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16. Abstract

In addition to conserving energy and protecting the environment, the use of reclaimed asphalt pavement (RAP) can significantly reduce the increasing cost of asphalt mixes. However, one of the key problems with RAP mixes is its variability, which is the main reason why many states including Texas Department of Transportation (TxDOT) limit the use of RAP. In most circumstances, RAP variability is closely related to RAP stockpiles management and RAP processing.

This report first documents the state of the practice of RAP stockpile management and RAP processing in Texas. In contrast to the RAP stockpiles owned by TxDOT, most contractors currently combine materials from different RAP sources and sometimes waste into a single pile and then process it into a usable material by crushing and/or fractionation. During the first year of this study it was found that the contractors visited are doing a good job of managing the processed RAP stockpiles. To quantify the RAP variability, samples were collected from several stockpiles and evaluated using asphalt ignition oven test. The results showed that both TxDOT's and contractors' RAP materials, in terms of aggregate gradation and asphalt content, are consistent and slightly better than those reported at the national level.

However, one concern raised during the visits is with mixing multiple-source RAP stockpiles before crushing or fractionation. RAP stockpiles are often processed or dug from a single angle or sequentially and then directly fed into a crushing or fractionating machine. If there is no further blending after crushing or fractionation, the processed RAP may still be multiple-source. In this report guidelines are proposed to address this and other issues related to stockpiles management and RAP processing. The key points are to 1) eliminate contamination of RAP stockpiles, 2) keep RAP stockpiles separate as possible, 3) blend thoroughly before processing or fractionating the multiple-source RAP stockpiles, 4) avoid over-processing (avoid generating too much fines passing # 200 sieve size), 5) use good practices when storing the processed RAP (such as using paved, sloped storage area), and 6) characterize and number the processed RAP stockpiles. To better control the RAP variability, both good stockpile management practices and RAP processing techniques described in this report should be followed.

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There is no invention or discovery conceived or first actually reduced to practice in the course of or under this contract, including any art, method, process, machine, manufacture, design or composition of matter, or any new useful improvement thereof, or any variety of plant, which is or may be patentable under the patent laws of the United States of America or any foreign country.

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- Dar-Hao Chen, Ph.D., P. E.
- Feng Hong, Ph.D., P. E.

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CHAPTER 1.
INTRODUCTION

1.1 BACKGROUND

Since 1970s, millions of tons of reclaimed asphalt pavement (RAP) have been used to produce recycled hot-mix asphalt (HMA). In addition to conserving energy and protecting the environment, the use of RAP can significantly reduce the increasing cost of HMA paving. Meanwhile, historical data showed that the RAP mixes, when properly designed and constructed, could have the same or similar performance as virgin HMA mixes. A fine example is the RAP asphalt overlay sections on US175 near Dallas, which was part of long-term pavement performance (LTPP) test sections. The performance of the four overlay sections with 35 percent RAP is still acceptable even after 17 years of service. However, this does not necessarily mean that RAP mixes always perform well. One of the key problems is RAP uniformity or variability in terms of RAP aggregate gradation, asphalt content, and asphalt characteristics, which is the main reason why many state departments of transportation (DOT) including Texas, limit the use of RAP in HMA.

Recently, RAP processing equipment and procedures have undergone significant technological advancements. RAP is typically processed into smaller pieces through RAP crushing and fractionating the material into two or three fractions. The fractionated material is more uniform and can, it is claimed, be used in higher percentage in HMA without compromising its quality. Also, HMA plants are better able to handle higher amounts of reclaimed pavement without detrimental effects. As a result, it is now possible to produce better quality HMA containing more than 25 percent RAP. However, both lab and field studies on high RAP mixes are not very extensive, especially for the fractionated RAP. Documented experience with both mix design and the long-term field performance is very limited. The inclusion of RAP materials into HMA mixes can improve the resistance to rutting, but it may greatly jeopardize its resistance to cracking, which becomes a significant concern when RAP is used in current dry HMA mixes.

Therefore, it is necessary to systematically study the high RAP mix design with the objective of balancing both rutting and cracking requirements.

1.2 OBJECTIVES

The main objectives of Project 0-6092 are to 1) develop guidelines for RAP stockpile management, 2) develop a RAP mix design procedure with balanced rutting and cracking requirements, and 3) recommend specification for HMA containing more than 25 percent RAP. In the first fiscal year, the research team focused on the first objective and this report documents the studies conducted. All the other objectives will be addressed in the later reports.

1.3 REPORT ORGANIZATION

This report is organized into four chapters. A brief introduction is presented in Chapter 1. Chapter 2 discusses state of the practice of RAP processing and stockpiles management. Chapter 3 presents the proposed guidelines for RAP stockpiles management. Finally, Chapter 4 presents a brief summary of this report.

CHAPTER 2.
STATE OF THE PRACTICE OF RAP STOCKPILES MANAGEMENT AND RAP PROCESSING

2.1 INTRODUCTION

As noted previously, the major concerns of many state DOTs is the variability in the RAP's aggregate gradation, asphalt content, and asphalt characteristics, which makes it difficult to control the gradation, asphalt content, and volumetric properties of the produced RAP mix. Because of these variability concerns, Texas and other states limit the amount of RAP that can be included in HMA mixes. The RAP variability may be caused by the following factors:

- When RAP is removed from an old roadway, it may include the original pavement materials, plus patches, chip seals, and other maintenance treatments.
- Base, intermediate, and surface courses from the old roadway may all be mixed together in the RAP.
- RAP from several projects is sometimes mixed in a single stockpile.
- RAP stockpiles may include waste trial batches of HMA mixes.
- RAP stockpiles may also include "deleterious material," such as wood, concrete, trash, etc.

