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ANALYSIS OF USING RECLAIMED ASPHALT PAVEMENT (RAP) AS A BASE COURSE MATERIAL

Robert Locander

February 2009

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16. Abstract

The Colorado Department of Transportation (CDOT) has used Reclaimed Asphalt Pavement (RAP) as a base on many projects as a reconstruction strategy. CDOT's specifications allow RAP to be substituted for unbound aggregate base course (ABC). The laboratory tested properties of reclaimed asphalt pavement are similar to CDOT's aggregate base course specifications. Conclusions are: RAP has pavement design properties similar to aggregate base course; a suggested gradation specification band is presented for RAP; RAP requirements for PI and LL may be the same as ABC Class 6, PI not to exceed six and LL not greater than 30; the stiffness strength properties obtained from laboratory testing shows that RAP has stiffness strength above an unbound ABC Class 6 ; and the permeability of RAP showed a slight increase over an unbound ABC Class 6.

Implementation:

The analysis was performed on limited data. It is recommended to do additional RAP testing for R-value and correlate with CDOT standard correlation equations. Cold milling projects would create material stockpiles of 100% RAP. Gradations, densities, and R-value testing could be sampled and tested from this material.

Long-term performance has not been addressed. A recommendation is to obtain performance data at five and ten years. This should be compared to an unbound aggregate base material. The comparison is to see if any distresses prematurely appear, if the stiffness strength changes negatively, or if permanent deformations occur.

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Pavement Design Program

Report No. CDOT-2009-5

Sponsored by
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1.0 INTRODUCTION

1.1 Background

The Colorado Department of Transportation (CDOT) has used reclaimed asphalt pavement (RAP) as a base on many projects as a reconstruction strategy. CDOT specifications allow RAP to be substituted for aggregate base course (ABC). RAP may be generated during cold milling of existing hot mix asphalt (HMA) pavement. The RAP material is milled into a well-graded gradation. The millings are loaded onto trucks by the milling machine, removed from the site, and are generally stockpiled. Sometimes the RAP material is processed further to conform to a specific project gradation requirement.

RAP samples obtained for this study were well-graded and consistent throughout the state. A Colorado procedure and a project special provision to determine the macro-texture of cold planed HMA pavement were implemented in the 2007 paving season to ensure acceptable surface textures for the placement of HMA overlays. RAP generated during cold milling of HMA pavement appears to be consistently well-graded as a result of the new procedures.

1.2 Objectives of the Study

Stiffness strength and permeability are two areas of concern regarding the use of RAP material. One objective of the study is to compare the stiffness strength and permeability of milled RAP and virgin aggregate base course material. Another research objective is to establish reasonable default design input values to be used by pavement designers when using RAP as a substitute for virgin aggregate base course or subbase material.

1.3 Research Approach

The research will be managed and performed by the Research Branch and the Materials & Geotechnical Branch except that all the materials testing will be conducted by a commercial laboratory. The research work will consist of the following tasks:

- Literature review
- Review of other state practices
- Laboratory testing of 100% RAP (10 samples from maintenance stock piles across the state) and virgin Class 6 aggregate base course materials (10 samples from various sources) to obtain the values for each of the following test parameters:
    - Gradation
    - Permeability
    - Plasticity Index (PI)
    - Density
    - Poisson's ratio
    - Unit weight
    - Resilient Modulus
    - R-Value
    - Optimum moisture
    - AC content in RAP
- Analysis test data
- Final report

1.4 Revisions to the Research Approach

A limited literature review was performed.

Florida

Developing Specifications for Using Recycled Asphalt Pavement as Base, Subbase or General Fill Materials, Phase II, is a complete, comprehensive report(11). Florida uses a stiffness strength value of Limerock Bearing Ratio (LBR) that is similar to a California Bearing Ratio. Previous laboratory testing research reports were compared. This research report did a field test deck. RAP and blends of RAP and soil mixtures were tested. A series of tests were performed, including gradations, moisture densities, temperature profiles, FWD using MODULUS 5.1 program to process data, permeability, etc. The resilient modulus decreased with the addition of material passing the #40 sieve. The study recommended that a long-term strength deformation (i.e., creep or large strain) behavior of RAP and RAP-soil mixes should be investigated.

New Jersey

The Development of a Performance Specification for Granular Base and Subbase Material. This research project encompassed evaluating the performance of New Jersey DOT specified aggregates at the respective New Jersey DOT gradation ranges (high end, middle, and low end) and provided guidance as how to modify the gradation ranges to provide better performance in the field(12). Base and subbase materials were sampled from three regions in that state and evaluated under the following performance tests: permeability (falling and constant head conditions), triaxial shear strength, cyclic triaxial loading, California Bearing Ratio (CBR) and resilient modulus. Testing was also conducted on reclaimed asphalt pavement (RAP) and reclaimed concrete aggregate (RCA) to evaluate their potential use as base and subbase materials. The testing of the RAP, RCA, and their blends with the base material, showed that as the % RAP increased in the blend, both the CBR value and permeability decreased. RAP also caused larger permanent deformations during the cyclic triaxial testing.

CDOT laboratory testing of 100% RAP and Class 6 aggregate base course

Laboratory testing was performed on 11 samples of aggregate base course and 12 samples of RAP. One aggregate base course sample did not meet CDOT criteria because the liquid limit (LL) and plasticity index (PI) were out of specification; testing of this sample was discontinued. Overall, the resilient modulus (M_R) testing was reduced because of funding issues. Poisson's ratio testing was suspended because quotes obtained were greater than the total cost of the study's testing budget.

2.0 SPECIFICATIONS

2.1 Material Specifications

Aggregate base course (Class 6) is one of seven classes of unbound aggregate bases that may be used. ABC Class 6 is the prevalent base type that is used through out the state. Specifications for aggregate bases are specified in Section 703.03 Aggregate for Bases in CDOT *2007 Standard Specifications for Road and Bridge Construction*(1).

Aggregates for bases shall be crushed stone, crushed slag, crushed gravel, natural gravel, or crushed reclaimed concrete or asphalt material which conforms to the quality requirements of AASHTO M 147 except that the requirements for the ratio of minus No. 200 sieve fraction to the minus No. 40 Sieve fraction, stated in 2.2.2 of AASHTO M 147, shall not apply. See Table 2.1 CDOT Classification for Aggregate Base Course for gradation requirements. The requirements for the Los Angeles wear test (AASHTO T 96) shall not apply to Class 1, 2, and 3. The liquid limit shall be as shown in Table 2.1 and the plasticity index shall not exceed six when the aggregate is tested in accordance with AASHTO T 89 and T 90 respectively.

Table 2.1 CDOT Classification for Aggregate Base Course

Sieve Size	Mass Percent Passing Square Mesh Sieves						
	LL not greater than 35			LL not greater than 30			
	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7
6"			100				
4" (100 mm)		100					
3" (75 mm)		95-100					
2-1/2" (60 mm)	100						
2" (50 mm)	95-100			100			
1-1/2" (37.5 mm)				90-100	100		
1" (25 mm)					95-100		100
3/4" (19 mm)				50-90		100	
#4 (4.75 mm)	30-65			30-50	30-70	30-65	
#8 (2.36 mm)						25-55	20-85
#200 (75 µm)	3-15	3-15	20 max.	3-12	3-15	3-12	5-15
NOTE: Class 3 material shall consist of bank or pit-run material.							

Specifications for aggregate base compaction are specified in Section 304.06 Shaping and Compaction in CDOT *2007 Standard Specifications for Road and Bridge Construction*(1). Placement and compaction of each lift layer shall continue until a density of not less than 95 percent on the maximum density determined in accordance with AASHTO T 180 has been achieved.

CDOT specifies a minimum R-value by project special provision. CDOT does not specify the any limits on specific gravity, absorption, permeability or resilient modulus.

2.2 Design Criteria

CDOT uses the *AASHTO 1993 Guide For Design of Pavement Structures* and the *1998 Supplement to the AASHTO Guide For Design of Pavement Structures*(2)(3). CDOT has incorporated these two publications into a pavement design manual. The current manual at this time is the *2009 Pavement Design Manual*(4). Structural stiffness strength, exposure to moisture levels, and an explanation and use of RAP and FDR are addressed in the manual.

2.2.1 Structural Number

The Structural Number (SN) is indicative of the total pavement thickness required.

$$SN = a_1D_1 + a_2D_2m_2 + a_3D_3m_3 \qquad \text{Eq. 2.1}$$

Where:

a_1, a_2, a_3 = structural layer coefficients

D_1 = thickness of bituminous surface course (inches)

D_2 = thickness of base course (inches)

D_3 = thickness of subbase (inches)

m_2 = drainage coefficient of base course

m_3 = drainage coefficient of subbase

The structural layer coefficients represent the strength of the layers. The drainage coefficients represent the drainage performance of the base and subbase layers.

2.2.2 Base Design Stiffness Strength Criteria

CDOT uses the following equations to determine M_R from measured R-value and calculated soil support value(4).

$$S_1 = [(R - 5)/11.29] + 3 \qquad \text{Eq. 2.2}$$

$$M_R = 10^{[(S_1+18.72)/6.24]} \qquad \text{Eq. 2.3}$$

Where:

M_R = resilient modulus (psi).

S_1 = the soil support value.

R = the R-value obtained from the Hveem stabilometer.

Table 2.2 shows the relationship of design criteria to field requirements.

Table 2.2 Recommended Values for the Base Layer Coefficients

Component	Coefficient
Aggregate Base with R-Value ≥ 83	0.14
Aggregate Base with 77 ≤ R-Value <83	0.12
Aggregate Base with 69 ≤ R-Value < 77	0.11
Aggregate Base with R-Value < 69	0.10
RAP Base, with RAP portion of material ≤ 30% of mixture	0.10 - 0.14
RAP Base, with RAP portion of material > 30% of mixture	0.15 - 0.25

2.2.3 Base Design Moisture Criteria

In the pavement structure, the moisture and the drainage of water must be accounted for. Quality of the base drainage must be determined. The determination is an assessment of water removed. The method used to establish the quality of drainage involves calculating the time required to drain the base layer to 50% saturation (damp). Refer to Table 2.3 for permeability information. If the permeability of the AASHO Road Test materials was 0.1 foot per day (ft/day) (or less), and the length of the drainage path (lane width) was 12 feet, the time required to drain the unbound layers would be on the order of 5 to 10 days (approximately one week). If the length of the drainage path had been 24 feet, it would have taken 18 to 36 days (approx. one month) to drain(5).

Table 2.3 Time (Days) to Drain Base Layer to 50% Saturation (Damp)

Permeability, k (ft/day)	Porosity, n	Slope, S	Base Thickness			
			1 Foot		2 Feet	
			Drainage Path		Drainage Path	
			12 feet	24 feet	12 feet	24 feet
0.1	0.015	0.01	10	36	6	20
		0.02	9	29	5	18
1.0	0.027	0.01	2	6	5	18
		0.02	2	5	1	3
10.0	0.048	0.01	0.3	1	0.2	0.6
		0.02	0.3	1	0.2	0.6
100	0.08	0.01	0.05	0.2	0.03	0.1
		0.02	0.05	0.2	0.03	0.1

See Table 2.4 to select the quality of drainage assessment when it has been determined how fast the water is removed along the drainage path from Table 2.3.

Table 2.4 Quality of Pavement Drainage

Water Removed Within	Quality of Drainage
2 Hours	Excellent
1 Day	Good
1 Week	Fair
1 Month	Poor
Water Will Not Drain	Very Poor

The quality assessment is applied by modifying the structural layer coefficients. The drainage conditions at the AASHO Road Test was considered to be fair, i.e., free water was removed within one week. Table 2.5 is used to modify the structural coefficients. This table recommends the m_i values as a function of the quality of drainage and the percent of time during the year the pavement structure would be exposed to moisture levels approaching saturation. These values apply only to the effects of drainage on untreated base and subbase layers(4).

Table 2.5 Recommended m_i Values* for Modifying Structural Layer Coefficients of Untreated Base and Subbase Materials in Flexible Pavements

Quality of Drainage	Percent of Time Pavement Structure Is Exposed to Moisture Levels Approaching Saturation			
	Less Than l%	1 - 5%	5 - 25%	Greater Than 25%
Excellent	1.40 - 1.35	1.35 - 1.30	1.30 - 1.20	1.20
Good	1.35 - 1.25	1.25 - 1.15	1.15 - 1.00	1.00
Fair	1.25 - 1.15	1.15 - 1.05	1.05 - 0.80	0.80
Poor	1.15 - 1.05	1.05 - 0.80	0.80 - 0.60	0.60
Very Poor	1.05 - 0.95	0.95 - 0.75	0.75 - 0.40	0.40

*Note: Designer shall use a value of m_i = 1.0 unless specific drainage information indicates otherwise.

3.0 SAMPLING

CDOT's six Region Materials Engineering Laboratories sampled ABC Class 6 and 100% RAP. Each Lab submitted two samples of both of these materials. Appendix A provides sampling instructions and descriptions. Figure 3.1 shows the locations where the samples were taken.

