DRAFT

Evaluation of Recycled Asphalt Concrete Materials as Aggregate Base

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District 2 Materials Branch

By:

Manuel Bejarano,
University of California, Berkeley
Pavement Research Center

Pavement Research Center
University of California Berkeley
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SUMMARY

The following is a draft report of the field tests conducted on HWY 395 and laboratory tests conducted on the recycled asphalt concrete and two California aggregate base class 2 materials. This information was used to evaluate the performance of the recycled asphalt concrete material for use as unbound base.

1.0 INTRODUCTION

This technical memorandum summarizes the evaluation of a rehabilitation strategy that involves recycling an existing asphalt concrete surface and a portion of the base material into a new base layer. A series of field and laboratory tests were conducted to evaluate this rehabilitation strategy. Field tests included destructive and non-destructive testing conducted on a pavement section located on California State Highway 395 between PM 13 and PM 10, which is about 10 miles south of Alturas, CA. For purposes of analysis and discussion, the starting station is 0.0 (m) at PM 13 and the ending station is 4800.0 (m) at PM 10. The recycling process was conducted between stations 0.0m and 3125.0 m. Laboratory tests included static and dynamic tests on the recycled asphalt concrete and two California aggregate base class 2 materials.

1.1 Objectives

The objectives of the study are 1) to evaluate the performance of the recycling process in the field by analyzing destructive and non-destructive data before and after the recycling process, 2) to characterize the recycled asphalt concrete material under standard and triaxial laboratory tests, and 3) to compare the laboratory performance of the recycled material with typical

California aggregate base class 2 materials. Based on the results, recommendations are given to Caltrans on the use of recycled asphalt concrete materials.

1.2 Field Testing Program

Two series of field tests were conducted along HWY 395 between PM 13 and PM 10. The first series of tests was conducted on the existing pavement on June 1, 2001. The second series of tests was conducted on September 27, 2001 on the rehabilitated road, which had been constructed using the recycling process. The field tests included 1) coring of the pavement, 2) dynamic cone penetrometer (DCP) testing, and 3) falling weight deflectometer (FWD) testing. These tests were conducted along the southbound (SB) and northbound (NB) lanes.

1.2.1 Coring

Coring of the asphalt concrete (AC) layer was conducted to obtain asphalt concrete thickness profiles along the pavement section. Asphalt concrete thicknesses were used during the pavement analysis for estimating pavement layer moduli. Coring was conducted before and after the recycling process by the Caltrans District 2 crew along the southbound and northbound lanes. After the recycling process, coring was conducted on the shoulder, approximately 0.5-m from the shoulder paint mark, in order to keep the cores out of the wheelpath. Figures 1 and 2 show the asphalt concrete and base material thickness profiles along the pavement section before and after the recycling process, respectively.

