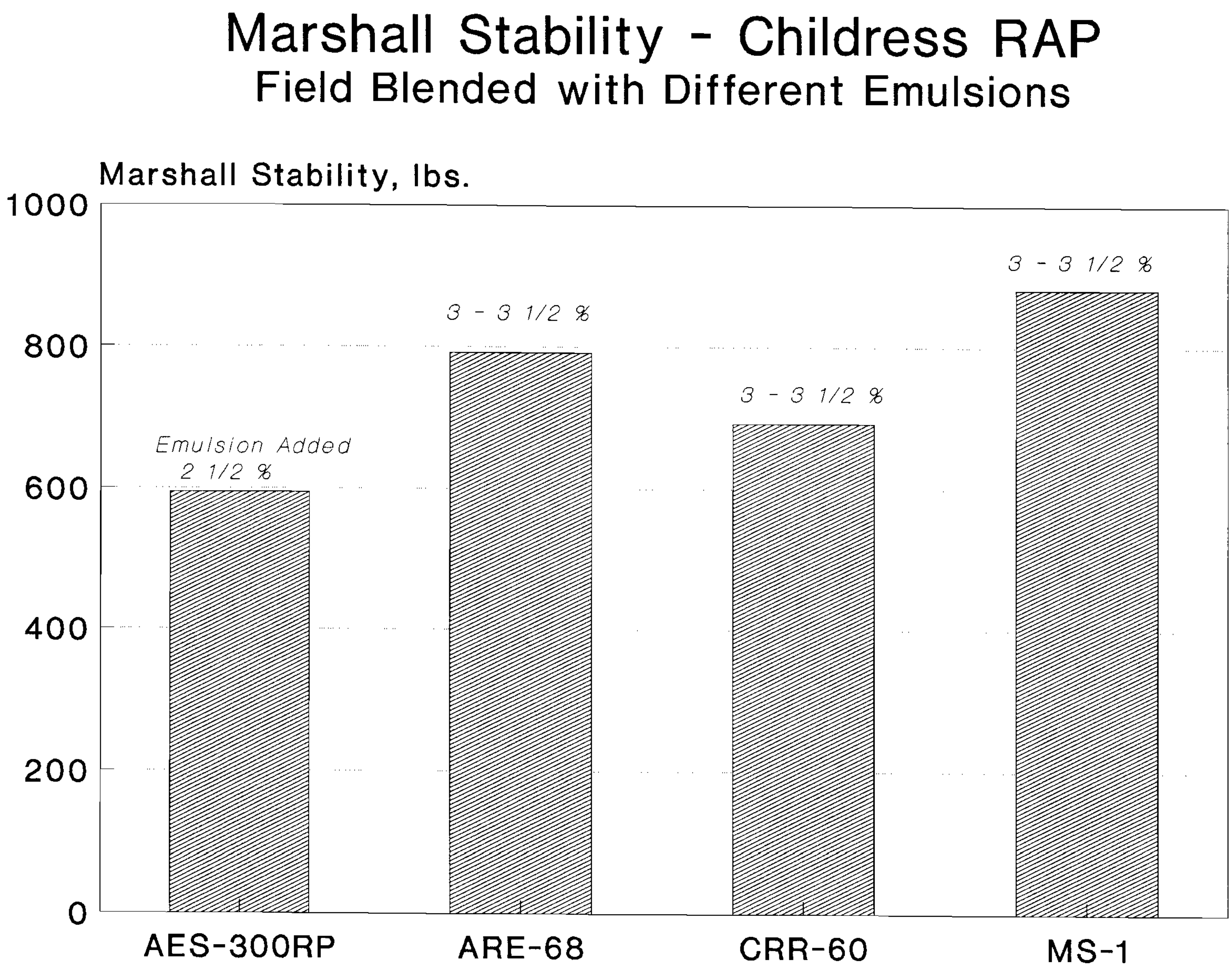

Figure 31. Marshall Stability Data for Childress Test Sections.

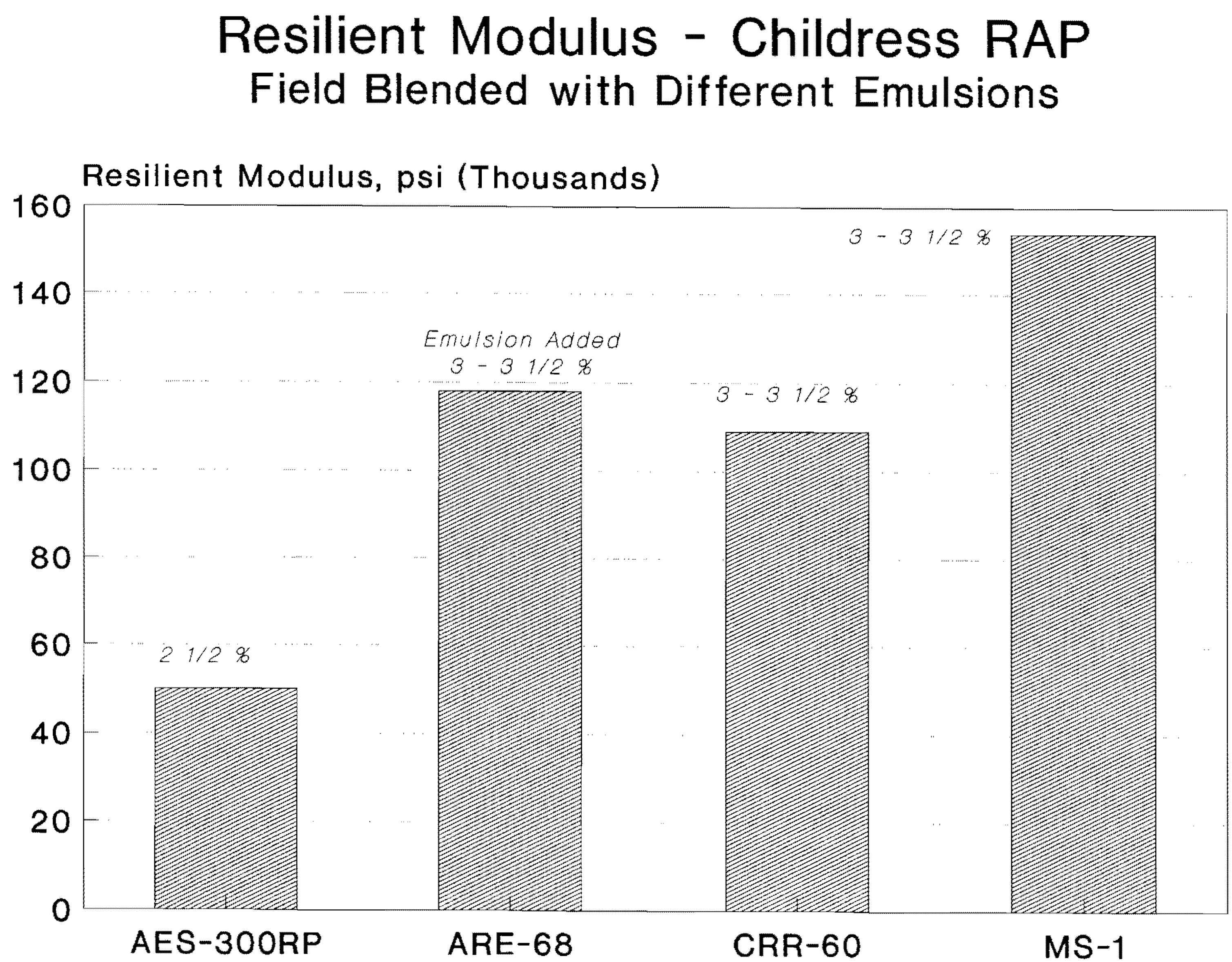

Figure 32. Resilient Modulus Data for Childress Test Sections.

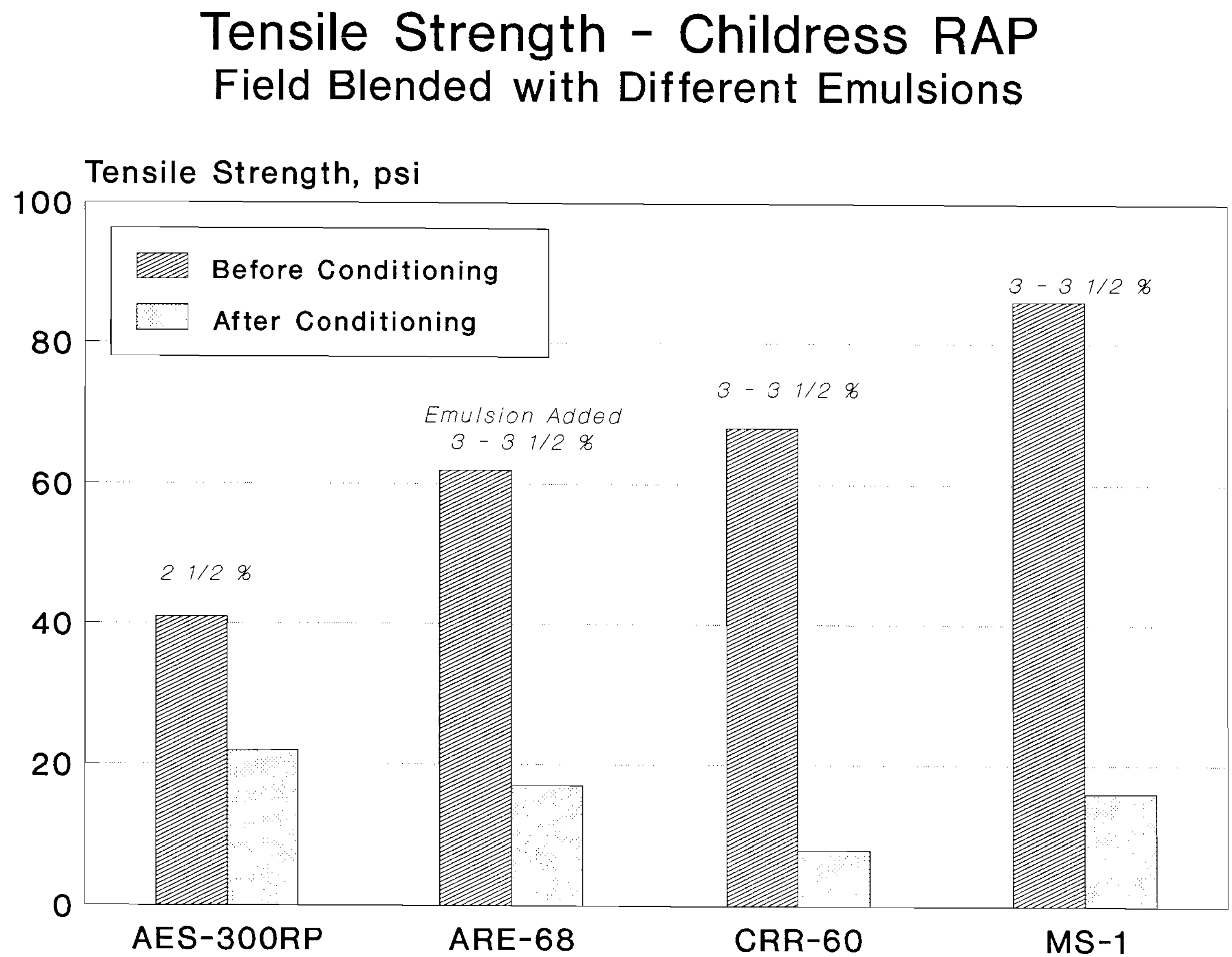

Figure 33. Tensile Strength Data Before and After Moisture Conditioning for Childress Test Sections.

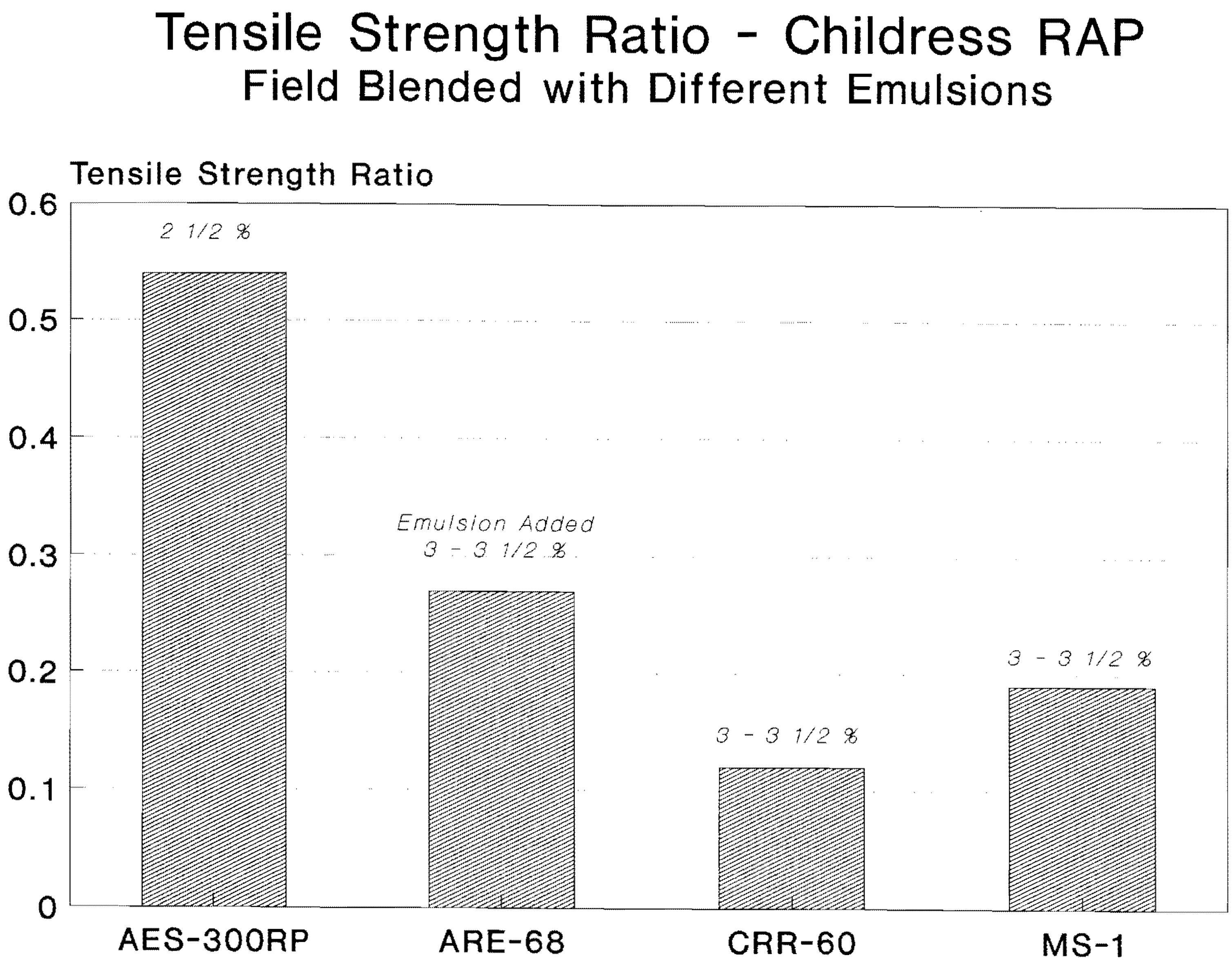

Figure 34. Tensile Strength Ratio for Childress Test Sections.

(60/40) with RAP, and treated RAP. The RAP test section consisted of RAP which was blade/pulver-mixed with three percent AES-300RP.

Results of the laboratory tests are shown in Figures 35 through 39. Stabilities, modulus and tensile strength values are better for this treated RAP than for any of the others observed in this study indicating that the aged asphalt binder present in the RAP may have been very stiff. Tensile strength ratio, however, is quite low at 0.22.

Properties of McKinney Test Sections

Six field test sections were constructed in the Dallas district near McKinney. These materials were tested in the laboratory and consist of the following:

- HMCL, Item 350, Type D, Fine Graded Surface Course
- HMCL (Item 350, Type D) blended with treated RAP (50/50),
- HMCL (Item 350, Type D) blended with untreated RAP (60/40),
- LRA, Item 330, Class A, Type D
- LRA (Item 330, Type D) blended with treated RAP (50/50),
- LRA (Item 330, Type D) blended with untreated RAP (60/40).

The treated RAP consisted of RAP blended in a pugmill with AES-300RP. Note that the untreated RAP and the treated RAP used in this experiment were from different sources. Laboratory test results are presented in Figures 40 through 44.

All Hveem stability values for the RAP mixtures are higher than the treated RAP mixtures discussed earlier. The treated RAP mixtures which contained the AES-300RP had more fluids than the raw RAP mixtures which is probably the reason for the lower Hveem stability values. While the Hveem stability test is not sensitive to binder viscosity, it is sensitive to binder content. The raw RAP blended with LRA and HMCL have the highest values. This may be because the raw RAP blends had more crushed aggregate resulting in greater interparticle friction within the mix.

Marshall stability for the HMCL was quite low at 500 pounds but increased to over 1000 pounds when blended with both treated and untreated RAPs. Marshall stability for the LRA was over 2000 pounds but dropped to 1700 pounds when blended with the treated RAP. However, Marshall stability increased to over 2500 pounds when blending the LRA with the untreated RAP. Similar trends were observed in the resilient modulus data as shown in Figure 42.

Tensile strength data before and after moisture conditioning are presented

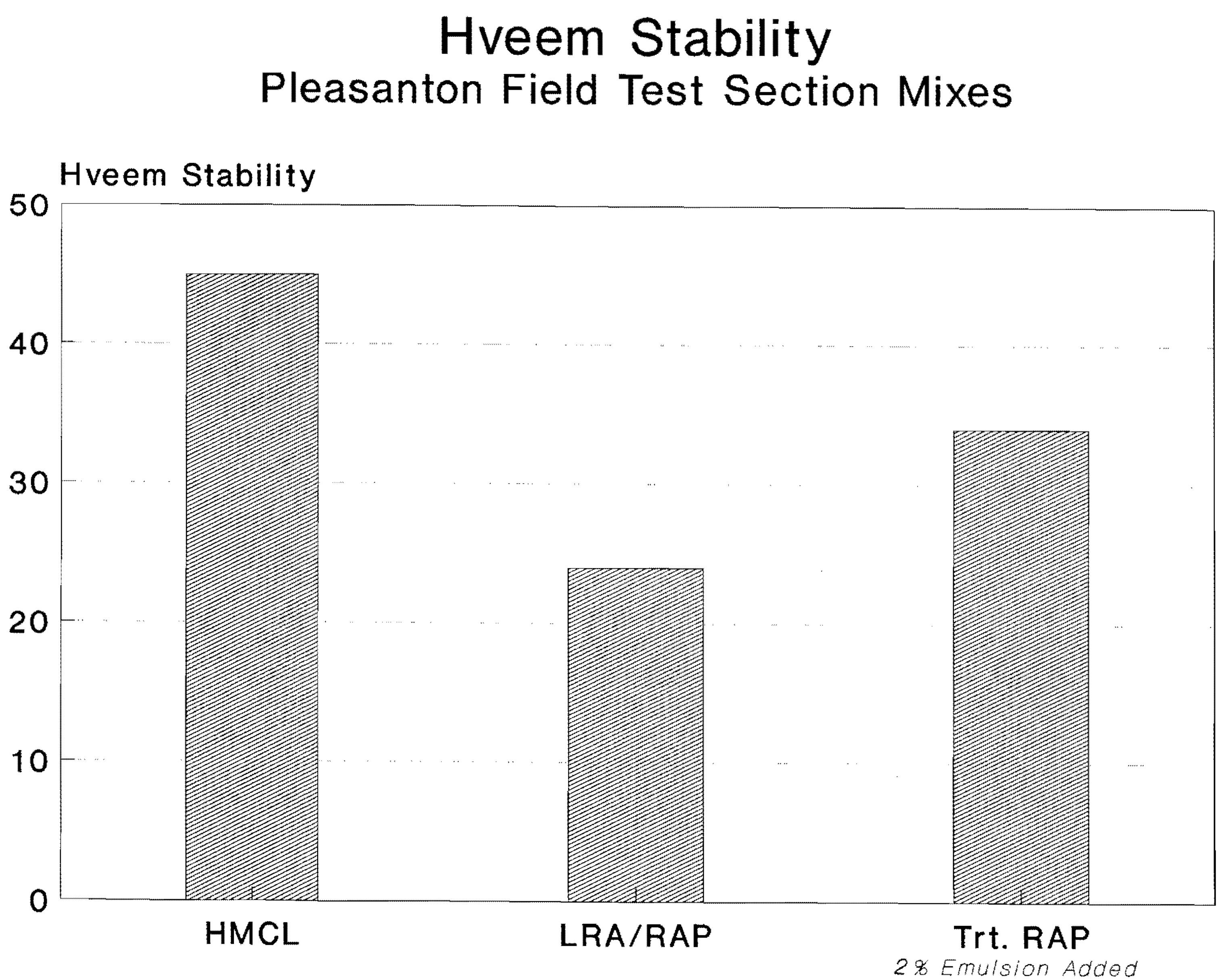

Figure 35. Hveem Stability Data for Pleasanton Test Sections.

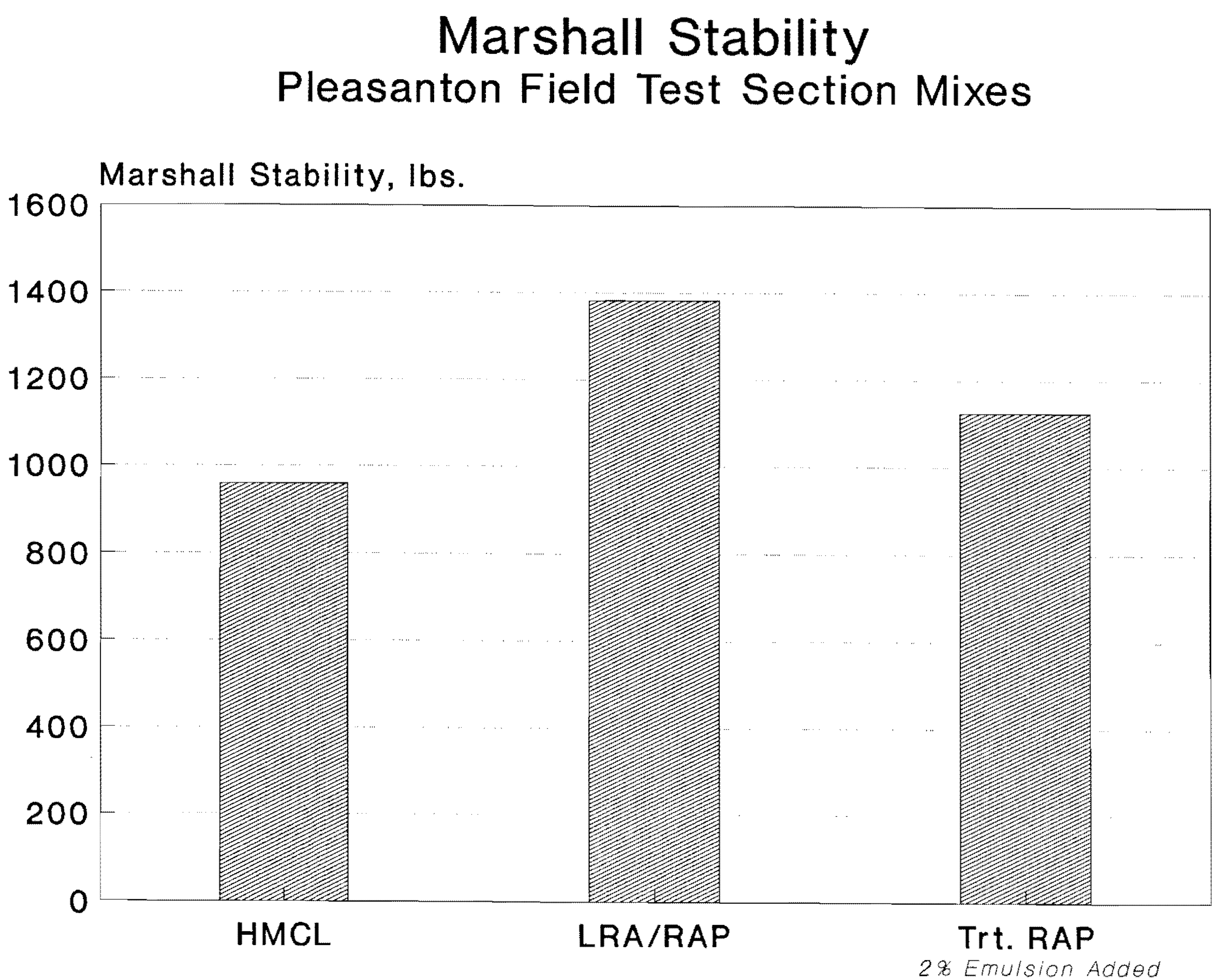

Figure 36. Marshall Stability Data for Pleasanton Test Sections.

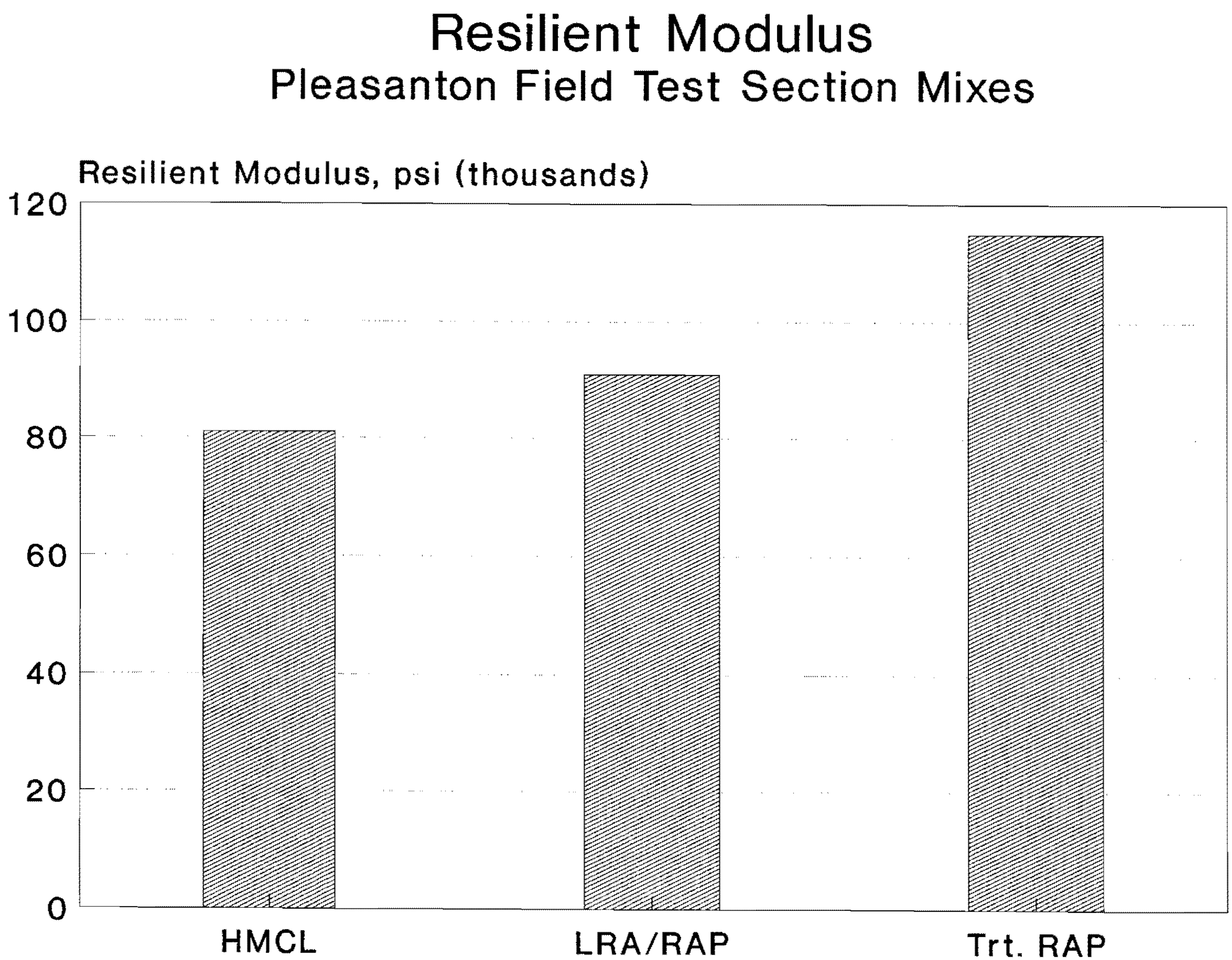

Figure 37. Resilient Modulus Data for Pleasanton Test Sections.