To control the RAP variability, good stockpile management practices are essential and should be followed. So the focus of this chapter is on the state of the practice of RAP stockpiles management in Texas. This chapter will discuss the observations of current RAP stockpiles management and RAP processing and lab test results of the RAP samples from both, TxDOT owned stockpiles and contractors owned stockpiles.

2.2 RAP STOCKPILES MANAGEMENT: STATE OF THE PRACTICE

The research team and the project director, Mr. Robert Lee, visited different stockpiles owned by both TxDOT and contractors around the state. During each visit, RAP samples were collected from stockpiles and brought back to the Texas Transportation Institute (TTI) for further lab characterization including aggregate gradation, asphalt content, and asphalt binder Performance-Grade (PG). Both field survey (RAP stockpiles management and RAP processing) and lab test results are presented below.

2.2.1 State of the Practice of RAP Stockpiles Management

As mentioned previously, both TxDOT's and contractors' RAP stockpiles were surveyed. Field observations on the surveyed RAP stockpiles are discussed below.

2.2.1.1 TxDOT's RAP Stockpiles

To reduce RAP variability, it is critical to separate stockpiles from different sources, although this requires more space. The space limitation, in most cases, is not a problem for TxDOT. So the overall observation is that TxDOT manages the RAP stockpiles well in terms of separating them. As an example, Figure 2-1 shows two separated RAP stockpiles.

Figure 2-1. Two Separated RAP Stockpiles.

Another observation is that the majority of TxDOT's stockpiles are large, as shown in Figure 2-2. Meanwhile, most stockpiles are piled in horizontal shape.

(a) Large, horizontal RAP Stockpile #1.

(b) Large, horizontal RAP stockpile #2.

Figure 2-2. TxDOT's Large RAP Stockpiles.

The concerns with these large, horizontal RAP stockpiles include: 1) the compaction (Figure 2-3) from material handling machines (such as front-end loaders and bulldozers), which often makes it difficult for the loader to handle the RAP later, and 2) greater amounts of trapped moisture than tall, conical stockpiles.

Figure 2-3. Compacted RAP Stockpiles.

2.2.1.2 Contractors' Non-Processed RAP Stockpiles

A total of five Contractors, C1, C2, C3, C4, and C5, were visited. During each visit, the research team and the project director met the contractors' lab personnel, visited RAP stockpiles, and sampled the RAP stockpiles. Generally speaking, the contractors' RAP stockpiles are blended piles from multiple sources due to limited storage space, although some contractors did separate the stockpiles based on the sources. The common observation is that the multiple-source RAP stockpiles contain paving materials from small milling jobs, plant waste, rejected asphalt pavement material, pavement rubble from complete demolition of roads or parking lots, and even lab molded HMA samples. Figure 2-4 shows an example of the blended stockpile containing RAP, wasted plant mix (or trial batch), lab molded Hamburg samples, etc. Figure 2-5 presents another example of multi-source of RAP stockpiles. In some cases, the RAP stockpile may be contaminated with other materials (such as ground soil), which is indicated in Figure 2-6. In other cases, the RAP stockpiles have been well compacted, as displayed in Figure 2-7.

Figure 2-4. Blended RAP Stockpile.

Figure 2-5. Multiple-Source RAP Stockpiles.

Figure 2-6. RAP Stockpile Contaminated with Subgrade Soil.

Figure 2-7. Trafficked and Compacted RAP Stockpile.

One good practice on stockpiles management that was observed and which some contractors adopt is paving the stockpiles resting area with a certain slope (Figure 2-8). In the past stockpile paving and drainage have been overlooked. Yet, it is one of the easiest ways to save money, increase production capacity, and enable the use of higher percentage of RAP materials. So when dealing with stockpiles management, it is important to use paved, sloped areas for piling RAP materials.

Figure 2-8. Paved, Sloped Stockpiles Surface.

2.2.2 State of the Practice of RAP Processing and Processed RAP Stockpiles

In addition to RAP stockpiles management, another important step to reduce the variability is RAP processing. Depending on the size of RAP materials, different types of equipments have been used to process RAP materials before using them. In general, full-depth RAP or large sized RAP is often crushed using crushers (such as horizontal impact crushers) prior to recycling it into a new pavement construction or an asphalt overlay. For milling RAP materials, RAP screening or crushing and screening, depending on where they are to be used, may be necessary.

In order to use high percentages of RAP in a mix and still meet the gradation and volumetric requirements, fractionating RAP materials into different sizes is very important. **Fractionating RAP is the act of processing it to screen, crush, size, and separate the various sizes into stockpiles that are more consistently uniform in size and composition.** When fractionating, both milled RAP and material ripped up from the roadway require crushing and screening to control the gradation. Note that a large portion of milled RAP will pass through the 1/2 in. sieve and will therefore not need to be crushed. By fractionating RAP into two/three different sizes such as 1 in.–1/2 in. and 1/2 in.–0, or even further to 1/2 in.–1/4 in. and 1/4 in.–0, one will have much better control over the gradation, asphalt content, and volumetric properties of the produced mix. Regardless of whether the recycled materials are from the same project or different projects, it was designed that RAP fractionation through separating coarse and fine RAP stockpiles will minimize segregation of RAP particles and allow greater flexibility in adjusting the RAP content for the final aggregate gradation. Generally speaking, the fine RAP material will have higher asphalt content than coarse RAP stockpiles due to the higher surface area of the fine material. The asphalt binder content in both the fine and coarse RAP stockpiles can be expected to be more uniform than the asphalt content of a single RAP stockpile.

In Texas contractors are using all techniques to crush, screen, or fractionate RAP materials. The general observations on RAP processing during the survey are presented as follows:

1) In most cases, they simply ***crush*** all RAP stockpiles to a single size: either 1/2 in. or 3/8 in., and then there is no further fractionation. This observation is also similar to the national survey results (Figure 2-9) conducted by NCAT (National Center for Asphalt Technology).