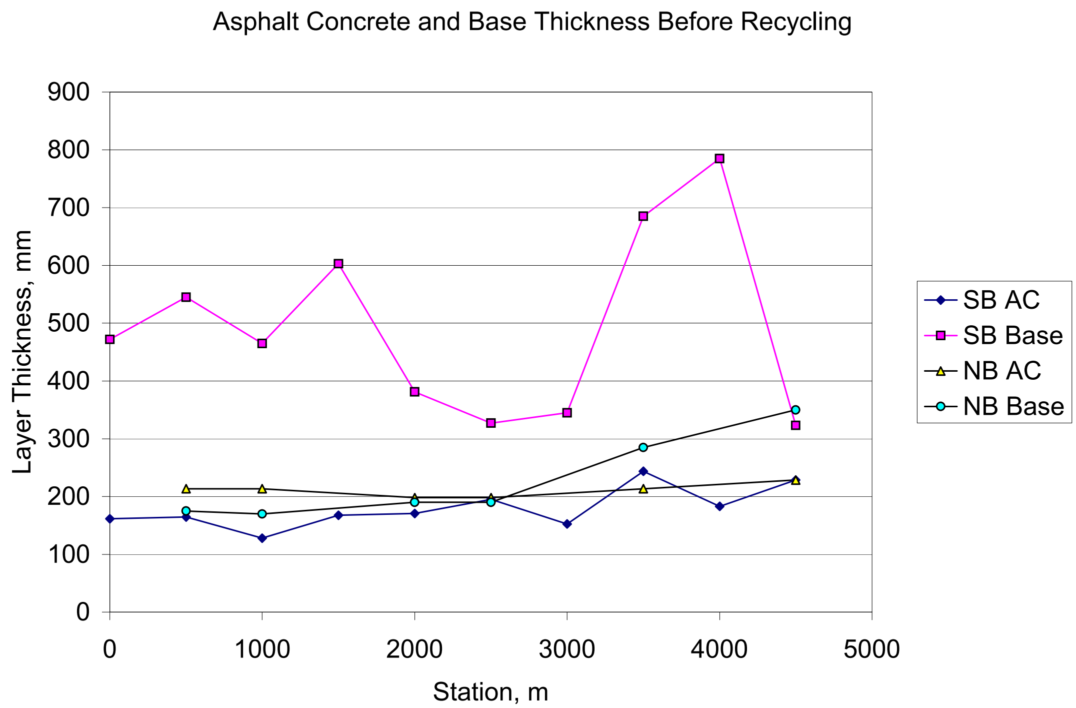

Figure 1. Pavement thickness profile before recycling process.

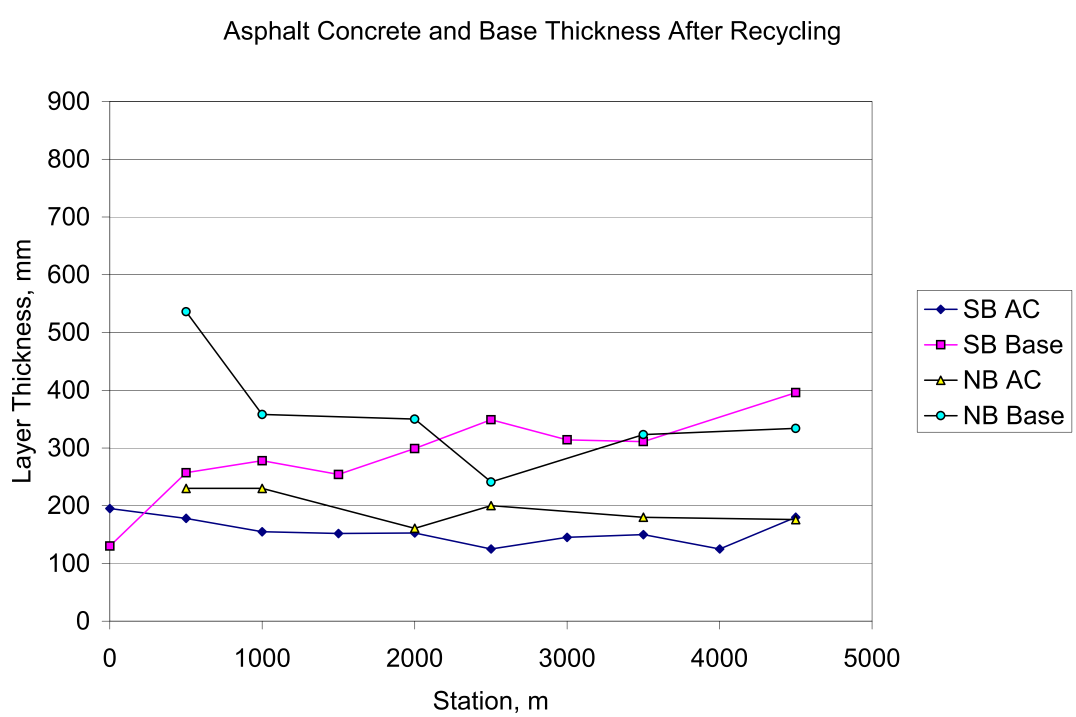

Figure 2. Pavement thickness profile after reycling process.