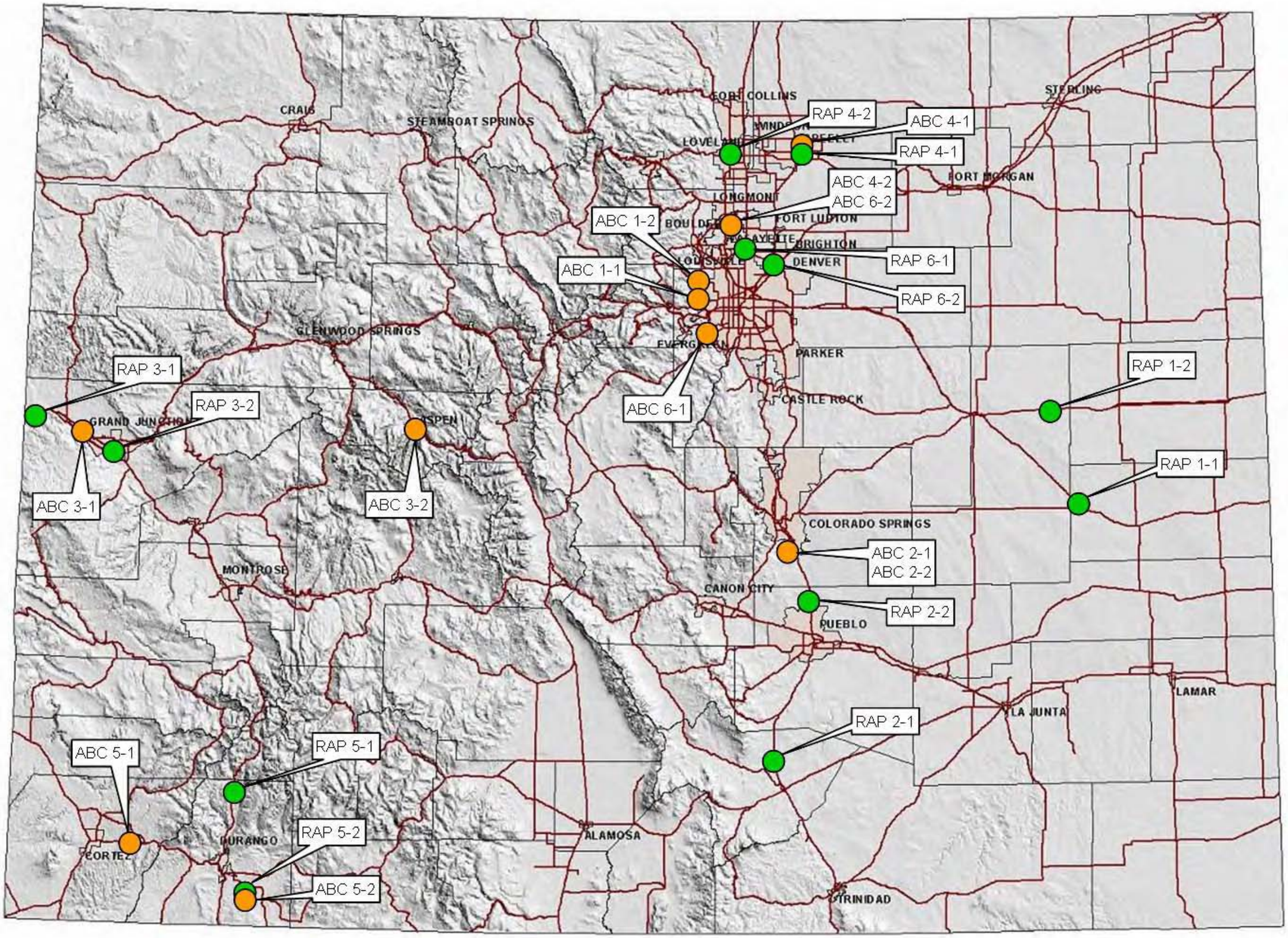

Figure 3.1 Sample Locations

4.0 TEST RESULTS

JA Cesare and Associates, Inc., a geotechnical engineering consultant, was awarded the contract to do the laboratory testing. Their test results are shown in Appendix B. Figures B.1 and B.2 are the results in tabular form. Figure B.3 is the gradation plots of the aggregate base course with the upper and lower specification limits shown. Figure B.4 is the gradation plots of the reclaimed asphalt pavement. The upper and lower specification limits are shown for ABC Class 6 for information only. The RAP gradations are well graded, but specified with larger top size.

JA Cesare and Associates, Inc. did not have the capability to perform resilient modulus testing. The resilient modulus testing was subcontracted to Ground Engineering Consultants of Denver, Colorado. The resilient modulus test data and results are also shown in Appendix B.

5.0 ANALYSIS OF DATA

5.1 Structural Stiffness Strength

The ABC Class 6 R-values varied more than expected. Samples ABC 1-2(1) and ABC 1-2(2) were excluded from further analysis because they did not meet the aggregate base course criteria. The R-values confirmed that they did not meet the ABC criteria. Sample ABC 3-1 had the lowest value of 54 and was below the expected minimum of 69 as shown in Table 2.2. Historically base materials are all above 69 R-value. It is probable that these materials would have been never placed as a base material; CDOT would have rejected the stockpiles before placement. Therefore these samples were excluded from further M_R strength testing for not meeting ABC criteria.

All of the RAP R-values were consistently above 80. Based on Table 2.2, the values were high, providing very good strength properties.

Funding issues reduced the M_R strength testing. A selection system was presented by the testing consultant. The system used was selecting by ranging the maximum dry density, determining the average maximum dry density and selecting a sample from approximately the average, a sample from approximately one standard deviation lower and a sample from approximately one standard deviation higher than the average. The resilient modulus test data did not follow the assumed order of maximum dry density to strength correlation.

Figure 5.1 shows the relationship to Equations 2.2 and 2.3. The values of ABC Class 6 are reasonability close to the correlation equations. The three RAP tests are above the correlation equations, showing excellent stiffness strengths. The testing was performed in general accordance with AASHTO T 307.

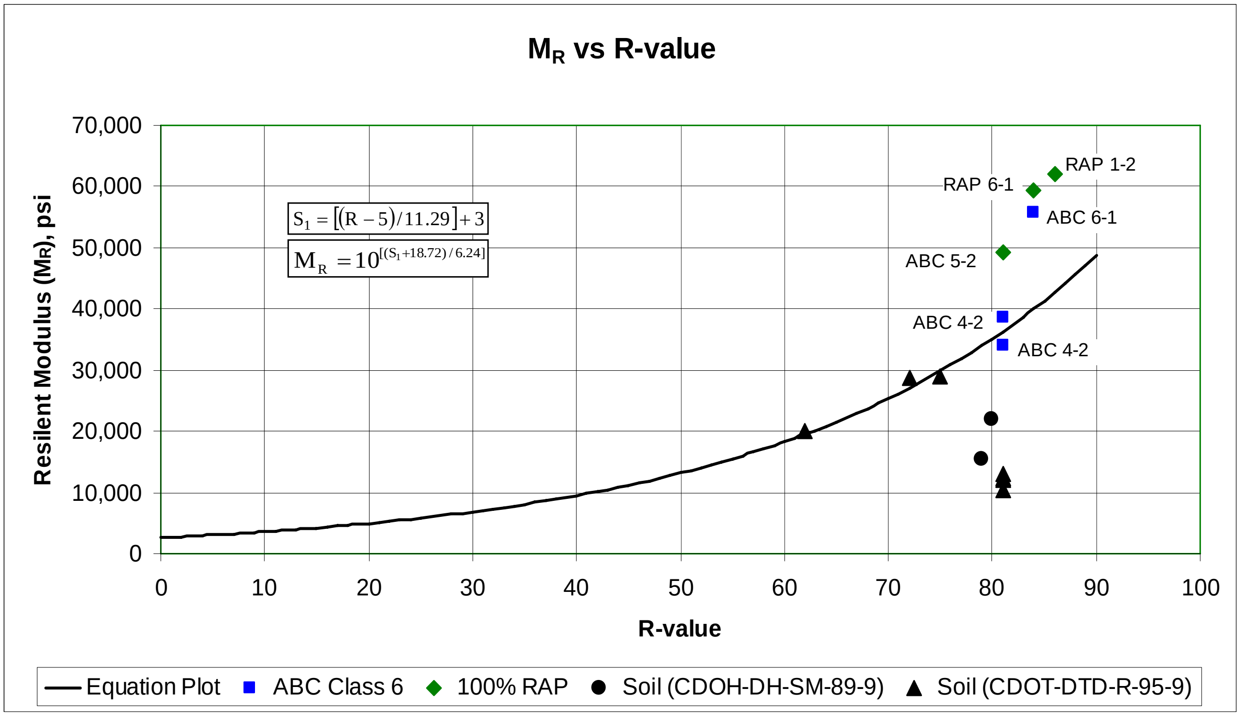

Figure 5.1 Unbound Aggregate Base M_R vs. R-value Plot

Two previous CDOT research reports have been published comparing R-values to resilient modulus values. The reports are *CDOH-DH-SM-89-9, Resilient Properties of Colorado Soils, Final Report* and *CDOT-DTD-R-95-9, Resilient Modulus of Granular Soils with Fines Content*.(9)(10) Both reports used soils for their testing. Table 5.1 shows results of their soil testing of only soils having greater than R-values of 79 and greater than M_R values of 20,000 psi. This is for information only. The soils testing procedure used was AASHTO T 274-82.

Table 5.1 Data of Previous CDOT Reports

Report	Sample No.	Classification	% Passing No. 200	LL	PI	Dry Unit Wt. (pcf)	OMC (%)	R-Value	M_R AASHTO T274-82
CDOH-DH-SM-89-9	10	A-1-b(0)	10	NV	NP	118.2	6.2	79	15,500
	C	A-1-b(0)	9	NV	NP	129.9	8.5	80	21,900
CDOT-DTD-R-95-9	2	A-1-a	6	NV	NP	133.0	5.9	81	10,300
	8	A-1-b	14	NV	NP	124.4	9.0	81	12,400
	15	A-2-4(0)	15	NV	NP	118.7	9.45	81	13,000
	20	A-1-a(0)	8	NV	NP	132.0	5.8	81	12,000
	3	A-1-b	8		NP	128.0	8.0	72	28,800
	4	A-1-b	8		NP	129.3	7.0	75	29,000
	17	A-2-4(0)	32		4	123.5	10.1	62	20,000

Note: NV – no value; NP – non-plastic

Table 5.1 is of soil samples obtained from ongoing construction projects at the time of their testing. These results are plotted on Figure 5.1 for comparison only. ABC Class 6 and RAP are man-made manufactured materials. The M_R values of the soils are lower than the manufactured ABC Class 6 and RAP samples.

Eq. 5.1 is Equation GG.1 from Appendix GG, *AASHTO Guide for Design of Pavement Structures, Volume 2, August 1986*.(5) Figure 5.2 Unbound Aggregate Base a_2 vs. M_R Plot is the plot of Eq. 5.1.

$$a_2 = 0.249(\log_{10}(M_R)) - 0.977 \quad \text{Eq. 5.4}$$

Where:

a_2 = unbound aggregate base structural coefficient.

M_R = resilient modulus (psi).

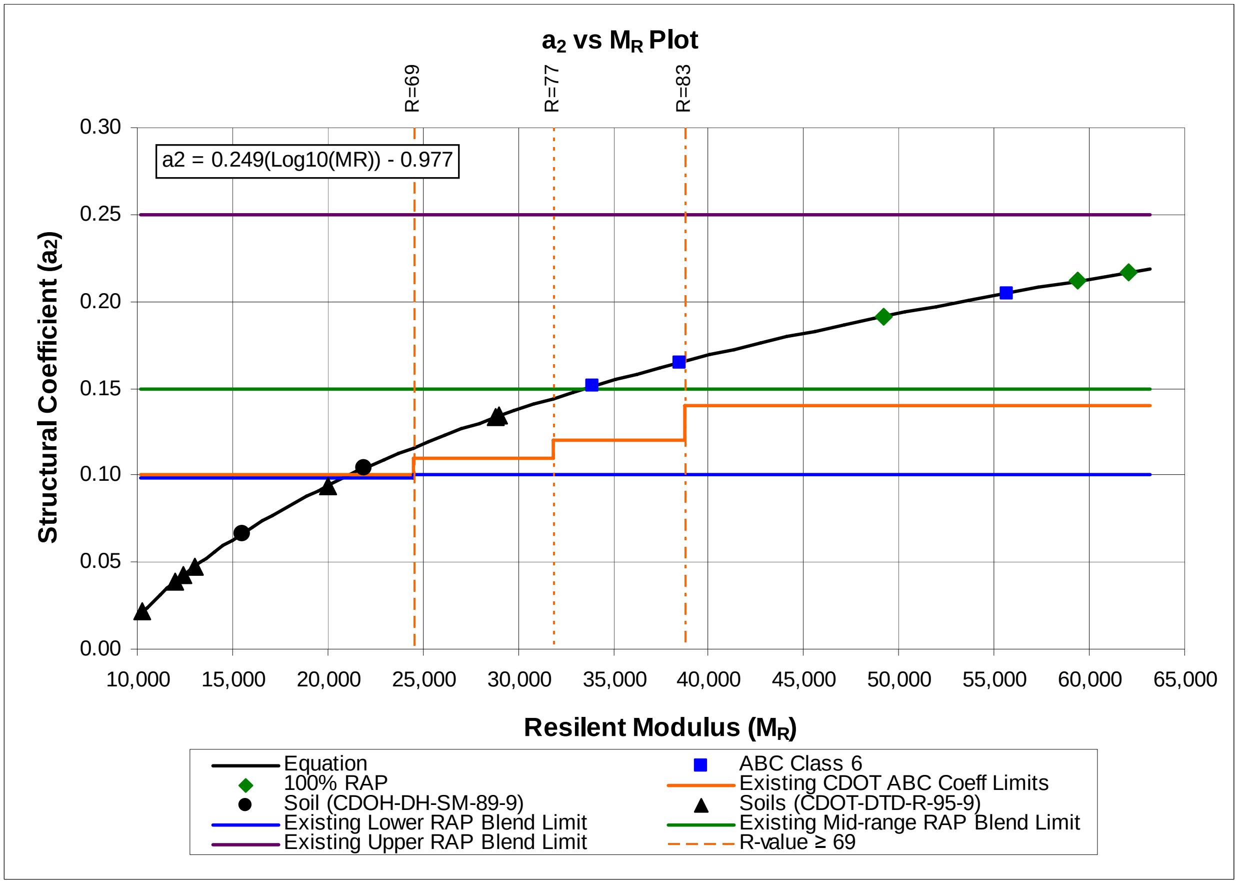

Figure 5.2 Unbound Aggregate Base a2 vs. M_R Plot

CDOT does not have the capability of doing resilient modulus testing at this time. Equations 2.2 and 2.3 are used to determine M_R values. Shown on Figure 5.2 are unbound aggregate base limits from Table 2.2 converted from R-values to M_R values and plotted against structural coefficient. The red line is the existing aggregate base limits. The soil results are also shown for information only. The soils show weak structural stiffness strengths for bases, and are borderline to unacceptable.