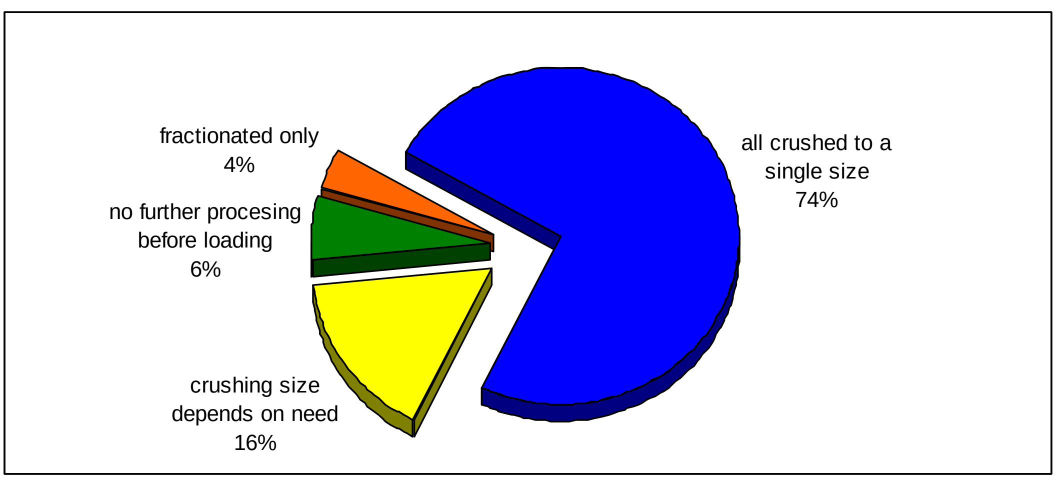

Figure 2-9. Summary of How RAP is Crushed (*1*).

2) Only one contractor further crushed the 1/2 in. RAP to 1/2 in.-1/4 in. and minus 1/4 in. The problem with the additional crushing is to generate too much fines (dust), which can potentially limit the percentage of RAP use.

3) In most cases, only one cold RAP feed bin is used due to single size of RAP, although some plants are equipped with two RAP feed bins (Figure 2-10).

Figure 2-10. Two RAP Bins.

4) RAP fractionation has also been used by contractors, as shown in Figure 2-11. RAP is divided into coarse and fine fractions. The coarse RAP stockpile will contain only material retained over a 3/8 in. screen or 1/2 in. screen; the fine RAP stockpile will contain only material passing the 3/8 in. screen or 1/2 in. screen.

Figure 2-11. RAP Fractionation.

5) Unlike the non-processed RAP stockpiles, the processed RAP stockpiles are well managed. The processed RAP stockpiles are not only separated, but they are also well numbered or marked, as shown in Figure 2-12. In fact, some contractors have already characterized these processed RAP stockpiles in terms of aggregate gradation and asphalt content.

Figure 2-12. Numbered/Marked RAP Stockpiles after Processing.

6) For milling RAP material, the most economical way of processing it into multiple sizes is to screen it first. Since most of the milling material is surface mix, it is 1/2 in. minus material. With milling RAP material, 70–80 percent of the material will pass a 1/2 in. screen.

In general, the contractors visited are doing a good job of processing and managing the processed RAP. However, one concern raised during the visits relates to blending or mixing multiple-source RAP stockpiles before crushing or fractionation. It has been observed that contractors often dig into the multi-source RAP stockpile from a single angle or sequentially. If there is no further blending after crushing or fractionation, the processed RAP may still be multiple-source. So it is important for contractors to blend the multiple-source RAP stockpile using a front-end loader or other appropriate equipment before processing it or randomly rather than sequentially dig into the stockpile to feed into a RAP crushing or fractionating machine during RAP processing. Detailed lab characterization on RAP materials collected during the visits is presented in the next section.

2.3 LAB CHARACTERIZATION OF RAP MATERIALS SAMPLED FROM DIFFERENT STOCKPILES

As mentioned previously, RAP samples were collected when visiting each RAP stockpile. A front-end loader was used to make the sampling platform and then the samples were collected, as shown in Figure 2-13. Also, it is worth noting that the collected RAP samples were either from single source RAP stockpile or relatively small stockpile was sampled from processed small stockpiles. In most cases, 7 RAP samples were collected around the RAP stockpile and then brought back to the Texas Transportation Institute (TTI) for lab characterization. A series of lab tests were conducted, and Tables 2-1 to 2-12 shows the ignition oven test results.

It can be seen from Tables 2-1 to 2-12 that there is not much variability in the RAP materials collected during the field visits, in terms of aggregate gradation and asphalt content. For example, the largest standard deviation of passing #8 sieve size for all 12 RAP materials is 5.0 percent and most of them are below 4.0 percent, which is better than the national survey results (average=4.32 percent and ranging from 0.78 to 9.0 percent) reported by NCAT. The standard deviations of passing #200 sieve size in this study range from 0.5 to 2.3 percent, which is a little bit better than the NCAT survey results ranging from 0.3 to 3.0 percent; regarding the asphalt content, the standard deviations ranging from 0.1 to 0.5 percent are much smaller than the national results which are between 0.1 to 1.5 percent. Therefore, the survey results from this study show that both TxDOT and contractors' RAP materials, in terms of aggregate gradation and asphalt content, are consistent.

Figure 2-13. Sampling RAP Stockpiles.

Table 2-1. TxDOT Owned Stockpile #1: Unfractionated RAP.