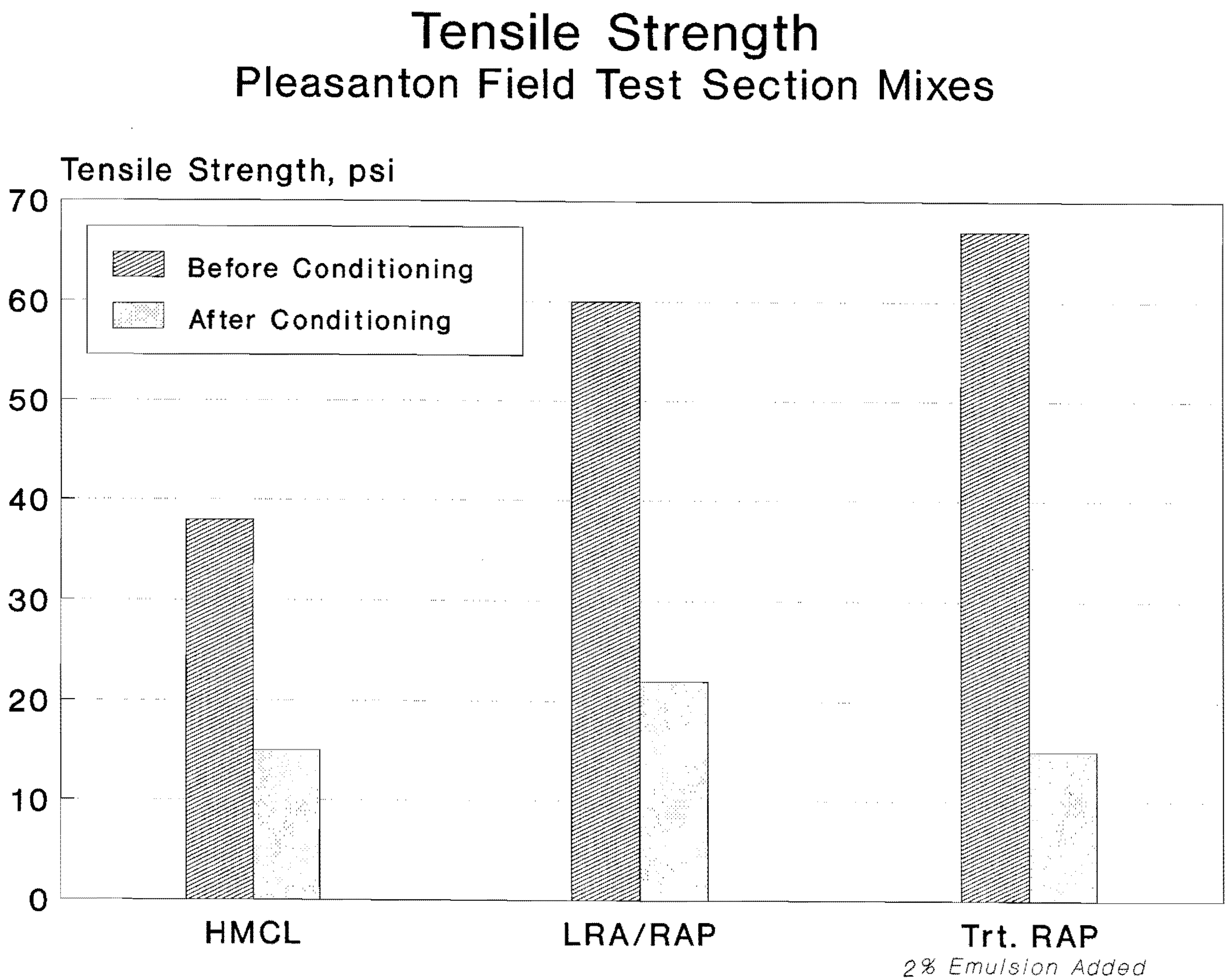

Figure 38. Tensile Strength Data Before and After Moisture Conditioning for Pleasanton Test Sections.

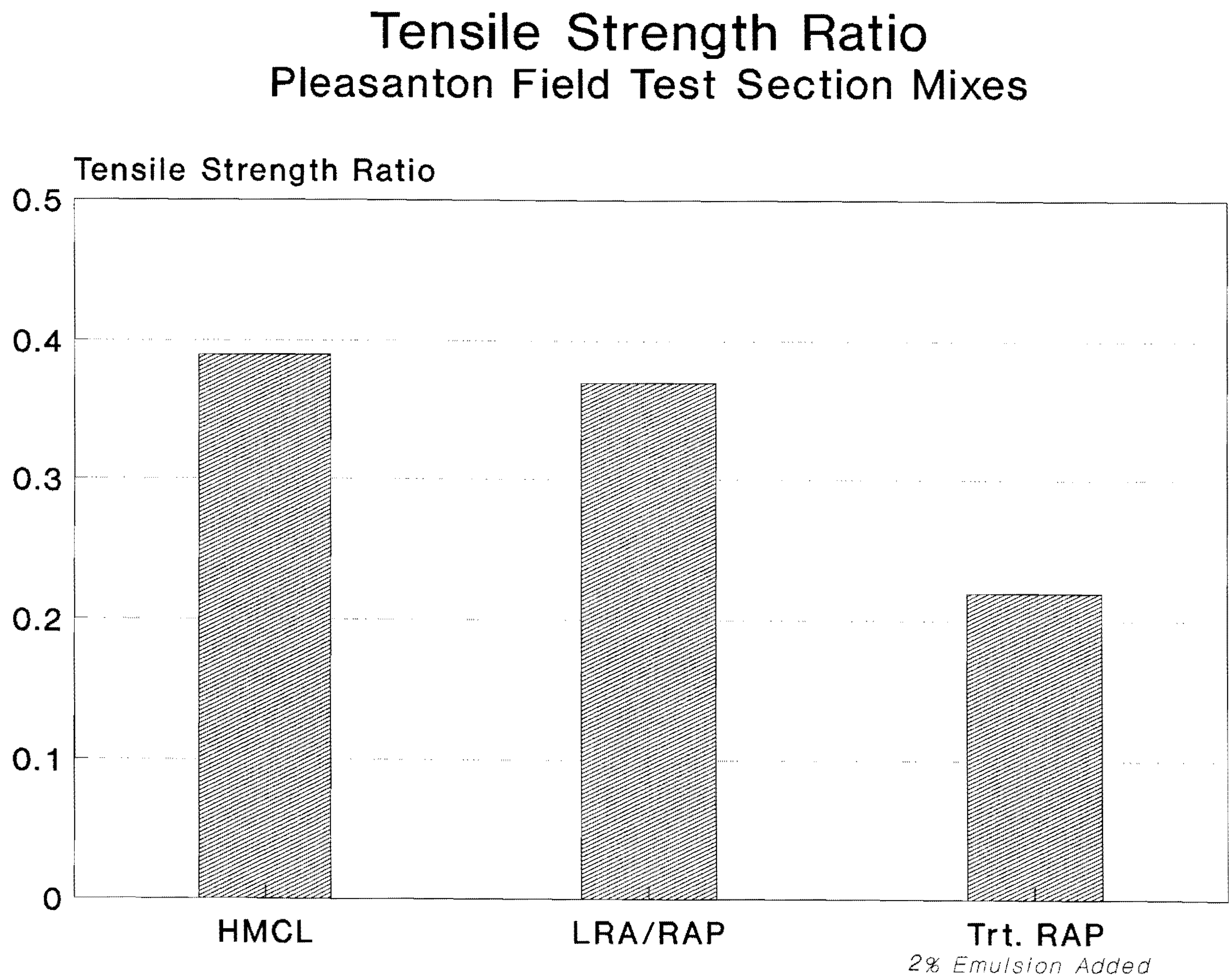

Figure 39. Tensile Strength Ratio for Pleasanton Test Sections.

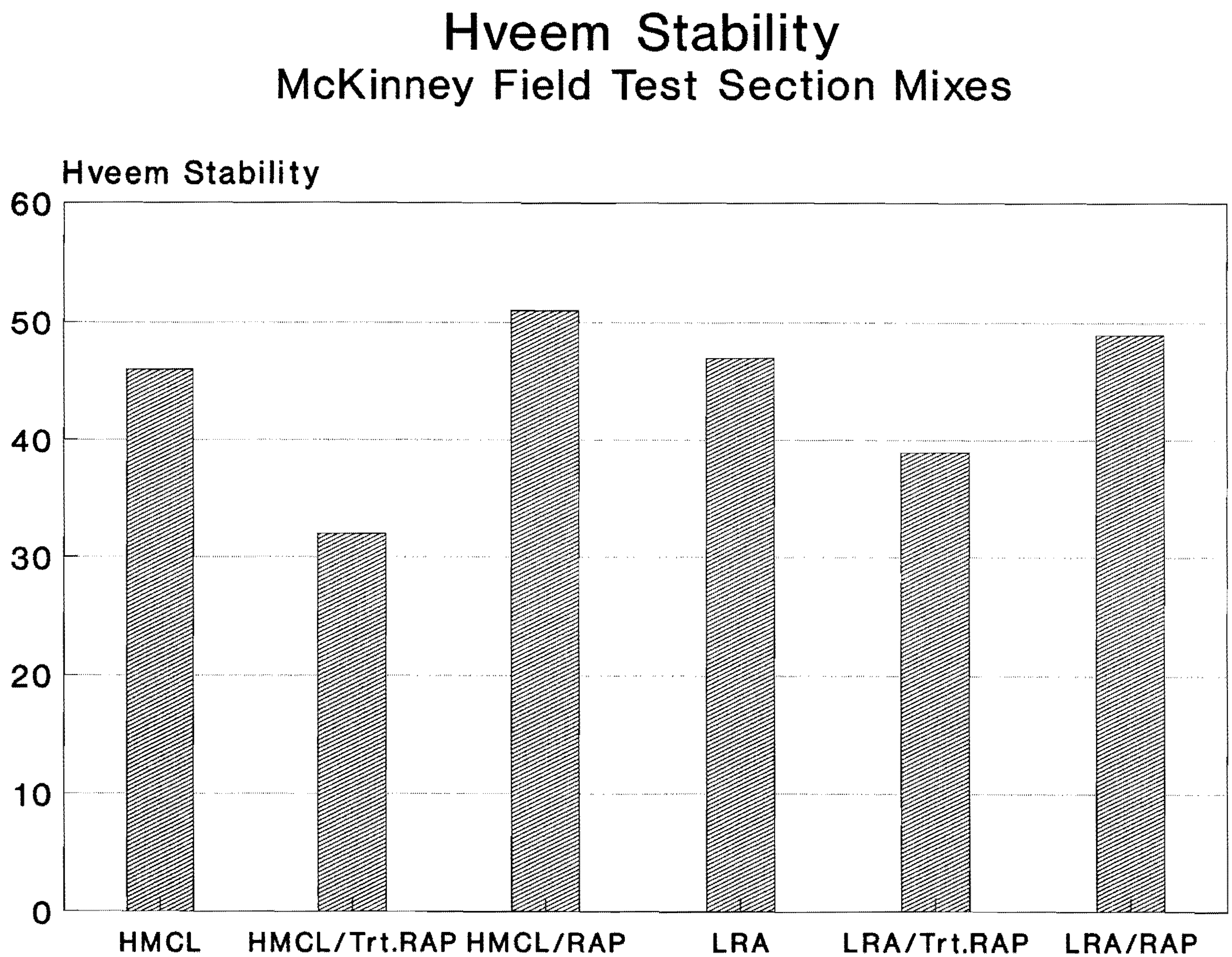

Figure 40. Hveem Stability Data for McKinney Test Sections.

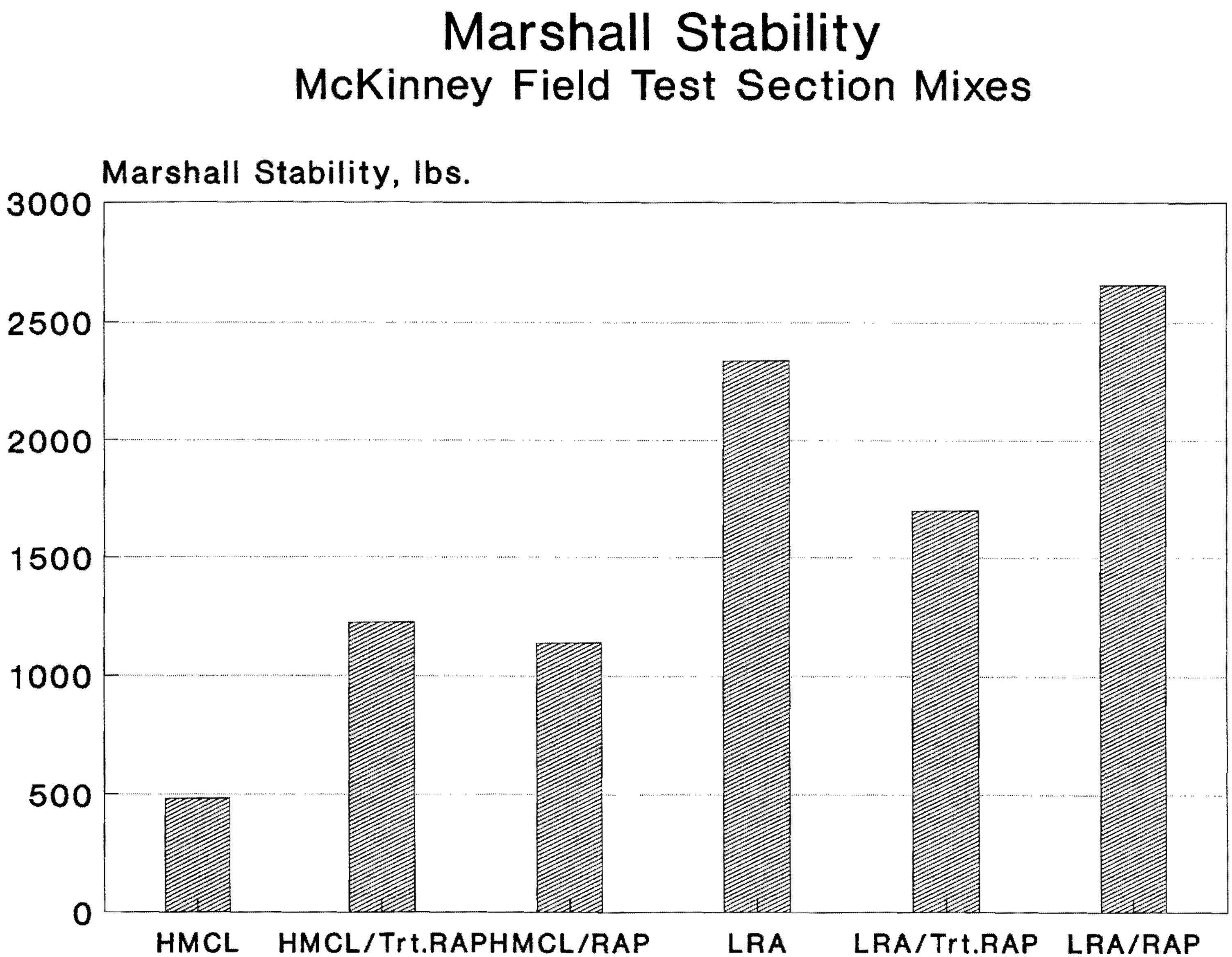

Figure 41. Marshall Stability Data for McKinney Test Sections.

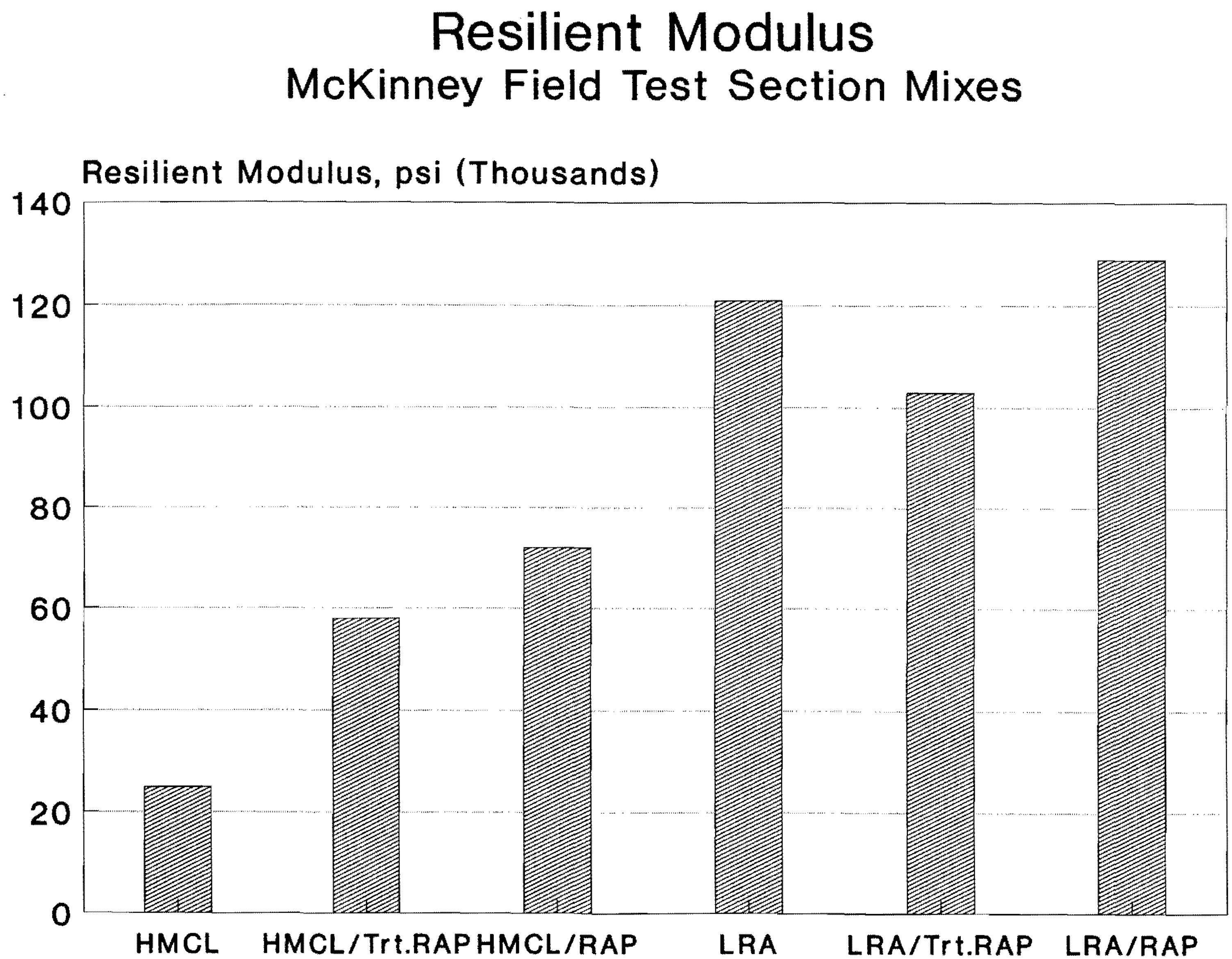

Figure 42. Resilient Modulus Data for McKinney Test Sections.

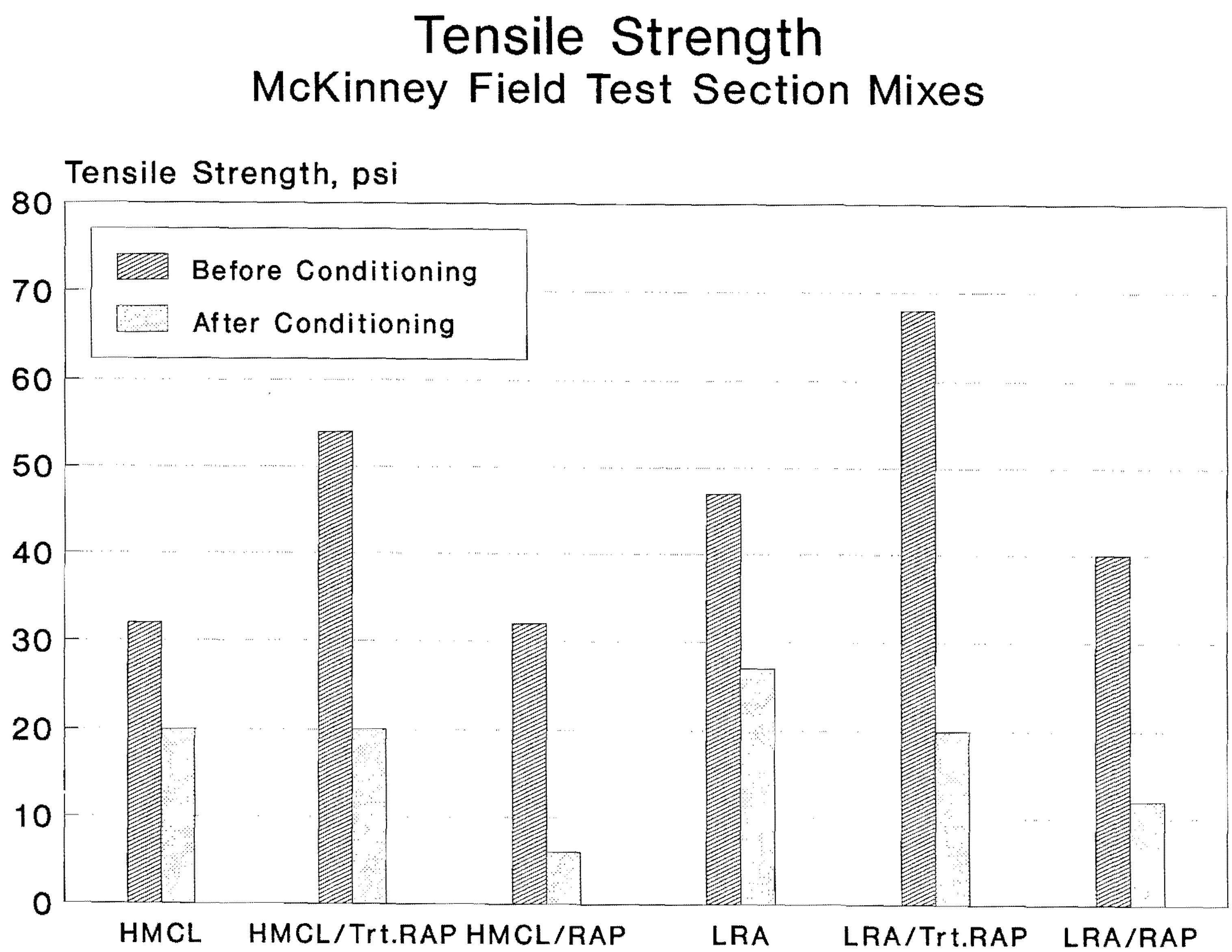

Figure 43. Tensile Strength Data Before and After Moisture Conditioning for McKinney Test Sections.

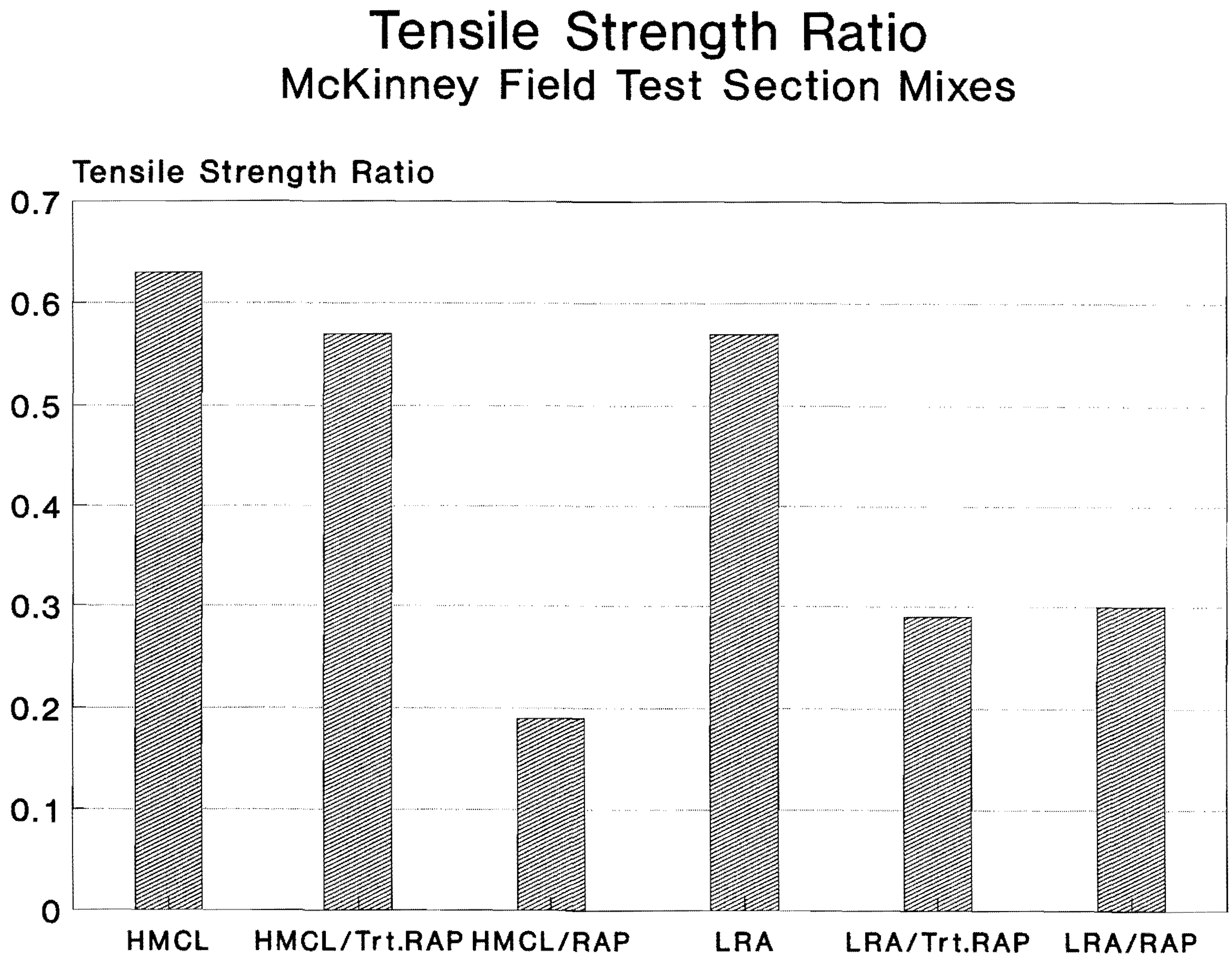

Figure 44. Tensile Strength Ratio for McKinney Test Sections.

in Figure 43. The treated RAP blended with the HMCL and the LRA had the highest tensile strength values before conditioning. Most of the mixtures showed a significant drop in tensile strength after moisture conditioning as shown in both Figure 43 and 44. Tensile strength ratio (Figure 44) is quite low for the untreated RAP blends indicating a susceptibility to moisture damage. It is also low for the LRA/treated RAP blend; however, as shown in Figure 43, the LRA/treated RAP blend had a very high strength before conditioning and after conditioning the strength is the same as the HMCL/treated RAP blend.