As shown, the RAP is a high quality base material because of initial hot mix asphalt requirements. Using a design structural coefficient of 0.19 for 100% RAP would be reasonable and specifying a minimum R-value of 90. ABC shows very good base stiffness strengths. Using a design structural coefficient of 0.15 for ABC Class 6 is also reasonable and specifying a minimum R-value of 79.

Blending of ABC Class 6 and RAP would produce a similar very good structural stiffness strength. CDOT uses this blending process as a rehabilitation strategy. The strategy is known as Full Depth Reclamation (FDR). FDR is a rehabilitation technique in which the full thickness of asphalt pavement and a predetermined portion of the underlying materials (base, subbase, and/or subgrade) are, without heat, uniformly pulverized and blended to provide an upgraded, homogeneous material. FDR is a two-phase operation. The first operation is to create the base material. No traffic is placed on the roadway after this operation. The final operation is to place a flexible overlay on top of the base material. For pavement design, the full depth reclaimed material is considered a base material. This report only obtained engineering properties of ABC Class 6 and not of any of the other base classes. The pavement designer must make a determination that the existing base material to be blended is similar to ABC Class 6. The stiffness strength properties of both ABC Class 6 and the 100% RAP are similar. Therefore, the proportioning of the blend does not seem to be critical for stiffness strength. For any blending proportion of ABC Class 6 and RAP, using the ABC Class 6 limit of 0.15 structural coefficient would be prudent. If the existing base does not conform to ABC Class 6 requirements because of "dirtiness", then the stiffness strength would be compromised. A gradation and an R-value test would confirm its "dirtiness." The "dirtiness" would take on the properties of a soil subgrade.

Blending of subgrade is undesirable. High R-values of soils do not translate into high resilient modulus for a base. Subgrade would need an R-value of 65 or greater so that the designer would have a good confidence that the blend has a good base stiffness strength. A design structural coefficient of 0.10 for the soil/RAP blend may be used.

The data indicates the upper structural coefficient range limit of 0.25 for RAP base with RAP having a blend greater than 30% would too high as shown in Table 2.2. A design structural coefficient of 0.14 as an upper limit for a blend would be reasonable. That limit is set by historical aggregate base limits. The lower structural coefficient range limit of 0.10 with RAP having a blend is also reasonable with an R-value greater than or equal to 65.

Table 5.2 is a summary of the suggestions stated above. Figure 5.3 is a plot of the summary of suggestions.

Table 5.2 Suggested Values for Base Layer Coefficients

Component	Design Coefficient	Design M_R (psi)
100% RAP with R-value ≥ 90	0.19	48,675
Aggregate Base Course Class 6 or 100% RAP with R-value ≥ 79	0.15	33,975
Other Aggregate Base Classes and RAP Blends with R-value ≥ 83	0.14	38,721
Other Aggregate Base Classes and RAP Blends with 77 ≤ R-value <83	0.12	31,826
Other Aggregate Base Classes and RAP Blends with 69 ≤ R-value < 77	0.11	24,503
Other Aggregate Base Classes and RAP Blends with 65 ≤ R-value < 69	0.10	21,500

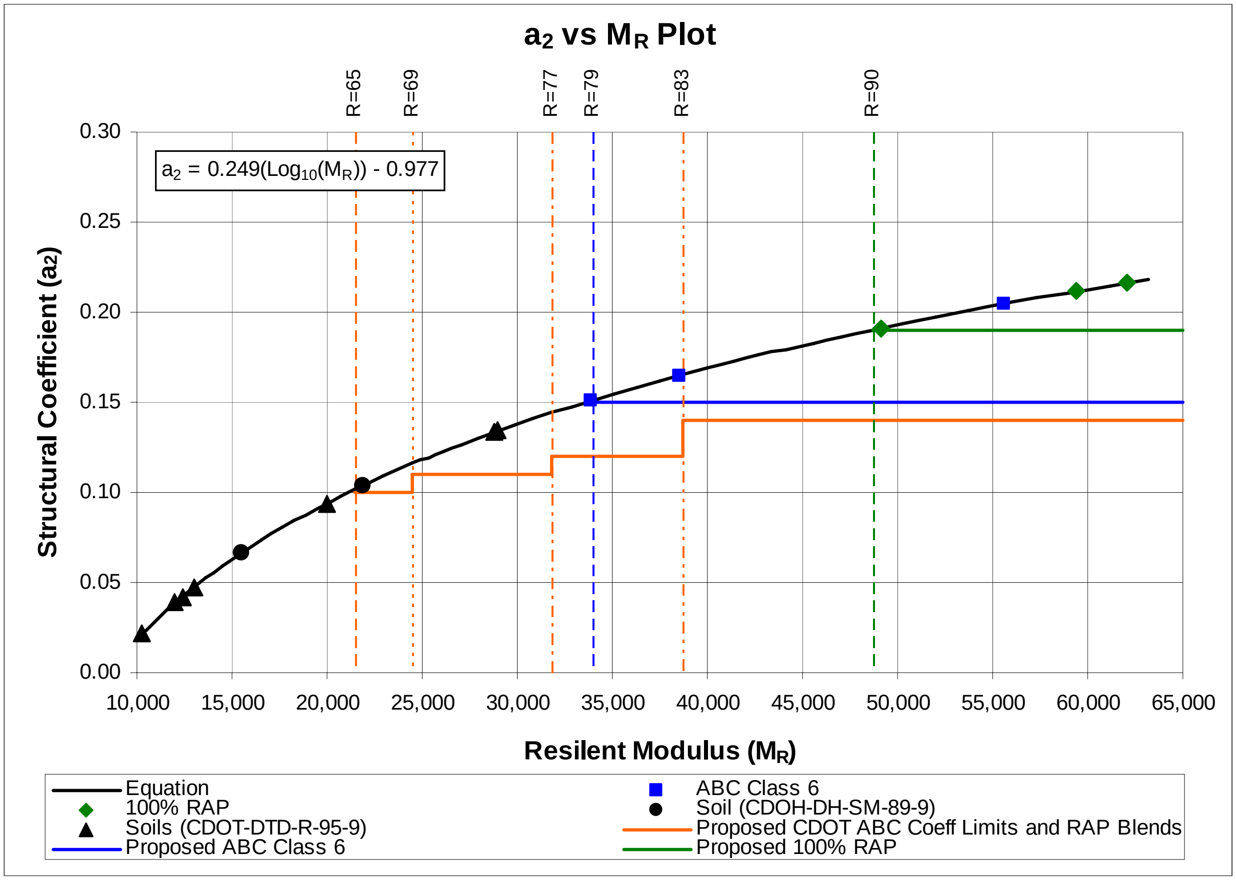

Figure 5.3 Plot of Summary of Suggestions

5.2 Permeability

JA Cesare and Associates, Inc. tested the permeability of the ABC Class 6 and 100% RAP using United States Bureau of Reclamation (USBR) Test Method 5605, Amended. Porosity is the ratio (percent) of the volume of openings (voids) to the total volume of material. Hydraulic conductivity is also known as coefficient of permeability or simply permeability (symbol k). Permeability of a soil is a measure of continuous voids. The voids must be connected for water to flow through them. Hydraulic conductivity (permeability) has units of volume per unit area per unit time, which is equivalent to length divided by time (units of velocity). Basically, a laboratory permeability test is a timed test of a volume of water flowing through an area. Tables 5.3 and 5.4 show the permeability results with the last column converted to feet/day units, which is the standard convention used in roadway drainage design.

ABC Class 6 permeabilities range from 0.9 to 48.2 feet/day with an average of 16.3 feet/day. Four of eleven samples exhibit permeabilities above 20. RAP permeabilities range from 20.7 to 425.2 feet/day with an average of 197.1 feet/day. Only three of twelve samples exhibit permeabilities below 100. No explanation is given in this report as to why the aggregate base course and RAP vary as shown.

Table 5.5 shows typical ranges of roadway soil permeabilities(8). The ranges in the table shown are for comparing ABC Class 6 and RAP permeabilities. The ABC Class 6 samples range from Medium to Low relative permeability. The RAP samples range from High to Medium relative permeability.

Tables 5.6 and 5.7 show typical values from Standard Special Provision, *Revision of Sections 208, 420, 605 and 712 Geosynthetics and Geotextiles*, dated October 19, 2006.

Table 5.3 Permeability of ABC Class 6

CDOT Sample ID	Sample ID	Material Type	Flow, cc/sec	Permeability, k (cm/sec)	Permeability, k (feet/day)
ABC 1-1	75422	ABC Class 6	0.017	7.2E-03	20.4
ABC 1-2	75423(1)	ABC Class 6	*		
ABC 6-1	75425	ABC Class 6	0.078	3.0E-04	0.9
ABC 4-1	75428	ABC Class 6	0.067	8.9E-04	2.5
ABC 3-2	75427	ABC Class 6	2.314	5.0E-04	1.4
ABC 1-2	75423(2)	ABC Class 6	0.116	7.7E-04	2.2
ABC 2-2	75424	ABC Class 6	0.689	1.1E-02	31.2
ABC 4-2	75429	ABC Class 6	1.281	1.7E-02	48.2
ABC 5-1	75430	ABC Class 6	0.161	1.7E-03	4.8
ABC 5-2	75431	ABC Class 6	0.135	2.1E-03	6.0
ABC 3-1	75426	ABC Class 6	0.728	1.6E-02	45.4

*(does not meet CDOT ABC Class 6 criteria)

Table 5.4 Permeability of RAP

CDOT Sample ID	Sample ID	Material Type	Flow, cc/sec	Permeability, k (cm/sec)	Permeability, k (feet/day)
RAP 5-2	75441	1/2" RAP	0.474	8.2E-03	23.2
RAP 3-1	75436	RAP	1.767	2.5E-02	70.9
RAP 6-1	75589	RAP	5.372	7.7E-02	218.3
RAP 2-1	75434	RAP	1.974	4.3E-02	121.9
RAP 1-1	75432	RAP	4.737	7.4E-02	209.8
RAP 2-2	75435	RAP	0.529	7.3E-03	20.7
RAP 5-1	75440	RAP	4.106	8.5E-02	240.9
RAP 4-2	75439	RAP	5.836	8.4E-02	238.1
RAP 1-2	75433	RAP	13.676	7.3E-02	206.9
RAP 6-2	75590	RAP	6.585	1.2E-01	340.2
RAP 4-1	75438	RAP	5.293	8.8E-02	249.4
RAP 3-2	75437	RAP	10.369	1.5E-01	425.2

Table 5.5 Typical Ranges of Coefficient of Permeabilities

Permeability Coefficient, k (cm/sec)	Permeability Coefficient, k (feet/day)	Relative Permeability	Soil Type
$<10^{-7}$ (0.0000001)	< 0.00028	Impervious	Clay
10^{-7} (0.0000001) - 10^{-5} (0.00001)	0.00028 - 0.0283	Very Low	Silt
10^{-5} (.00001) - 10^{-3} (0.001)	0.0283 - 2.83	Low	Sand, dirty
10^{-3} (.001) - 10^{-1} (0.1)	2.83 - 283	Medium	Sand, clean
$>10^{-1}$ (0.1)	>283	High	Coarse gravel

Table 5.6 Typical Values of Permeability Coefficients of Turbulent Flow[1]

Turbulent Flow	Particle Size Range		Effective Size	Permeability Coefficient, k (cm/sec)	Permeability Coefficient, k (feet/day)
	D_{max} mm (inches)	D_{min} mm (inches)	D_{20} mm (inches)		
Derrick STONE	3000 (120)	900 (36)	1200 (48)	100	283,465
One-man STONE	300 (12)	100 (4)	150 (60)	30	85,039
Clean, fine to coarse GRAVEL	80 (3)	10 (1/4)	13 (1/2)	10	28,346
Fine, uniform GRAVEL	8 (3/8)	1.5 (1/16)	3 (1/2)	5	14,173
Very coarse, clean, uniform SAND	3 (1/2)	0.8 (1/32)	1.5 (1/16)	3	8,504

[1] Basic Soils Engineering, R.K. Hough, 2nd Edition, Ronald Press Co.; 1969, Page 76.

Note: Since the permeability coefficient of the soil will be unknown in most non-critical, non-severe applications for erosion control and drainage, the soil-permeability coefficients listed may be used as a guide for comparing the permeability coefficient of the fabric with that of the in-place soil.

Table 5.7 Typical Values of Permeability Coefficients of Laminar Flow[1]

Laminar Flow	Particle Size Range		Effective Size	Permeability Coefficient, k (cm/sec)	Permeability Coefficient, k (feet/day)
	D_{max} mm (inches)	D_{min} mm (inches)	D_{10} mm		
Uniform, coarse SAND	2 (1/8)	0.5 (1/64)	0.6	0.4	1,134
Uniform, medium SAND	0.5	0.25	0.3	0.1	283
Clean, well-graded SAND & GRAVEL	10	0.05	0.1	0.01	28.3
Uniform, fine SAND	0.25	0.05	0.06	40×10^{-4}	11.34
Well-graded, silty SAND & GRAVEL	5	0.01	0.02	4×10^{-4}	1.134
Silty SAND	2	0.005	0.01	1×10^{-4}	0.283
Uniform SILT	0.05	0.005	0.006	0.5×10^{-4}	0.142
Sandy CLAY	1.0	0.001	0.002	0.05×10^{-4}	0.0142
Silty CLAY	0.05	0.001	0.0015	0.01×10^{-4}	0.00283
CLAY (30% to 50% clay sizes)	0.05	0.0005	0.0008	0.001×10^{-4}	0.000283
Colloidal CLAY (-2 µm 50%)	0.01	10	40	10^{-5}	0.0283

[1] Basic Soils Engineering, R.K. Hough, 2nd Edition, Ronald Press Co.; 1969, Page 76.