Sieve Size	Cumulative % Passing of RAP Samples							Ave	Stdev
	#1	#2	#3	#4	#5	#6	#7		
3/4	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.0
1/2	97.9	99.6	99.8	98.4	99.4	99.1	100.0	99.2	0.8
3/8	88.7	90.2	94.2	89.7	91.4	94.2	95.3	92.0	2.6
#4	59.4	63.2	69.8	61.6	62.6	69.1	69.8	65.1	4.4
#8	40.6	43.7	49.2	41.7	40.6	48.4	50.6	45.0	4.3
#16	31.8	33.8	38.2	32.7	31.3	37.1	40.4	35.0	3.5
#30	26.0	26.6	30.5	26.3	25.5	29.7	32.4	28.1	2.7
#50	17.9	19.0	21.0	17.7	17.8	21.0	21.8	19.4	1.8
#100	11.0	11.1	13.1	10.5	11.2	13.5	13.7	12.0	1.4
#200	6.9	7.0	8.2	6.3	7.1	8.6	9.1	7.6	1.1
AC (%)	5.3	5.4	5.6	5.4	5.2	5.8	5.3	5.4	0.2

Table 2-2. TxDOT Owned Stockpile #2: Unfractionated RAP.

Sieve Size	Cumulative % Passing of RAP Samples							Ave	Stdev
	#1	#2	#3	#4	#5	#6	#7		
3/4	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.0
1/2	95.9	97.9	99.0	98.7	98.3	97.0	97.0	97.7	1.1
3/8	89.7	94.7	90.3	90.8	92.9	90.7	90.7	91.4	1.8
#4	73.1	81.6	67.1	67.8	68.3	73.8	73.8	72.2	5.1
#8	43.5	53.4	43.9	47.7	46.4	46.5	46.5	46.8	3.3
#16	29.3	36.5	31.6	35.3	33.9	31.9	31.9	32.9	2.5
#30	21.6	26.2	24.3	27.4	25.6	23.4	23.4	24.6	2.0
#50	15.5	18.7	18.5	20.8	18.6	17.1	17.1	18.0	1.7
#100	10.0	12.0	12.4	13.7	12.1	11.2	11.2	11.8	1.2
#200	6.4	7.6	8.0	8.8	7.5	7.2	7.2	7.5	0.7
AC (%)	7.5	8.1	7.7	8.6	8.2	8.0	7.4	7.9	0.4

Table 2-3. TxDOT Owned Stockpile #3: Lab Fractionated RAP (1/2 in.-1/4 in.).

Sieve Size	Cumulative % Passing of RAP Samples					Ave	Stdev
	#1	#2	#3	#4	#5		
1/2	100.0	100.0	99.9	99.7	100.0	99.9	0.1
3/8	87.1	86.3	84.6	88.8	88.4	87.1	1.7
#4	39.3	31.6	38.2	41.4	38.9	37.9	3.7
#8	25.6	17.4	24.9	27.8	25.5	24.3	4.0
#16	21.0	14.1	20.3	23.0	21.1	19.9	3.4
#30	17.9	11.9	17.1	19.6	18.0	16.9	2.9
#50	14.3	9.5	13.5	15.9	14.5	13.5	2.4
#100	9.3	6.0	8.3	10.8	9.3	8.7	1.8
#200	5.3	3.3	6.3	6.7	5.2	5.4	1.3
AC (%)	3.52	2.62	3.5	3.6	3.34	3.3	0.4

Table 2-4. TxDOT Owned Stockpile #3: Lab Fractionated RAP (Passing 1/4 in.).

Sieve Size	Cumulative % Passing of RAP Samples					Ave	Stdev
	#1	#2	#3	#4	#5		
1/2	100.0	100.0	100.0	100.0	100.0	100.0	0.0
3/8	100.0	100.0	100.0	100.0	100.0	100.0	0.0
#4	100.0	100.0	99.9	99.9	100.0	99.9	0.0
#8	79.3	81.4	78.7	77.9	84.4	80.4	2.6
#16	60.1	59.6	60.7	59.6	67.7	61.5	3.5
#30	46.1	42.4	47.0	47.2	53.8	47.3	4.1
#50	33.7	28.4	34.7	35.3	39.4	34.3	4.0
#100	21.1	16.3	21.8	22.0	24.7	21.2	3.0
#200	12.5	8.5	12.5	13.3	14.6	12.3	2.3
AC (%)	6.2	5.3	6.2	6.4	6.5	6.1	0.5

Table 2-5. Contractor Owned Stockpile: C1-Crushed RAP.

Sieve Size	Cumulative % Passing of RAP Samples							Ave	Stdev
	#1	#2	#3	#4	#5	#6	#7		
3/4	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.0
1/2	99.1	99.3	99.1	95.4	99.7	97.8	98.4	98.4	1.5
3/8	93.6	93.7	95.5	86.8	96.1	90.6	92.5	92.7	3.2
#4	76.3	74.4	77.9	69.9	77.2	71.2	74.5	74.5	3.0
#8	57.5	54.4	58.1	55.7	60.0	52.0	56.3	56.3	2.6
#16	45.7	41.8	44.7	45.6	47.5	40.0	45.1	44.3	2.5
#30	36.5	32.2	33.6	35.3	35.5	31.1	35.5	34.2	2.0
#50	27.4	23.1	23.0	23.6	23.1	22.6	25.5	24.0	1.8
#100	18.7	15.3	14.8	14.7	14.7	15.4	17.0	15.8	1.5
#200	13.8	11.3	11.0	10.6	10.8	11.5	12.4	11.6	1.1
AC (%)	5.5	5.0	5.1	5.1	5.0	4.6	5.5	5.1	0.3

Table 2-6. Contractor Owned Stockpile: C2-Crushed RAP.