Laboratory Properties of Cleburne Test Sections

Test sections were constructed in Cleburne using the following materials:

- HMCL, Item 350, Type FF, Fine Graded Surface Course
- HMCL (Item 350, Type FF)/Treated RAP,
- HMCL (Item 350, Type FF)/Untreated RAP,
- LRA, Item 330, Type CC.
- LRA (Item 330, Type CC)/Treated RAP.

The treated RAP in this experiment consisted of RAP which was blade-mixed with MS-1. The addition of RAP and treated RAP to HMCL and LRA did not cause a reduction in the Hveem stability values as shown in Figure 45. Marshall stability (Figure 46) is improved when HMCL and LRA are blended with RAP. A similar trend is observed with resilient modulus and tensile strength data (Figures 47 and 48). Tensile strength after moisture conditioning (Figure 48) was not adversely affected by the addition of RAP. Tensile strength ratio is shown in Figure 49.

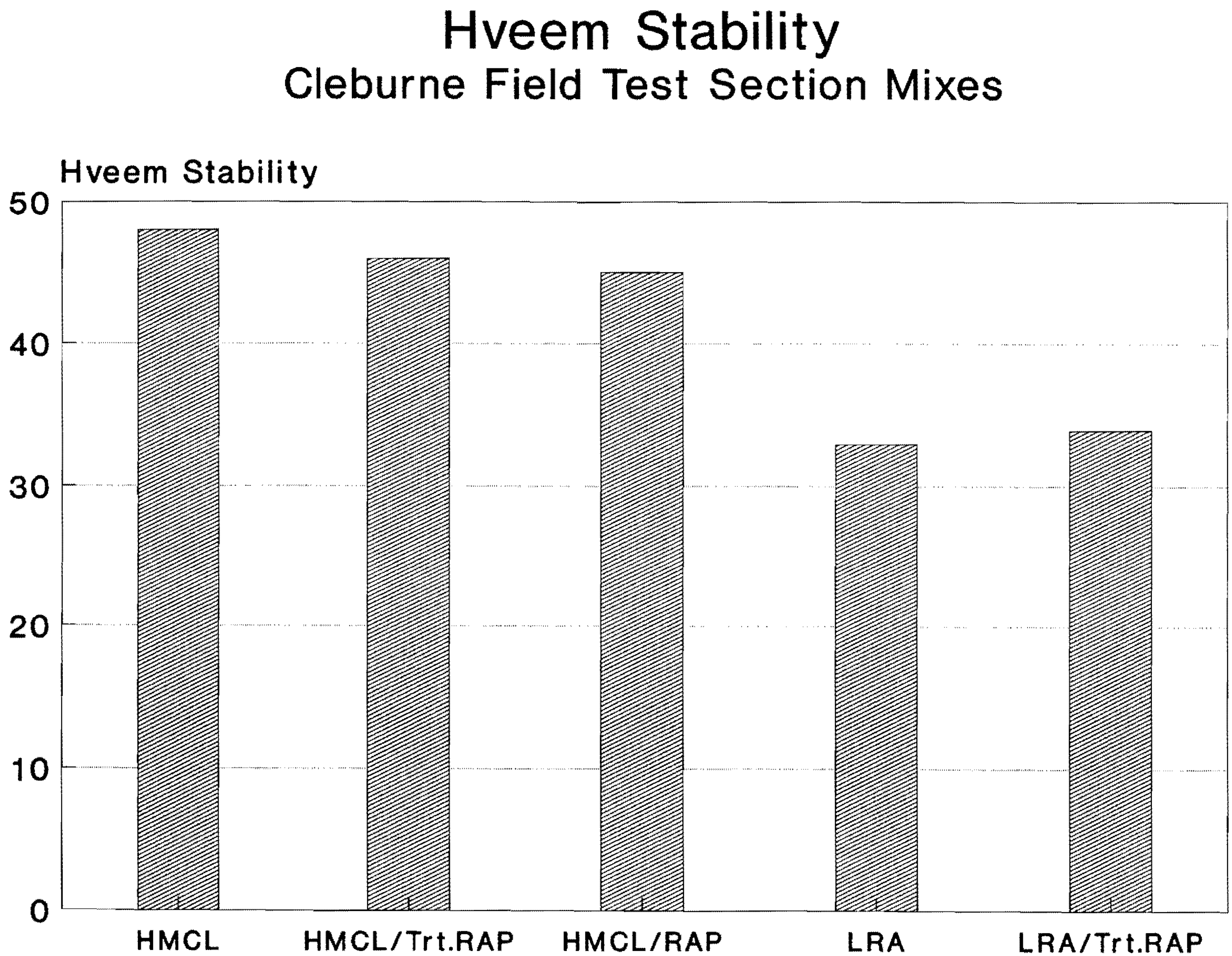

Figure 45. Hveem Stability Data for Cleburne Test Sections.

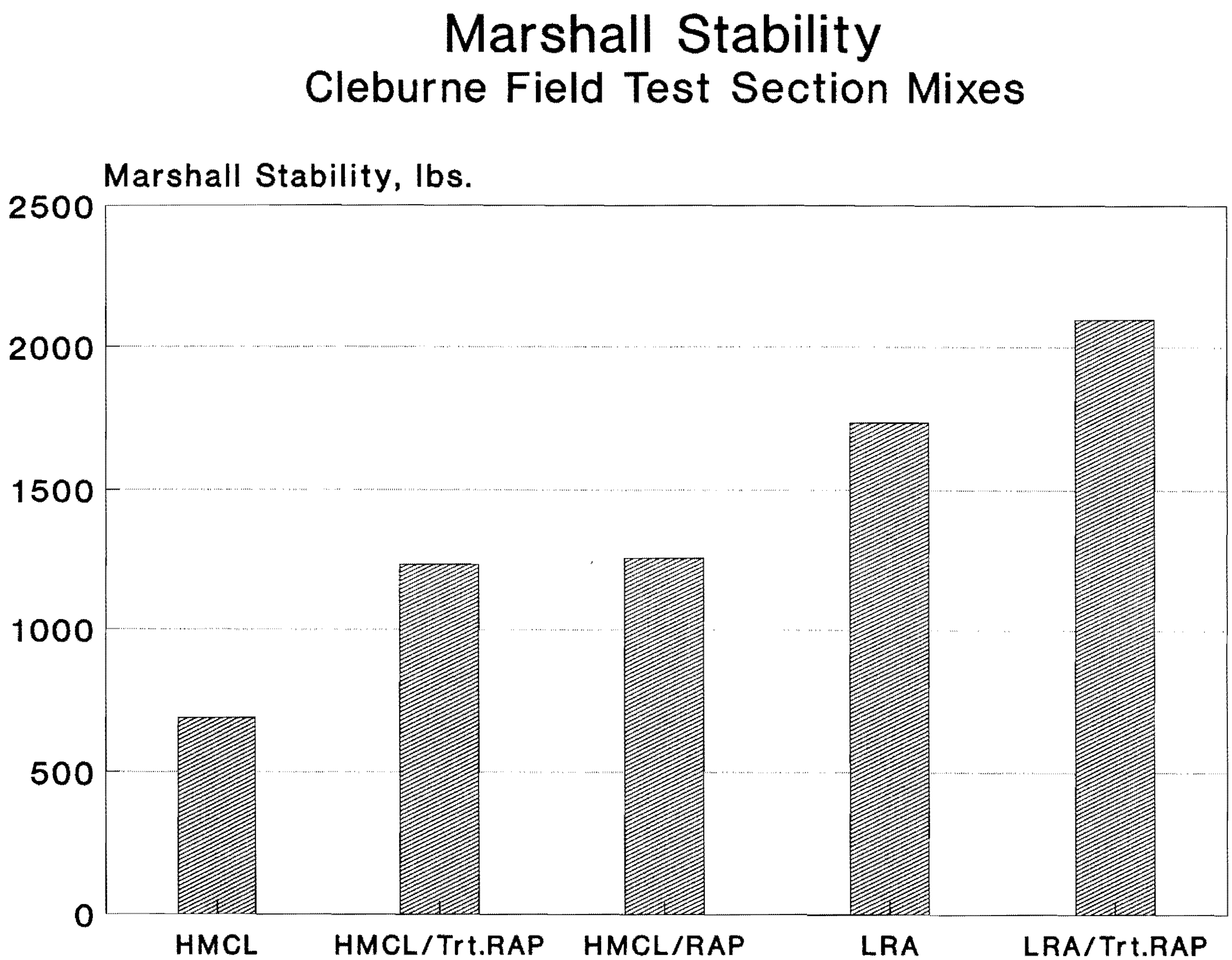

Figure 46. Marshall Stability Data for Cleburne Test Sections.

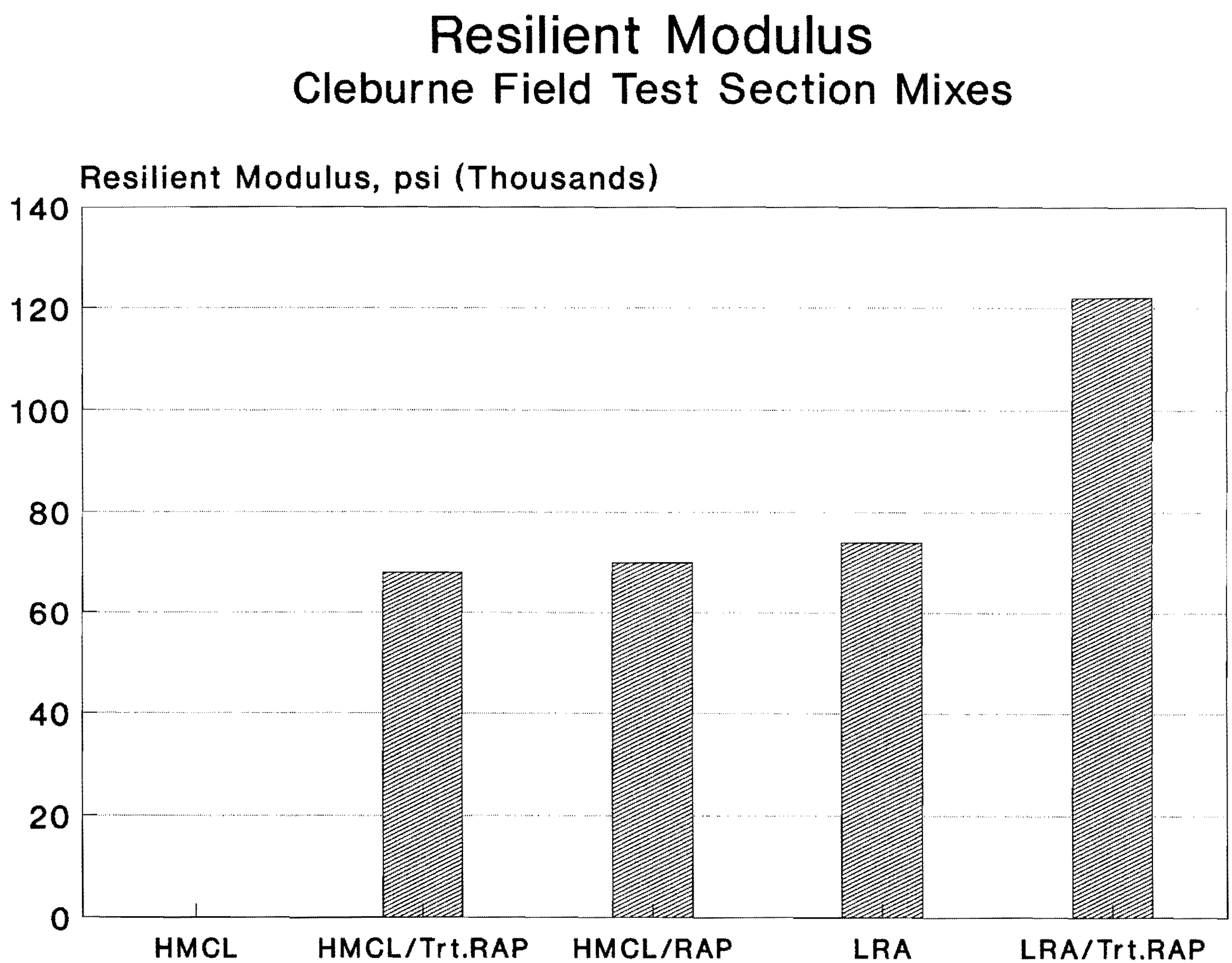

Figure 47. Resilient Modulus Data for Cleburne Test Sections.

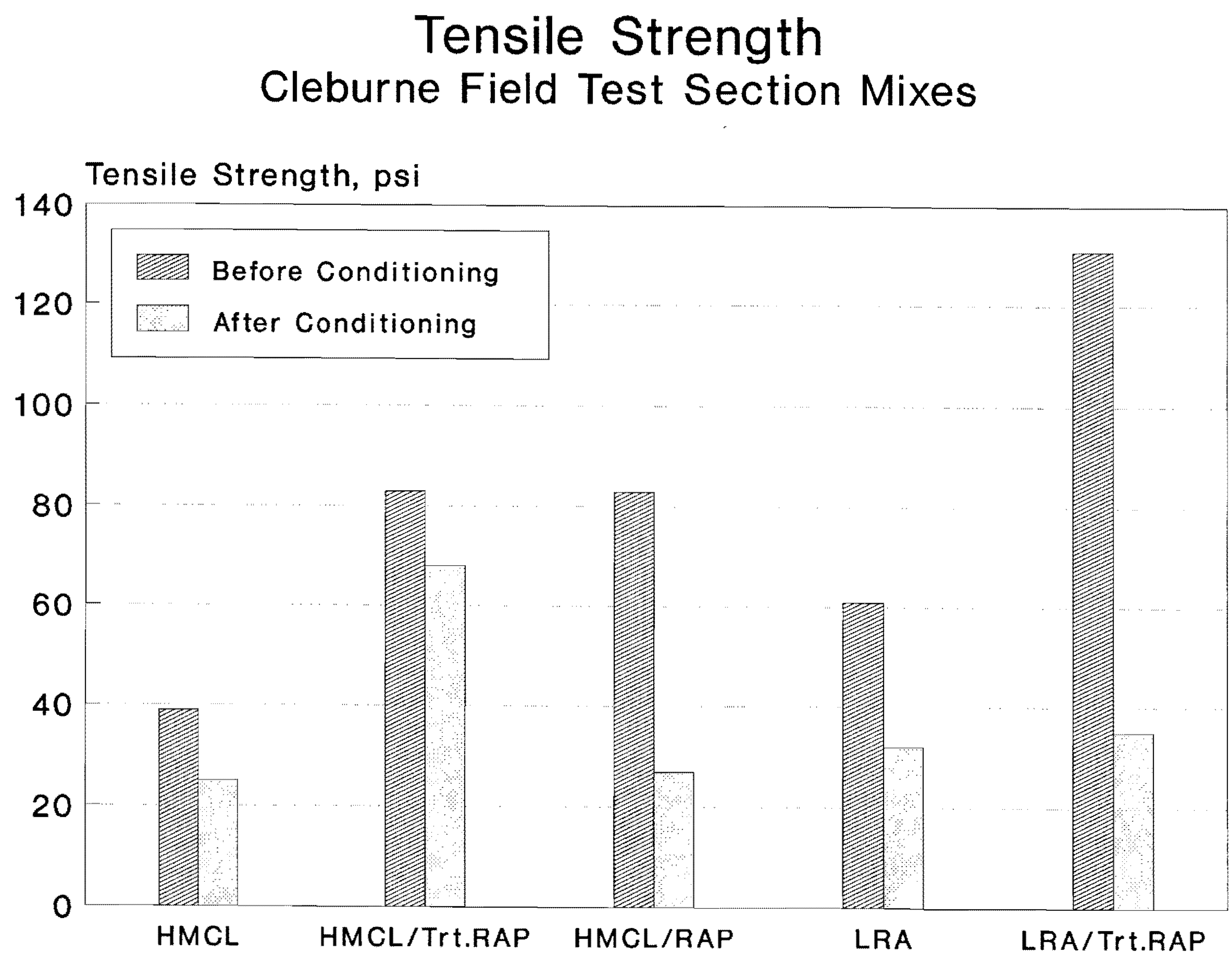

Figure 48. Tensile Strength Data Before and After Moisture Conditioning for Cleburne Test Sections.

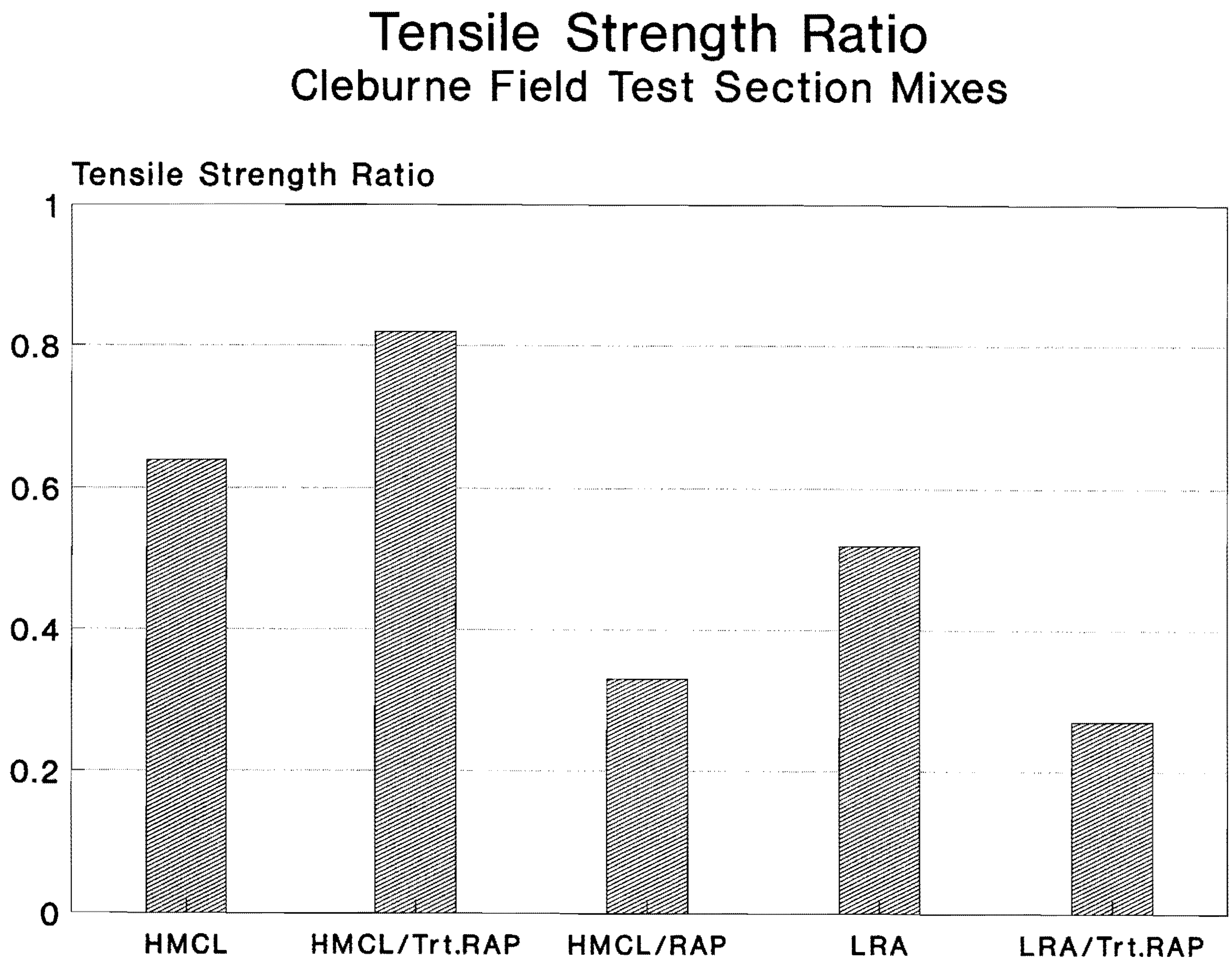

Figure 49. Tensile Strength Ratio for Cleburne Test Sections.

SUMMARY OF FINDINGS

This summary of findings is based on surveys of TxDOT districts and other state highway agencies as well as laboratory and field studies of RAP quality, mixture design procedures, and potential uses of RAP in maintenance and construction of highways.

Survey Results

1. In Fiscal Year (FY) 1991, the Department was reusing about half of the RAP millings produced annually. In FY 1992, the first year after legislation requiring the Department to retain ownership, the Department used about 60 percent of the RAP received.
2. The most common maintenance uses for RAP at the time this study began was for driveways, mailbox turnouts and shoulder repairs.
3. RAP millings generally have a particle size less than 1½ inches; therefore, further crushing is unnecessary for most maintenance uses.
4. At the time this study began, district maintenance personnel reported improvements in RAP quality as a result of blending the RAP with emulsions or with other maintenance mixes.
5. Over 80 percent of the millings being produced in the state are considered to be of a reusable quality for asphalt paving and/or pavement repair.
6. Based on the survey conducted in this study there was approximately 550,000 cubic yards of RAP stockpiled in the state as of October of 1990.

Use of RAP by Other State DOTs

7. Only about 20 percent of State DOTs retain ownership of RAP.
8. Most State DOTs use RAP in hot recycled mixtures. Allowable percentages of RAP in hot mix range from zero to 70 percent. Less RAP is often allowed in surface mixtures than in mixtures for base or binder courses.
9. Several states allow routine use of small quantities of RAP in hot mix, often without altering the mixture design. These small percentages (about 10 percent) have a negligible effect on the selection of asphalt grade and are not a significant factor in plant emissions.
10. Texas DOT now allows the use of RAP in all hot-mixed asphalt concrete pavements and asphalt-stabilized base.

Successful Methods for Improving Quality of RAP

11. The laboratory and field performance of RAP as a maintenance mixture can be improved by mixing the RAP with a recycling agent. In this study, AES-300RP proved to be successful for this use. For guidelines on determination of the quantity of recycling agent to add, see TTI Research Report 1272-2F, "Guidelines on the Use of RAP in Maintenance Activities".

12. The laboratory properties and field performance of raw RAP and RAP which has been processed with a recycling agent can be significantly improved when blended with commonly available maintenance mixtures such as hot-mixed, cold-laid (HMCL) ACP and cold-mixed limestone rock asphalt pavement. When mixing a conventional maintenance mixture with RAP which as been processed with a recycling agent, it is recommended that the two materials be blended at the following ratio:

    50 percent treated or processed RAP
    50 percent conventional maintenance mix.

    When mixing untreated or raw RAP with conventional maintenance mixes, a more appropriate proportion is

    40 percent raw RAP
    60 percent conventional maintenance mix.

Field Study

13. Two processes for blending RAP with emulsion were evaluated in this study: pugmill mixing and blade/pulver-mixing. A uniform blend was achieved with both processes and costs were comparable for both processes; however, the blade/pulver-mixing process is more time-consuming and labor-intensive. For contracted pugmill mixing, at least 5000 cubic yards of RAP should be blended in order to be cost effective.

14. A raw RAP stockpile should be processed with a recycling emulsion or used within one year to prevent stockpile from "setting up". A RAP stockpile which has been treated with a recycling emulsion should also be used within one year of processing.

15. When RAP is blended with a recycling emulsion and stockpiled for maintenance use, the stockpile should be allowed to cure for time period specified by the emulsion manufacturer. This time is needed for the recycling emulsion to have a softening effect on the aged binder in the RAP.

16. Handling of RAP material should be kept to a minimum to keep its cost low.
17. When blending RAP or treated RAP with conventional maintenance mixtures, blending should be done at stockpile or a location other than the jobsite where it is to be placed. This reduces the time of construction activity on the road.
18. Test sections of RAP and treated RAP blended with conventional maintenance mixtures (HMCL and LRA) were placed in five locations across the state. All test sections are performing satisfactorily at this time.
19. RAP was used as a base material or to supplement the base in three successful maintenance projects in this study:
    - Bryan District - A base failure was repaired using untreated RAP,
    - Yoakum District - Asphalt pavement surface was pulverized and blended in place with existing base and stabilized with asphalt cement,
    - Houston District - Stockpiled RAP was blade-mixed with cement and water and used to construct the base for a new parking lot at the district office.

Laboratory Study

20. Degradation of the aggregate occurs during the milling process as shown in Figure 10.
21. Conventional mix design procedures do not always apply to mixes of 100 percent RAP. This may be because the RAP is already at or above an optimum asphalt content.
22. Increasing levels of emulsion (AES-300RP and MS-1) generally cause a decrease in Hveem stability, resilient modulus, and tensile strength.
23. Laboratory samples of RAP blended with LRA (50/50) exhibited increases in Hveem stability, Marshall stability, and resilient modulus over that of the LRA alone.
24. Of the mixture tests examined in this study, Hveem stability appears to be the best test for characterizing RAP and RAP blends in terms of expected performance.
25. Hveem stabilities for RAP blended with AES-300RP are generally less than 25; however, field performance in routine maintenance for low-traffic areas has been satisfactory on these mixtures.

26. Laboratory properties of RAP and treated RAP are significantly improved when blended with conventional maintenance mixtures such as HMCL and LRA.
27. RAP mixtures are generally more susceptible to moisture damage than conventional maintenance mixtures.

Additional Information

For more information regarding the results of this research study refer to the following:

- Estakhri, C. , "Guidelines on the Use of RAP in Routine Maintenance Activities," Field Manual, Research Report 1272-2F, Texas Transportation Institute, College Station, February 1993.
- Guidelines on the Use of RAP in Routine Maintenance Activities, 15-minute video, will be available from TxDOT's Division of Transportation Planning - Research Section.
- Guidelines on the Use of RAP in Pavement Engineering Applications, 15-minute video, will be available from TxDOT's Division of Transportation Planning - Research Section.

Recommended Research

Most engineers consider RAP to be a quality paving material. TxDOT has used RAP for many years in pavement maintenance and construction activities. The results of this study have provided information to assist the districts in increasing the use and improving the qualities of RAP in maintenance activities.

There appears to be an economic burden to the State of Texas as a result of the legislation requiring the State to retain ownership of RAP. Many of the costs associated with the requirement are virtually unknown: bookkeeping, administrative, land-use for RAP storage, maintenance of RAP stockpiles, RAP hauling costs. Most of the other states and European countries give ownership of the RAP to the contractor because they believe it is most economical. This ostensibly gives contractors flexibility and a competitive edge which should be seen in lower bid prices which, in turn, would save the State money.

Research is needed to determine the costs to the State of Texas associated with retaining ownership of the RAP under the new law. This research should also include an investigation to determine the savings, if any, when the contractor retains ownership of RAP to be reused in paving applications.

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1. Epps, J. A., Little, D. N., Holmgreen, R. J. and Terrel, R. L., "Guidelines for Recycling Pavement Materials," National Cooperative Highway Research Program Report 224, Transportation Research Board, National Research Council, Washington, D.C., September, 1980.

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4. Perez, I., Kennedy, T. W., and Adedimila, A. S., "Development of a Mixture Design Procedure for Recycled Asphalt Mixtures," Report 183-10, Center for Transportation Research, University of Texas, Austin, Texas, November, 1978.