Note: Since the permeability coefficient of the soil will be unknown in most non-critical, non-severe applications for erosion control and drainage, the soil-permeability coefficients listed may be used as a guide for comparing the permeability coefficient of the fabric with that of the in-place soil.

Tables 2.3 and 2.4 are dependent on the specific roadway. The drainage depends on a number of factors. Some of the factors are the length of the drainage path and the slope of the path. Refer to Table 2.3 to help determine how fast the base layer drains.

Example 1: The drainage path is 12 feet, cross slope of 1%, zero percent grade, and the base layer thickness of one foot. Using a low limit permeability of approximately one foot per day for ABC Class 6, the time to drain would be two days. Two days drainage removal would have a quality drainage rating of Good, as shown in Table 2.4.

Example 2: This example would have the same geometric drainage path as Example 1, but using the high limit of 50 feet per day for ABC Class 6 the drainage removal would be maybe two hours. The quality drainage rating from Table 2.4 would be Excellent.

Example 3: Using the same scenario, all of the RAP samples would have a quality drainage rating of Excellent.

The above examples are for flow of water through the base. The flow of water has to continue out from the base. If the base is sealed, meaning the water cannot readily flow out of the base, the base becomes saturated. The water sits in the base and has no place to go.

The pavement designer must understand this to apply the drainage coefficients (m_i). Applying drainage coefficients, the water must continue on flowing outside the base layer. And, the permeabilities should be equal to or better than the base permeability.

5.3 RAP Gradation

RAP samples were obtained throughout the state. The RAP gradations were well-graded and consistent. A project special provision and a Colorado procedure were developed to determine the macro-texture of cold planed HMA pavement in order to provide an acceptable surface texture for the placement of an HMA overlay. The specification and procedure were implemented in the 2007 paving season. It is believed the gradations are well-graded because of the specification and Colorado procedure. Refer to Appendix C for the specification and procedure. A gradation envelope could be obtained from the gradation plots. Assigning a lower and upper limit to the RAP samples, a gradation band has been determined. Sample RAP 5-2 had a top size of 1/2". No gradation band is being suggested for this size gradation. See Table 5.8 for a suggested RAP lower and upper specification band for gradation. The sieve sizes used are similar to the HMA gradations. Figure 5.4 shows how the sample gradation plots conform to the suggested RAP gradation specification.

Table 5.8 Suggested RAP Gradation Specifications

Sieve Size	Mass Percent Passing Square Mesh Sieves	
	2" RAP	
	Lower Limit	Upper Limit
2" (50 mm)	100	
1-1/2" (37.5 mm)		
1" (25 mm)	88	100
3/4" (19 mm)	75	100
1/2" (12.5 mm)	56	88
3/8" (9.5 mm)	44	80
#4 (4.75 mm)	25	55
#8 (2.36 mm)		
#16 (1.18 mm)	7	25
#30 (600 µm)		
#50 (300 µm)		
#100 (150 µm)		
#200 (75 µm)	0	5

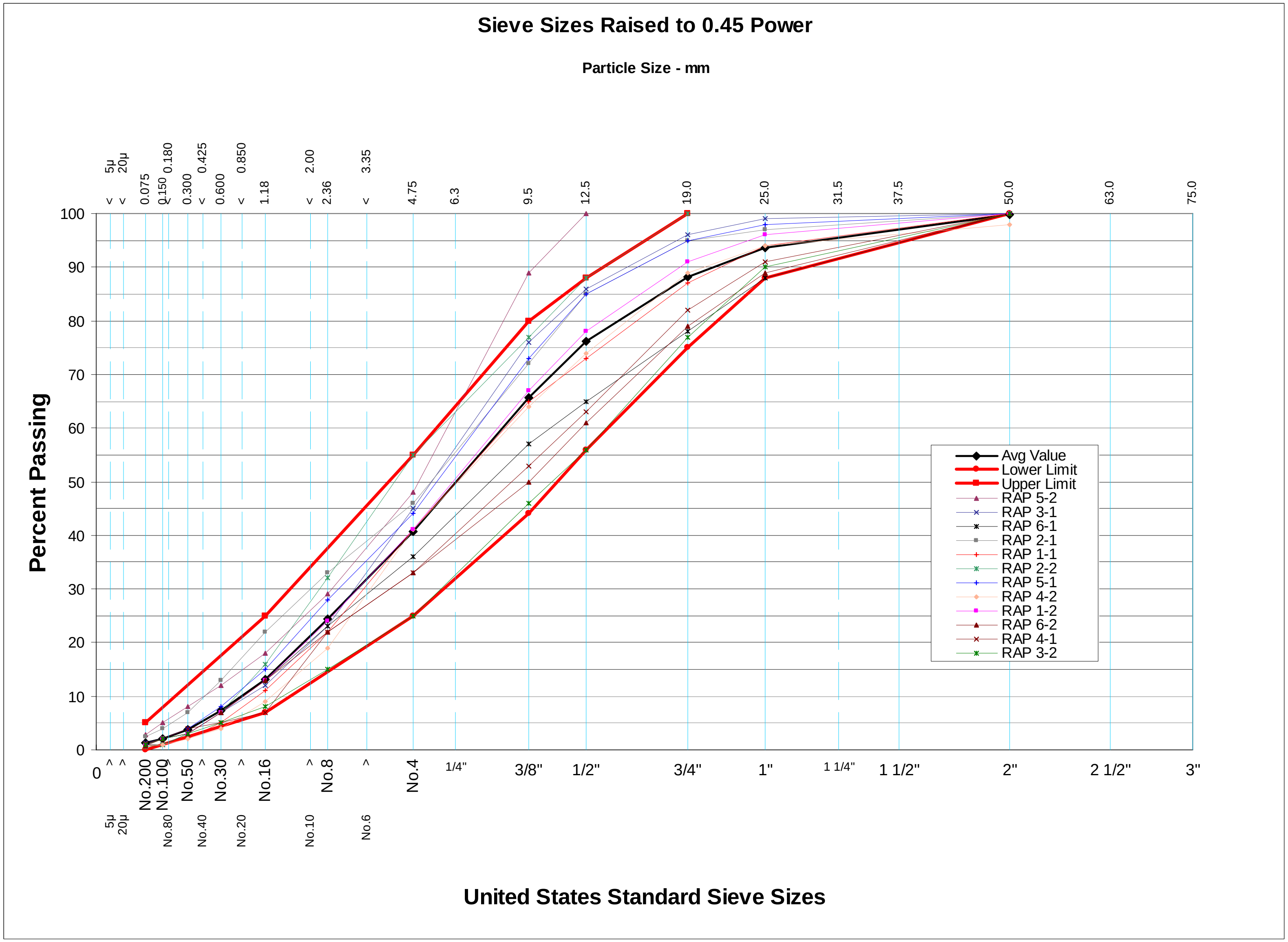

Figure 5.4 Multi-Sample Gradation Plots

5.4 Atterberg Limits

In this study the results of Atterberg Limit tests were similar. Both the ABC Class 6 and RAP samples had no value (NV) for liquid limit (LL) and the plasticity index (PI) was non-plastic (NP). All classes of ABC have a requirement that the PI is not to exceed six. ABC classes 1, 2, and 3 have a requirement of not greater than 36 for LL. ABC classes 4, 5, 6, and 7 have a requirement of not greater than 30 for LL. Atterberg Limit testing indicated that requirements for RAP may be the same, with PI not to exceed six and LL not greater than 30.

5.5 Classification

The RAP had a soil classification on the average of GW (gravelly, well-graded materials with little or no fines) in the Unified Soil Classification system and A-1-a in AASHTO Soil Classification.

5.6 LA Abrasion

CDOT Standard Specifications require that aggregate base course comply with AASHTO M 147-65. According to M 147-65 no more than 50 percent wear shall occur for a coarse aggregate run through the Los Angeles abrasion test. The ABC Class 6 had an average loss of 28.7% and a minimum and maximum of 17% and 45%. The eleven RAP samples averaged a loss of 23.9%, with a minimum and maximum of 13% and 29% respectively. The RAP samples proved to be more durable than aggregate base course materials that were tested.

5.7 Proctor

Aggregate base course compaction is required to follow AASHTO T 180 to obtain the maximum dry density of the soils. The typical maximum dry density range for a GW soil is between 125 lb/ft^3 and 135 lb/ft^3. The aggregate base course had an average maximum density of 136.8 lbs/ft^3 with minimum and maximum values of 132.8 lbs/ft^3 and 142.7 lbs/ft^3 respectively. On the other hand, the RAP had an average maximum density of 120 lbs/ft^3 with a values ranging from 110.4 lbs/ft^3 to 126.9 lb/ft^3.

The decreased compacted density is due to the coating of asphalt cement on RAP aggregate, which inhibits compaction by consolidating and minimizing the number of fines. The limited number of fines prevent the RAP from filling all the voids, thereby decreasing its density and increasing its permeability. The increased permeability also limits the soils' ability to hold enough water to allow the soil particles to easily shift and properly interlock during compaction. The Proctor curves obtained from other research demonstrate the limited impact water has on RAP compaction because they are much flatter than those of a standard base course.

5.8 Specific Gravity

Specific gravity is a ratio of the density of a material (same weight as water) to that of water. The average specific gravity of the aggregate base course was found to be 2.6 with a range of 2.5 to 2.7. The values from the RAP tests established a specific gravity of 2.34 with a range of 2.25 to 2.41. These specific gravity results compare well to the Proctor densities of the aggregate and RAP. The lower density of RAP also implies a lower specific gravity, and both of these are a result of the minimal fines in RAP. The specific gravity tests that were performed followed AASHTO T 85.

5.9 Absorption

The absorption test performed on the RAP and aggregate also conformed to AASHTO T 85. The aggregate's average absorption is 1.3% by mass with a range of values between 0.9 and 2.0. The RAP was found to have a higher absorption of 1.7% with a minimum of 1.4% and a maximum of 2.2%. This seems counterintuitive that RAP would be able to absorb more moisture than a virgin aggregate, and makes it difficult to explain these results. Further testing may be required to come to a conclusion.

5.10 Asphalt Content

The asphalt content for the RAP was tested in accordance with AASHTO T 308. The average asphalt content for all the samples was 5.6% with a minimum and maximum value of 4.65% and 6.2% respectively. Depending on the Superpave gradation, current projects in Colorado have asphalt contents between 5% and 6.5%, so future RAP projects should remain consistent with the test samples.

6.0 SUMMARY AND CONCLUSIONS

It appears that RAP material may be substituted for unbound aggregate base course. The laboratory tested properties of RAP are similar to CDOT's aggregate base course specifications. RAP has pavement design properties comparable to those of virgin aggregate base course.

- A suggested gradation specification band is presented for RAP. The RAP would have a top size of two inches. This proposed top size and gradation is what comes directly from the milling operation and therefore, no additional processing would be needed. All the testing performed in this report was done on that gradation.

- RAP requirements for PI and LL may be the same as unbound ABC Class 6, with PI not to exceed six and LL not greater than 30.

- The stiffness strength properties obtained from laboratory testing shows the RAP has stiffness strength above an unbound ABC Class 6. It is suggested to use a structural coefficient of 0.19 when the R-value is greater than or equal to 90. The ABC Class 6 had a high stiffness strength. The structural coefficient is suggested to be raised to 0.15 with an R-value greater than or equal to 79. Other aggregate base classes would keep the historical ranges of structural coefficients, and would require a minimum R-value of 65 so that no weak material is used as a base. RAP blends would have the same historical ranges as the other aggregate classes.

- The permeability of RAP showed a slight increase over an unbound ABC Class 6 material. The quality of drainage is good to excellent.

The laboratory testing of RAP compared to ABC Class 6 has demonstrated that these materials have similar engineering pavement design properties. Usage of RAP as an unbound aggregate base course is an appropriate alternative design and construction approach.

Limited funds were available for this study, and therefore, a whole spectrum of resilient modulus testing was not performed. Only three samples of each ABC Class 6 and RAP were tested to determine values of resilient modulus. At the time of this study, no construction projects were being built using RAP material as a base or subbase. Therefore, no field data was obtained, and consequently, no long-term performance could be tracked.

7.0 RECOMMENDATIONS

The analysis was performed on limited data; CDOT does not have the capability to do resilient modulus testing. It is recommended to do additional RAP testing for R-value and correlate with CDOT standard correlation equations, Eq. 2.2 and Eq. 2.3. Cold milling projects would create material stockpiles of 100% RAP. Gradations, densities, and R-value testing could be sampled and tested from this material.

Long-term performance has not been addressed. A recommendation is to obtain performance data at five and ten years. This should be compared to an unbound aggregate base material. The comparison is to see if any distresses prematurely appear, if the stiffness strength changes negatively, or if permanent deformations occur.

Lastly, full depth reclamation (FDR) is a blend of RAP and aggregate base material. This study did not address FDR. A complete study should be done. The study should include initial engineering properties of the existing structure. A control section with a matrix of predetermined blends should be proposed. The blend proportioning would need to be tightly controlled in the field during construction. This means the test sections are to be placed in the contract plans and specifications. The coordination with falling weight deflectometer testing and construction is to be part of the testing requirements. Different thicknesses of FDR are to be considered. A matrix of traffic loadings should be considered. The study may need to be extended into other projects to get the traffic mix needed. The study would not be complete until performance data is obtained, possibility at years five and ten.

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APPENDIX A
SAMPLING INSTRUCTIONS AND DESCRIPTIONS

Instructions on sampling ABC (Class 6) and RAP were sent out by email memo.

It is requested and needed that each region helps in the above research study. There are two parts to this memo.