Sieve Size	Cumulative % Passing of RAP Samples							Ave	Stdev
	#1	#2	#3	#4	#5	#6	#7		
3/4	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.0
1/2	98.0	99.2	98.1	98.5	95.7	98.9	98.8	98.1	1.1
3/8	90.6	95.2	92.7	94.0	84.0	91.5	91.9	91.4	3.6
#4	67.8	74.3	69.1	69.5	53.9	68.1	69.8	67.5	6.4
#8	46.1	52.3	47.8	47.4	36.0	46.9	48.6	46.5	5.0
#16	34.5	39.7	36.0	35.6	28.1	34.5	36.3	35.0	3.5
#30	27.6	31.8	28.9	28.9	23.8	27.2	29.6	28.3	2.5
#50	21.8	25.1	22.6	22.7	19.8	20.6	23.4	22.3	1.8
#100	12.9	15.1	13.4	13.1	12.4	11.5	13.5	13.1	1.1
#200	7.9	9.5	8.3	7.9	7.8	6.8	8.2	8.1	0.8
AC (%)	4.5	4.7	4.4	4.3	4.2	4.2	4.6	4.4	0.2

Table 2-7. Contractor Owned Stockpile: C2-Crushed RAP+RAS.

Sieve Size	Cumulative % Passing of RAP Samples							Ave	Stdev
	#1	#2	#3	#4	#5	#6	#7		
3/4	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.0
1/2	98.3	100	99.0	97.7	98.7	99.1	97.3	98.6	0.9
3/8	93.6	94.2	93.4	91.7	92.9	93.2	92.6	93.1	0.8
#4	75.0	75.2	73.6	70.6	70.3	72.8	73.6	73.0	2.0
#8	59.4	58.1	57.4	55.5	54.3	57.0	57.4	57.0	1.7
#16	45.9	45.6	44.9	45.1	43.6	45.7	44.9	45.1	0.8
#30	34.4	35.8	35.0	37.1	35.7	37.0	35.1	35.7	1.0
#50	25.4	28.3	27.7	31.0	29.9	30.6	27.4	28.6	2.0
#100	15.0	17.6	17.3	20.7	20.2	20.2	16.6	18.2	2.2
#200	8.6	10.5	10.5	13.0	13.0	13.0	10.2	11.3	1.8
AC (%)	7.5	8.1	7.7	8.6	8.2	8.0	7.4	7.9	0.4

Table 2-8. Contractor Owned Stockpile: C3-Crushed RAP.

Sieve Size	Cumulative % Passing of RAP Samples			Ave	Stdev
	#1	#2	#3		
3/4	100.0	100.0	100.0	100.0	0.0
1/2	99.3	100.0	100.0	99.8	0.4
3/8	97.7	96.9	97.1	97.3	0.4
#4	79.6	77.7	77.1	78.2	1.3
#8	59.1	57.5	56.1	57.6	1.5
#16	48.0	47.1	45.9	47.0	1.0
#30	40.1	40.6	39.2	39.9	0.7
#50	26.3	28.9	27.7	27.6	1.3
#100	11.3	15.5	13.5	13.4	2.1
#200	5.9	8.9	7.4	7.4	1.5
AC (%)	4.0	4.2	4.3	4.2	0.1

Table 2-9. Contractor Owned Stockpile: C4-Crushed Coarse RAP.

Sieve Size	Cumulative % Passing of RAP Samples						Ave	Stdev
	#1	#2	#3	#4	#5	#6		
¾	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.0
1/2	96.1	93.9	94.2	94.4	96.6	94.9	95.0	1.1
3/8	79.6	68.1	70.2	73.8	70.5	70.6	72.1	4.1
#4	30.2	21.1	19.2	22.6	23.2	18.9	22.5	4.1
#8	21.5	14.3	13.6	15.9	16.8	12.8	15.8	3.1
#16	17.2	11.2	11.8	13.2	14.4	10.9	13.1	2.4
#30	14.9	9.6	10.5	11.9	12.9	10.0	11.6	2.0
#50	13.1	8.2	9.3	10.6	11.5	9.0	10.3	1.8
#100	7.7	7.9	5.5	6.2	6.7	5.4	6.6	1.1
#200	4.4	5.2	3.1	3.4	3.6	2.9	3.8	0.9
AC (%)	2.7	2.3	2.1	2.4	2.7	2.3	2.4	0.2

Table 2-10. Contractor Owned Stockpile: C4-Crushed Fine RAP.

Sieve Size	Cumulative % Passing of RAP Samples							Ave	Stdev
	#1	#2	#3	#4	#5	#6	#7		
3/4	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.0
1/2	99.5	100.0	100.0	99.5	100.0	100.0	100.0	99.8	0.3
3/8	98.6	98.8	99.1	97.5	99.1	99.5	99.0	98.8	0.6
#4	83.2	84.6	84.9	84.5	85.6	87.6	85.7	85.2	1.4
#8	57.0	58.0	56.2	57.2	59.2	63.2	60.1	58.7	2.4
#16	43.9	45.2	42.5	43.4	45.6	49.2	46.9	45.2	2.3
#30	36.8	38.7	35.7	36.4	38.1	40.8	39.4	38.0	1.8
#50	27.7	29.5	26.4	26.2	27.5	29.7	29.5	28.1	1.5
#100	15.8	16.3	14.2	13.7	14.1	15.5	15.9	15.1	1.0
#200	8.0	8.2	6.8	6.6	6.8	7.9	8.3	7.5	0.7
AC (%)	5.6	5.1	5.1	5.3	5.6	5.3	5.3	5.3	0.2

Table 2-11. Contractor Owned Stockpile: C5-Crushed Coarse RAP.