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8. Kandahl, K., Brown, E.R., and Cross, S., "Guidelines for Hot Mix Recycling in Georgia," Report No. FHWA-GA-89-8807, National Center for Asphalt Technology, Auburn University, September, 1989.

9. Eaton, M., "Asphalt Recycling and Reclaiming," Roads & Bridges Magazine, October, 1990.

10. "Handling and Processing of Reclaimed Asphalt Pavement (RAP)", National Asphalt Pavement Association, Information Series 88, July 1983.

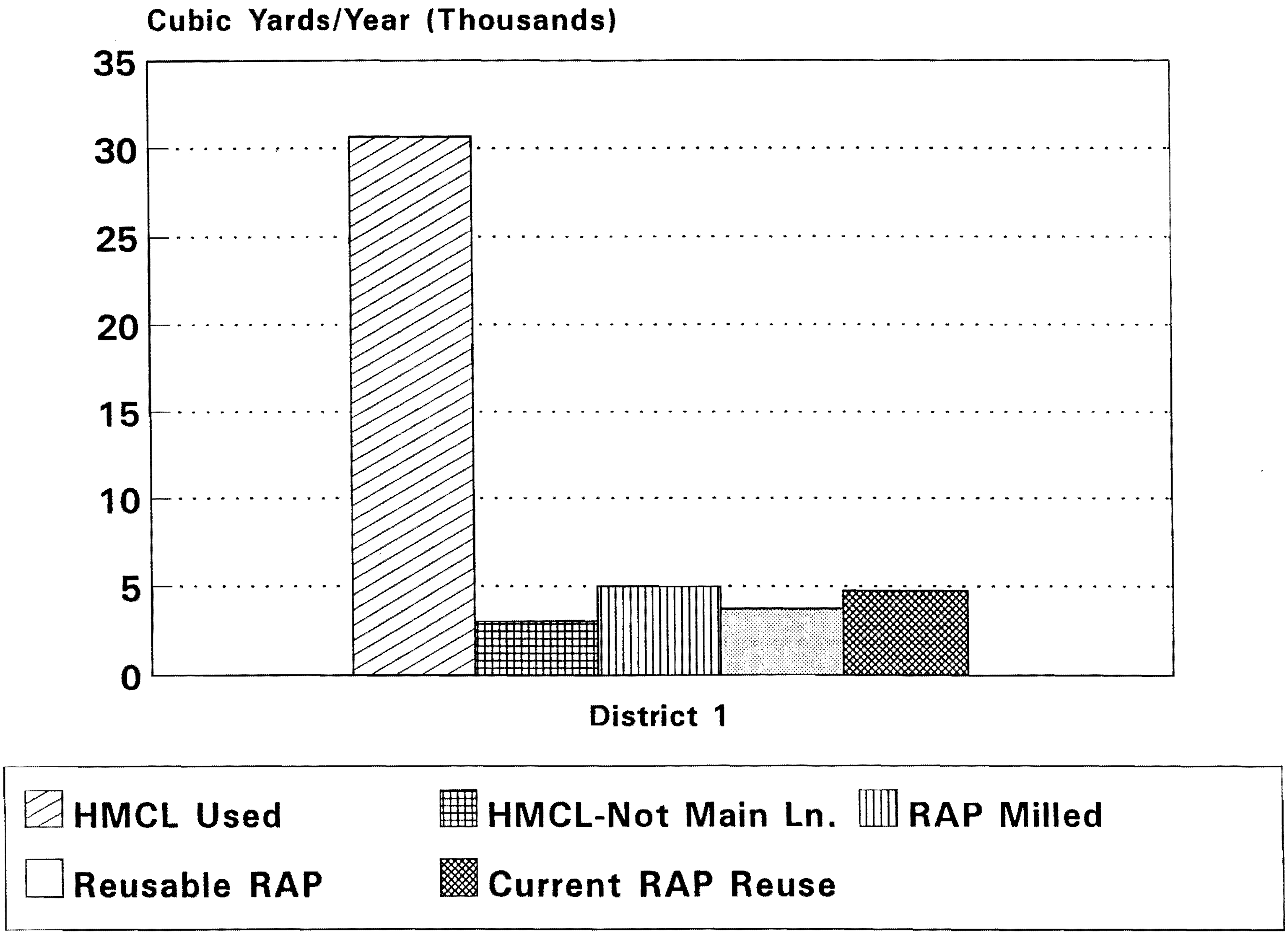
11. <u>Manual of Testing Procedures</u>, Texas Department of Transportation, Austin, Texas.

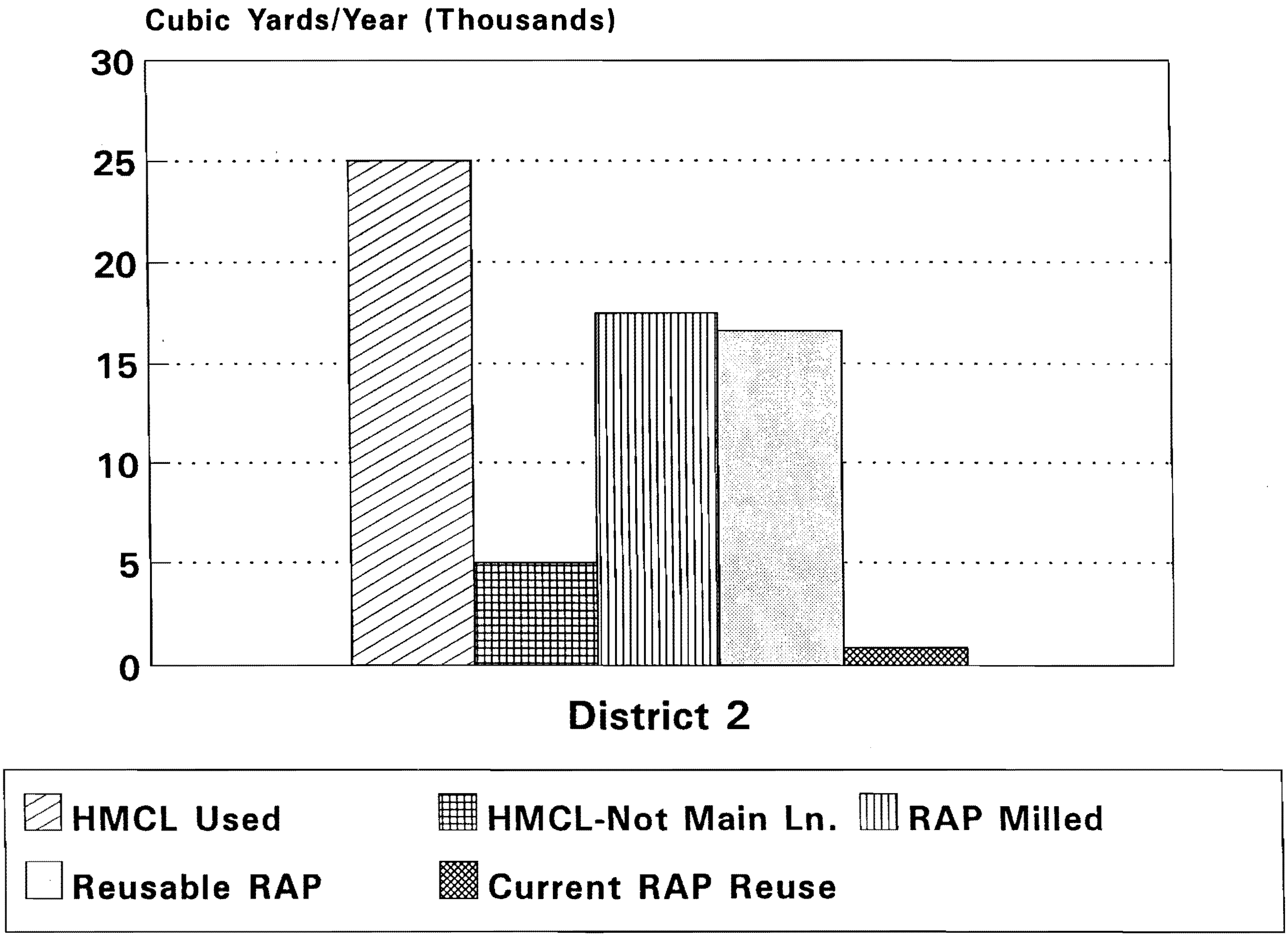
APPENDIX A

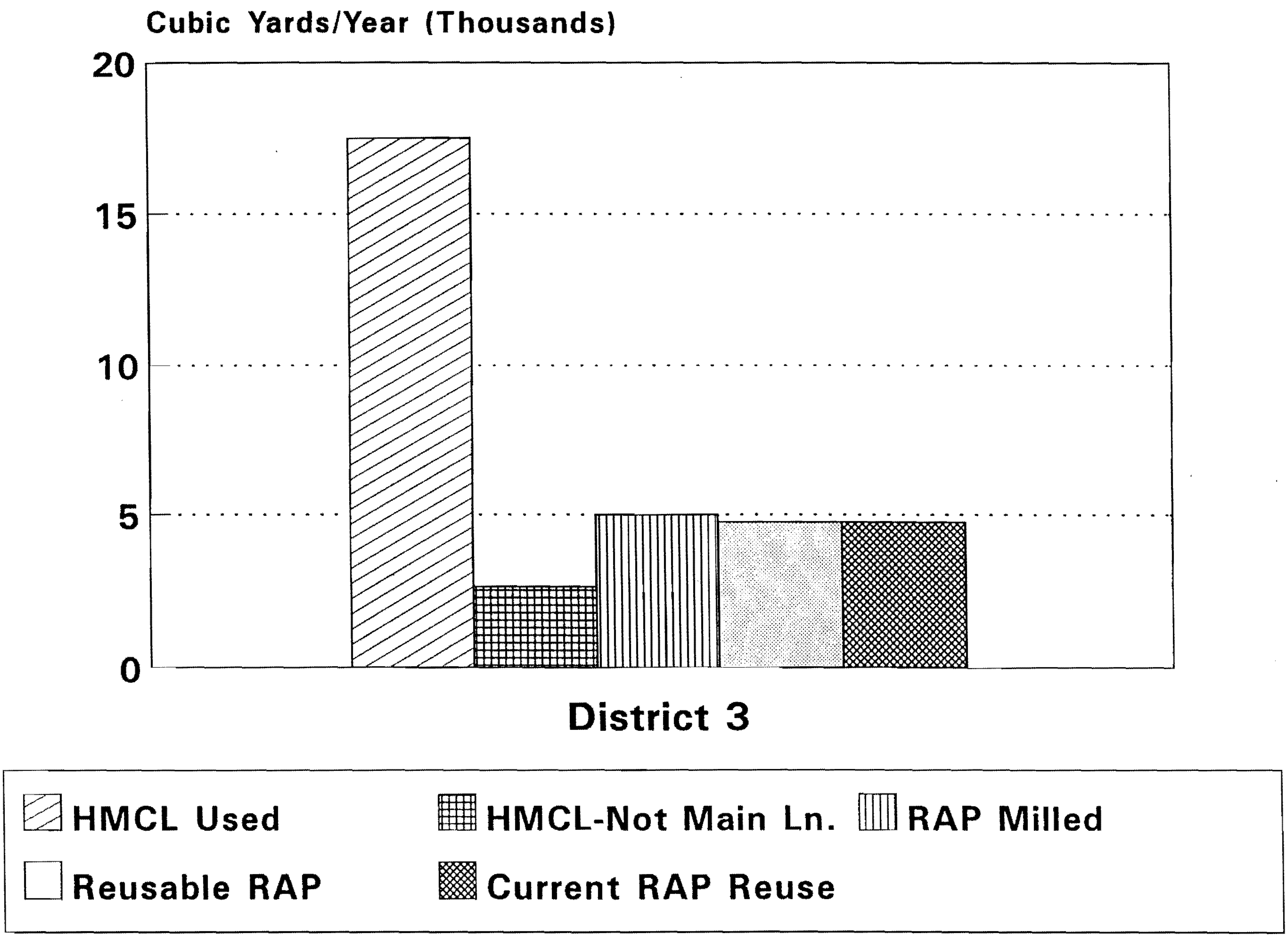
QUESTIONNAIRE RESULTS FOR INDIVIDUAL DISTRICTS

Table A1. Results of RAP Questionnaire.

District	Quantity of Bituminous Material Milled, yd^3/year	Quantity of Millings Considered Reusable, yd^3/year	Percentage of Millings Considered Reusable	Quantity of Millings Reused, yd^3/year	Percentage of Millings Given to Contractor	Stockpiled Quantity of Millings as of October 1990, yd^3	Use of HMCL, Asphalt-Concrete Pavement, yd^3/year	Use of HMCL in Location Other than Main Lanes, yd^3/year
1	5,000	3,750	75	4,750	5	5,000	30,650	3,065
2	17,500	16,625	95	875	95	37,500	25,000	5,000
3	5,000	4,750	95	4,750	5	17,500	17,500	2,625
4	17,500	13,125	75	4,375	75	17,500	11,200	1,960
5	30,000	15,800	53	4,000	87	400	2,300	2,070
6	37,500	28,125	75	1,875	95	5,000	5,000	1,250
7	5,000	4,750	95	4,750	5	5,000	8,200	410
8	62,500	46,875	75	3,125	95	5,000	30,000	3,000
9	17,500	16,625	95	4,375	75	5,000	43,000	3,010
10	5,000	4,750	95	4,750	5	5,000	60,000	3,000
11	5,000	5,000	100	5,000	0	5,000	25,000	2,500
12	5,000	3,750	75	4,750	5	37,500	10,000	250
13	5,000	3,750	75	4,750	5	5,000	28,000	2,240
14	17,500	13,125	75	875	95	5,000	53,000	2,650
15	5,000	4,750	95	4,750	5	50,000	20,000	1,000
16	5,000	4,750	95	250	95	5,000	73,000	3,650
17	5,000	3,750	75	4,000	20	17,500	6,600	660
18	62,500	59,375	95	59,375	95	175,000	75,000	75,000
19	37,500	28,125	75	30,000	20	37,500	20,000	2,000
20	17,500	13,125	75	16,625	5	17,500	40,000	4,000
21	17,500	16,625	95	9,625	45	17,500	20,000	4,000
23	5,000	4,750	95	4,750	5	37,500	75,050	7,505
24	5,000	4,750	95	4,750	5	5,000	1,000	200
25	17,500	16,625	95	16,625	5	37,500	6,600	1,650
Total	412,500	337,425	82	203,750	51	555,400	686,100	132,695


Cubic Yards/Year (Thousands)
35
30
25
20
15
10
5
0
District 1
HMCL Used
HMCL-Not Main Ln.
RAP Milled
Reusable RAP
Current RAP Reuse


Cubic Yards/Year (Thousands)
30
25
20
15
10
5
0
District 2
HMCL Used
HMCL-Not Main Ln.
RAP Milled
Reusable RAP
Current RAP Reuse


Cubic Yards/Year (Thousands)
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15
10
5
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District 3
HMCL Used
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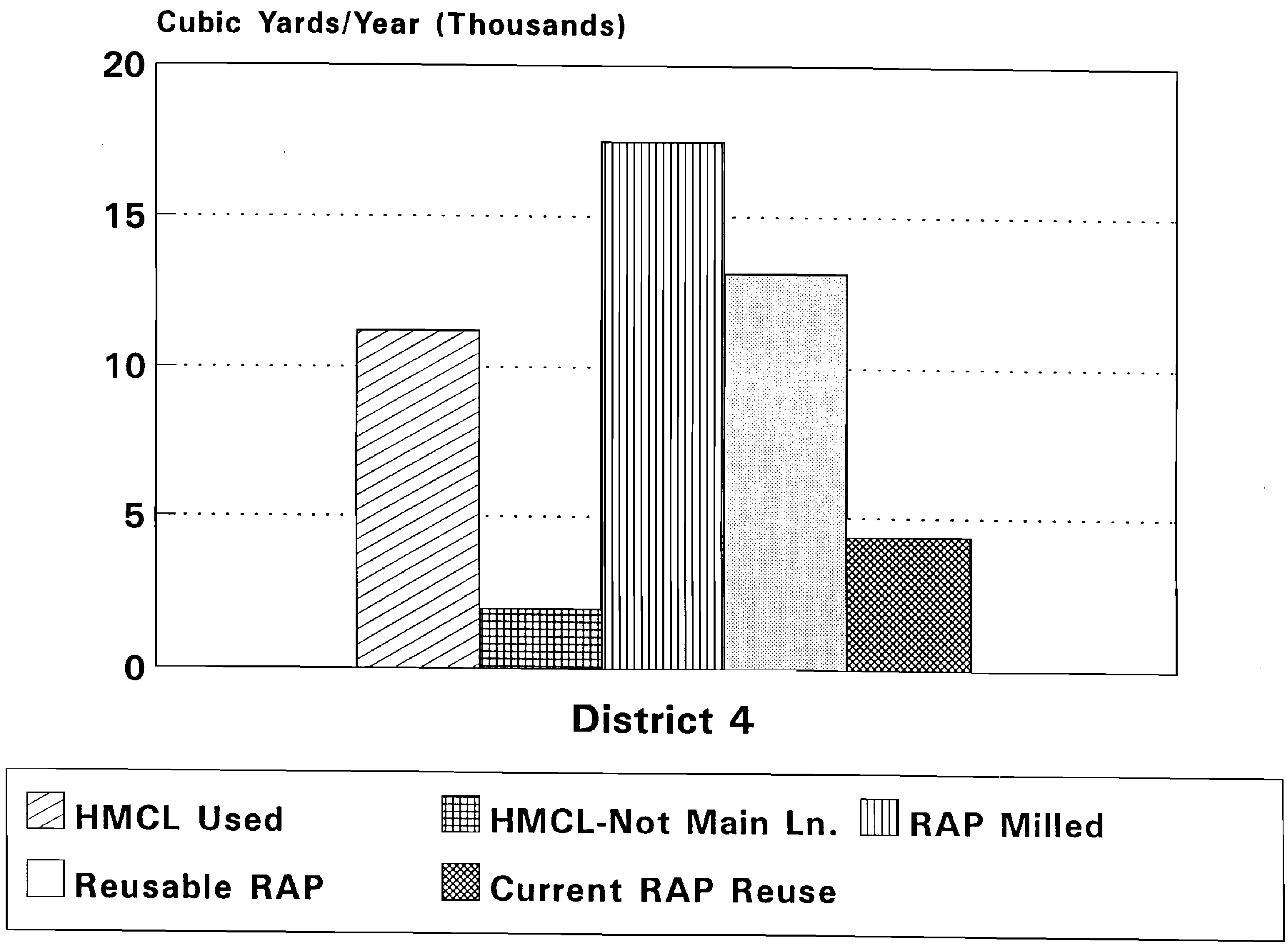
RAP Milled
Reusable RAP
Current RAP Reuse


Cubic Yards/Year (Thousands)
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15
10
5
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District 4
HMCL Used
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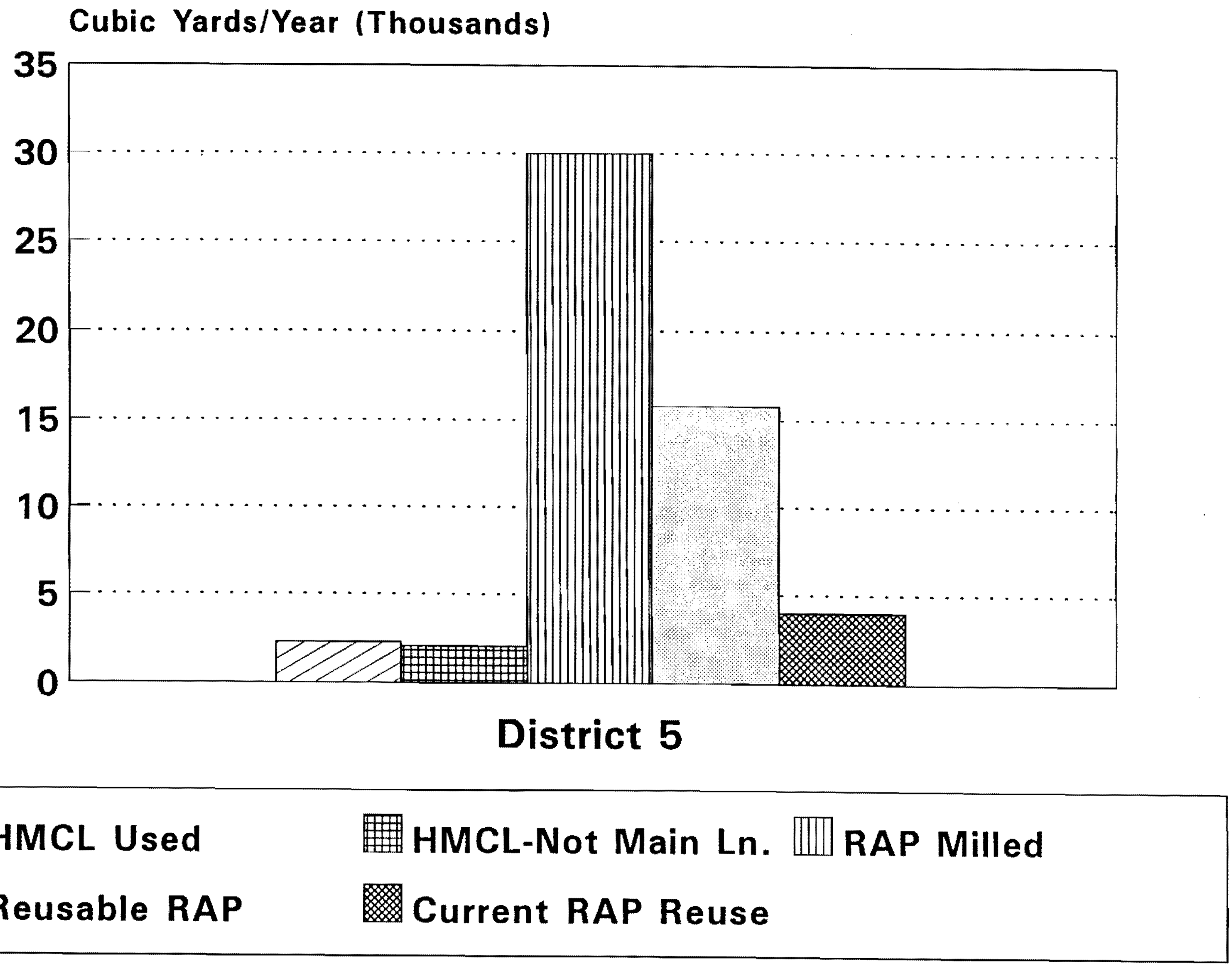
RAP Milled
Reusable RAP
Current RAP Reuse


Cubic Yards/Year (Thousands)
35
30
25
20
15
10
5
0
District 5
HMCL Used
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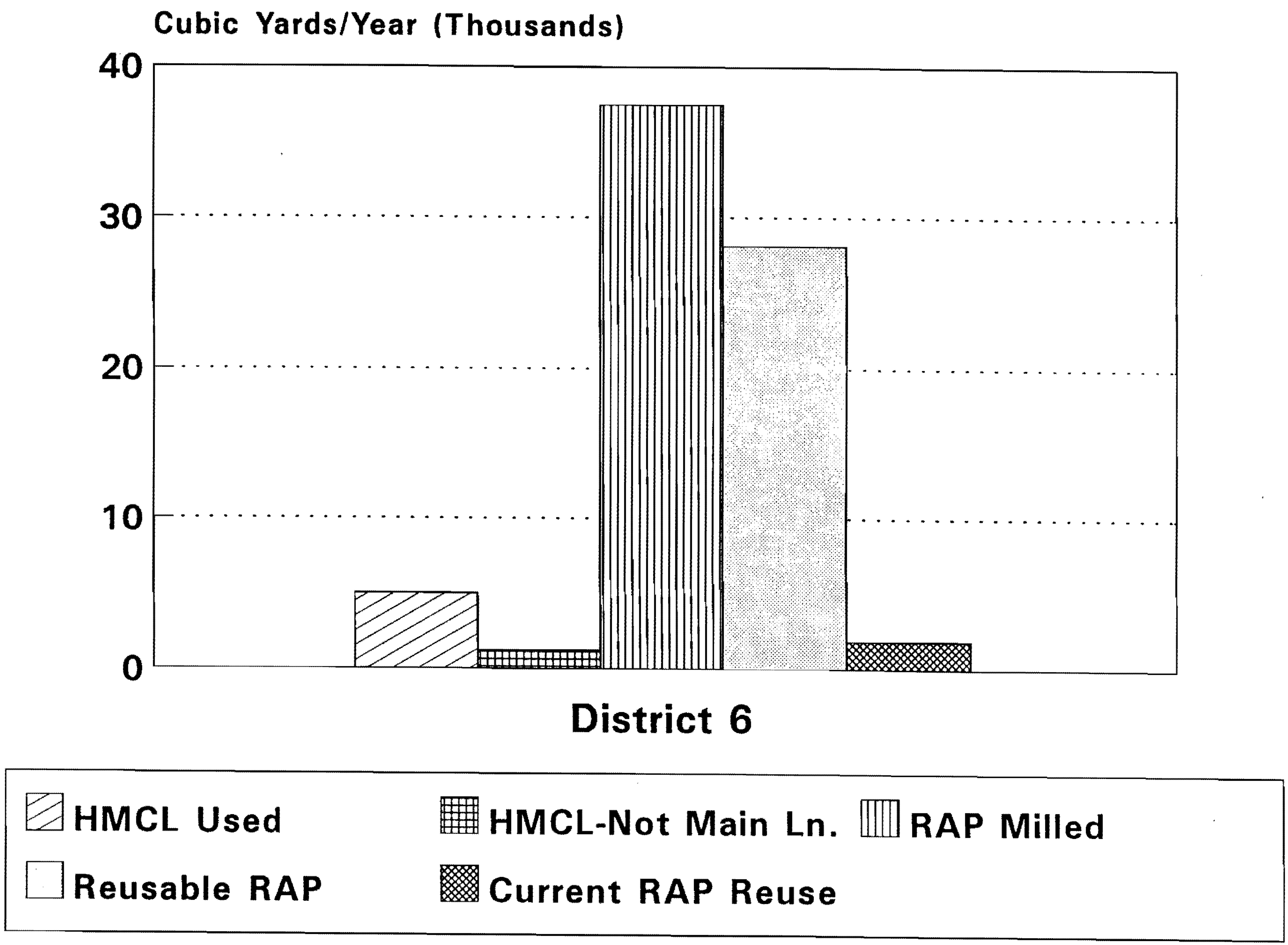
RAP Milled
Reusable RAP
Current RAP Reuse