Part 1:

It is requested to provide project information of 100% Reclaimed Asphalt Pavement (RAP) as an aggregate base course and Full Depth Reclamation (FDR) that will be done this paving season. The task force would like to have Falling Weight Deflectometer (FWD) run on the 100% RAP base course or FDR. FWD would be run on the top of the RAP lift and again on the top of the new asphalt layer. We would also like to run a 500-foot test section of RAP with no existing base or soil in the RAP mixture. The same process could be used, but the depth would be limited to recycling the pavement only. The test section would be 100% RAP. The rest of the project would be normally done as per specification 310 - Full Depth Reclamation of Hot Mix Asphalt Pavement. This is to simulate RAP being placed as a separate operation. Obtaining the FWD data may be difficult. It will depend on CDOT FWD crew's schedule. If their schedule is in conflict, then the services of your Non-Project Specific (NPS) contractor is required. The task force has no funds available for this testing. All the funds are allotted to an outside consultant to do the laboratory testing. The FWD testing needs to be coordinated with project field personnel. The goal is to obtain a reasonable value of resilient modulus using back-calculation FWD data on field 100% RAP aggregate base course or FDR. The FWD thumper needs a larger plate to test soils or in this case the top of the RAP layer. Please submit the projects that will be using 100% RAP aggregate base course layer using RAP as substitute for aggregate base course or FDR.

Part 2:

Sampling is needed from each of the six regions. The task force is hiring a consultant to do laboratory testing on RAP samples and aggregate base course (Class 6) samples. Two samples of each are needed from each region. The consultant will perform a battery of tests. The sample size is huge. Four full buckets totaling 200 pounds is needed per sample. 2 (samples) x 4 (buckets) x 2 (types) = 16 buckets total or 800 pounds of material total from each region.

Aggregate base course (Class 6) samples:
ABC (Class 6) may be obtained from projects or aggregate suppliers at the pits. The two different samples per region are to be obtained. It is hoped a representative of quality is obtained. The task force is looking for a spectrum of quality aggregate base course throughout the state. Labeling of the samples should include region, date of sample, project or pit, and source of pit and in what area of the pit.

100% RAP:
Two different sources of 100% RAP are needed. Sampling from projects is most desirable. If cold millings from projects are not available then sampling from maintenance stockpiles may be used. The labeling of the samples should include the region, date of sampling, and source of RAP. Source of RAP from projects would include the highway and milepost. Source of RAP of maintenance stockpile would include the highway from hence it came or the state highway project from which it came.

All samples need to be delivered to Central Laboratory - Flex Lab. Because of the number of anticipated buckets (96 buckets), it is requested to hold the samples at each of their respective regions until June 4, 2007. Delivery in the previous week is acceptable. The consultant will do a battery of tests. The tests the consultant will perform are gradation, permeability, plasticity index, liquid limit, specific gravity of soils, unit weight, resilient modulus, R-value, moisture-density relations, and asphalt content of RAP.

All samples were delivered to Central Laboratory by June 25, 2007.

Listed are the descriptions of the submitted samples.

Region 1

- ABC (Class 6)
  - Sample 1 (ABC 1-1)
    - Producer: LaFarge
    - Pit: Specification Aggregate
    - Date Sampled: 2007-05-01
  - Sample 2 (ABC 1-2)
    - Producer: Asphalt Paving
    - Pit: Ralston
    - Date Sampled: 2007-05-01
- RAP
  - Sample 1 (RAP 1-1)
    - Project Number: STA 0405-031
    - Subaccount: 15659R
    - Highway: 40/287
    - Milepost: 405.9-408.5
    - Year: 2006
  - Sample 2 (RAP 1-2)
    - Project Number: IM 0704-203
    - Subaccount: 14560
    - Highway: I-70
    - Milepost: 373.8 - 385.8
    - Year: 2004

Region 2

- ABC (Class 6)
  - Sample 1 (ABC 2-1)
    - Schmidt Construction, sampled from yard stockpile, material source: Schmidt's Fountain Pit
  - Sample 2 (ABC 2-2)
    - LaFarge, sampled from yard stockpile, material source: LaFarge's Fountain Pit

    Note: Although both samples indicate they were from a "Fountain" pit, LaFarge and Schmidt both have separate Fountain pits. They are near each other though. The deposit they are mining is an alluvial slope wash/pit run material.
- RAP
  - Sample 1 (RAP 2-1)
    - The first was located on I-25 between MP 59 to MP 69.5. The project number was IM 0251-172, SA 15562. The millings were generated from the top 2-1/2 inches of the interstate surface. The materials on this segment consisted of 3/4" Plant Mix Seal Coat from MP 59 to MP 65 underlain by Grade C HMA. The asphalts used in these layers were AC-20R and AC-20, respectively. From MP 65 to MP 69, the material consisted of Grade CX HMA with AC-20P asphalt. This was subsequently filled with 2.5 inches of Grade SX(100)(PG 64-22) HMA.
    - Year: 2006
  - Sample 2 (RAP 2-2)
    - The second was located on I-25 between MP 102.8 to MP 109. The project number was IM 0252-378, SA 15160. The millings were generated from the top 2 inches of the interstate surface. The top 2 inches of the existing surface consisted of 3/4" Plant Mix Seal Coat, underlain by Grade C HMA. The asphalts used in these layers were AC-20R and AC-20, respectively. This was subsequently filled with 2 inches of Grade SX(100)(PG 64-22) HMA, and was then overlaid with another 2 inches of Grade SX(100)(PG 64-28) HMA which contained 15% RAP.
    - Year: 2006

Region 3

- ABC (Class 6)
  - Sample 1 (ABC 3-1)
    - Class 6 sample #1 was procured from combined belt cut samples taken by United Companies of Mesa County for their quality control. The pit is United’s 15 Road Pit located approximately 1 mile north of the Colorado River and 15 miles east of the Colorado/Utah state line. The material being mined was deposited by the Colorado River but I do not know the location of the pit that the material came from. This Class 6 was used as shouldering

material (Class 7) for the Utah Line Project. Region 3 materials reported an R-Value of 83 from a different sample of this material. The date sampled is on the tag.

Sample 2 (ABC 3-2)

Class 6 sample #2 came from a stockpile in the Elam Construction Inc. Wagner pit. This pit is located beside Woody Creek near Aspen. The material being mined is from glacial deposits and, again, I do not know the area of the pit being mined. The class 6 is being used at the SH 82 Maroon Creek Bridge Project, CC 0821-068, 14834. Region 3 reported an R-Value of 80 and Central Lab reported an R-Value of 84 on different samples of this material. The date sampled is on the tag.

RAP

Sample 1 (RAP 3-1)

RAP sample #1 was taken from millings that were removed from various locations on I-70 between milepost 0 and 5 for leveling purposes. The millings were then stockpiled and a sample was taken from the stockpile so no precise location can be given. The project info is: HB 0701-180, 15435, I-70 Utah State Line East. I don't remember the date sampled but is on the tag.

Sample 2 (RAP 3-2)

RAP sample #2 came from project # C 0501-049, 15111, US50 @ 29 Road. The date and the location are on the tag. This project is an intersection improvement engineered by the Traffic Dept. The millings were removed to meet elevation requirements.

Region 4

ABC (Class 6)

Sample 1 (ABC 4-1)

NH 0853-057

Hwy 85 & 31st St (approx MP 265)

Agg. Industries / 83rd Ave Pit – Greeley

Sample 2 (ABC 4-2)

IM 0253-160

Stockpile

Asphalt Specialties / Turnpike Pit

RAP

Sample 1 (RAP 4-1)

NH 0853-057

Hwy 85 @ Str C-18-K (approx MP 265)

Sample 2 (RAP 4-2)

NH 0341-070

Hwy 34: Loveland E&W (MP 93.5-96.1)

Region 5

ABC (Class 6)

Sample 1 (ABC 5-1)

Sky Ute Sand and Gravel Noland pit located adjacent to US Hwy 160 (M.P. 51.8) on the North side. Valley side alluvial pit on Mud Creek.

Sample 2 (ABC 5-2)

4-Corners Materials Group Cugnini pit located approximately 4 miles South of SH 172 (M.P. 22.9) down LaPlata County road 322. Valley side alluvial pit on the Florida River.

RAP

Sample 1 (RAP 5-1)

CDOT owned millings stockpiled at Silverton Colorado. These milling are exclusively from CDOT project NH 5502-052, S.A. #15137 constructed in the summer of 2006. Removal of asphalt mat (planing) was performed on US Hwy 550 between M.P. 45.5 and 48.5 approximately.

Sample 2 (RAP 5-2)

4-corners Materials Group production stockpile at Cugnini pit described above. This material is utilized in their production of RAP HMA mixes and is processed each off-season from milling or asphalt removals from various CDOT, County, and City projects in the Durango area. This material is crushed and sized to provide for more uniformity. The other attachment is the required production records (Gradations and Asphalt Contents) from this processing.

Region 6

ABC (Class 6)

Sample 1 (ABC 6-1)

Class 6 Road base, Aggregate Inds., Morrison Pit
IM R600-224, 14777, I-25/Speer Interchange

Sample 2 (ABC 6-2)

Class 6 Road base, Asphalt Specialties, Turnpike Pit - SH 52 & County Line Rd.

RAP

Sample 1 (RAP 6-1)

HMA Millings, from I-25 @ MP 222.8 to MP 223.8, Project # IM 0253-173, 13622
Placed at Broadway / I-25, RTD Parking lot. (PCCP), IM 0252-384, 15699

Sample 2 (RAP 6-2)

HMA Millings, from I-76 @ MP 12.4 to MP 16.0, IM 076A-007, 15361
Stockpiled at Brannan's, 74th Ave. plant. (Use is unknown)

APPENDIX B
TEST RESULTS

J.A. Cesare & Associates, Inc. / Construction Technical Services
7108 South Alton Way, Bldg. B
Centennial, Colorado 80112
Phone: (303) 783-9965; Fax: (303) 783-9964

CDOT Research - Study No.: 013.00
RAP as a Base or Sub-base Material
JA Cesare/CTS Project #07.050

JAC/CTS Sample ID	CDOT Sample ID	Material Type	Sample Location	Gradation (AASHTO T 27)												Atterberg Limits (AASHTO T89 & T90)		
				2"	1"	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#100	#200	Liquid Limit	Plastic Limit	Plasticity Index
75422	ABC 1-1	Class 6, ABC	Specification Aggregates Quarry	100	100	100	88	77	57	46	38	31	22	15	9.9	NV	NP	NP
75423(1)	ABC 1-2	Class 6, ABC	Asphalt Paving, ABC 2	100	100	100	92	79	53	40	31	24	18	14	10.6	24	18	6
75425	ABC 6-1	Class 6, ABC	Morrison Quarry, I 25 and Speer	100	100	100	90	76	52	42	34	28	21	15	9.8	NV	NP	NP
75428	ABC 4-1	Class 6, ABC	Aggregate Industries, 83rd Pit	100	100	100	85	77	59	46	35	23	14	10	6.4	NV	NP	NP
75427	ABC 3-2	Class 6, ABC	Stockpile	100	100	100	85	73	52	40	31	22	14	10	7.8	NV	NP	NP
75423(2)	ABC 1-2	Class 6, ABC	Asphalt Paving, ABC 2	100	100	100	85	70	44	34	26	21	17	13	10.8	31**	19	12 **
75424	ABC 2-2	Class 6, ABC	Lafarge, Fountain Pit	100	100	99	81	72	56	42	28	18	11	8	6.1	NV	NP	NP
75429	ABC 4-2	Class 5, ABC	ASCI Turnpike Pit	100	100	100	81	68	53	43	35	24	14	7	3.7	NV	NP	NP
75430	ABC 5-1	Class 6, ABC	Noland	100	100	100	87	75	54	42	32	26	19	13	9.5	NV	NP	NP
75431	ABC 5-2	Class 6, ABC	Cugnini Pit	100	100	100	94	86	64	49	39	30	22	14	9.0	NV	NP	NP
75426	ABC 3-1	Class 6, ABC	United Company's 15 Road Pit	100	100	100	86	68	43	34	29	25	15	7	3.8	NV	NP	NP
MINIMUM VALUE, excludes APCO ABC				100.0	100.0	99.0	81.0	68.0	43.0	34.0	26.0	18.0	11.0	7.0	3.7	0	0	0
MAXIMUM VALUE, excludes APCO ABC				100.0	100.0	100.0	94.0	86.0	64.0	49.0	39.0	31.0	22.0	15.0	9.9	0	0	0
RANGE, excludes APCO ABC				0.0	0.0	1.0	13.0	18.0	21.0	15.0	13.0	13.0	11.0	8.0	6.2	0	0	0
AVERAGE VALUE, excludes APCO ABC				100.0	100.0	99.9	86.3	74.7	54.4	42.7	33.4	25.2	16.9	11.0	7.3	0	0	0
STANDARD DEVIATION, simple, excludes APCO ABC				0.0	0.0	0.3	4.1	5.5	5.8	4.3	3.8	4.1	4.1	3.3	2.5	0	0	0

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CDOT Research - Study No.: 013.00
RAP as a Base or Sub-base Material
JA Cesare/CTS Project #07.050