Sieve Size	Cumulative % Passing of RAP Samples							Ave	Stdev
	#1	#2	#3	#4	#5	#6	#7		
3/4	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.0
1/2	96.3	98.2	99.5	97.7	99.1	96.6	95.3	97.5	1.5
3/8	79.4	88.0	86.9	86.0	84.0	86.9	80.3	84.5	3.4
#4	51.6	56.1	56.8	57.5	55.0	58.7	45.7	54.5	4.5
#8	36.0	38.2	39.3	38.7	38.0	40.2	28.4	37.0	4.0
#16	25.8	26.9	28.0	27.6	27.0	28.9	18.9	26.2	3.3
#30	19.9	20.2	20.9	20.9	20.4	22.2	14.1	19.8	2.6
#50	15.1	14.6	14.9	15.1	14.7	16.6	10.4	14.5	1.9
#100	8.1	7.3	7.5	7.7	7.3	8.8	5.6	7.5	1.0
#200	4.0	3.3	3.5	3.7	3.2	4.2	3.0	3.6	0.5
AC (%)	3.0	2.9	3.0	2.9	2.9	3.1	2.2	2.8	0.3

Table 2-12. Contractor Owned Stockpile: C5-Crushed Fine RAP.

Sieve Size	Cumulative % Passing of RAP Samples							Ave	Stdev
	#1	#2	#3	#4	#5	#6	#7		
3/4	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.0
1/2	100.0	100.0	99.6	100.0	100.0	100.0	99.8	99.9	0.2
3/8	99.9	99.2	98.8	99.2	99.5	99.4	99.6	99.4	0.4
#4	91.0	88.2	89.8	89.2	90.4	90.6	88.2	89.6	1.1
#8	70.6	63.2	69.9	67.5	69.7	69.9	64.1	67.8	3.1
#16	54.0	47.5	54.6	51.7	53.5	52.4	45.5	51.3	3.5
#30	42.4	38.3	44.1	41.0	42.0	39.0	33.6	40.1	3.5
#50	29.9	27.7	32.2	28.5	28.5	25.5	22.8	27.9	3.0
#100	14.2	13.0	17.4	13.1	12.9	10.9	10.2	13.1	2.3
#200	6.7	5.7	10.4	5.7	5.5	4.4	4.3	6.1	2.1
AC (%)	4.7	4.9	5.0	5.3	5.0	4.6	4.3	4.8	0.3

2.4 SUMMARY AND CONCLUSIONS

This chapter presents the observations of RAP stockpiles management and summary results of the variability of stockpiles around Texas. In general, TxDOT often separates RAP stockpiles as they have plenty of space for the purpose. Most contractors currently follow simple practices of managing RAP materials. Most plants combine RAP materials from different sources and sometimes waste (such as trial batch) into a single pile and then process it into a usable RAP material by crushing and/or screening. But the contractors visited are doing a good job managing the processed RAP stockpiles. The lab ignition oven test results for both TxDOT and contractors' RAP materials are consistent, in terms of aggregate gradation and asphalt content, and slightly better than those in the national level.

A good practice that some contractors adopted is paving the stockpile storage area with a certain slope to facilitate drainage. However, one concern raised during the visits relates to blending or mixing multiple-source RAP stockpiles before crushing or fractionation. It has been observed that contractors often dig into the multi-source RAP stockpile from a single angle or sequentially. If there is no further blending after crushing or fractionation, the processed RAP may still be multiple-source. This observation or claim seems contradictory to the ignition oven test results that show that the RAP samples are consistent in terms of aggregate gradation and asphalt content, but it should be kept in mind that the RAP material from a specific contractor was sampled from a smaller RAP stockpile at a specific date. So it is still very important for contractors to blend the multiple-source RAP stockpile using a front-end loader or other appropriate equipment before processing it or randomly rather than sequentially dig into the stockpile to feed into a RAP crushing or fractionating machine during RAP processing. To further address this issue, some guidelines are proposed for RAP stockpiles management and are presented in the next chapter.

CHAPTER 3.
PROPOSED GUIDELINES FOR RAP STOCKPILES MANAGEMENT TO CONTROL RAP VARIABILITY

Many DOTs including TxDOT are limiting the amount of RAP in asphalt mixes because of concerns with the variability of RAP materials. Generally, the use of higher percentages of RAP could have a negative effect on the consistency of asphalt mixes and consequently on the asphalt pavement performance. To better control the RAP variability, both good stockpile management practices and RAP processing should be followed. The key issues here are to:

- eliminate contamination of RAP stockpiles,
- keep RAP stockpiles as separate as possible,
- avoid over-processing (avoid generating too much fines passing # 200 sieve size),
- minimize the moisture trapped in the RAP stockpiles, and
- thoroughly blending before processing or fractionating the multiple-source RAP stockpiles.

Based on the field observation and interaction with TxDOT's personnel and contractors, some general guidelines for RAP stockpiles management and RAP processing were proposed and are presented below:

1. **Eliminate contamination.**

   The first step to control the quality of RAP materials is to eliminate contamination. It is acknowledged that RAP processing/fractionating is a critical step in reducing the RAP variability. It should be noted that RAP fractionation in itself will help. However, it will not solve all the RAP variability and other problem. For example, if you fractionate one contaminated pile of RAP, you will get two contaminated piles of RAP. Both TxDOT and contractors will benefit from keeping deleterious materials out of any RAP stockpile from the beginning.

Contamination may occur from milled-up paving geosynthetics (fabrics, grid), reflective lane markers (yellow or white), and dumping general road debris with dirt and vegetation on the pile. In some cases, the multiple-source RAP stockpiles were believed to contain construction trash. Figure 3-1 shows an extreme example in which concrete trash and reinforcing steel were mixed with RAP stockpile. Contamination problems are likely if the stockpile is on untreated, rough natural ground. Any potential contamination to RAP stockpiles should be avoided in order to improve the RAP quality and accordingly pavement performance.

Figure 3-1. Contaminated RAP Stockpile.

2. **Separate RAP stockpiles from different sources.**

   It is always important to separate RAP stockpiles obtained from different sources. In most cases, it is unnecessary to crush or fractionate a single source RAP stockpile with a known source. As demonstrated in Chapter 2, the separated, unfractionated RAP materials owned by TxDOT have a similar quality to that of crushed RAP. Well separated stockpiles can save lots of time and cost for crushing or fractionating RAP. In particular, when a large quantity of millings occurs from a single project, it is always worthwhile to keep the milled RAP separate from other RAP stockpiles.