Cubic Yards/Year (Thousands)
40
30
20
10
0
District 6
HMCL Used
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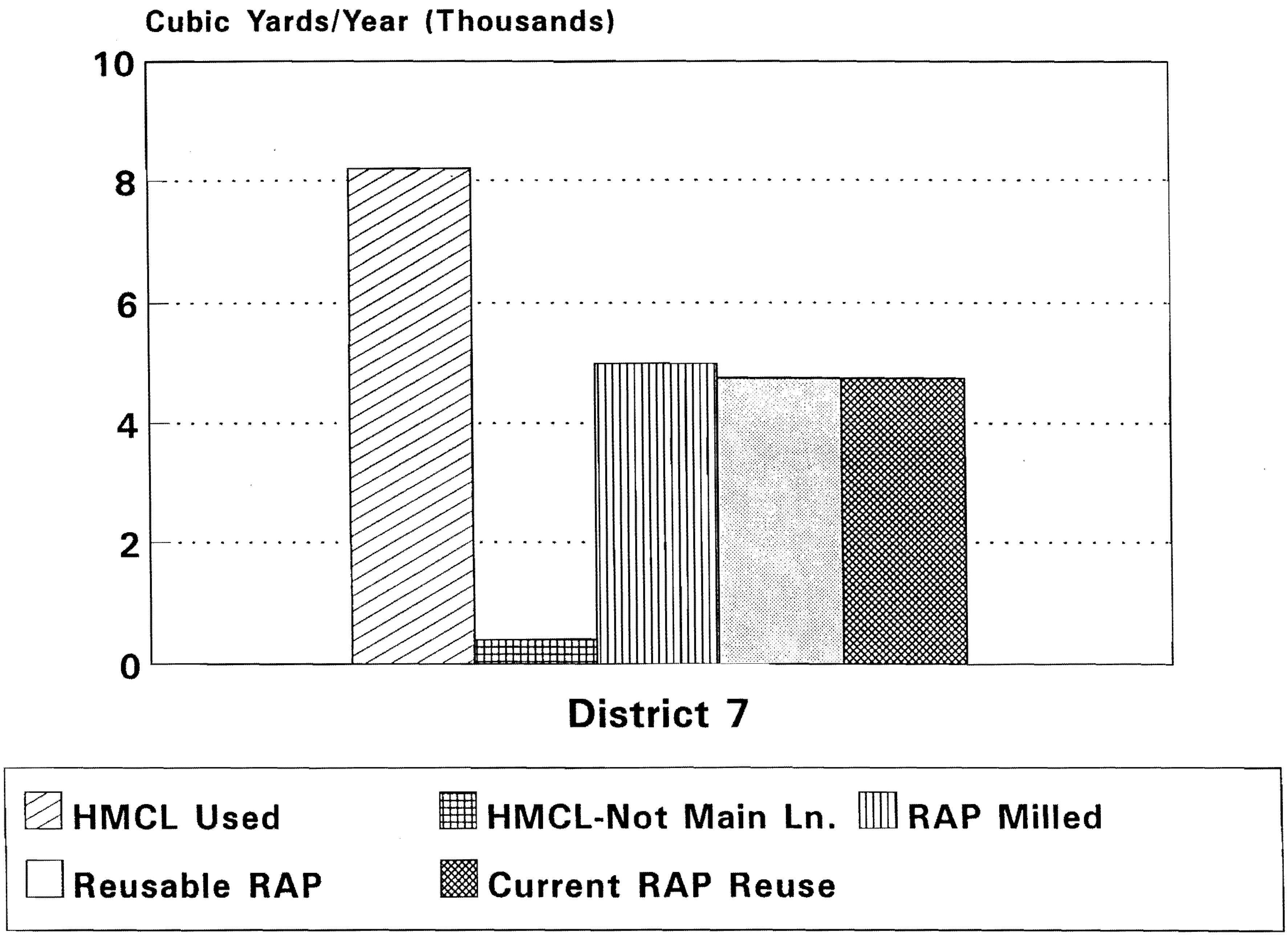
RAP Milled
Reusable RAP
Current RAP Reuse


Cubic Yards/Year (Thousands)
10
8
6
4
2
0
District 7
HMCL Used
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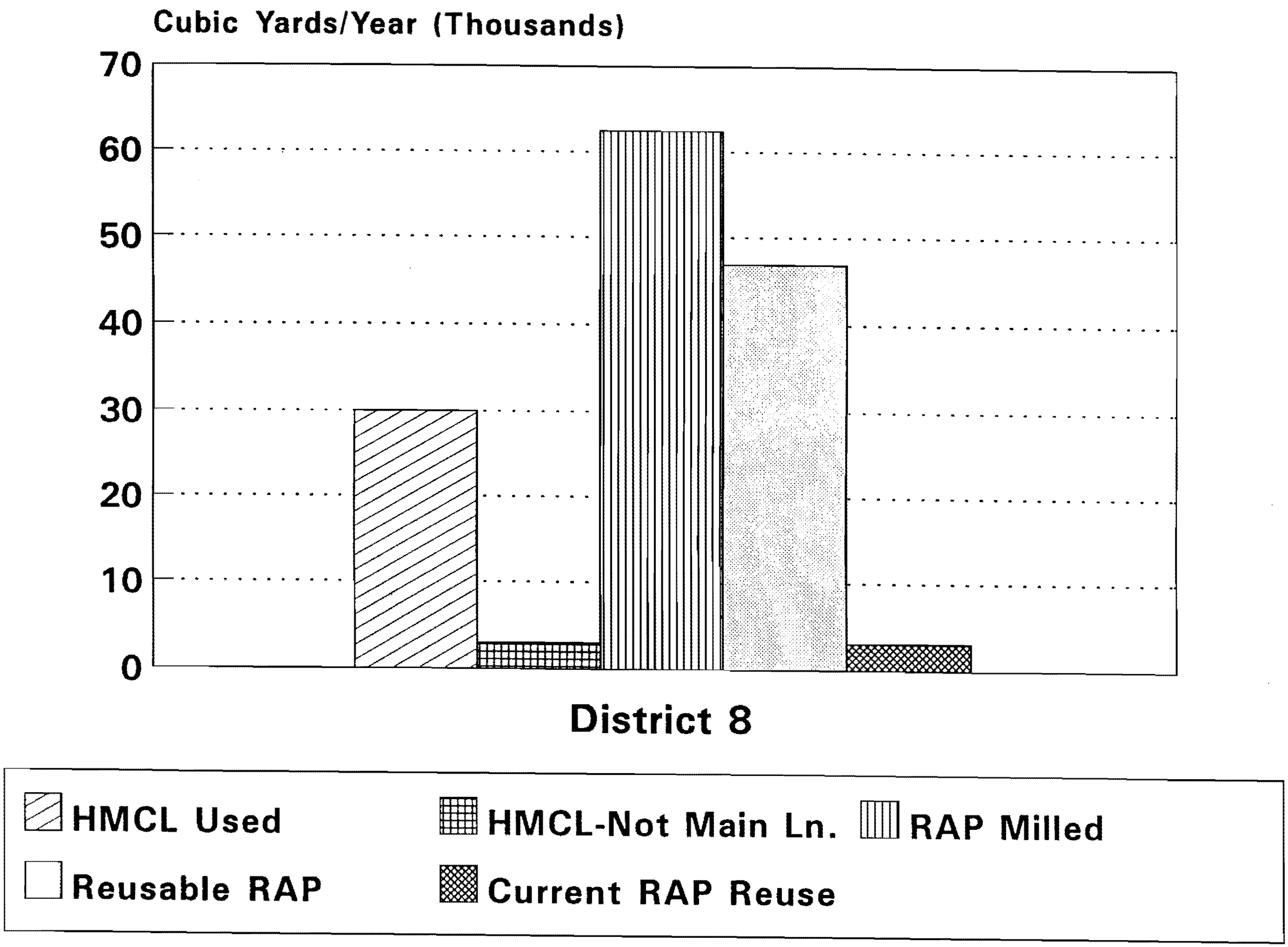
RAP Milled
Reusable RAP
Current RAP Reuse


Cubic Yards/Year (Thousands)
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60
50
40
30
20
10
0
District 8
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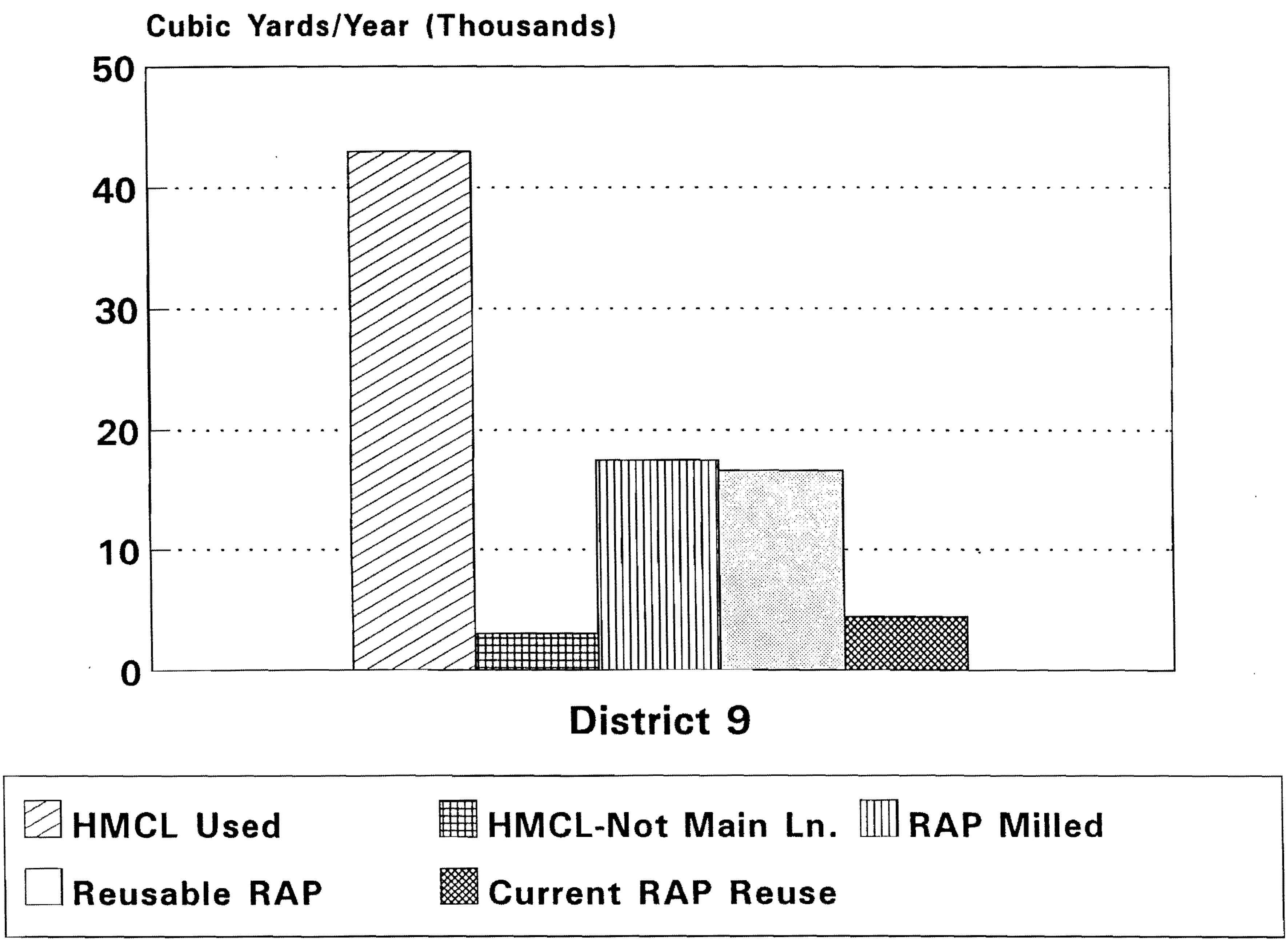
RAP Milled
Reusable RAP
Current RAP Reuse


Cubic Yards/Year (Thousands)
50
40
30
20
10
0
District 9
HMCL Used
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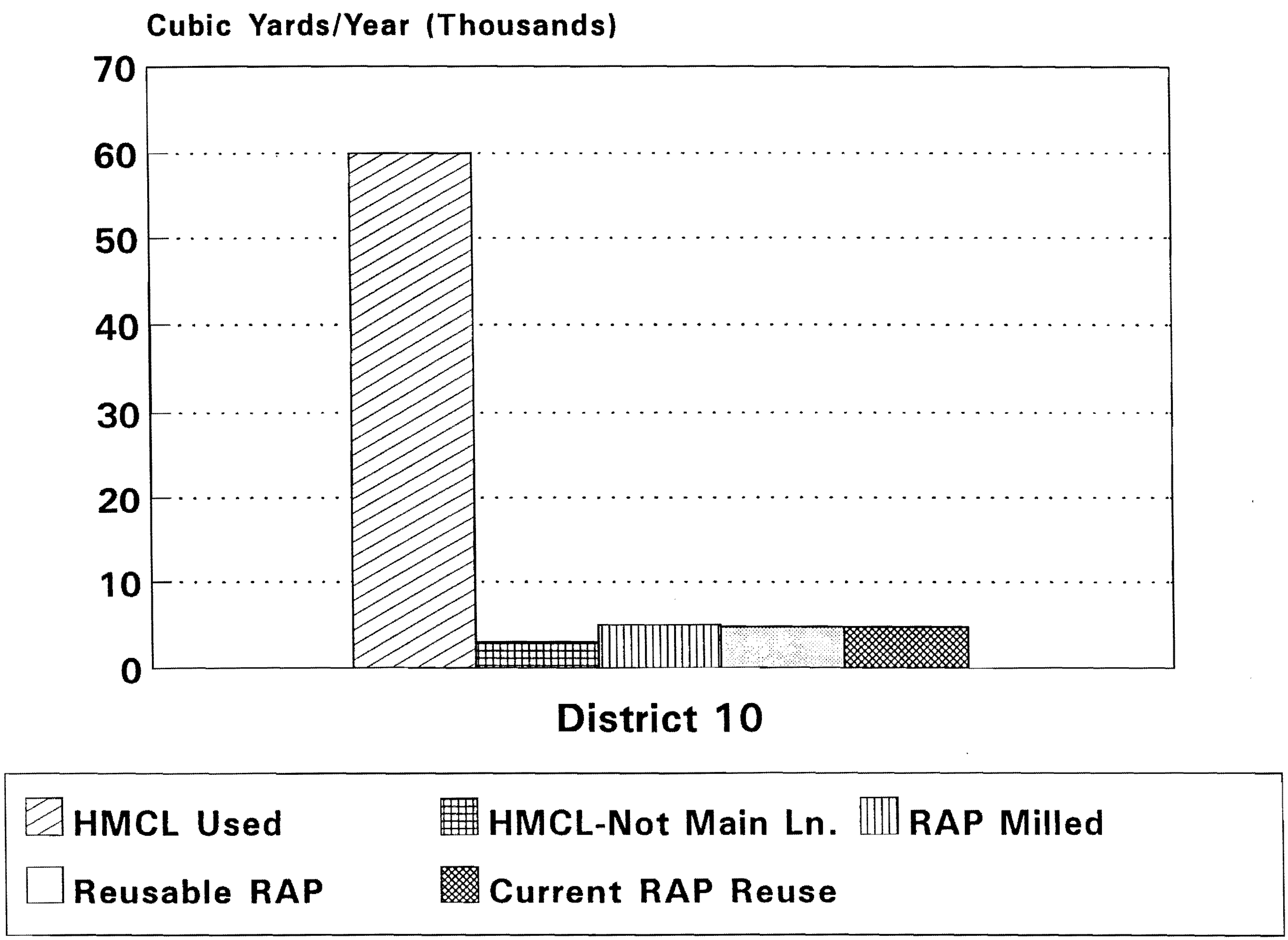
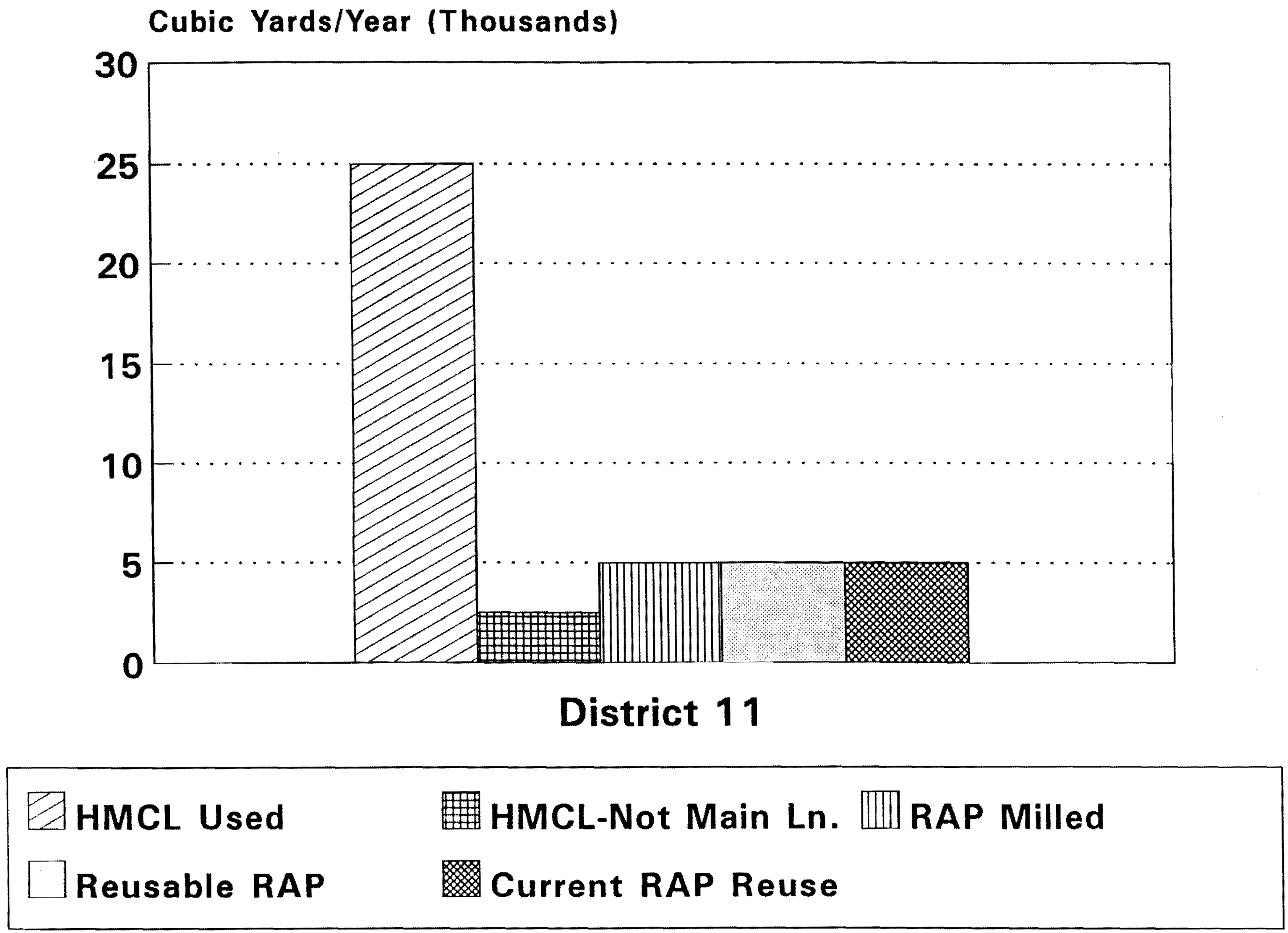
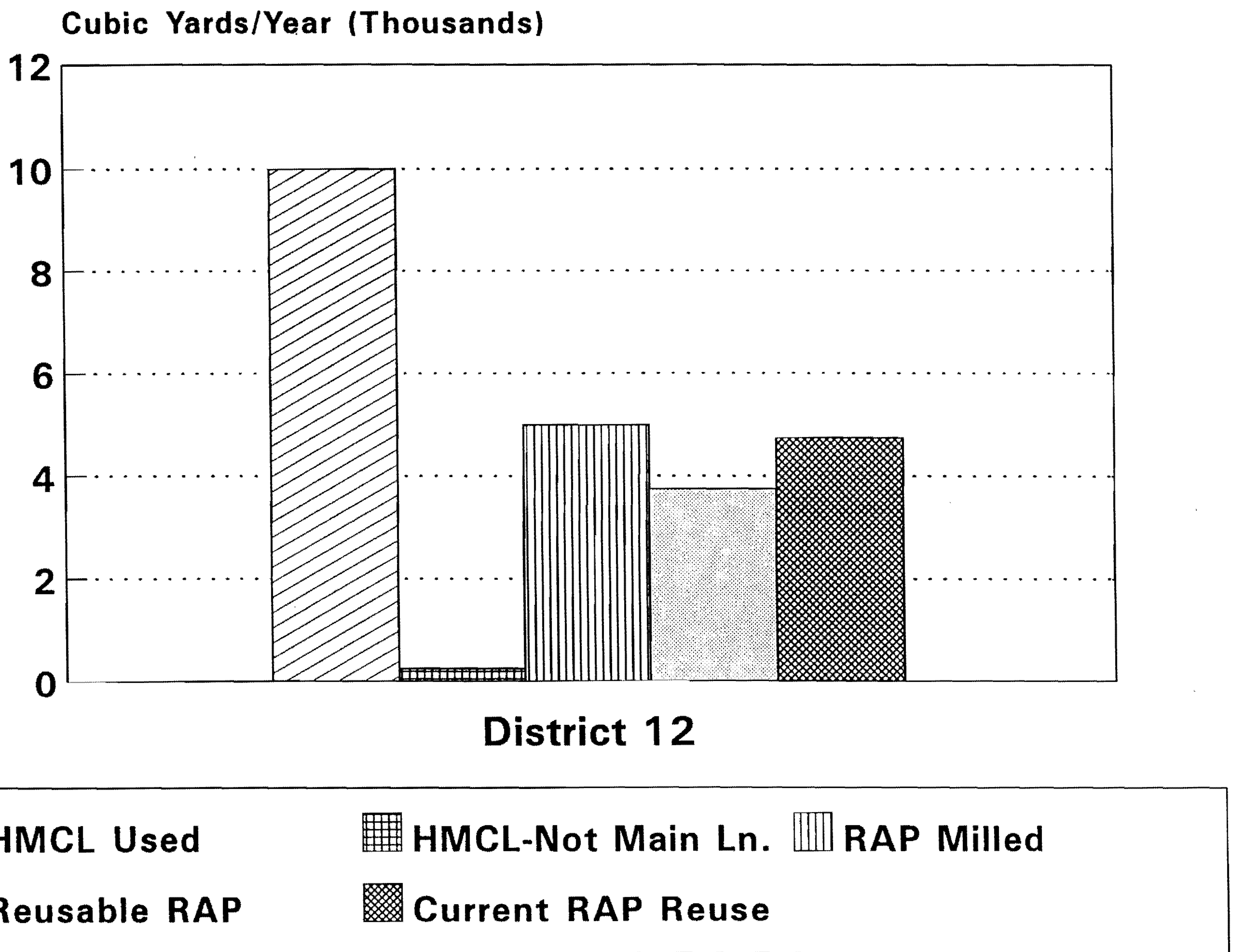
RAP Milled
Reusable RAP
Current RAP Reuse



Cubic Yards/Year (Thousands)
70
60
50
40
30
20
10
0
District 10
HMCL Used
HMCL-Not Main Ln.
RAP Milled
Reusable RAP
Current RAP Reuse



Cubic Yards/Year (Thousands)
30
25
20
15
10
5
0
District 11
HMCL Used
HMCL-Not Main Ln.
RAP Milled
Reusable RAP
Current RAP Reuse


Cubic Yards/Year (Thousands)
12
10
8
6
4
2
0
District 12
HMCL Used
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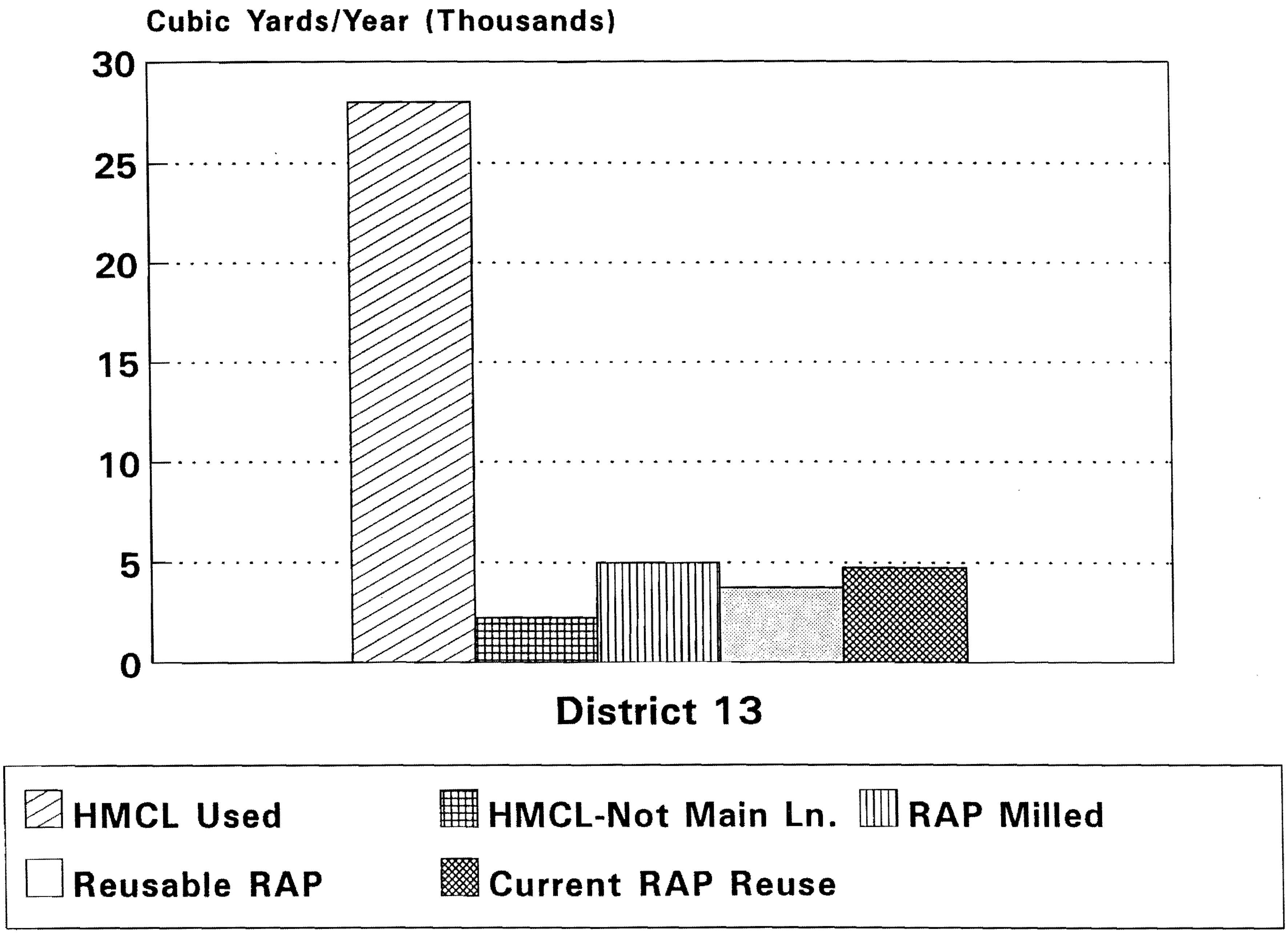
RAP Milled
Reusable RAP
Current RAP Reuse