As can be observed from the data, asphalt concrete layer thicknesses varied both before and after the rehabilitation, ranging from 128 mm to 244 mm. Note that the AC layer thicknesses were determined by direct observation while the base layer thicknesses were determined using the dynamic cone penetrometer (DCP), as noted in Section 1.2.2.

1.2.2 Dynamic Cone Penetrometer (DCP) Testing

After the asphalt concrete cores were removed from the core holes, DCP testing was conducted for field measurements of thickness and strength of unbound layers. The DCP equipment and test procedure is relatively simple (see Figure 3). It consists of a 60° metal cone attached to a rod and an 8-kilogram hammer dropped from a height of 575 mm to drive the cone into the in-situ pavement material, typically through a core hole. A measuring tape is secured to the rod to enable the technician to record the depth of penetration with the increasing blows of the DCP hammer. The associated DCP penetration in the pavement is plotted against the number of blows. Changes in the penetration rate (DN = slope of the penetration-blow count relationship in mm/blow) were used to determine thickness of unbound layers. The penetration rate at a given layer was also used to define its strength. In general, lower penetration rates are indicative of stronger materials. Typical DCP data recorded during this study are presented in Figure 4.

Base thicknesses estimated from DCP are shown in Figures 1 and 2, before and after the recycling process, respectively.

The data indicate significant variability for the base thickness estimated before the recycling process. Base thicknesses along the southbound lane ranged from 310 mm to 600 mm. Base thicknesses along the northbound lane were less variable and ranged from 180 mm to 350 mm.

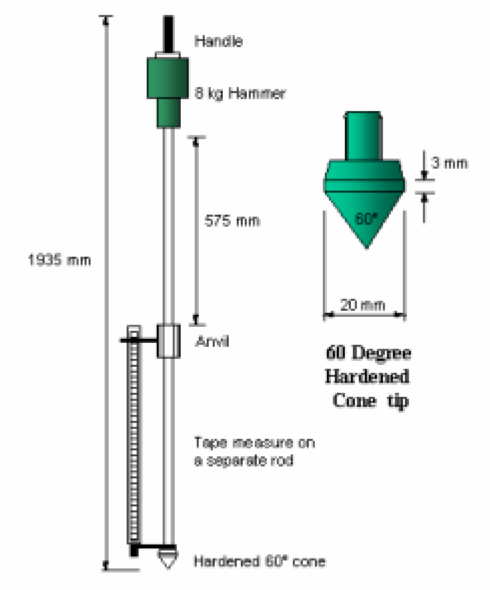

Figure 3. Schematic illustration of DCP device.