3. **Blend or mix before processing RAP stockpiles.**

   The whole purpose of processing a multiple-source RAP stockpile is to obtain a uniform RAP. One of the observations during the field visits is that the mixing process is rarely carried out before RAP crushing or fractionation. Current practice for processing multiple-source RAP stockpiles is to use a front-end loader or other machines to sequentially dig into the stockpiles to feed into a RAP crushing or fractionating machine. Such operating sequence often makes it difficult to truly meet the purpose of processing the multiple-source RAP stockpiles. Therefore, when the RAP materials are excavated, it is essential to randomly dig into the RAP pile from different angles so that the RAP material feeding into the crusher or fractionating machine at any time gets adequately mixed.

4. **Process (crush or fractionate) RAP stockpiles.**

   4.1. <u>Crush or Fractionate RAP</u>

   There has been a lot of discussion about fractionating RAP, but the current practice for RAP processing, as presented in Chapter 2, is to crush all RAP materials to a single maximum size, in most cases, either 1/2 in. or 3/8 in. Unlike crushing, fractionating the RAP is to simply screen RAP materials into two or more sizes. The fractionated RAP is often split into coarse and fine fractions. The coarse RAP stockpile will contain only the RAP material retained over a 3/8 in. screen or 1/2 in. screen; the fine RAP stockpile will contain only the RAP material passing the 3/8 in. screen or 1/2 in. screen. When compared with simply crushing RAP, there are benefits and some additional costs for RAP fractionation. For example, RAP fractionation can provide designers more flexibility to choose different percentages of the coarse and fine RAP with virgin aggregates to meet both gradation and volumetric requirements. Generally speaking, it is easier to use more total fractionated RAP than crushed RAP.

4.2. Avoid over crushing

As discussed in Chapter 2, most contractors crush all RAP materials to a single maximum size, such as 1/2 in. or 3/8 in., so that the crushed RAP can be used in, for most cases, asphalt overlay mixes (dense-graded Type C or D). When crushing large aggregate particles in the RAP, it may generate too much fines (or dust passing #200 sieve size). It should be kept in mind that the excess dust often controls the percentage of RAP being used in a new mix during RAP mix design process. Another scenario is to further crush the RAP materials to 1/4 in. size. Theoretically, it is always better to crush RAP materials into finer size so that it is possible to better control the gradation and use more fine RAP with high asphalt binder content. However, crushing RAP to smaller size often generates more dust which, on the contrary, limits the percentage of smaller RAP used in the new mix. The authors of this report have experienced such a scenario when designing RAP mixes for field experimental test sections. Therefore, it is important to avoid excessive crushing of RAP materials.

5. **Store the processed RAP using paved, sloped surface.**

Another aspect of managing RAP stockpiles is to store the RAP processed using a crusher or fractionation machine. It is a well known fact that RAP has a tendency to hold water and under lots of scenarios it is the RAP moisture content that limits the percentage of RAP use, reducing the overall production rates, and raising the drying and heating cost for superheating the virgin aggregates. Therefore, it is beneficial and critical to minimize the RAP moisture content. Several measures can be proposed to reduce RAP moisture content during stockpiling the processed RAP and are discussed below:

5.1. Conical vs. horizontal stockpiles

As documented in "Recycling Hot-Mix Asphalt Pavements" (*2*), the RAP in the early days were piled in low, horizontal shape for fear that high, conical stockpiles would cause RAP to pack together with the weight of the pile. Past experience indicated, however, that this is not the case. Additionally, RAP has a tendency to hold water and the low, horizontal stockpiles often retain higher moisture accumulation than the tall, conical stockpiles. In general, tall, conical stockpiles are preferred.

5.2. Use a paved, sloped storage area

As noted in Chapter 2, at least one contractor already started using the paved, sloped surface to stockpile RAP materials. Using the paved surface under stockpiles can not only contribute to drainage from RAP stockpiles, but it also provides an even hard-surfaced area to minimize material loss and contamination with underlying materials. Meanwhile, providing a slope to the paved surface under the stockpile away from the side where the front-end loader moves RAP materials to cold feed bind, as shown in Figure 3-2, will allow rainwater to drain away, so that drier materials go into the plant.

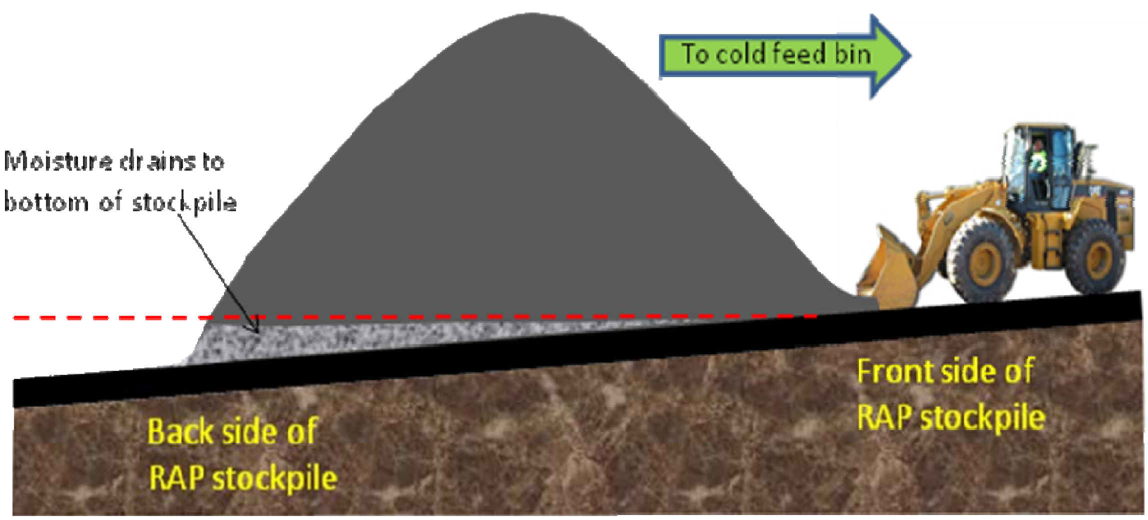

Figure 3-2. Illustration of Paved, Sloped Surface under RAP Stockpiles.