Cubic Yards/Year (Thousands)
30
25
20
15
10
5
0
District 13
HMCL Used
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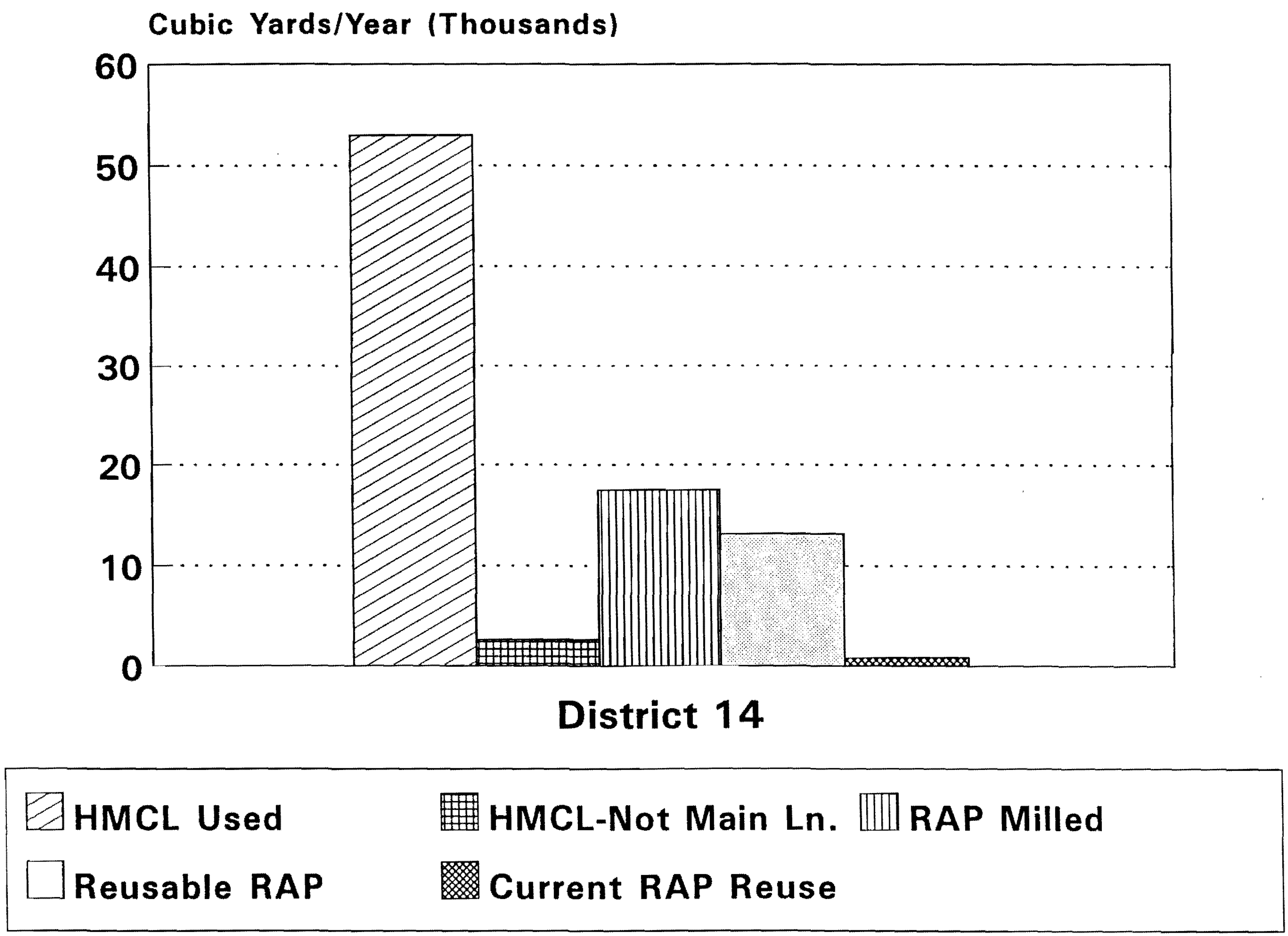
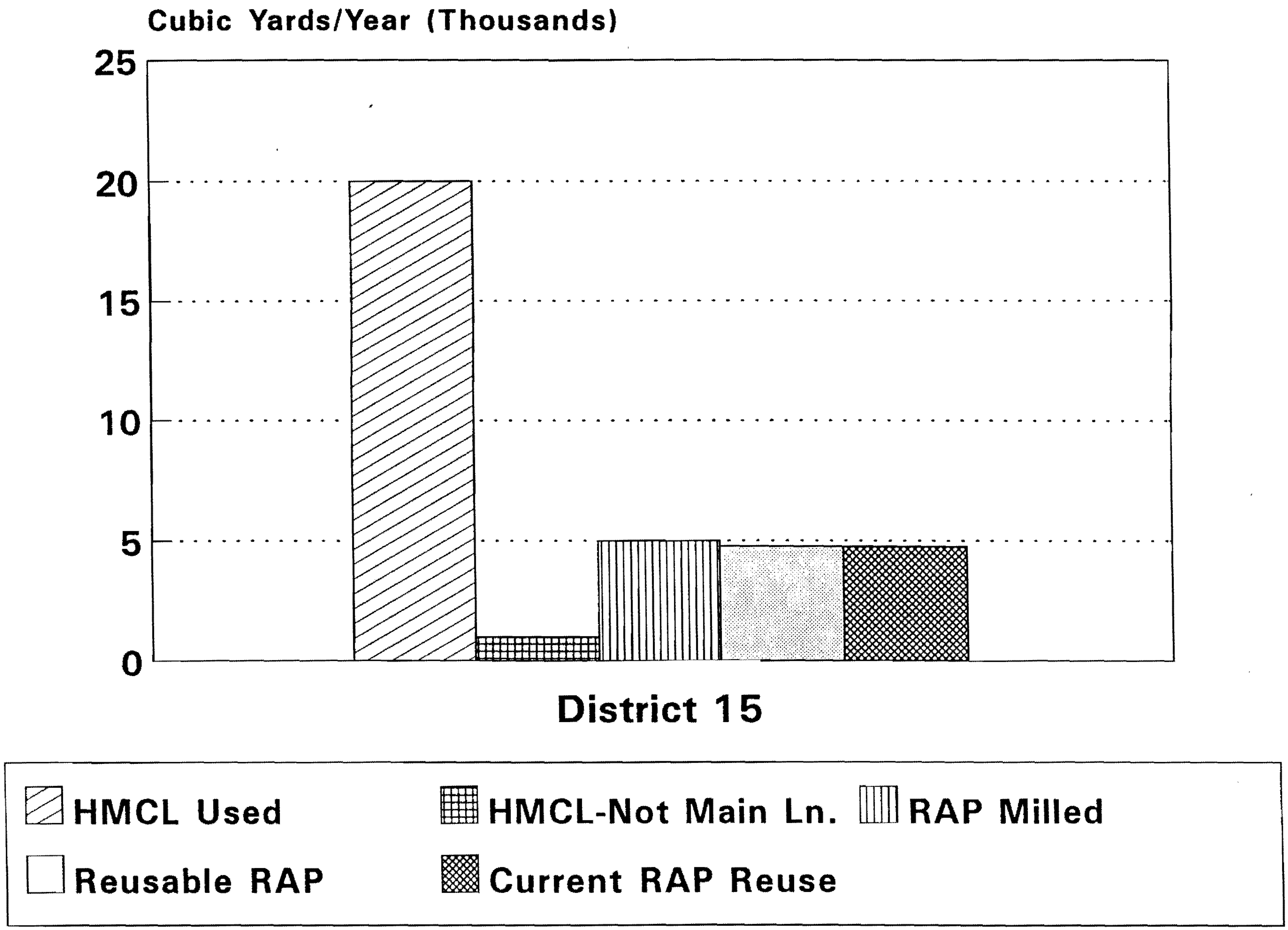
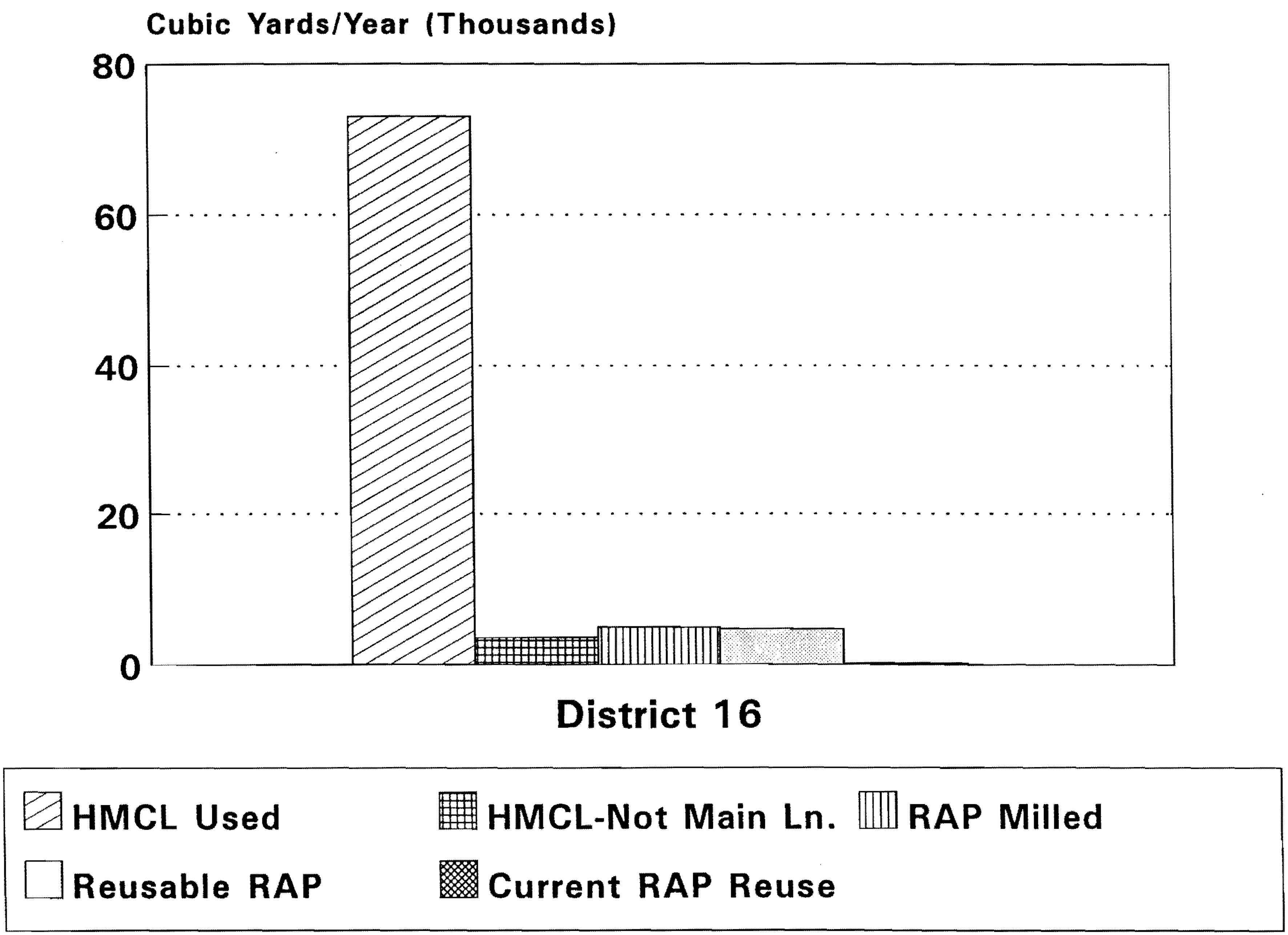
RAP Milled
Reusable RAP
Current RAP Reuse


Cubic Yards/Year (Thousands)
60
50
40
30
20
10
0
District 14
HMCL Used
HMCL-Not Main Ln.
RAP Milled
Reusable RAP
Current RAP Reuse


Cubic Yards/Year (Thousands)
25
20
15
10
5
0
District 15
HMCL Used
HMCL-Not Main Ln.
RAP Milled
Reusable RAP
Current RAP Reuse


Cubic Yards/Year (Thousands)
80
60
40
20
0
District 16
HMCL Used
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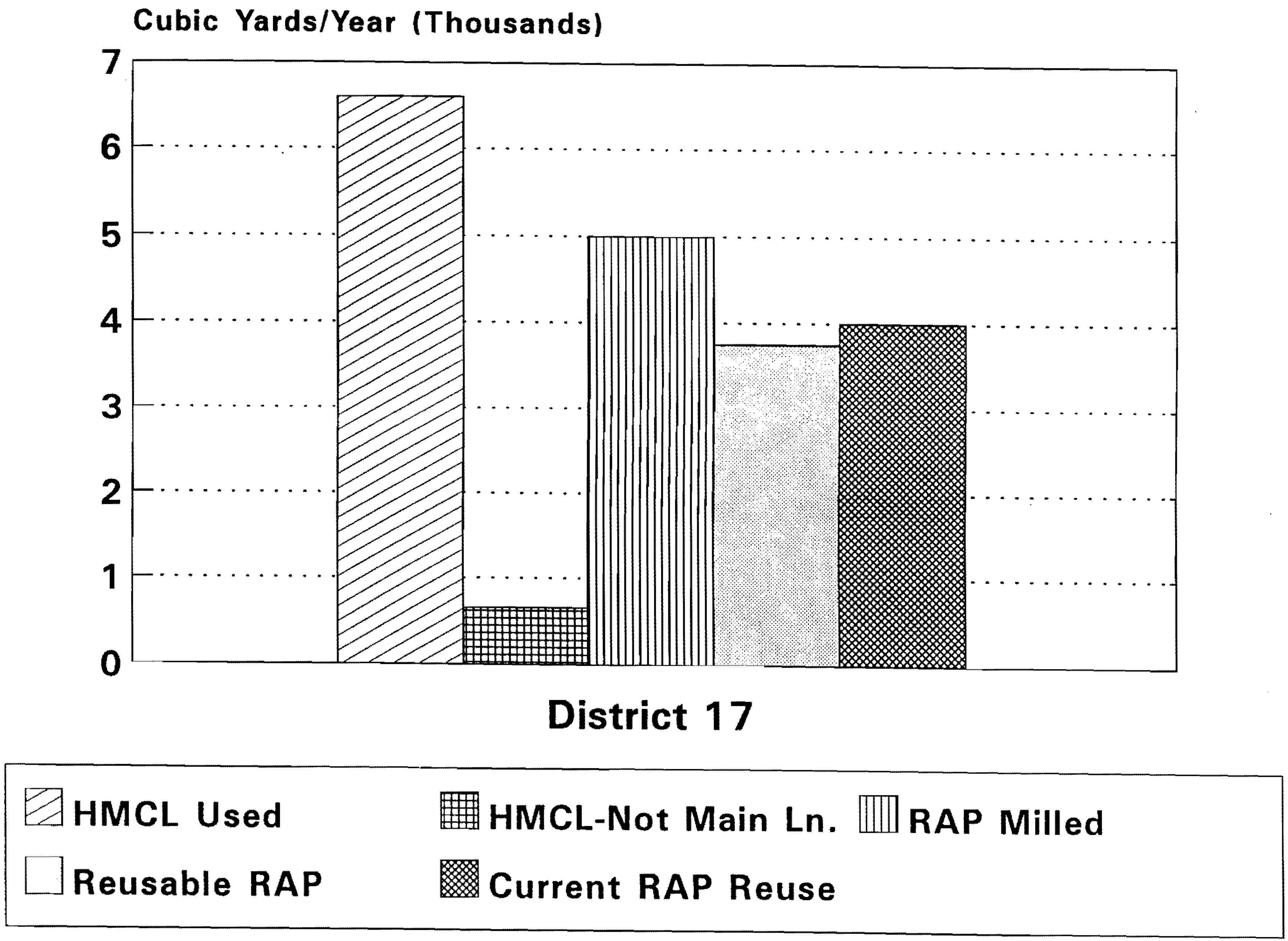
RAP Milled
Reusable RAP
Current RAP Reuse


Cubic Yards/Year (Thousands)
0
1
2
3
4
5
6
7
District 17
HMCL Used
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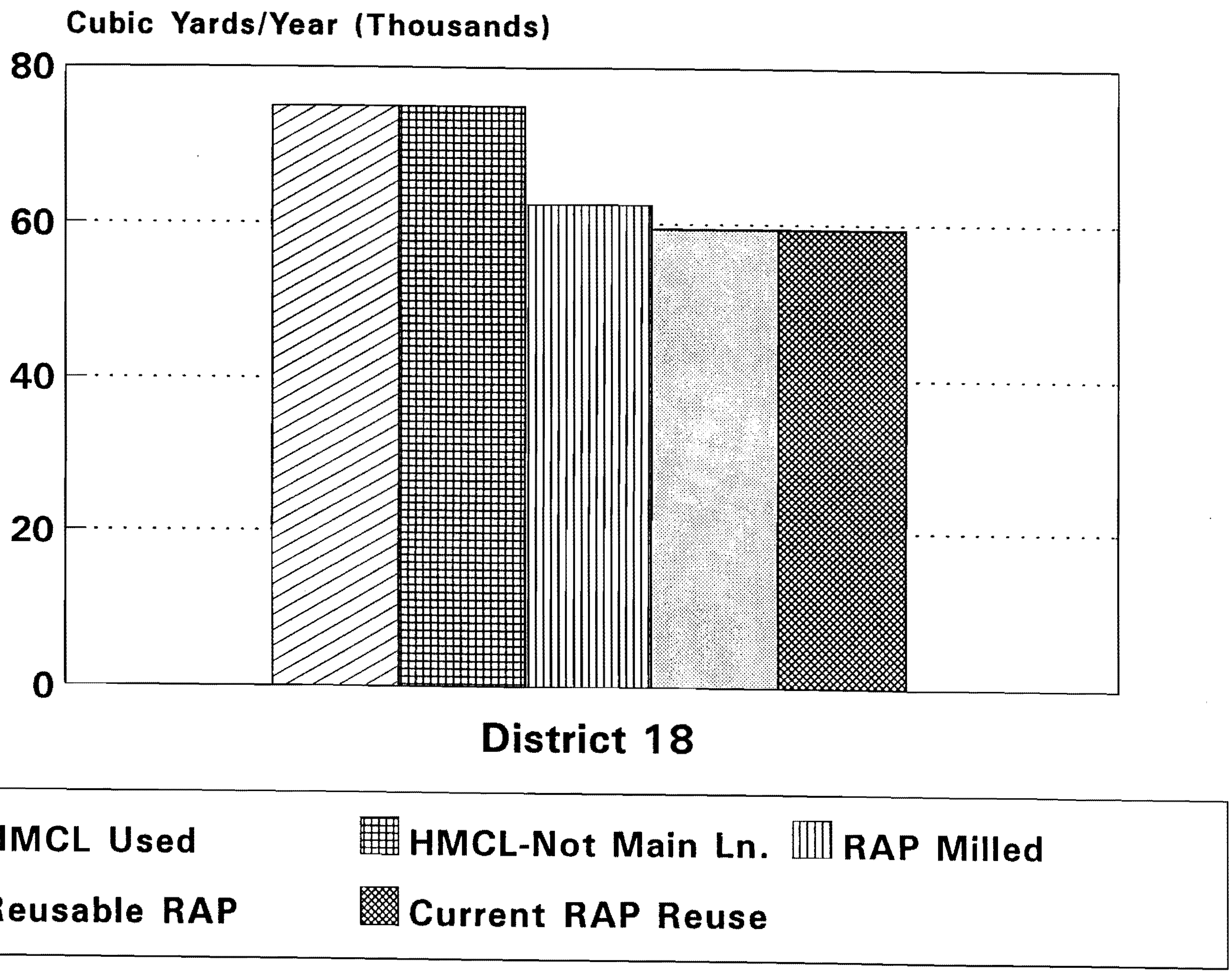
RAP Milled
Reusable RAP
Current RAP Reuse


Cubic Yards/Year (Thousands)
80
60
40
20
0
District 18
HMCL Used
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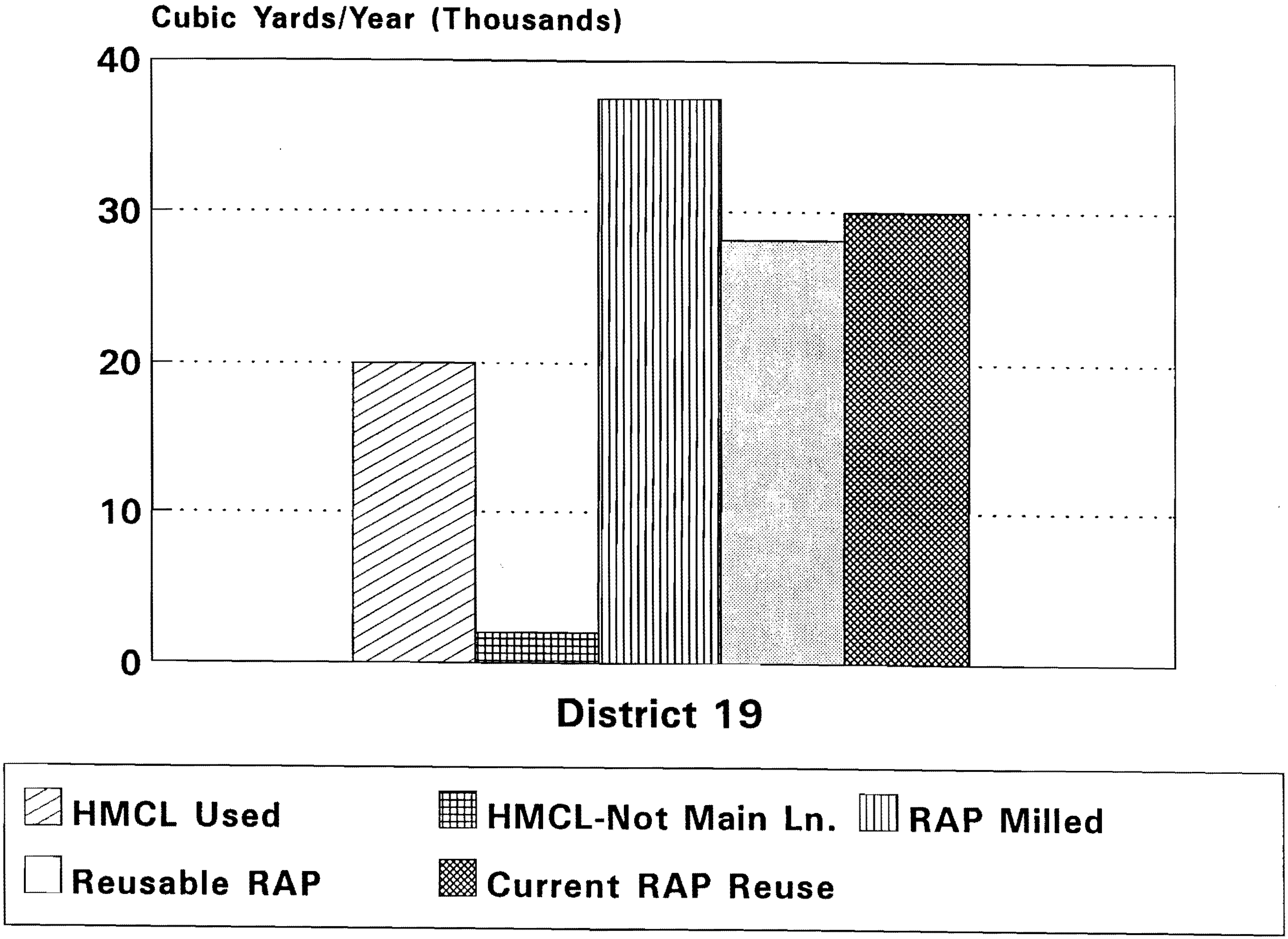
RAP Milled
Reusable RAP
Current RAP Reuse


Cubic Yards/Year (Thousands)
40
30
20
10
0
District 19
HMCL Used
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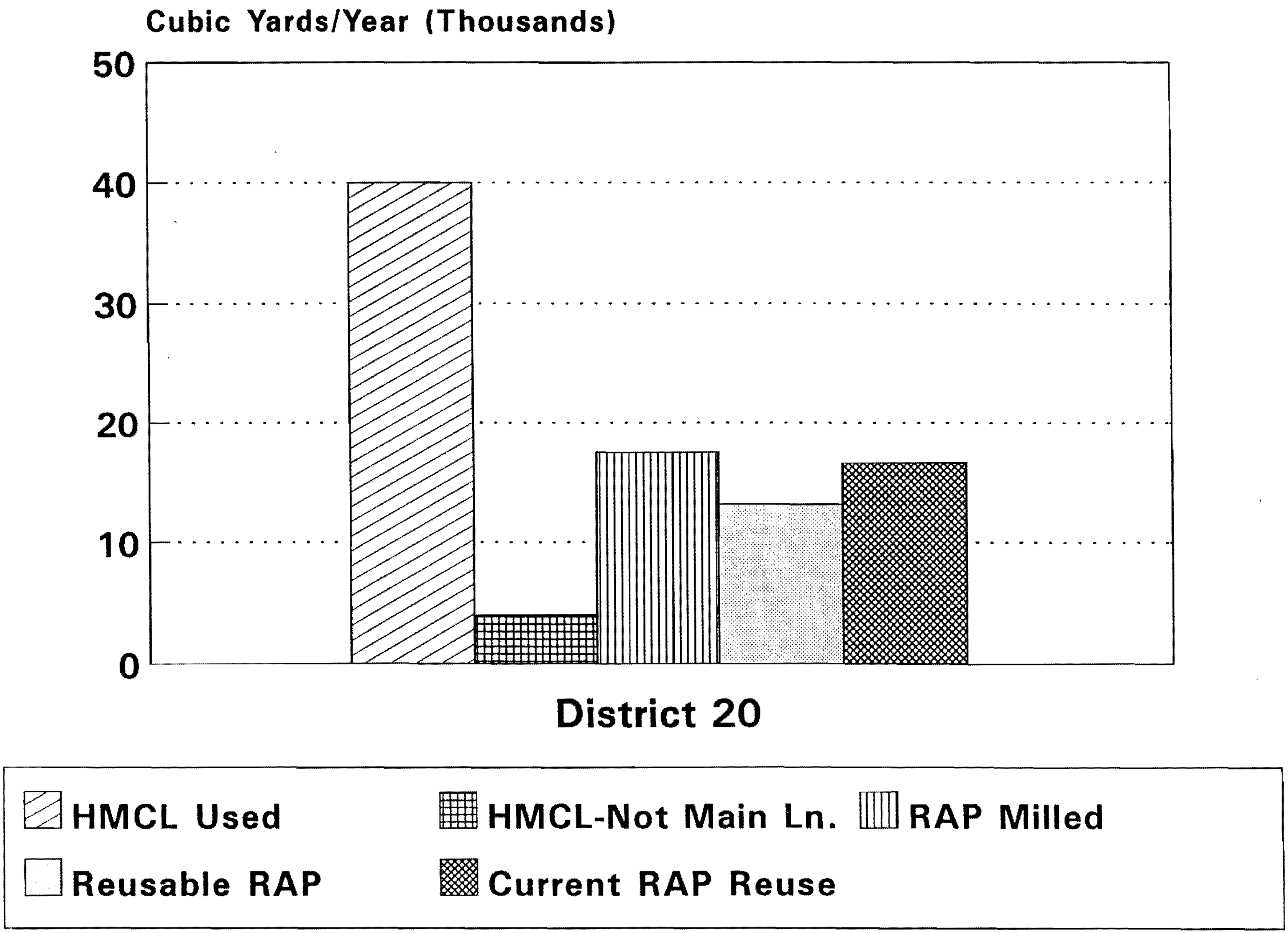
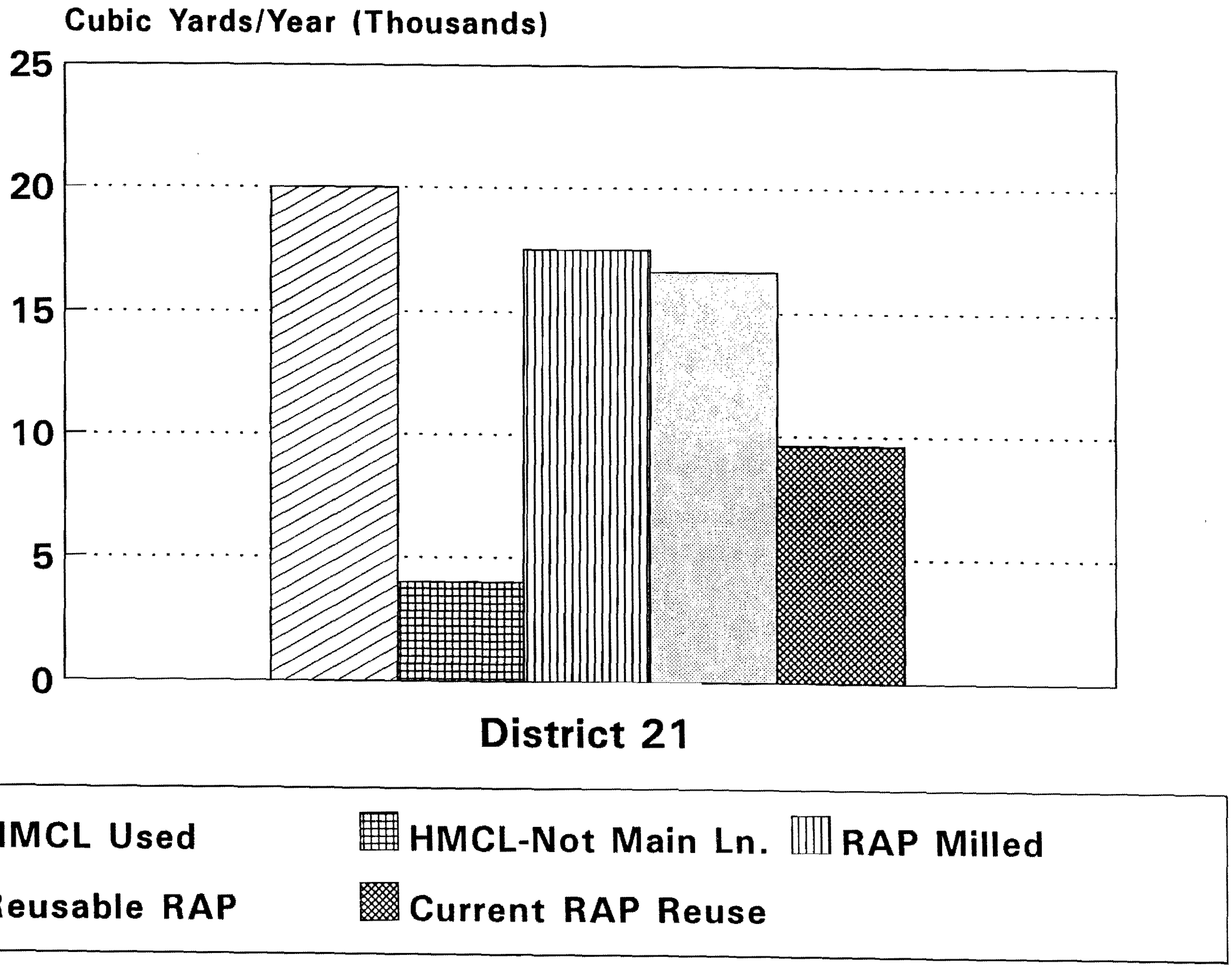
RAP Milled
Reusable RAP
Current RAP Reuse