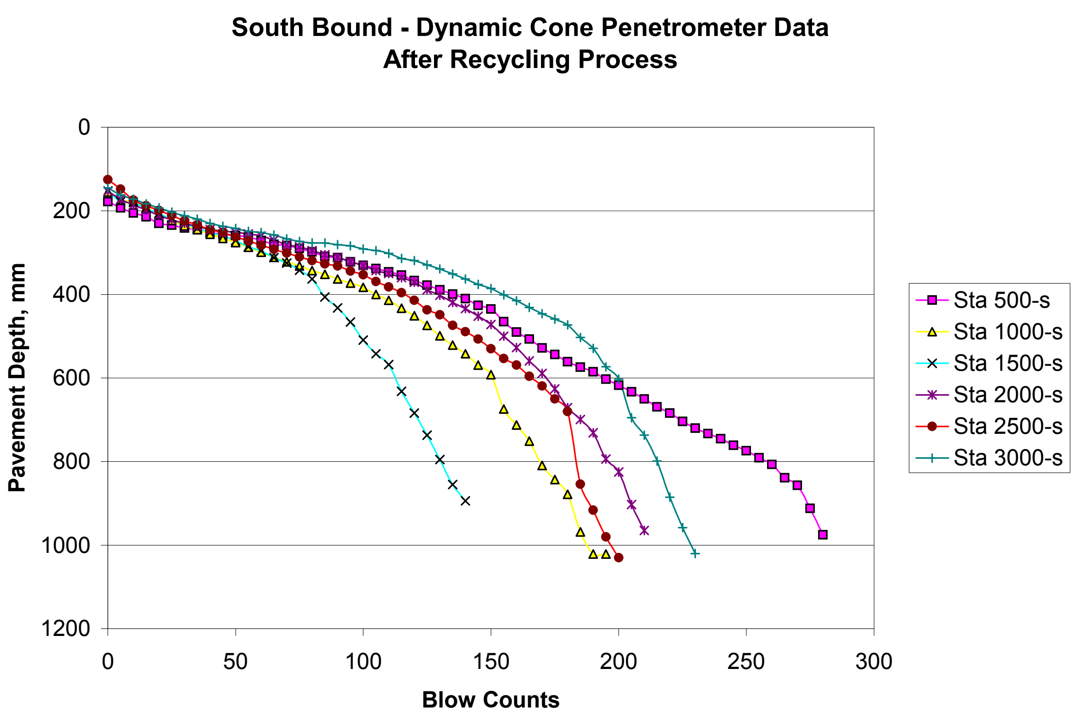

Figure 4. Typical DCP data from I-395.

Base thicknesses measured after the recycling process showed less variability than before the recycling process. Recycled asphalt concrete base thicknesses ranged from 260 mm to 400 mm across both the northbound and southbound lanes.

DCP penetration rates for the base and subgrade along the section before and after the recycling process are presented in Figures 5 and 6, respectively. Table 1 summarizes average penetration rates for the pavement section.

Table 1 Summary of (DN) Penetration Rates

Unbound Layer	**DN (mm/blow count)**			
	Before Recycling Process		**After Recycling Process**	
	South Bound	**North Bound**	**South Bound**	**North Bound**
Base	5.1	6.6	3.2	3.6
Subgrade	13.7	11.9	6.3	9.0

The data indicate that the recycling process has generally produced a stronger base (lower penetration rate) compared to the base existing before the recycling process. A lower penetration rate indicates a material with higher strength to resist the penetration of the DCP cone.

1.2.3 Falling Weight Deflectometer Testing

The Dynatest Model 8082 Heavy Weight Deflectometer (HWD) test system (see Figure 7) was used to generate the required non-destructive load-deflection data for this report. The HWD is similar to the FWD with the main difference being that the loading range of the HWD is significantly greater than the FWD.