JAC/CTS Sample ID	CDOT Sample ID	Material Type	Sample Location	Proctor Values (AASHTO T180)		R-Value (AASHTO T190)	LA Abrasion (AASHTO T96), % Loss	Specific Gravity (AASHTO T85)	Absorption (AASHTO T85)	Asphalt Content (AASHTO T308), %	Permeability (USBR 5605, Amended)		Ultimate Resilient Modulus*** (AASHTO T307)
				Optimum Moisture Content (OMC),	Max. Dry Density (MDD), pcf						Flow cc/sec	Permeability k, cm/sec	
75422	ABC 1-1	Class 6, ABC	Specification Aggregates Quarry	6.0	142.7	88	29	2.70	1.1	N/A	0.017	7.2E-05	N/A
75423(1)	ABC 1-2	Class 6, ABC	Asphalt Paving, ABC 2	6.6	141.6	25**	*	*	*	N/A	*	*	N/A
75425	ABC 6-1	Class 6, ABC	Morrison Quarry, I 25 and Speer	5.3	139.7	81	30	2.62	1.4	N/A	0.078	3.0E-04	38,527
75428	ABC 4-1	Class 6, ABC	Aggregate Industries, 83rd Pit	5.3	138.4	80	33	2.61	0.9	N/A	0.067	8.9E-04	N/A
75427	ABC 3-2	Class 6, ABC	Stockpile	6.8	138.3	86	21	2.63	1.3	N/A	2.314	6.0E-04	N/A
75423(2)	ABC 1-2	Class 6, ABC	Asphalt Paving, ABC 2	7.4	137.7	66**	17	2.76	1.0	N/A	0.116	7.7E-04	N/A
75424	ABC 2-2	Class 6, ABC	Lafarge, Fountain Pit	7.5	135.7	73	45	2.57	0.9	N/A	0.689	1.1E-02	N/A
75429	ABC 4-2	Class 5, ABC	ASCI Turnpike Pit	6.7	135.4	81	35	2.58	1.4	N/A	1.281	1.7E-02	33,914
75430	ABC 5-1	Class 6, ABC	Noland	6.9	135.2	84	18	2.55	1.9	N/A	0.161	1.7E-03	N/A
75431	ABC 5-2	Class 6, ABC	Cugnini Pit	6.7	133.4	84	24	2.54	2.0	N/A	0.135	2.1E-03	55,642
75426	ABC 3-1	Class 6, ABC	United Company's 15 Road Pit	9.0	132.8	54**	23	2.61	1.0	N/A	0.728	1.6E-02	N/A
MINIMUM VALUE, excludes APCO ABC				5.3	132.8	73.0	17.0	2.5	0.9		0.0		33914
MAXIMUM VALUE, excludes APCO ABC				9.0	142.7	88.0	45.0	2.7	2.0		2.3		55642
RANGE, excludes APCO ABC				3.7	9.9	15.0	28.0	0.2	1.1		2.3		21728
AVERAGE VALUE, excludes APCO ABC				6.7	136.8	82.1	28.7	2.6	1.3		0.6		42694
STANDARD DEVIATION, simple, excludes APCO ABC				1.1	3.2	4.6	8.3	0.0	0.4		0.8		11448

Figure B.1 Aggregate Base Course Class 6 (ABC Class 6)

J.A. Cesare & Associates, Inc. / Construction Technical Services
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CDOT Research - Study No.: 013.00

RAP as a Base or Sub-base Material

JA Cesare/CTS Project #07.050

JAC/CTS Sample ID	CDOT Sample ID	Material Type	Sample Location	Proctor Values (AASHTO T180)		R-Value (AASHTO T190)	LA Abrasion (AASHTO T96), % Loss	Specific Gravity (AASHTO T85)	Absorption (AASHTO T85)	Asphalt Content (AASHTO T308), %	Permeability (USBR 5605, Amended)		Ultimate Resilient Modulus*** (AASHTO T307)
				Optimum Moisture Content (OMC),	Max. Dry Density (MDD), pcf						Flow cc/sec	Permeability k, cm/sec	
~~75441~~	~~RAP 5-2~~	~~1/2" Rap~~	~~4 Corners Material~~	8.0	126.9	80	13	2.41	1.8	4.65	0.474	6.2E-03	N/A
75436	RAP 3-1	RAP	I 25, MP 0 - 5	8.5	123.2	84	24	2.25	1.9	6.05	1.767	2.5E-02	N/A
75589	RAP 6-1	RAP	I 25 and 120th, Millings, RAP #1	7.2	123.2	81	26	2.36	1.4	5.90	5.372	7.7E-02	49,177
75434	RAP 2-1	RAP	I 25, MP 59 - 69.5	6.5	122.3	80	26	2.30	1.9	5.72	1.974	4.3E-02	N/A
75432	RAP 1-1	RAP	Specification Aggregates Quarry	10.7	121.4	86	29	2.33	2.1	5.60	4.737	7.4E-02	62,093
75435	RAP 2-2	RAP	I 25, MP 103 - 109	10.1	121.2	82	28	2.38	1.6	5.22	0.529	7.3E-03	N/A
75440	RAP 5-1	RAP	Silverton	5.7	120.6	82	15	2.38	1.7	5.27	4.106	6.5E-02	N/A
75439	RAP 4-2	RAP	Loveland Hwy 34, East and West	6.4	119.9	83	28	2.37	1.5	5.51	5.236	8.4E-02	N/A
75433	RAP 1-2	RAP	I 70, MP 373.8 - 385.8	8.8	119.8	84	25	2.34	1.8	5.39	13.676	7.3E-02	59,364
75590	RAP 6-2	RAP	I 76, SH 85, Cold Millings	7.7	117.7	85	28	2.36	1.4	5.53	6.585	1.2E-01	N/A
75438	RAP 4-1	RAP	Hwy 85 at STA. C-18-K, MP 263.7	7.5	113.5	80	27	2.28	2.2	6.20	5.293	9.8E-02	N/A
75437	RAP 3-2	RAP	US 50 + 29th	4.4	110.4	82	18	2.29	1.4	6.20	10.369	1.5E-01	N/A
			MINIMUM VALUE	4.4	110.4	80.0	13.0	2.25	1.4		0.474		49177
			MAXIMUM VALUE	10.7	126.9	86.0	29.0	2.41	2.2		13.676		62093
			RANGE	6.3	16.5	6.0	16.0	0.17	0.8		13.202		12916
			AVERAGE VALUE	7.6	120.0	82.4	23.9	2.34	1.7		5.060		56878
			STANDARD DEVIATION, simple	1.8	4.4	2.0	5.5	0.05	0.3		3.913		6807

* Discontinued testing due to sample being out of specification.
** Does not meet Aggregate Base Course criteria.
*** The value for Ultimate Resilent Modulus at a Chamber Pressure of 20 psi and Axial Load of 40 psi is reported in the spread sheet. For all other Resilent Modulus tesing data please see the attached results supplied by Gound Engineering Consultants.
NV = No Value; NP = Non Plastic

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CDOT Research - Study No.: 013.00

RAP as a Base or Sub-base Material

JA Cesare/CTS Project #07.050

JAC/CTS Sample ID	CDOT Sample ID	Material Type	Sample Location	Gradation (AASHTO T 27)												Atterberg Limits (AASHTO T89 & T90)		
				2"	1"	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#100	#200	Liquid Limit	Plastic Limit	Plasticity Index
75441	RAP 5-2	1/2" Rap	4 Corners Material	100	100	100	100	89	48	29	16	12	8	5	2.9	NV	NP	NP
75436	RAP 3-1	RAP	I 25, MP 0 - 5	100	99	96	86	76	45	23	12	7	3	2	1.4	NV	NP	NP
75589	RAP 6-1	RAP	I 25 and 120th, Millings, RAP #1	100	88	78	65	57	36	23	13	7	3	1	0.9	NV	NP	NP
75434	RAP 2-1	RAP	I 25, MP 59 - 69.5	100	97	95	85	72	46	33	22	13	7	4	2.4	NV	NP	NP
75432	RAP 1-1	RAP	Specification Aggregates Quarry	100	94	87	73	65	41	22	11	5	2	1	0.8	NV	NP	NP
75435	RAP 2-2	RAP	I 25, MP 103 - 109	100	100	100	88	77	55	32	16	7	3	1	0.6	NV	NP	NP
75440	RAP 5-1	RAP	Silverton	100	98	95	85	73	44	28	15	8	4	2	1.0	NV	NP	NP
75439	RAP 4-2	RAP	Loveland Hwy 34, East and West	98	94	89	74	64	41	19	9	4	2	1	0.8	NV	NP	NP
75433	RAP 1-2	RAP	I 70, MP 373.8 - 385.8	100	96	91	75	67	41	24	13	7	3	2	1.0	NV	NP	NP
75590	RAP 6-2	RAP	I 76, SH 85, Cold Millings	100	89	79	61	50	33	22	13	7	3	2	0.8	NV	NP	NP
75438	RAP 4-1	RAP	Hwy 85 at STA. C-18-K, MP 263.7	100	91	82	63	53	33	22	7	5	4	2	1.2	NV	NP	NP
75437	RAP 3-2	RAP	US 50 + 29th	100	90	77	56	46	25	15	8	5	3	2	0.9	NV	NP	NP
			MINIMUM VALUE	98.0	88.0	77.0	56.0	46.0	25.0	15.0	7.0	4.0	2.0	1.0	0.6	0	0	0
			MAXIMUM VALUE	100.0	100.0	100.0	100.0	89.0	55.0	33.0	22.0	13.0	8.0	5.0	2.9	0	0	0
			RANGE	2.0	12.0	23.0	44.0	43.0	30.0	18.0	15.0	9.0	6.0	4.0	2.3	0	0	0
			AVERAGE VALUE	99.8	94.7	89.1	76.2	65.8	40.7	24.3	13.1	7.3	3.8	2.1	1.2	0	0	0
			STANDARD DEVIATION, simple	0.6	4.3	8.4	13.2	12.6	8.0	5.3	4.3	2.7	1.9	1.2	0.7	0	0	0

* Discontinued testing due to sample being out of specification.
** Does not meet Aggregate Base Course criteria.
*** The values for Ultimate Resilent Modulus at a Chamber Pressure of 20 psi and Axial Load of 40 psi are reported in the spread sheet. For all other Resilent Modulus testing data please see the attached results supplied by Gound Engineering Consultants.
NV = No Value; NP = Non Plastic

Figure B.2 Reclaimed Asphalt Pavement (RAP)

Figures B.3 and B.4 are multi-sample gradation plots with ABC Class 6 upper and lower specification limits shown as an envelope.