Cubic Yards/Year (Thousands)
50
40
30
20
10
0
District 20
HMCL Used
HMCL-Not Main Ln.
RAP Milled
Reusable RAP
Current RAP Reuse


Cubic Yards/Year (Thousands)
25
20
15
10
5
0
District 21
HMCL Used
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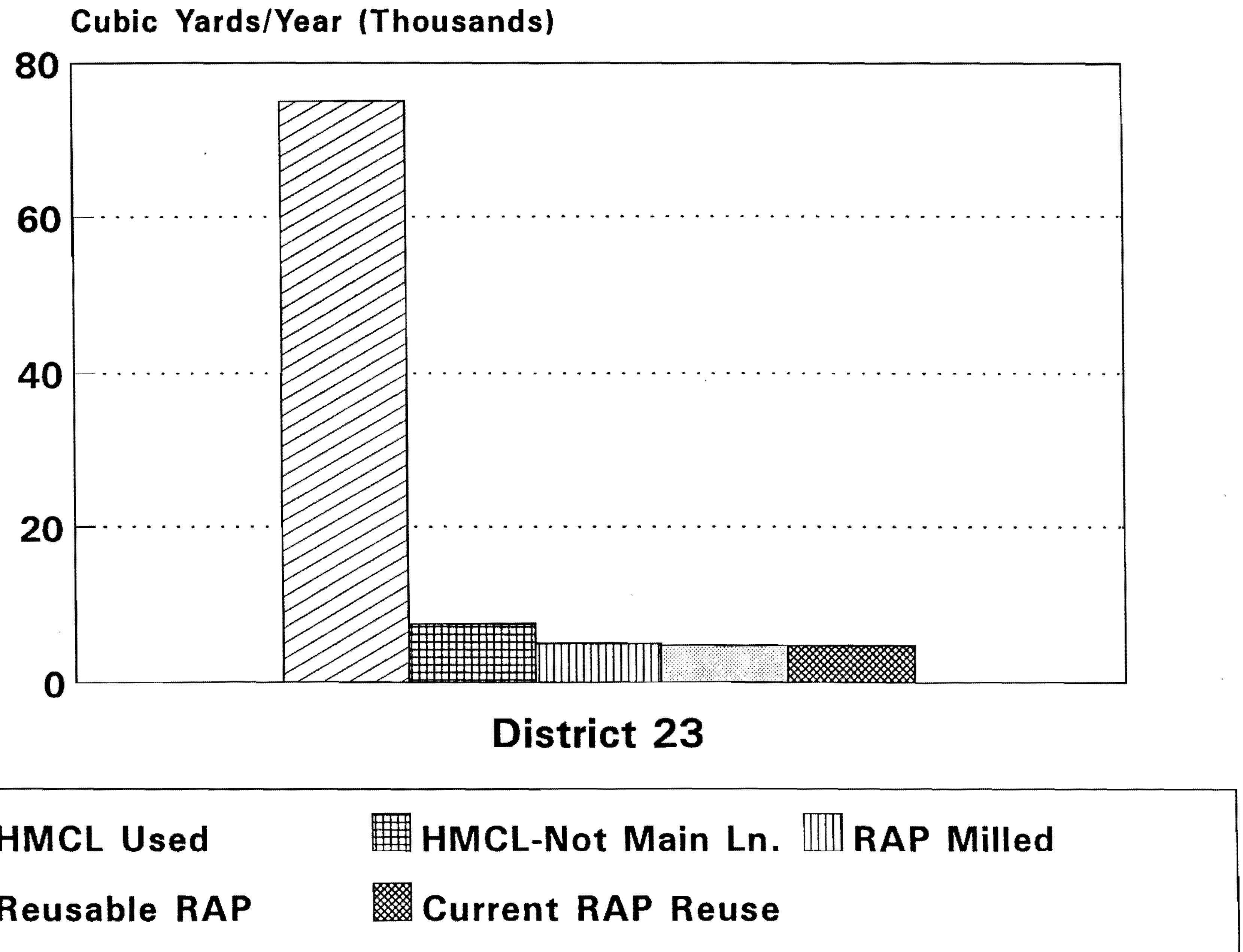
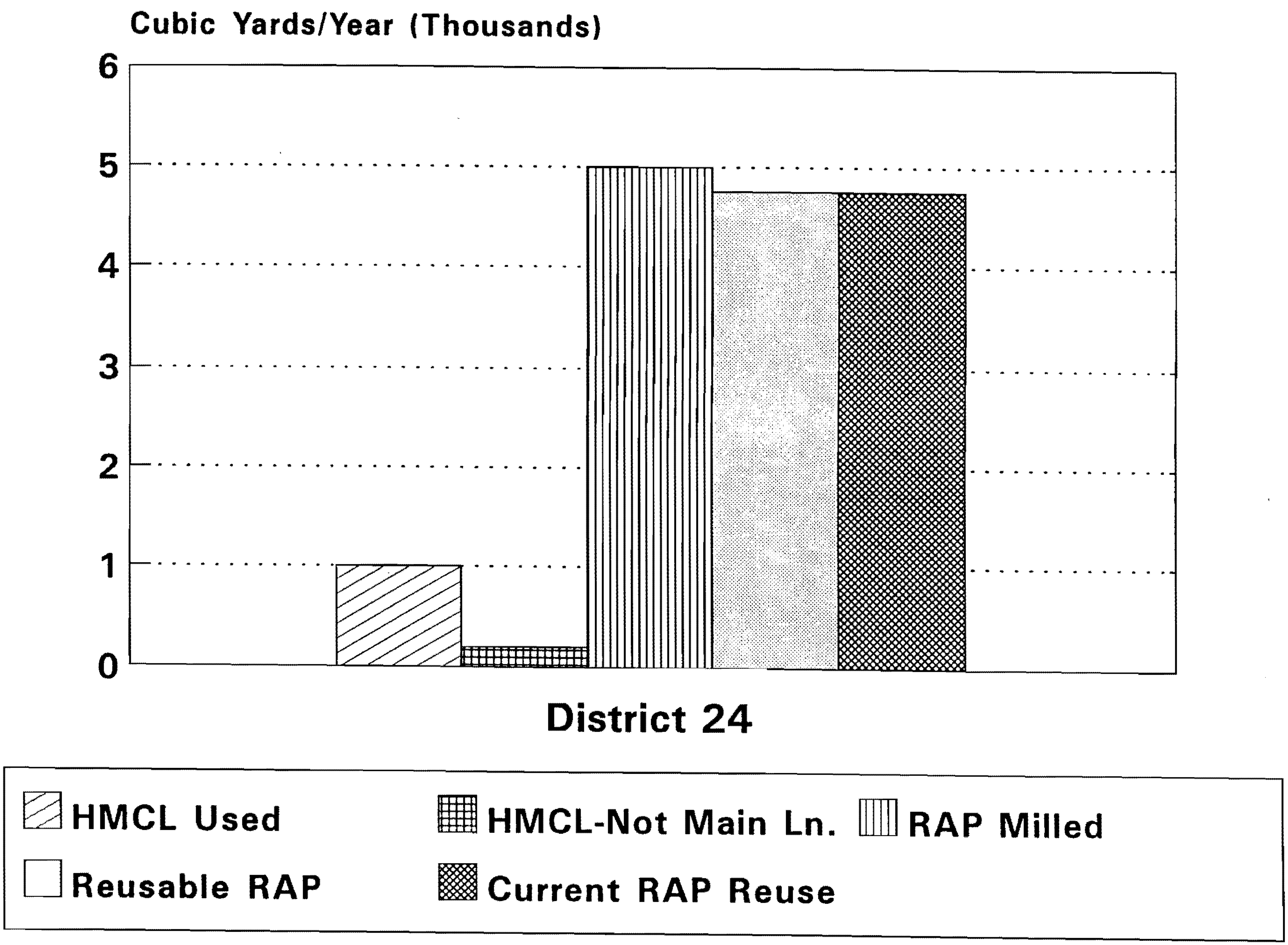
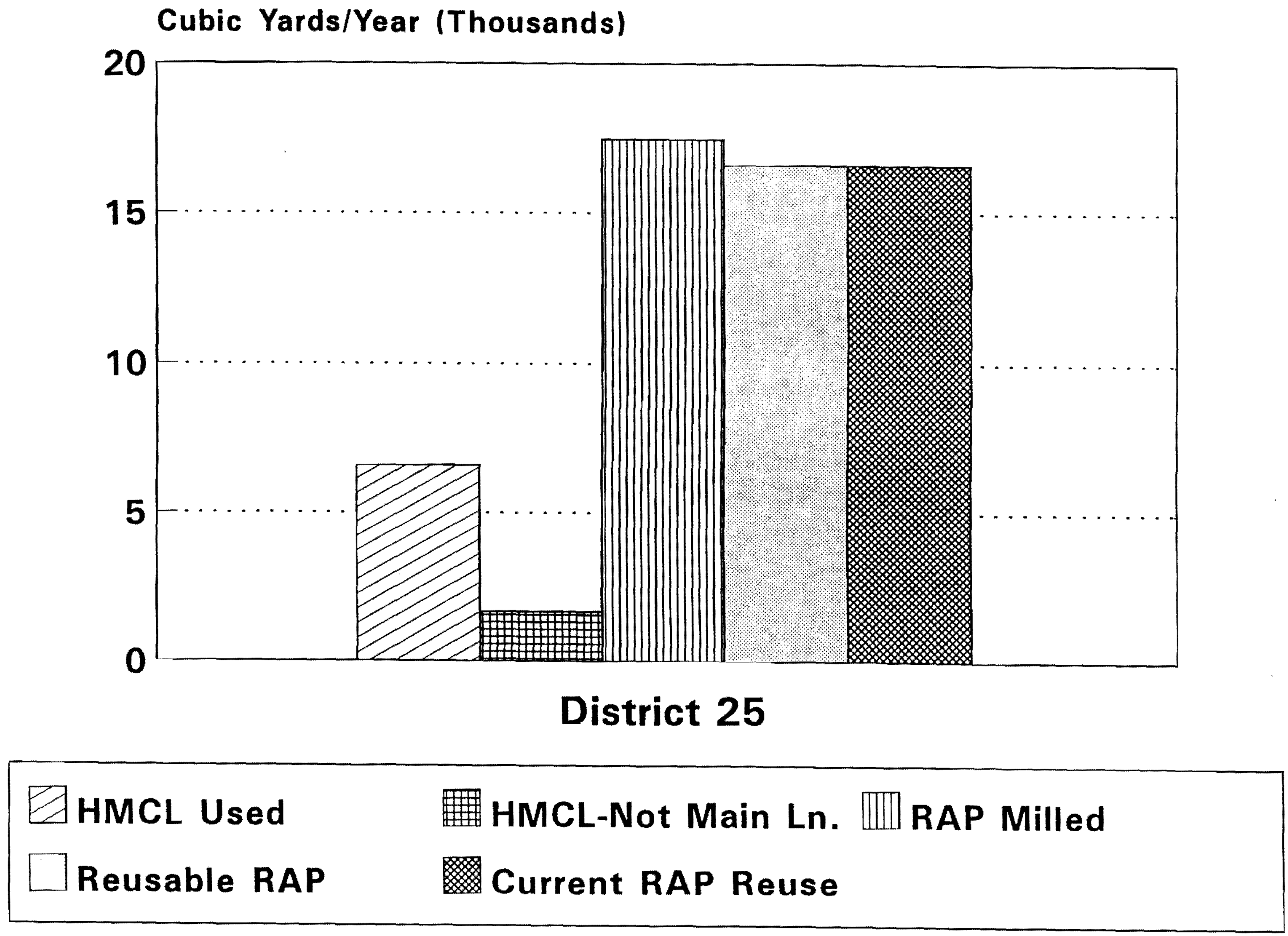
RAP Milled
Reusable RAP
Current RAP Reuse


Cubic Yards/Year (Thousands)
80
60
40
20
0
District 23
HMCL Used
HMCL-Not Main Ln.
RAP Milled
Reusable RAP
Current RAP Reuse



Cubic Yards/Year (Thousands)
6
5
4
3
2
1
0
District 24
HMCL Used
HMCL-Not Main Ln.
RAP Milled
Reusable RAP
Current RAP Reuse


Cubic Yards/Year (Thousands)
20
15
10
5
0
District 25
HMCL Used
HMCL-Not Main Ln.
RAP Milled
Reusable RAP
Current RAP Reuse

APPENDIX B

SPECIFICATIONS FOR RECYCLING EMULSIONS

SPECIFICATION AES-300RP

The emulsion is designed to mix at ambient temperature with reclaimed asphalt pavement (RAP). The resulting mixture is then capable of being stockpiled for future use as a patching material or for overlays. It is recommended that the initial blending of the RAP and emulsion be done during warm summer conditions to aid in proper fluxing of the materials. The purpose of the polymer in the formulation is to improve the cohesion of the mix and improve the resistance to ravelling of the RAP mixture. This emulsion may also be used for surface recycling projects where heat is used to soften aged pavements and are then fluxed with this type of emulsion.

The asphalt shall be polymer modified prior to emulsification. The emulsion shall be smooth and homogeneous and conform to the following specifications:

TESTS ON EMULSION:	MIN.	MAX.
Viscosity @ 122°F, SSF	75	400
Sieve, %		0.1
24-Hour Storage Stability, %		1
Coating Test [1]	PASS	
Residue from distillation @ 350°F, %	65	
Oil Portion from distillation, ml of oil per 100 g. of emulsion		7

TESTS ON RESIDUE FROM DISTILLATION:

Float Test @ 140°F, sec.	1200

TESTS ON RESIDUE FROM ROLLING THIN-FILM OVEN TEST:

Penetration @ 77°F, 5 sec.	300
Torsional Recovery [3], %	20

[1] Texas procedure.

[2] The residue from distillation shall be subjected to the standard rolling thin-film oven test.

[3] Procedure attached.

METHOD OF TEST FOR RECOVERY FROM DEFORMATION OF POLYMER MODIFIED ASPHALT EMULSION RESIDUE (TORSIONAL RECOVERY)

A. SCOPE

This method of test is an indication of the amount of elasticity that a polymer has imparted to an asphalt.

B. APPARATUS

1. Container -

   The container in which the sample is to be tested shall be a flat-bottom, cylindrical seamless tin box, 2.17 in. (55 mm) in diameter and 1.38 in (33 mm) in depth. The container is commonly known as a three ounce ointment can.

2. Disc Assembly -

   The disc assembly is shown in Figure 1. The disc shall be made of aluminum. The spider pointer and nut shall be made of steel.

3. Wrench -

   A 5/16 inch open-end or box-end wrench.

4. Timer -

   A stop watch, clock or other timing device graduated in divisions of one second or less.

5. Scale -

   A flexible plastic scale graduated in millimeters.

C. PROCEDURE

1. Using the residue from the specified method, weight 50 = 1 g. of thoroughly mixed emulsified asphalt residue into one 3 ounce

can. Immerse the disc assembly into the molten asphalt, align the notches in the spider with the can so that the disc is centered, and adjust the disc height such that the asphalt surface is even with the top of the disc. Put the can and assembly in a 325°F oven to allow bubbles to escape and to break the surface tension around the disc. Prepare a duplicate assembly similarly. After ten minutes in the oven, remove the cans and allow them to cool at room temperature for two hours.

2. Mark the can for the reference points of 0° and 180° based on the pointer location after mold preparation. Hold the can and spider rigidly. With a wrench attached to the top of the disc shaft, rotate the disc 180° and release immediately. The rotation should be done at a steady rate taking approximately five seconds to accomplish. Begin timing the recovery at the release of the disc. Mark the pointer location of the can at 30 minutes. Repeat the procedure for the second sample.

D. CALCULATION AND REPORT

1. Calculate the percent recovery from the deformation as follows:

$$\text{Percent Recovery} = 100 \quad \left(\frac{A}{B/2}\right)$$

Where:

A = the arc of the can, in millimeters, between the starting mark and the mark at 30 minutes, and

b = the circumference of the can, in millimeters.

2. Report the percent of recovery as an average of the two results.

CRR-60

SPECIFICATION FOR R.A.P. MATERIAL RECYCLER

FOR STOCK PILE USE

The Recycler Emulsion is designed as a year-round recycling agent to be mixed at ambient temperature with Recycled Asphalt Pavement (R.A.P.) material. The recycling agent will restore the plasticity of the recycled material. This product will be a water miscible emulsion. This material can be used with recycler, pugmill or conventional mixing equipment and can be stock piled for future use.

****

SPECIFICATION

TEST ON EMULSION	Min.	Max.
Viscosity Saybot Furol @ 77F.		150
Sieve %	-	1
Particle Charge	positive	
Specific Gravity @ 77F.	.910	1.16
Cement mixing test D244.33(ASTM)	passing	
DISTILLATION		
Residue: percent from Distillation @ 325 F	60	
TEST ON RESIDUE FROM DISTILLATION TEST		
Penetration, 77F. Extrapolation function	1400	-
Asphaltene %	2.1	11.6
Resins, % wt.	1.0	8.9
Cyclics	68	95.6
Saturates	2.6	16.8
Flash Point, C.O.C.F.	390	-

Laboratory tests will be taken of all R.A.P. material to be recycled. Application rates of the recycling agent must be determined by lab tests before the starting of every recycling job. Lab test data will become property of the DOT. Supplier shall provide field supervision during application of the product as requested by the Department. All costs for testing and supervision will be paid by supplier.

ARE-68 ASPHALT RECYCLING AND REJUVENATING AGENT SPECIFICATION

TEST ON EMULSION	Min.	Max.
Viscosity Saybolt Furol @ 122 deg. F.	10	180
Sieve, %	-	0.5
Particle		positive
Specific Gravity @ 77°F	91	1.18
Cement Mixing Test D244.33 (ASTM)	passing	
DISTILLATION		
Residue: % from distillation @ 360 deg. F.	60	
TEST RESIDUE FROM DISTILLATION TEST		
Penetration, 77 deg. F.	1400	
Viscosity @ 210 deg. F. SS	70	250
*Asphaltene, % wt.	3.1	18.0
*Resins	1.2	8.9
*Cyclics	65.0	95.0
*Saturates	2.8	18.3

* Asphaltenes, Resins, Cyclics, Saturates content must be specifically formulated based on laboratory data of RAP material in relation to rejuvenation demand.

APPENDIX C

TABULATED LABORATORY DATA FOR CHAPTER

"LABORATORY INVESTIGATION OF RAP AND TREATED RAP"

Table C1. Laboratory Test Results of Brownwood RAP Blended with Increasing Levels of AES-300RP.

AES-300RP Added Percent	Theoretical Maximum Specific Gravity	Theoretical Maximum Density lb/ft^3	Bulk Specific Gravity	Bulk Density lb/ft^3	Air Voids Percent	Hveem Stability Percent	Resilient Modulus psi
0	2.079	129.4	1.760 1.789 1.790	109.6 111.4 111.4	15.3 13.9 13.9 AVG 14.4	41 44 46 AVG 44	174,000 185,000 193,000 AVG 184,000
0.5	2.095	130.4	1.829 1.819 1.870	113.8 113.2 116.4	12.7 13.2 10.7 AVG 12.2	36 34 32 AVG 34	-- -- --
1.0	2.080	129.5	1.891 1.829 1.856	117.7 113.8 115.5	9.1 12.1 10.8 AVG 10.7	36 34 35 AVG 35	164,000 175,000 176,000 AVG 172,000
1.5	2.079	129.4	1.900 1.920 1.915	118.3 119.5 119.2	8.6 7.6 7.9 AVG 8.0	21 22 25 AVG 23	153,000 138,000 185,000 AVG 159,000
2.0	2.076	129.2	1.940 1.911 1.892	120.8 119.0 117.8	6.6 7.9 8.9 AVG 7.8	22 20 24 AVG 22	118,000 92,400 131,000 AVG 114,000
2.5	2.062	128.3	1.926 1.894 1.914	119.9 117.9 119.1	6.6 8.1 7.2 AVG 7.3	20 23 20 AVG 21	70,000 67,100 74,200 AVG 70,400
3.0	2.040	127.0	1.846 1.867 1.802	114.9 116.2 112.2	9.5 8.5 11.7 AVG 9.9	16 15 16 AVG 16	40,000 40,400 41,200 AVG 40,500
3.5	2.022	125.9	1.880 1.873 1.879	117.0 116.6 117.0	7.0 7.4 7.1 AVG 7.2	14 14 13 AVG 14	27,300 31,800 27,600 AVG 28,900

Table C2. Laboratory Test Results of Dallas RAP Blended with Increasing Levels of AES-300RP.

AES-300RP Added, Percent	Theoretical Maximum Specific Gravity	Theoretical Maximum Density, lb/ft^3	Bulk Specific Gravity	Bulk Density, lb/ft^3	Air Voids, Percent	Hveem Stability Percent	Resilient Modulus, psi
0	2.480	154.4	2.272 2.272 2.264	141.4 141.4 140.9	8.4 8.4 8.7 AVG 8.5	45 43 44 AVG 44	260,000 236,000 229,000 AV 242,000
0.5	2.465	153.4	2.353 2.349 2.339	146.5 146.2 145.6	4.5 4.7 5.1 AVG 4.8	34 44 42 AVG 40	194,000 206,000 193,000 AV 198,000
1.0	2.458	153.0	2.355 2.352 2.357	146.6 146.4 146.7	4.2 4.3 4.1 AVG 4.2	39 32 38 AVG 36	174,000 148,000 180,000 AV 167,000
1.5	2.455	152.8	2.299 2.286 2.310	143.1 142.3 143.8	6.4 6.9 5.9 AVG 6.4	21 18 22 AVG 20	47,400 55,100 96,900 AV 66,500
2.0	2.446	152.3	2.276 2.289 2.289	141.7 142.5 142.5	7.0 6.4 6.4 AVG 6.6	16 18 21 AVG 18	40,300 73,200 82,500 AV 65,300
2.5	2.430	151.3	2.263 2.270 2.270	140.9 141.3 141.3	6.9 6.6 6.6 AVG 6.7	14 15 14 AVG 14	22,300 49,700 32,500 AV 34,800
3.0	2.425	150.9	2.324 2.319 2.322	144.7 144.3 144.5	4.2 4.4 4.2 AVG 4.3	18 18 15 AVG 17	17,500 34,000 17,500 AVG 23,000
3.5	2.400	149.4	2.316 2.320 2.302	144.2 144.4 143.3	3.5 3.3 4.1 AVG 3.6	10 16 9 AVG 12	18,100 34,800 15,600 AVG 22,800

Table C3. Laboratory Test Results of Houston RAP Blended with Increasing Levels of AES-300RP.

AES-300RP Added Percent	Theoretical Maximum Specific Gravity	Theoretical Maximum Density lb/ft^3	Bulk Specific Gravity	Bulk Density lb/ft^3	Air Voids Percent	Hveem Stability Percent	Resilient Modulus psi
0	2.449	152.4	2.215 2.229 2.215	137.9 138.7 137.9	9.6 9.0 9.6 AVG 9.4	42 46 47 AVG 45	251,000 301,000 295,000 AV 282,000
0.5	2.442	152.0	2.227 2.295 2.289	141.7 142.9 142.5	6.8 6.0 6.3 AVG 6.4	40 37 34 AVG 37	294,000 310,000 289,000 AV 298,000
1.0	2.436	151.6	2.303 2.268 2.293	143.4 141.2 142.7	5.5 6.9 5.9 AVG 6.1	29 32 25 AVG 29	214,000 264,000 204,000 AV 227,000
1.5	2.406	149.8	2.267 2.250 2.252	141.1 140.1 140.2	5.8 6.5 6.4 AVG 6.2	23 23 26 AVG 24	159,000 124,000 147,000 AV 143,000
2.0	2.389	148.7	2.270 2.261 2.265	141.3 140.7 141.0	5.0 5.4 5.2 AVG 5.2	25 22 22 AVG 23	120,000 95,300 98,800 AV 105,000
2.5	2.385	148.5	2.274 2.274 2.279	141.5 141.5 141.9	4.7 4.7 4.4 AVG 4.6	21 14 19 AVG 18	- 74,200 67,900 AVG 47,400
3.0	2.383	148.3	2.270 2.257 2.269	141.3 140.5 141.2	4.7 5.3 4.8 AVG 4.9	11 11 9 AVG 10	66,100 63,400 60,900 AVG 63,500
3.5	2.372	147.6	2.253 2.259 2.266	140.2 140.6 141.0	5.0 4.8 4.5 AVG 4.8	-- 8 3 AVG 6	14,200 42,600 23,600 AVG 26,800

Table C4. Laboratory Test Results of Brownwood RAP Blended with Increasing Levels of MS-1.