5.3. Cover RAP stockpiles if necessary

Currently, relatively few contractors cover any of their RAP stockpiles, but covering RAP stockpiles to minimize RAP moisture content is even more economical than covering virgin aggregate stockpiles. RAP should never be covered with a tarp or plastic, however. It is best to store RAP materials under the roof of an open-sided building (Figure 3-3). Free air can pass over the RAP, but the RAP is protected from precipitation.

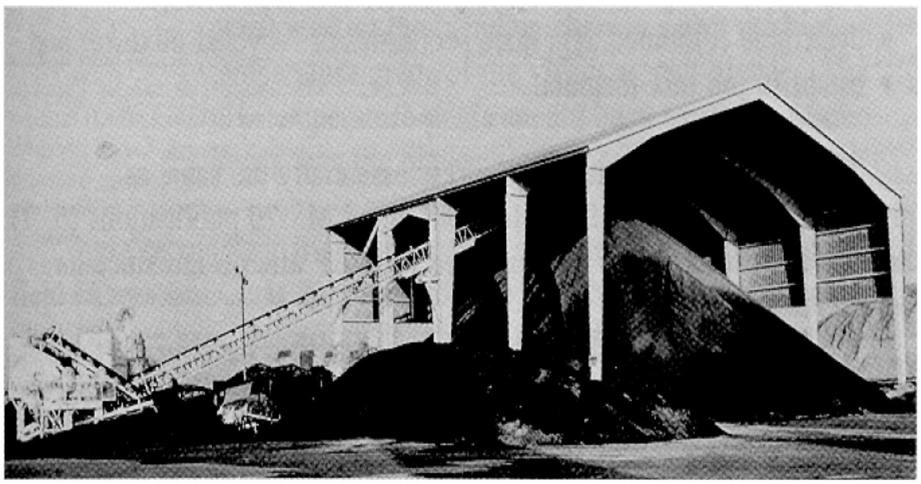

Figure 3-3. Storing RAP under a Covered Roof (*2*).

6. Characterize the processed RAP and mark stockpiles.

A good practice some contractors have been adopting is to characterize the processed RAP right after the stockpile is being built at its final location, and marking or numbering the stockpile, as shown in Chapter 2. A minimum of five RAP samples collected from each RAP stockpile should be obtained and tested before making a mix design. It is worthwhile that both average values and associated standard deviations of RAP asphalt content and aggregate gradation should be recorded. To produce a consistent RAP mix the associated standard deviations of the RAP asphalt content and aggregate gradation should be carefully observed. With these measured data including both average values and associated standard deviations of RAP asphalt content and aggregate gradation, contractors can make an evaluation on their

RAP processing operations, and consider improving their processing operations.

The guidelines proposed above may not completely solve the RAP variability problem, but they do provide a good starting point to reduce the RAP variability through stockpiles management and RAP processing.

CHAPTER 4.
SUMMARY

In addition to conserving energy and protecting the environment, the use of RAP can significantly reduce the increasing cost of HMA paving. When properly designed and constructed, RAP mixes could have the same or similar performance as virgin HMA mixes. However, this does not mean that RAP mixes always perform well. One of the key problems is RAP uniformity or variability in terms of RAP aggregate gradation and asphalt content, which is the main reason why many state DOTs including TxDOT limit the use of RAP in HMA mixes.

In most circumstances, RAP variability is closely related to RAP stockpiles management and RAP processing. So this report first documented the state of the practice of RAP stockpiles management and RAP processing in Texas. In general, TxDOT often separates RAP stockpiles due to no space limitation. Most contractors currently follow simple practices of managing RAP materials. Most plants combine RAP materials from different sources and sometimes waste into a single pile and then process it into a usable RAP material by crushing and/or fractionation. But the contractors visited are doing a good job to manage the processed RAP stockpiles. Furthermore, to quantify the RAP variability, RAP samples were collected from visited RAP stockpiles and evaluated in TTI lab using the ignition oven test. The results showed that both TxDOT and contractors' RAP materials, in terms of aggregate gradation and asphalt content, are consistent and slightly better than those reported at the national level.

However, one concern raised during the visits is with mixing multiple-source RAP stockpiles before crushing or fractionation. RAP stockpiles are often processed or dug from a single angle or sequentially and then directly fed into a crushing or fractionating machine. If there is no further blending after crushing or fractionation, the processed RAP may still be multiple-source. So it is still very important for contractors to blend the multiple-source RAP stockpile using a front-end loader or other appropriate equipment before processing it or randomly rather than sequentially dig into the stockpile to feed into a RAP crushing or fractionating machine during RAP processing. To further address this and other issues related to stockpiles management, some guidelines are proposed and the key points are to 1) eliminate contamination of RAP stockpiles, 2) keep RAP stockpiles separate as possible, 3) blend thoroughly before processing or fractionating the multiple-source RAP stockpiles, 4) avoid over-processing (avoid generating too much fines passing # 200 sieve size), 5) use good practice when storing the processed RAP (such as using the paved, sloped storage area), and 6) characterize and number the processed RAP stockpiles. To better control the RAP variability, both good stockpile management practices and RAP processing techniques described in this report should be followed.

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