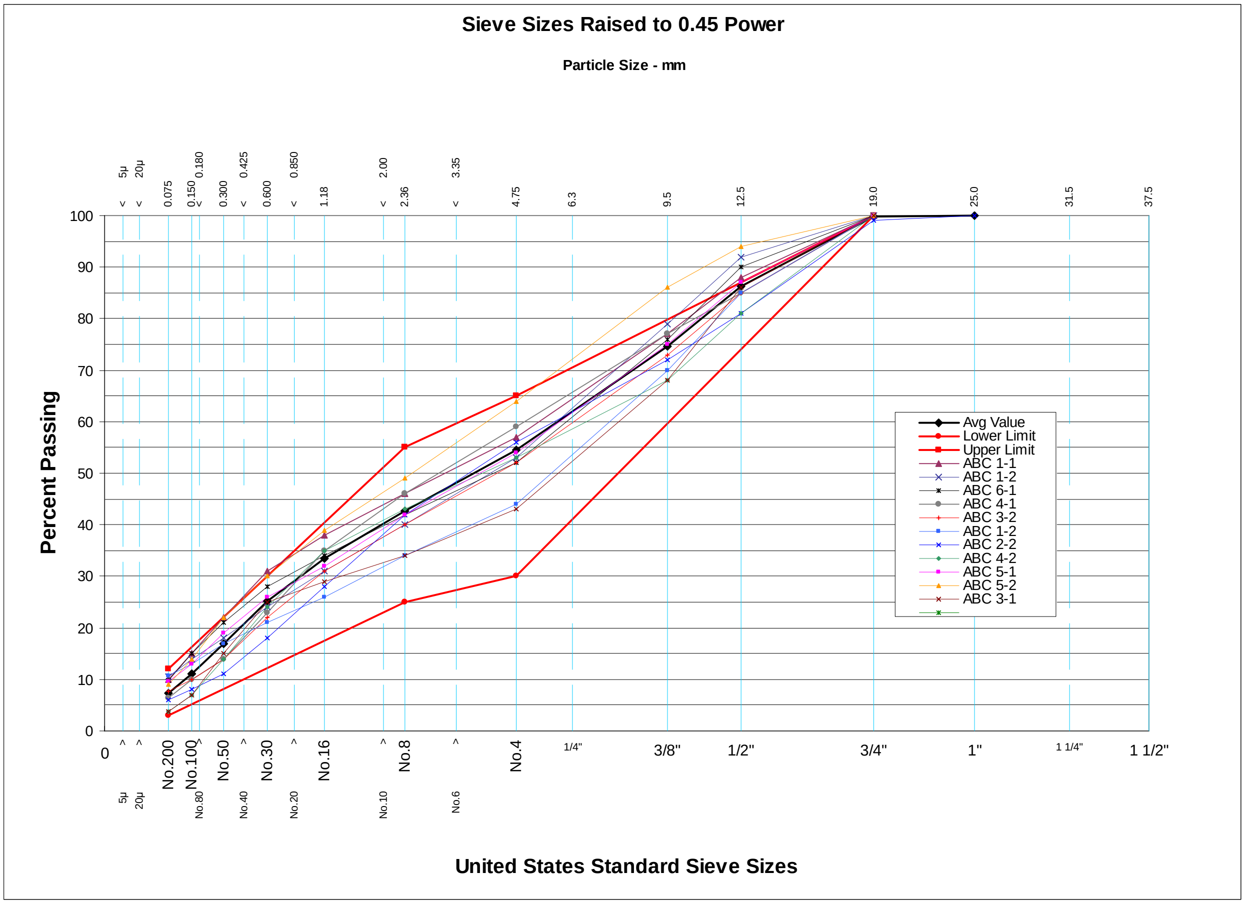

Figure B.3 Aggregate Base Course Class 6 (ABC Class 6) Gradation Plot

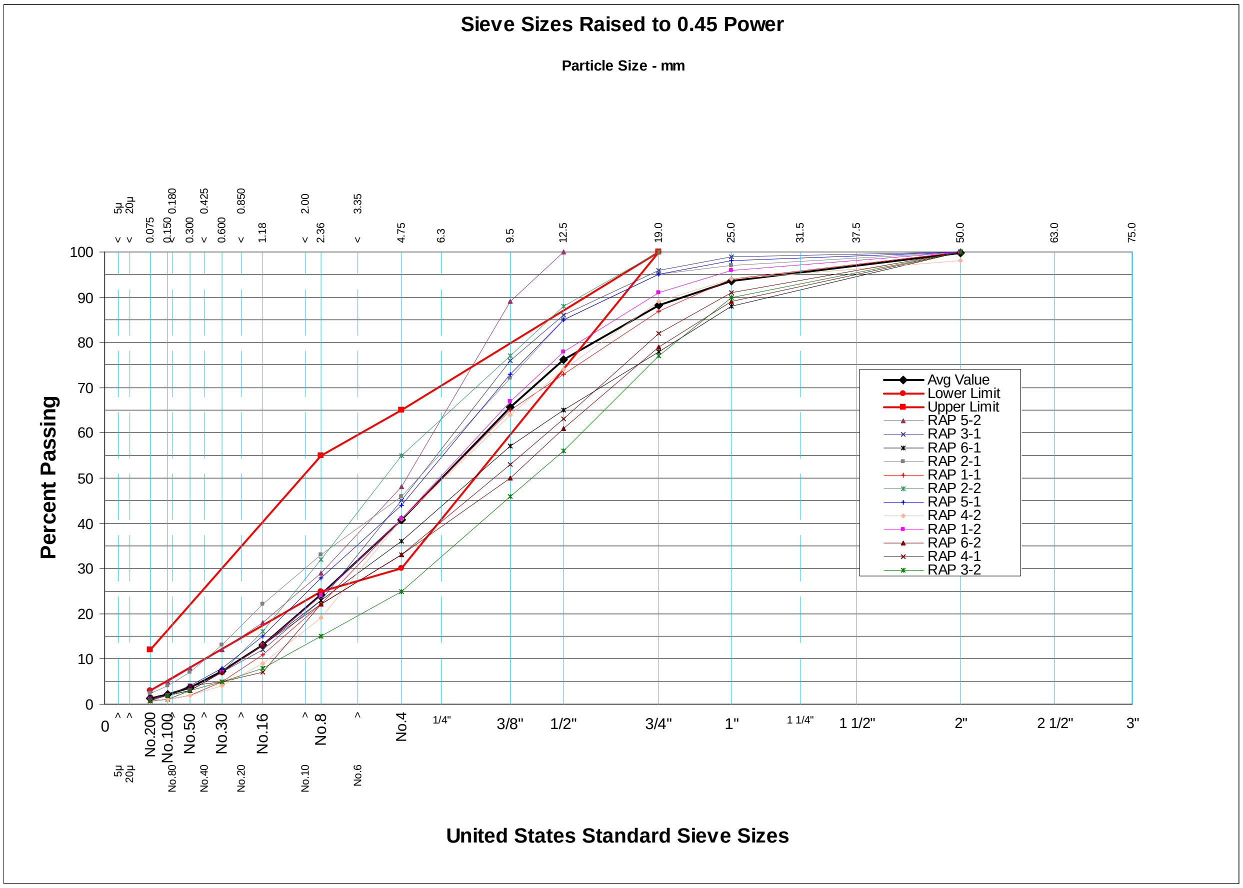

Figure B.4 Reclaimed Asphalt Pavement (RAP) Gradation Plot

GROUND
ENGINEERING CONSULTANTS

RESILIENT MODULUS TEST DATA

Job Name: J.A. Cesare / C.T.S. Resilient Modulus Testing
Job Number: 08-1118
Date: 06/01/08

Sample #: 75425
Received From: J.A.Cesare And Associates, Inc / Construction Technical Services
Location: Morrison Quarry, I-25 and Speer
Soil Type: Class 6, ABC
Dry Density *(pcf)*: 133.8 Sample Height *(inches)*: 12.00
Moisture Content *(%)*: 6.5 Sample Diameter *(inches)*: 6.00

Chamber Pressure *(psi)*	Axial Load *(psi)*	Resilient Modulus *(psi)*	Recoverable Deformation *(inches x 10^{-3})*
3.0	3.0	17,853	1.0
3.0	6.0	14,115	4.6
3.0	9.0	12,377	8.1
5.0	5.0	15,301	3.2
5.0	10.0	15,834	7.5
5.0	15.0	17,623	10.1
10.0	10.0	19,350	5.6
10.0	20.0	22,797	10.2
10.0	30.0	27,276	12.6
15.0	10.0	23,145	4.3
15.0	15.0	26,423	7.0
15.0	30.0	31,731	10.8
20.0	15.0	27,765	5.5
20.0	20.0	31,038	7.4
20.0	40.0	38,527	11.7

Testing was performed in general accordance with AASHTO T-307, Base / Subbase Materials loading sequence. Samples were conditioned for 500 cycles under a confining pressure of 15 psi with an axial load of 15 psi prior to testing. Each Cell Pressure and Axial Load was applied for 100 cycles; the Resilient Modulus shown above is the average of the last 3 cycles recorded (generated by the software, no additional data is available).

Comments:
The sample was remolded to approximately 95% of the maximum dry density at approximately two percent above the optimum moisture content. The moisture density relationship, of this soil sample, was provided to our laboratory.

GROUND
ENGINEERING CONSULTANTS

RESILIENT MODULUS TEST DATA

Job Name: J.A. Cesare / C.T.S. Resilient Modulus Testing
Job Number: 08-1118
Date: 06/01/08

Sample # 75429
Received From: J.A.Cesare And Associates, Inc / Construction Technical Services
Location: ASCI Turnpike Pit
Soil Type: Class 5, ABC
Dry Density *(pcf)*: 128.2 Sample Height *(inches)*: 12.00
Moisture Content *(%)*: 7.8 Sample Diameter *(inches)*: 6.00

Chamber Pressure *(psi)*	Axial Load *(psi)*	Resilient Modulus *(psi)*	Recoverable Deformation *(inches x 10^{-3})*
3.0	3.0	13,885	0.9
3.0	6.0	9,881	5.3
3.0	9.0	10,747	9.6
5.0	5.0	12,037	4.3
5.0	10.0	13,392	8.2
5.0	15.0	14,382	11.5
10.0	10.0	18,246	5.9
10.0	20.0	21,013	10.6
10.0	30.0	22,870	14.9
15.0	10.0	20,404	5.2
15.0	15.0	22,783	7.7
15.0	30.0	27,406	12.1
20.0	15.0	25,088	5.8
20.0	20.0	28,202	8.1
20.0	40.0	33,914	13.2

Testing was performed in general accordance with AASHTO T-307, Base / Subbase Materials loading sequence. Samples were conditioned for 500 cycles under a confining pressure of 15 psi with an axial load of 15 psi prior to testing. Each Cell Pressure and Axial Load was applied for 100 cycles; the Resilient Modulus shown above is the average of the last 3 cycles recorded (generated by the software, no additional data is available).

Comments:
The sample was remolded to approximately 95% of the maximum dry density at approximately two percent above the optimum moisture content. The moisture density relationship, of this soil sample, was provided to our laboratory.

GROUND
ENGINEERING CONSULTANTS

RESILIENT MODULUS TEST DATA

Job Name: J.A. Cesare / C.T.S. Resilient Modulus Testing
Job Number: 08-1118
Date: 06/01/08

Sample # 75431
Received From: J.A.Cesare And Associates, Inc / Construction Technical Services
Location: Cugnini Pit
Soil Type: Class 6, ABC
Dry Density *(pcf)*: 129.9 Sample Height *(inches)*: 12.00
Moisture Content *(%)*: 7.2 Sample Diameter *(inches)*: 6.00

Chamber Pressure *(psi)*	Axial Load *(psi)*	Resilient Modulus *(psi)*	Recoverable Deformation *(inches x 10^{-3})*
3.0	3.0	39,849	0.5
3.0	6.0	23,202	2.8
3.0	9.0	22,908	4.7
5.0	5.0	30,049	1.7
5.0	10.0	31,353	3.9
5.0	15.0	32,753	5.2
10.0	10.0	39,452	2.9
10.0	20.0	42,332	5.2
10.0	30.0	44,566	7.6
15.0	10.0	42,779	2.5
15.0	15.0	43,998	3.6
15.0	30.0	49,909	6.7
20.0	15.0	48,241	3.4
20.0	20.0	50,725	4.3
20.0	40.0	55,642	7.7

Testing was performed in general accordance with AASHTO T-307, Base / Subbase Materials loading sequence. Samples were conditioned for 500 cycles under a confining pressure of 15 psi with an axial load of 15 psi prior to testing. Each Cell Pressure and Axial Load was applied for 100 cycles; the Resilient Modulus shown above is the average of the last 3 cycles recorded (generated by the software, no additional data is available).

Comments:
The sample was remolded to approximately 95% of the maximum dry density at approximately two percent above the optimum moisture content. The moisture density relationship, of this soil sample, was provided to our laboratory.

GROUND
ENGINEERING CONSULTANTS

RESILIENT MODULUS TEST DATA

Job Name: J.A. Cesare / C.T.S. Resilient Modulus Testing
Job Number: 08-1118
Date: 06/01/08

Sample # 75432
Received From: J.A. Ceasare And Associates, Inc / Construction Technical Services
Location: Specification Aggregates Quarry
Soil Type: RAP
Density *(pcf)*: 116.2 Sample Height *(inches)*: 8.00
Moisture Content *(%)*: 6.6 Sample Diameter *(inches)*: 4.00

Chamber Pressure *(psi)*	Axial Load *(psi)*	Resilient Modulus *(psi)*	Recoverable Deformation *(inches x 10^{-3})*
3.0	3.0	56,404	0.3
3.0	6.0	43,759	0.8
3.0	9.0	36,539	1.4
5.0	5.0	49,120	0.6
5.0	10.0	38,642	1.8
5.0	15.0	34,757	3.5
10.0	10.0	47,042	1.4
10.0	20.0	46,198	3.6
10.0	30.0	46,450	5.2
15.0	10.0	56,773	1.0
15.0	15.0	55,151	2.0
15.0	30.0	54,037	4.2
20.0	15.0	61,341	1.4
20.0	20.0	61,592	2.3
20.0	40.0	62,093	4.5

Testing was performed in general accordance with AASHTO T-307, Base / Subbase Materials loading sequence. Samples were conditioned for 500 cycles under a confining pressure of 15 psi with an axial load of 15 psi prior to testing. Each Cell Pressure and Axial Load was applied for 100 cycles; the Resilient Modulus shown above is the average of the last 3 cycles recorded (generated by the software, no additional data is available).

Comments:
The sample was remolded to approximately 95% of the maximum dry density at approximately the respective optimum moisture content. The moisture density relationship, of this soil sample, was provided to our laboratory.

GROUND
ENGINEERING CONSULTANTS

RESILIENT MODULUS TEST DATA

Job Name: J.A. Cesare / C.T.S. Resilient Modulus Testing
Job Number: 08-1118
Date: 06/01/08

Sample # 75433
Received From: J.A. Ceasare And Associates, Inc / Construction Technical Services
Location: I-70, MP 373.8 - 385.8
Soil Type: RAP
Density *(pcf)*: 114.2 Sample Height *(inches)*: 8.00
Moisture Content *(%)*: 7.3 Sample Diameter *(inches)*: 4.00

Chamber Pressure *(psi)*	Axial Load *(psi)*	Resilient Modulus *(psi)*	Recoverable Deformation *(inches x 10^{-3})*
3.0	3.0	68,323	0.1
3.0	6.0	49,871	0.5
3.0	9.0	35,492	1.0
5.0	5.0	51,526	0.4
5.0	10.0	35,093	2.0
5.0	15.0	30,719	3.3
10.0	10.0	43,774	1.6
10.0	20.0	41,803	3.4
10.0	30.0	41,885	5.5
15.0	10.0	53,369	1.2
15.0	15.0	50,370	2.1
15.0	30.0	51,673	4.3
20.0	15.0	57,995	1.6
20.0	20.0	60,033	2.4
20.0	40.0	59,364	5.0

Testing was performed in general accordance with AASHTO T-307, Base / Subbase Materials loading sequence. Samples were conditioned for 500 cycles under a confining pressure of 15 psi with an axial load of 15 psi prior to testing. Each Cell Pressure and Axial Load was applied for 100 cycles; the Resilient Modulus shown above is the average of the last 3 cycles recorded (generated by the software, no additional data is available).

Comments:
The sample was remolded to approximately 95% of the maximum dry density at approximately the respective optimum moisture content. The moisture density relationship, of this soil sample, was provided to our laboratory.

GROUND
ENGINEERING CONSULTANTS

RESILIENT MODULUS TEST DATA

Job Name: J.A. Cesare / C.T.S. Resilient Modulus Testing
Job Number: 08-1118
Date: 06/01/08

Sample # 75589
Received From: J.A.Cesare And Associates, Inc / Construction Technical Services
Location: I-25 and 120th, Millings, RAP #11
Soil Type: RAP
Dry Density *(pcf)*: 119.2 Sample Height *(inches)*: 12.00
Moisture Content *(%)*: 5.6 Sample Diameter *(inches)*: 6.00

Chamber Pressure *(psi)*	Axial Load *(psi)*	Resilient Modulus *(psi)*	Recoverable Deformation *(inches x 10^{-3})*
3.0	3.0	19,954	1.0
3.0	6.0	20,029	3.4
3.0	9.0	19,369	5.4
5.0	5.0	23,470	2.2
5.0	10.0	25,648	4.7
5.0	15.0	26,271	6.8
10.0	10.0	30,409	3.5
10.0	20.0	33,734	6.7
10.0	30.0	35,559	9.5
15.0	10.0	32,943	3.2
15.0	15.0	36,548	4.5
15.0	30.0	42,042	7.9
20.0	15.0	39,325	3.8
20.0	20.0	43,811	5.3
20.0	40.0	49,177	9.1

Testing was performed in general accordance with AASHTO T-307, Base / Subbase Materials loading sequence. Samples were conditioned for 500 cycles under a confining pressure of 15 psi with an axial load of 15 psi prior to testing. Each Cell Pressure and Axial Load was applied for 100 cycles; the Resilient Modulus shown above is the average of the last 3 cycles recorded (generated by the software, no additional data is available).

Comments:
The sample was remolded to approximately 95% of the maximum dry density at approximately two percent above the optimum moisture content. The moisture density relationship, of this soil sample, was provided to our laboratory.