MS-1 Added, Percent	Theoretical Maximum Specific Gravity	Theoretical Maximum Density, lb/ft^3	Bulk Specific Gravity	Bulk Density, lb/ft^3	Air Voids, Percent	Hveem Stability Percent	Resilient Modulus, psi
0	2.079	129.4	1.760	109.6	15.3	41	174,000
			1.789	111.4	13.9	44	185,000
			1.790	111.4	13.9	46	193,000
					AVG 14.4	AVG 44	AV 184,000
0.5	2.070	128.8	1.710	106.4	17.4	33	--
			1.737	108.1	16.1	31	175,000
			1.745	108.6	15.7	32	160,000
					AVG 16.4	AVG 32	AV 168,000
1.0	2.039	126.9	1.774	110.4	13.0	34	154,000
			1.771	110.2	13.1	31	195,000
			1.769	110.1	13.2	31	162,000
					AVG 13.1	AVG 32	AV 170,000
1.5	2.030	126.4	1.902	118.4	6.3	31	148,000
			1.922	119.6	5.3	31	136,000
			1.933	120.3	4.8	31	142,000
					AVG 5.5	AVG 31	AV 142,000
2.0	2.019	125.7	1.897	118.1	6.0	31	164,000
			1.906	118.6	5.6	30	119,000
			1.891	117.7	6.3	30	129,000
					AVG 6.0	AVG 30	AV 137,000
2.5	2.019	125.7	1.874	116.6	7.2	26	112,000
			1.884	117.3	6.7	28	106,000
			1.889	117.6	6.4	27	115,000
					AVG 6.8	AVG 27	AV 111,000
3.0	2.026	126.1	1.863	116.0	8.0	24	75,500
			1.888	117.5	6.8	25	67,100
			1.888	117.5	6.8	24	71,600
					AVG 7.2	AVG 24	AVG 71,400
3.5	2.029	126.3	1.906	118.6	6.1	22	85,500
			1.886	117.4	7.0	22	74,800
			1.894	117.9	6.7	22	93,200
					AVG 6.6	AVG 22	AVG 84,500

Table C5. Laboratory Test Results of Dallas RAP Blended with Increasing Levels of MS-1.

MS-1 Added, Percent	Theoretical Maximum Specific Gravity	Theoretical Maximum Density, lb/ft^3	Bulk Specific Gravity	Bulk Density, lb/ft^3	Air Voids, Percent	Hveem Stability, Percent	Resilient Modulus, psi
0	2.480	154.4	2.272 2.272 2.264	141.4 141.4 140.9	8.4 8.4 8.7 AVG 8.5	45 43 44 AVG 44	260,000 236,000 229,000 AVG 242,000
0.5	2.460	153.1	2.293 2.287 2.280	142.7 142.4 141.9	6.8 7.0 7.3 AVG 7.0	39 43 43 AVG 42	242,000 211,000 225,000 AVG 226,000
1.0	2.453	152.7	2.285 2.300 2.297	142.2 143.2 143.0	6.8 6.2 6.4 AVG 6.5	34 38 36 AVG 36	179,000 193,000 189,000 AVG 187,000
1.5	2.452	152.6	2.213 2.218 2.227	137.7 138.0 138.6	9.7 9.5 9.2 AVG 9.5	27 27 28 AVG 27	168,000 188,000 179,000 AVG 178,000
2.0	2.458	153.0	2.239 2.223 2.240	139.4 138.4 139.4	8.9 9.6 8.8 AVG 9.1	26 25 25 AVG 25	177,000 137,000 153,000 AVG 156,000
2.5	2.456	152.9	2.251 2.244 2.260	140.1 139.7 140.7	8.3 8.6 8.0 AVG 8.3	25 24 24 AVG 24	163,000 167,000 159,000 AVG 163,000
3.0	2.445	152.2	2.227 2.231 2.229	138.6 138.9 138.7	8.9 8.8 8.8 AVG 8.8	22 21 22 AVG 22	144,000 119,000 138,000 AVG 134,000
3.5	2.400	149.4	2.240 2.232 2.229	139.4 138.9 138.7	6.7 7.0 7.1 AVG 6.9	20 20 20 AVG 20	104,000 102,000 108,000 AVG 105,000

Table C6. Laboratory Test Results of Houston RAP Blended with Increasing Levels of MS-1.

MS-1 Added, Percent	Theoretical Maximum Specific Gravity	Theoretical Maximum Density, lb/ft^3	Bulk Specific Gravity	Bulk Density, lb/ft^3	Air Voids, Percent	Hveem Stability Percent	Resilient Modulus, psi
0	2.449	152.4	2.215	137.9	9.6	42	251,000
			2.229	138.7	9.0	46	301,000
			2.215	137.9	9.6	47	295,000
					AVG 9.4	AVG 45	AVG 282,000
0.5	2.439	151.8	2.202	137.1	9.7	32	315,000
			2.193	136.5	10.1	35	297,000
			2.197	136.8	9.9	31	322,000
					AVG 9.9	AVG 33	AVG 311,000
1.0	2.418	150.5	2.215	137.9	8.4	35	344,000
			2.215	137.9	8.4	41	334,000
			2.199	136.9	9.1	36	327,000
					AVG 8.6	AVG 37	AVG 335,000
1.5	2.423	150.8	2.249	140.0	7.2	32	389,000
			2.234	139.1	7.8	34	456,000
			2.241	139.5	7.5	32	439,000
					AVG 7.5	AVG 33	AVG 428,000
2.0	2.412	150.1	2.256	140.4	6.5	28	375,000
			2.241	139.5	7.1	28	367,000
			2.258	140.5	6.4	30	431,000
					AVG 6.7	AVG 29	AVG 391,000
2.5	2.402	149.5	2.261	140.7	5.9	22	312,000
			2.249	140.0	6.4	23	365,000
			2.263	140.9	5.8	20	309,000
					AVG 6.0	AVG 22	AVG 329,000
3.0	2.389	148.7	2.227	138.6	6.8	22	250,000
			2.226	138.6	6.8	23	209,000
			2.223	138.4	6.9	24	210,000
					AVG 6.8	AVG 23	AVG 223,000
3.5	2.362	147.0	2.228	138.7	5.7	16	213,000
			2.229	138.7	5.6	15	187,000
			2.223	138.4	5.9	17	184,000
					AVG 5.7	AVG 16	AVG 195,000

APPENDIX D

TABULATED LABORARATORY DATA FOR CHAPTER

"LABORATORY INVESTIGATION OF FIELD-PRODUCED RAP MIXES"

Table D1. Laboratory Results of Denton RAP Field Mixed with 2½ Percent AES-300RP in Pugmill.

Sample	Bulk Specific Gravity	Air Voids, Percent	Resilient Modulus, psi	Hveem Stability	Marshall		Indirect Tensile Strength		Tensile Strength Ratio
					Stability, lbs.	Flow, 0.01in	Dry, psi	After Moisture Conditioning, psi	
1	2.321	3.0	12,000				18		
2	2.309	3.5	10,000	4	300	27			
3	2.323	2.9	14,000				16		
4	2.285	4.5	11,000					10	
5	2.304	3.7	9,000					10	
6	2.312	3.4	18,000	0	310	23			
7	2.315	3.3	13,000				15		
8	2.301	3.8	13,000					12	
9	2.310	3.5	10,000	0	275	23			
Average	2.309	3.5	12,000	1	295	24	16	10	0.63

Table D2. Laboratory Results of Kilgore RAP Field Mixed with 2 Percent AES-300RP in Pugmill.

Sample	Bulk Specific Gravity	Air Voids, Percent	Resilient Modulus, psi	Hveem Stability	Marshall		Indirect Tensile Strength		Tensile Strength Ratio
					Stability, lbs.	Flow, 0.01in	Dry, psi	After Moisture Conditioning, psi	
1	1.882	2.8	**	0	320	23			
2	1.861	3.9	**					23	
3	1.872	3.3	**				28		
4	1.860	3.9	**					23	
5	1.876	3.1	**				31		
6	1.895	2.1	**	0	450	21			
7	1.851	4.4	**	0	375	25			
8	1.865	3.7	**						
9	1.864	3.7	**				27		
Average	1.870	3.4	**	0	380	23	29	23	0.79

* Tensile Strength Ratio = $\frac{\text{Tensile Strength After Moisture Conditioning}}{\text{Dry Tensile Strength}}$

** Unable to test sample (excessive sample deformation during test).

Table D3. Laboratory Test Results for Floresville RAP Blade-Mixed with 2 Percent AES-300RP.

Sample	Bulk Specific Gravity	Air Voids, Percent	Resilient Modulus, psi	Hveem Stability	Marshall		Indirect Tensile Strength		Tensile Strength Ratio*
					Stability, lbs.	Flow, 0.01in	Dry, psi	After Moisture Conditioning, psi	
1	2.299	4.2	93,000	25	580	26			
2	2.297	4.3	90,000	23	505	23			
3	2.300	4.2	92,000	25	530	23			
4	2.308	3.8	92,000				70		
5	2.296	4.4	91,000				67		
6	2.282	5.0	86,000				65		
7	2.300	4.2	91,000					31	
8	2.308	3.8	91,000					39	
9	2.300	4.2	86,000					36	
Average	2.299	4.2	90,000	24	540	24	67	35	0.52

Table D4. Laboratory Test Results for Brownwood RAP Field Mixed with 2 Percent AES-300RP in Pugmill.

Sample	Bulk Specific Gravity	Air Voids, Percent	Resilient Modulus, psi	Hveem Stability	Marshall		Indirect Tensile Strength		Tensile Strength Ratio*
					Stability, lbs.	Flow, 0.01in	Dry, psi	After Moisture Conditioning, psi	
1	1.928	10.6	103,000	17	590	22			
2	1.930	10.5	103,000	18	567	20			
3	1.918	11.2	94,000	20	603	23			
4	1.936	10.1	97,000					27	
5	1.963	8.4	117,000					21	
6	1.924	10.8	105,000					19	
7	1.899	12.3	106,000				42		
8	1.934	9.3	121,000				47		
9	1.913	10.3	89,000				48		
Average	1.927	10.4	104,000	18	587	22	46	22	0.48

$$* \text{ Tensile Strength Ratio} = \frac{\text{Tensile Strength After Moisture Conditioning}}{\text{Dry Tensile Strength}}.$$

Table D5. Laboratory Test Results for McKinney RAP Field Mixed with 2½ Percent AES-300RP in Pugmill.

Sample	Bulk Specific Gravity	Air Voids, Percent	Resilient Modulus, psi	Hveem Stability	Marshall		Indirect Tensile Strength		Tensile Strength Ratio*
					Stability, lbs.	Flow, 0.01in	Dry, psi	After Moisture Conditioning, psi	
1	2.075	9.6	98,000	22	420	20			
2	2.056	10.5	79,000	23	480	23			
3	2.018	12.1	88,000	26	470	25			
4	2.046	10.9	89,000					17	
5	2.049	10.8	102,000					17	
6	2.048	10.8	97,000					17	
7	2.050	10.7	73,000				43		
8	2.046	10.9	83,000				40		
9	2.053	10.6	85,000				47		
Average	2.049	10.8	88,000	24	460	23	43	17	0.40

Table D6. Laboratory Test Results for Childress RAP Field Mixed with 2½ Percent AES-300RP in Pugmill.

Sample	Bulk Specific Gravity	Air Voids, Percent	Resilient Modulus, psi	Hveem Stability	Marshall		Indirect Tensile Strength		Tensile Strength Ratio*
					Stability, lbs.	Flow, 0.01in	Dry, psi	After Moisture Conditioning, psi	
1	2.282	4.3	38,000					18	
2	2.306	3.3	43,000				39		
3	2.309	3.2	49,000				41		
4	2.313	3.0	48,000	5	576	25			
5	2.312	3.1	52,000	4	551	23			
6	2.305	3.4	52,000				43		
7	2.298	3.6	58,000					25	
8	2.313	3.0	61,000	10	657	25			
9	2.305	3.4	45,000					23	
Average	2.305	3.4	50,000	6	595	24	41	22	0.54

* Tensile Strength Ratio = $\frac{\text{Tensile Strength After Moisture Conditioning}}{\text{Dry Tensile Strength}}$.

Table D7. Laboratory Test Results for Childress RAP Field Mixed with 3 to 3½ Percent ARE-68 in Pugmill.

Sample	Bulk Specific Gravity	Air Voids, Percent	Resilient Modulus, psi	Hveem Stability	Marshall		Indirect Tensile Strength		Tensile Strength Ratio*
					Stability, lbs.	Flow, 0.01in	Dry, psi	After Moisture Conditioning, psi	
1	2.283	3.8	114,000				59		
2	2.271	4.3	116,000					15	
3	2.276	4.1	109,000					18	
4	2.287	3.6	121,000	13	815	20			
5	2.283	3.8	128,000	11	801	20			
6	2.281	3.9	118,000				62		
7	2.288	3.6	118,000	13	759	22			
8	2.283	3.8	123,000				64		
9	2.278	4.0	111,000					18	
Average	2.281	3.9	118,000	12	792	21	62	17	0.27

Table D8. Laboratory Test Results for Childress RAP Field Mixed with 3 to 3½ Percent CRR-60 in Pugmill.

Sample	Bulk Specific Gravity	Air Voids, Percent	Resilient Modulus, psi	Hveem Stability	Marshall		Indirect Tensile Strength		Tensile Strength Ratio*
					Stability, lbs.	Flow, 0.01in	Dry, psi	After Moisture Conditioning, psi	
1	2.274	3.9	95,000					7	
2	2.280	3.6	95,000					10	
3	2.276	3.8	104,000					8	
4	2.293	3.1	115,000	13	634	24			
5	2.290	3.2	105,000				68		
6	2.295	3.0	100,000	13	725	26			
7	2.297	2.9	128,000	16	720	27			
8	2.288	3.3	111,000				68		
9	2.282	3.6	127,000				69		
Average	2.286	3.4	109,000	14	693	26	68	8	0.12

* Tensile Strength Ratio = $\frac{\text{Tensile Strength After Moisture Conditioning}}{\text{Dry Tensile Strength}}$.

Table D9. Laboratory Test Results for Childress RAP Field Mixed with 3 to 3½ Percent MS-1 in Pugmill.

Sample	Bulk Specific Gravity	Air Voids, Percent	Resilient Modulus, psi	Hveem Stability	Marshall		Indirect Tensile Strength		Tensile Strength Ratio*
					Stability, lbs.	Flow, 0.01in	Dry, psi	After Moisture Conditioning, psi	
1	2.263	5.2	131,000					13	
2	2.271	4.9	149,000				84		
3	2.262	5.2	142,000					15	
4	2.277	4.6	166,000	17	888	26			
5	2.271	4.9	177,000				87		
6	2.272	4.8	167,000				87		
7	2.275	4.7	161,000	28	987	27			
8	2.261	5.3	155,000					20	
9	2.288	4.1	137,000	17	767	21			
Average	2.271	4.9	154,000	21	881	25	86	16	0.19

Table D10. Laboratory Test Results for Pleasanton RAP Field-Mixed with 2 Percent AES-300RP Using Pulver-Mixer.

Sample	Bulk Specific Gravity	Air Voids, Percent	Resilient Modulus, psi	Hveem Stability	Marshall		Indirect Tensile Strength		Tensile Strength Ratio*
					Stability, lbs.	Flow, 0.01in	Dry, psi	After Moisture Conditioning, psi	
1	2.278	6.2	133,000					20	
2	2.305	5.1	132,000				70		
3	2.316	4.6	105,000	37	1213	24			
4	2.304	5.1	102,000				66		
5	2.288	5.8	104,000					13	
6	2.287	5.8	107,000					12	
7	2.308	4.9	135,000	35	1066	21			
8	2.300	5.3	115,000				65		
9	2.309	4.9	99,000	30	1095	19			
Average	2.299	5.3	115,000	34	1125	21	67	15	0.22

$$* \text{ Tensile Strength Ratio} = \frac{\text{Tensile Strength After Moisture Conditioning}}{\text{Dry Tensile Strength}}.$$

Table D11. Laboratory Test Results for Pleasanton RAP Blade-Mixed with LRA (60/40 LRA/RAP blend).

Sample	Bulk Specific Gravity	Air Voids, Percent	Resilient Modulus, psi	Hveem Stability	Marshall		Indirect Tensile Strength		Tensile Strength Ratio*
					Stability, lbs.	Flow, 0.01in	Dry, psi	After Moisture Conditioning, psi	
1	2.268	5.7	80,000	23	1339	22			
2	2.254	6.3	93,000				61	19	
3	2.245	6.7	82,000						
4	2.270	5.6	95,000	25	1304	21			
5	2.248	6.5	85,000						
6	2.265	5.8	92,000	25	1502	22			
7	2.244	6.7	109,000						
8	2.248	6.5	94,000				60	21	
9	2.259	6.1	90,000				59	25	
Average	2.256	6.2	91,000	24	1382	22	60	22	0.37

Table D12. Laboratory Test Results for Pleasanton HMCL.

Sample	Bulk Specific Gravity	Air Voids, Percent	Resilient Modulus, psi	Hveem Stability	Marshall		Indirect Tensile Strength		Tensile Strength Ratio*
					Stability, lbs.	Flow, 0.01in	Dry, psi	After Moisture Conditioning, psi	
1	2.300	6.6	89,000	47	834	15			
2	2.300	6.6	74,000				36		
3	2.306	6.4	83,000	46	1000	13			
4	2.293	6.9	81,000					16	
5	2.265	8.0	83,000					17	
6	2.300	6.6	80,000				39		
7	2.293	6.9	74,000					13	
8	2.307	6.3	82,000	43	1044	14			
9	2.299	6.7	86,000				39		
Average	2.296	6.8	81,000	45	959	14	38	15	0.39

* Tensile Strength Ratio = $\frac{\text{Tensile Strength After Moisture Conditioning}}{\text{Dry Tensile Strength}}$.

Table D13. Laboratory Results of McKinney HMCL.

Sample	Bulk Specific Gravity	Air Voids, Percent	Resilient Modulus, psi	Hveem Stability	Marshall		Indirect Tensile Strength		Tensile Strength Ratio*
					Stability, lbs.	Flow, 0.01in	Dry, psi	After Moisture Conditioning, psi	
1	2.382	3.7	26,000					22	
2	2.382	3.7	25,000					21	
3	2.383	3.7	26,000					17	
4	2.381	3.8	23,000				32		
5	2.388	3.5	**				34		
6	2.387	3.5	**				30		
7	2.387	3.5	**	44	481	15			
8	2.382	3.7	**	47	465	17			
9	2.383	3.7	**	48	504	18			
Average	2.384	3.6	25,000	46	483	17	32	20	0.63

Table D14. Laboratory Results of McKinney HMCL/Treated RAP Blend (50/50 Ratio).

Sample	Bulk Specific Gravity	Air Voids, Percent	Resilient Modulus, psi	Hveem Stability	Marshall		Indirect Tensile Strength		Tensile Strength Ratio*
					Stability, lbs.	Flow, 0.01in	Dry, psi	After Moisture Conditioning, psi	
1	2.121	6.2	59,000	35	1094	23			
2	2.131	5.8	69,000					22	
3	2.138	5.4	61,000					21	
4	2.147	5.0	55,000	29	1378	26			
5	2.139	5.4	56,000	31	1203	23			
6	2.132	5.7	51,000					17	
7	2.132	5.7	57,000				44		
8	2.133	5.7	58,000				78		
9	2.133	5.7	54,000				40		
Average	2.134	5.6	58,000	32	1225	24	54	20	0.57

* Tensile Strength Ratio = $\dfrac{\text{Tensile Strength After Moisture Conditioning}}{\text{Dry Tensile Strength}}$.

Table D15. Laboratory Results of McKinney HMCL/RAP Blend (60/40 Ratio).

Sample	Bulk Specific Gravity	Air Voids, Percent	Resilient Modulus, psi	Hveem Stability	Marshall		Indirect Tensile Strength		Tensile Strength Ratio*
					Stability, lbs.	Flow, 0.01in	Dry, psi	After Moisture Conditioning, psi	
1	2.344	5.9	68,000					8	
2	2.344	5.9	57,000					4	
3	2.352	5.6	68,000					7	
4	2.358	5.3	71,000				32		
5	2.356	5.4	78,000				34		
6	2.373	4.7	69,000				30		
7	2.364	5.1	88,000	54	972	20			
8	2.364	5.1	69,000	48	1208	19			
9	2.374	4.7	79,000	50	1240	18			
Average	2.359	5.3	72,000	51	1140	19	32	6	0.19

Table D16. Laboratory Results of McKinney LRA.

Sample	Bulk Specific Gravity	Air Voids, Percent	Resilient Modulus, psi	Hveem Stability	Marshall		Indirect Tensile Strength		Tensile Strength Ratio*
					Stability, lbs.	Flow, 0.01in	Dry, psi	After Moisture Conditioning, psi	
1	2.203	8.2	86,000					27	
2	2.200	8.4	152,000					27	
3	2.200	8.2	123,000					27	
4	2.197	8.5	127,000				59		
5	2.206	8.1	112,000				32		
6	2.199	8.4	130,000				50		
7	2.189	8.8	126,000	51	2211	30			
8	2.225	7.3	101,000	44	2395	18			
9	2.194	8.6	130,000	47	2412	21			
Average	2.201	8.3	121,000	47	2339	23	47	27	0.57

$$\text{* Tensile Strength Ratio} = \frac{\text{Tensile Strength After Moisture Conditioning}}{\text{Dry Tensile Strength}}.$$

Table D17. Laboratory Results of McKinney LRA/Treated RAP Blend (50/50 Ratio).

Sample	Bulk Specific Gravity	Air Voids, Percent	Resilient Modulus, psi	Hveem Stability	Marshall		Indirect Tensile Strength		Tensile Strength Ratio*
					Stability, lbs.	Flow, 0.01in	Dry, psi	After Moisture Conditioning, psi	
1	2.065	7.5	94,000					24	
2	2.077	6.9	97,000				71		
3	2.057	7.8	92,000					17	
4	2.082	6.7	85,000				65		
5	2.058	7.8	113,000	37	1656	24			
6	2.060	7.7	109,000					19	
7	2.062	7.6	122,000				69		
8	2.045	8.4	105,000	43	1607	22			
9	2.048	8.2	111,000	37	1845	24			
Average	2.062	7.6	103,000	39	1702	23	68	20	0.29

Table D18. Laboratory Results of McKinney LRA/RAP Blend (60/40 Ratio).

Sample	Bulk Specific Gravity	Air Voids, Percent	Resilient Modulus, psi	Hveem Stability	Marshall		Indirect Tensile Strength		Tensile Strength Ratio*
					Stability, lbs.	Flow, 0.01in	Dry, psi	After Moisture Conditioning, psi	
1	2.257	7.6	148,000				42		
2	2.264	7.3	115,000	49	2641	18			
3	2.244	8.1	125,000					14	
4	2.252	7.8	124,000				39		
5	2.242	8.2	122,000					10	
6	2.258	7.6	135,000				40		
7	2.258	7.6	120,000	47	2688	18			
8	2.246	8.1	123,000					12	
9	2.254	7.7	151,000	51	2641	20			
Average	2.253	7.8	129,000	49	2657	19	40	12	0.3

* Tensile Strength Ratio = $\frac{\text{Tensile Strength After Moisture Conditioning}}{\text{Dry Tensile Strength}}$.

Table D19. Laboratory Results for Cleburne HMCL.

Sample	Bulk Specific Gravity	Air Voids, Percent	Resilient Modulus, psi	Hveem Stability	Marshall		Indirect Tensile Strength		Tensile Strength Ratio*
					Stability, lbs.	Flow, 0.01in	Dry, psi	After Moisture Conditioning, psi	
1	2.353	6.6	**				51		
2	2.371	5.9	**	46	689	20			
3	2.367	6.1	**	46	704	17			
4	2.363	6.2	**				33		
5	2.372	5.9	**	51	673	19			
6	2.376	5.7	**					25	
7	2.359	6.4	**				32		
8	2.374	5.8	**					24	
9	2.376	5.7	**					27	
Average	2.368	6.0	**	48	689	19	39	25	0.64

Table D20. Laboratory Test Results for Cleburne HMCL/RAP Blend (70/30 Ratio).

Sample	Bulk Specific Gravity	Air Voids, Percent	Resilient Modulus, psi	Hveem Stability	Marshall		Indirect Tensile Strength		Tensile Strength Ratio*
					Stability, lbs.	Flow, 0.01in	Dry, psi	After Moisture Conditioning, psi	
1	2.302	7.5	71,000					27	
2	2.310	7.0	74,000				83		
3	2.305	7.4	70,000					25	
4	2.287	8.1	72,000	42	1014	21			
5	2.315	6.9	63,000				82		
6	2.320	6.8	71,000				85		
7	2.313	7.0	77,000	47	1433	23			
8	2.298	7.6	70,000					30	
9	2.312	7.1	60,000	47	1323	19			
Average	2.306	7.4	70,000	45	1257	21	83	27	0.33

* Tensile Strength Ratio = $\frac{\text{Tensile Strength After Moisture Conditioning}}{\text{Dry Tensile Strength}}$.

** Unable to test sample (sample deformations too high).

Table D21. Laboratory Test Results for Cleburne HMCL/Treated RAP Blend (50/50 Ratio).

Sample	Bulk Specific Gravity	Air Voids, Percent	Resilient Modulus, psi	Hveem Stability	Marshall		Indirect Tensile Strength		Tensile Strength Ratio*
					Stability, lbs.	Flow, 0.01in	Dry, psi	After Moisture Conditioning, psi	
1	2.312	5.9	60,000					73	
2	2.285	7.0	72,000				84		
3	2.307	6.1	71,000					70	
4	2.315	5.8	67,000					61	
5	2.300	6.4	59,000	49	1207	22			
6	2.288	6.9	71,000				85		
7	2.297	6.6	69,000	48	1323	20			
8	2.288	6.9	71,000				79		
9	2.302	6.3	76,000	41	1176	22			
Average	2.299	6.4	68,000	46	1235	21	83	68	0.82

Table D22. Laboratory Test Results for Cleburne LRA.

Sample	Bulk Specific Gravity	Air Voids, Percent	Resilient Modulus, psi	Hveem Stability	Marshall		Indirect Tensile Strength		Tensile Strength Ratio*
					Stability, lbs.	Flow, 0.01in	Dry, psi	After Moisture Conditioning, psi	
1	2.197	7.9	78,000					32	
2	2.205	7.5	61,000				62		
3	2.198	7.8	71,000	32	1885	24			
4	2.212	7.3	68,000				61		
5	2.196	7.9	92,000					33	
6	2.186	8.3	68,000	36	1551	24			
7	2.197	7.9	86,000					32	
8	2.210	7.3	73,000				61		
9	2.186	8.3	68,000	32	1776	23			
Average	2.198	7.8	74,000	33	1737	24	61	32	0.52

* Tensile Strength Ratio = $\frac{\text{Tensile Strength After Moisture Conditioning}}{\text{Dry Tensile Strength}}$.

Table D23. Laboratory Test Results for Cleburne LRA/Treated RAP Blend (50/50 Ratio).

Sample	Bulk Specific Gravity	Air Voids, Percent	Resilient Modulus, psi	Hveem Stability	Marshall		Indirect Tensile Strength		Tensile Strength Ratio*
					Stability, lbs.	Flow, 0.01in	Dry, psi	After Moisture Conditioning, psi	
1	2.195	7.5	150,000	31	2241	19			
2	2.179	8.1	117,000	34	2196	21			
3	2.197	7.4	141,000					38	
4	2.205	7.0	118,000				133		
5	2.202	7.2	117,000				132		
6	2.197	7.4	112,000					32	
7	2.183	7.9	117,000	36	1856	22			
8	2.196	7.4	105,000					36	
9	2.206	7.0	126,000				129		
Average	2.196	7.4	122,000	34	2097	21	131	35	0.27