APPENDIX C
REMOVAL OF ASPHALT MAT (PLANING)

REVISION OF SECTION 202

REMOVAL OF ASPHALT MAT (PLANING)

Section 202 of the Standard Specifications is hereby revised for this project as follows:

Delete subsection 202.09, and replace with the following:

202.09 Removal of Asphalt Mat (Planing). Prior to beginning planing operations, the Contractor shall submit a planing plan and a Quality Control Plan (QCP) for approval by the Engineer. The planing plan shall include at a minimum:

(1) The number, types and sizes of planers to be used.
(2) The width and location of each planing pass.
(3) The number and types of brooms to be used and their locations with respect to the planers.
(4) The proposed method for planing and wedging around existing structures such as manholes, valve boxes, and inlets.
(5) The longitudinal and transverse typical sections for tie-ins at the end of the day.
(6) If requested by the Engineer, a plan sheet showing the milling passes.

The QCP shall include as a minimum:

(1) The schedule for replacing the cutting teeth.
(2) The daily preventive maintenance schedule and checklist.
(3) Proposed use of automatic grade controls.
(4) The surface testing schedule for smoothness.
(5) The process for filling distressed areas.
(6) The schedule for testing macrotexture of the milled surface.
(7) Corrective procedures if the milled surface does not meet the minimum macrotexture specification.
(8) Corrective procedures if the milled surface does not meet the minimum transverse or longitudinal surface finish when measured with a 10 foot straightedge.

The Contractor shall not start the planing operation until the hot mix asphalt (HMA) mix design has been approved and a Form 43 has been signed by the Engineer.

The existing pavement shall be milled to the cross-slope as shown on the plans, and shall have a surface finish that does not vary longitudinally or transversely more than 3/8 inch from a 10 foot straightedge. A 10 foot straightedge shall be supplied by the Contractor.

All milled surfaces shall be broomed with a pick-up broom, unless otherwise specified, before being opened to traffic. A sufficient number of brooms shall be used immediately after planing to remove all milled material remaining in the roadway.

If the Contractor fails to adequately clean the roadway, work shall cease until the Engineer has approved the Contractor's revised written proposal to adequately clean the roadway.

The milled surface shall have a macrotexture equal to or less than 0.170 inches for single-lift overlays and 0.215 inches for multiple-lift overlays as tested in accordance with CP 77. Milled surfaces that do not meet these criteria shall require corrective action in accordance with the QCP. The Contractor shall be responsible for testing the macrotexture of the milled surface at the location directed by the Engineer in accordance with CP 77 at a stratified random frequency of one test per 10,000 square yards or a minimum of once per work day.

At the completion of each day's work, longitudinal vertical edges greater than 1 inch shall be tapered. No transverse vertical edges will be allowed. Longitudinal milled surface tie-ins to existing pavement shall be tapered to not less than a 3:1 slope, transverse milled surface tie-ins to existing pavement shall be tapered to not less than a 50:1 slope. Transverse tapered joints may be tapered with the planing machine, a temporary asphalt ramp, or other methods approved by the Engineer. No longitudinal joint between the milled and existing surfaces shall fall between 1 to 5 feet of any lane line.

If the transverse joint is tapered with a temporary asphalt ramp, the milled surface at the joint shall be constructed as a butt joint the full depth of the lift of asphalt to be placed on the milled surface. The Contractor shall be responsible for maintaining this asphalt ramp until all corresponding HMA is placed. All work associated with this joint will not be paid for separately, but shall be included in the cost of planing.

If the transverse joint is tapered with a planing machine, a butt joint shall be cut into the taper the full depth of the lift of asphalt to be placed on the milled surface prior to commencement of resurfacing. All work associated with this joint will not be paid for separately, but shall be included in the cost of planing.

Other approved transverse joint tapers shall be maintained at the expense of the Contractor, and at a minimum shall incorporate a butt joint the full depth of the lift of asphalt to be placed on the milled surface prior to commencement of resurfacing.

Distressed or irregular areas identified in the planed surface by the Engineer shall be patched.

The roadway shall be left in a safe and usable condition at the end of each work day. The Contractor shall take appropriate measures to ensure that the milled surface does not trap or hold water. All required pavement markings removed by the planing shall be restored before the roadway is opened to traffic.

All milled surfaces to be overlaid with HMA shall be covered with new asphalt within ♦ working days. All areas on this project that are not overlaid within the specified working days will be assessed a lane rental fee of ▲ per occurrence for each day or fraction thereof and any required surface repairs shall be paid for by the Contractor.

All planing shall be completed full width and parallel to the travel lanes before resurfacing commences unless otherwise directed by the Engineer.

All material generated by the planing operation shall become the property of the Contractor unless otherwise noted in the Contract.

Add subsection 202.091 immediately following subsection 202.09 as follows:

202.091 Equipment

Each planer shall conform to the following:

The planer shall have sufficient power, traction and stability to maintain an accurate depth of cut. The propulsion and guidance system of the planer shall be maintained in such condition that the planer may be operated to straight and true lines.

The planer shall be capable of operating with automatic grade controls (contact or non-contact) on both sides of the machine using a 30 foot averaging system or other approved grade control systems. The use of such controls shall be described in the Contractor's QCP.

The planer shall be capable of picking up the removed material in a single operation. A self loading conveyor shall be an integral part of the planer. Windrows will not be allowed.

Subsection 202.12 shall include the following:

Macrotexture testing, macrotexture corrective actions, planers, brooms and all other work necessary to complete the item will not be measured and paid for separately, but shall be included in the work.

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Notes to the Designer:

♦ Insert the number of working days the planed surface may be exposed to traffic and weather before placing the HMA overlay. Seven days is recommended.`

▲ Insert the lane rental fee for the user cost due to reduced speed or extended lane closure. To download a copy of the User Cost software please use the attached link Download Area for User Cost Software

Colorado Procedure 77

Standard Procedure for

DETERMINATION OF MACROTEXTURE OF PLANED HOT MIX ASPHALT PAVEMENT

1.0 SCOPE.

1.1 This test method describes the means to evaluate the macrotexture of a planed pavement surface.

1.2 This CP may involve hazardous materials, operations, and equipment. This CP does not purport to address all of the safety problems associated with the CP's use. The CP user's responsibility is to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2.0 REFERENCE.

2.1 AASHTO Standards.
M 247-02, Type I Glass Beads Used In Traffic Paints

2.2 ASTM Standards.
E 1094-04 Pharmaceutical Glass Graduates or ISO Standard 6706 Plastic Laboratory Ware - Graduated Measuring Cylinders

2.3 CP Standards.
Appendix L Random Sampling

3.0 TERMINOLOGY. Terms and abbreviations shall be in accordance with the Department's Standard Specifications, and Field Materials Manual.

4.0 SIGNIFICANCE AND USE. This CP is used to evaluate the macrotexture of a milled pavement surface.

5.0 APPARATUS.

5.1 Filler: Type 1 glass beads in accordance with AASHTO M 247-02.

5.2 Spreader: A flat, stiff hard disk made from methyl methacrylate (Plexiglas) with a thickness of 0.5 ± 0.1 in., diameter of 8 ± 2 in. and a round handle affixed in the center used to spread the filler.

5.3 A conical or cylindrical shape graduate, Type 1, Class B or better, 250 ml capacity conforming to the volume and accuracy requirements of ASTM E 1094-04 or ISO Standard 6706 used to measure the volume of filler for the test.

5.4 Brushes: A stiff wire brush and a soft bristle brush used to clean the pavement.

5.5 Container: A small container with a secure and easily removable cover used to store 200 ml of filler.

5.6 Screen: A shield used to protect the test area from air turbulence created from wind or traffic.

6.0 LABORATORY PREPARATION.

6.1 Prepare one container for each sample location.

6.2 Fill the graduate with 200 ± 2 ml of filler.

6.3 Gently tap the side of the graduate to level the surface of the filler.

6.4 Place the measured volume of filler in the container.

6.5 Label the container with type and quantity of filler.

7.0 PROCEDURE.

7.1 Randomly determine a sample location on the milled pavement surface in accordance with Appendix L, to test the macrotexture.

7.2 Inspect the sample location and ensure it is a dry, homogeneous site, free of unique or localized features such as cracks, joints, stripping and patching.

7.3 If localized features are present, move up-station at the same transverse offset until a suitable site is found.

7.4 Gently clean an area of about 1 foot by 1 foot for the sample location using the stiff wire brush to remove any, residue, debris or loosely bonded material. Be careful not to dislodge bonded material. After using the stiff wire brush, gently brush the sample location with the soft bristle brush to remove any remaining debris.

7.5 Place the screen on the milled pavement surface to protect the sample location from air turbulence.

7.6 Hold the container with filler above the pavement at the sample location at a height not greater than 4in.

7.7 Pour the measured volume of filler from the container onto the milled pavement surface into a conical pile.

7.8 Place the spreader lightly on top of the conical pile of filler being careful not to compact the filler.

7.9 Move the spreader in a slow, circular motion to disperse the filler in a circular area and to create a defined crest around the perimeter.

7.10 Continue spreading the filler until it is well dispersed and the spreader rides on top of the high points of the milled pavement surface.

7.11 Measure and record the diameter of the circular area four times, at intervals of 45º and to the nearest 0.1 in., as shown below.

7.12 Measure the diameter of the circular area from the top (crest) of the slope on one side, through the center, and to the top (crest) of the slope on the other side of the circular area.

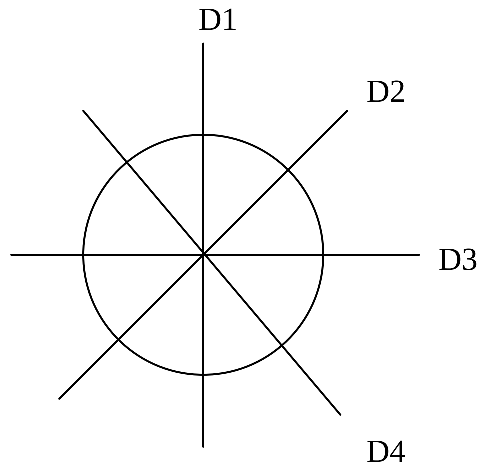
7.13 Calculate the average diameter of the circular area covered by the filler.

7.14 Determine the macrotexture thickness of the milled pavement surface by using the cross reference table on the bottom of the Macro-Texture Report form. Report the result to three decimal places.

7.15 Remove the filler material from the location using the soft bristle brush and repeat steps 7.5 through 7.14.

7.16 Determine the average macrotexture thickness by adding the two results determined in the previous step 7.14 and dividing by 2. Report the result to three decimal places.

8.0 CALCULATIONS. Calculate the average diameter of the circular area covered by the filler.



$Da = (D1 + D2 + D3 + D4) / 4$

Where:

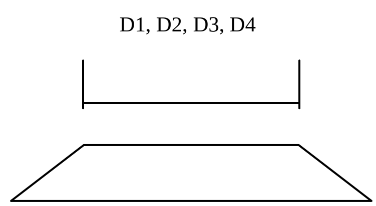
Da = Average diameter of the filler area, in

D1, D2, D3, D4 = Diameters of the filler area, in

Macrotexture Thickness:

1 in. = 2.54 cm; 1 in.^{3} = 16.387 cm^3 (cc) (ml)

Thus: 200 ml ➔ ((200 ml)/(16.387 ml/in.^{3})) = 12.20 in.^{3}



Thickness: Volume/Area

Example:

Da = 8 in.

Area = πr^2 ➔ $\pi (8/2)^2$ = 50.265 in.^{2}

Thickness = 12.20 in.^{3}/50.265 in.^{2} = 0.243 in.

9.0 REPORT. Report the following information.

Date of test	Name of prime contractor and representative
Project number	Diameter of filler area, D1, D2, D3, D4
Sub-Account Number	Average diameter of filler area, in
Station or Milepost of sample location	Macrotexture Thickness
Offset of sample location	Name of milling contractor and representative

MACRO-TEXTURE REPORT

Project No: ________________ Sub-Account No: _______________

Milling Contractor: _____________ Prime Contractor: _______________

Milling Rep.: __________________ Prime Rep.: ________________

Test #	Date	Sta	Offset	Dia. D1 (in)	Dia. D2 (in)	Dia. D3 (in)	Dia. D4 (in)	Dia. Avg (in)	Macro Texture
								Average =	

								Average =	

								Average =	

								Average =	

MACROTEXTURE THICKNESS BASED ON 200 ML OF FILLER AND AVERAGE DIAMETER

Average Diameter (inches)	Macrotexture Thickness (inches)	Average Diameter (inches)	Macrotexture Thickness (inches)	Average Diameter (inches)	Macrotexture Thickness (inches)
7.1	0.308	8.8	0.201	10.5	0.141
7.2	0.300	8.9	0.196	10.6	0.138
7.3	0.292	9.0	0.192	10.7	0.136
7.4	0.284	9.1	0.188	10.8	0.133
7.5	0.276	9.2	0.184	10.9	0.131
7.6	0.269	9.3	0.180	11.0	0.128
7.7	0.262	9.4	0.176	11.1	0.126
7.8	0.255	9.5	0.172	11.2	0.124
7.9	0.249	9.6	0.169	11.3	0.122
8.0	0.243	9.7	0.165	11.4	0.120
8.1	0.237	9.8	0.162	11.5	0.117
8.2	0.231	9.9	0.159	11.6	0.115
8.3	0.226	10.0	0.155	11.7	0.113
8.4	0.220	10.1	0.152	11.8	0.112
8.5	0.215	10.2	0.149	11.9	0.110
8.6	0.210	10.3	0.146	12.0	0.108
8.7	0.205	10.4	0.144	12.1	0.106

Force Account Item

F/A Interim HMA Surface Repair - This work consists of placing and compacting a machine scratch course in locations as directed by the Engineer. The machine scratch course may be used once the Contractor meets all the specification requirements for the Revision of Section 202, Removal of Asphalt Mat (Planing) and irregularities such as, but not limited to, delamination and raveling exceeding 10 percent within any ½ mile segment that are encountered prior to the specified time of the overlay.

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Instructions to Designer:

Insert the above paragraph in the Project Special Provisions for Force Account Items when the Revision of Section 202, Removal of Asphalt Mat (Planing) is used.

The Estimated Dollar Amount will be determined by the Region Materials Engineer and the Project Engineer.