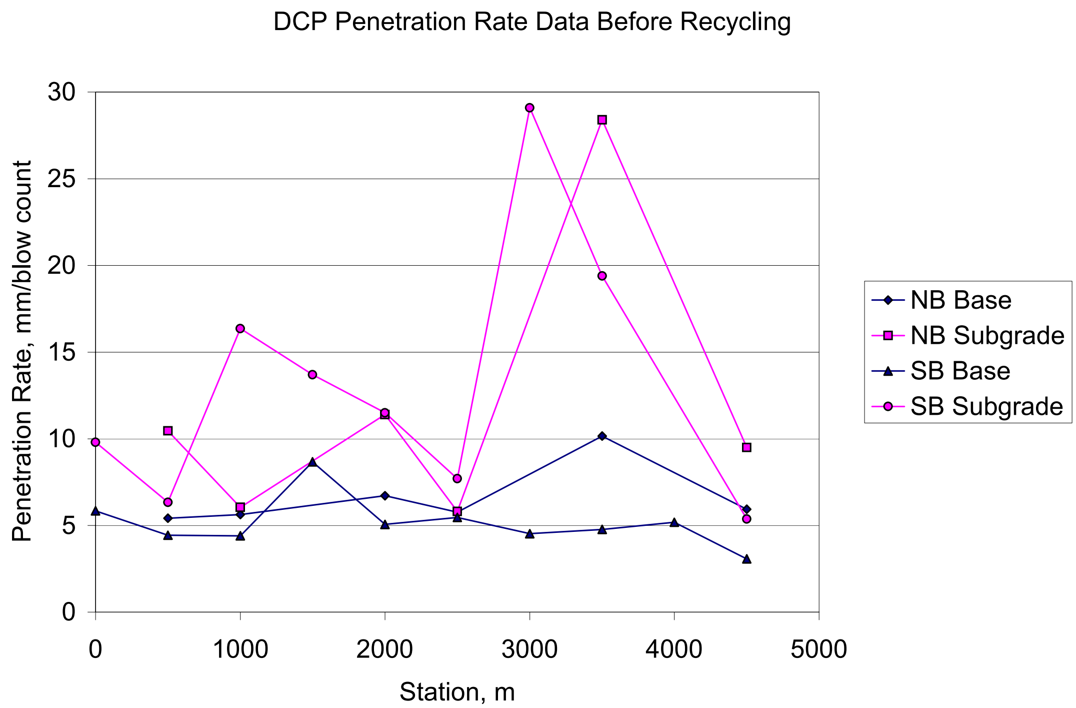

Figure 5. DCP penetration rate before recycling process.

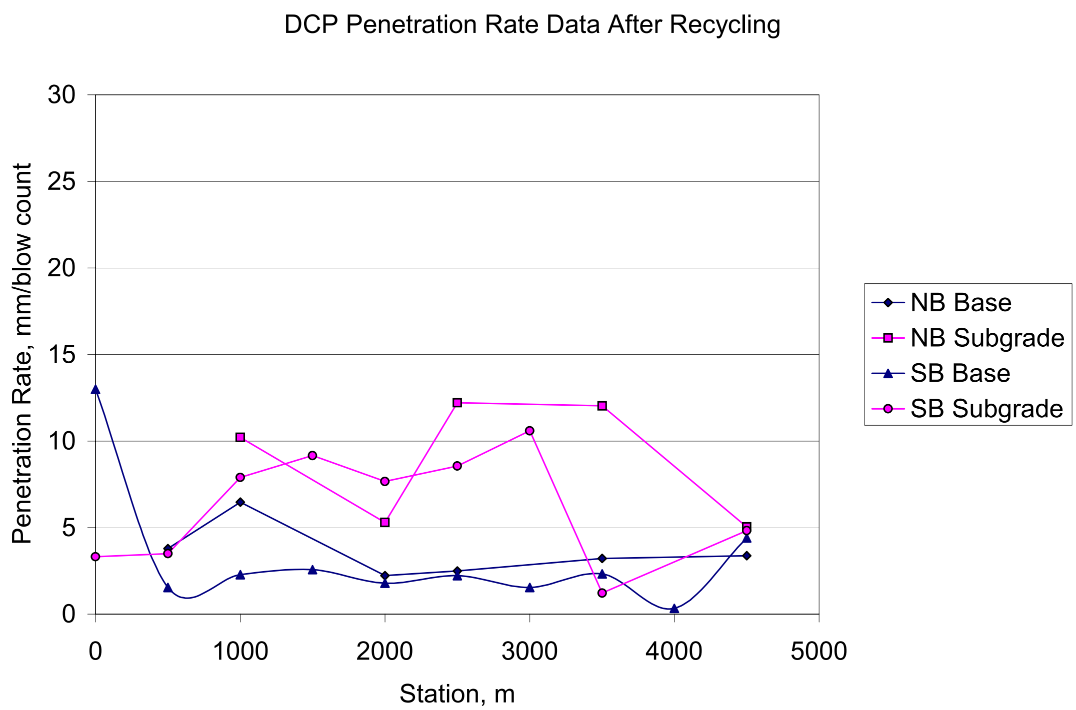

Figure 6. DCP penetration rate after recycling process.

Figure 7. Heavy Weight Deflectometer.

The HWD generates a transient, impulse-type load of 25–30 msec. duration, at any desired (peak) load level between 27 and 245 kN (6,000 and 55,000 lbf.), thereby approximating the effect of a 50–80 km/h (30-50 mph) moving wheel load. For this project, test loads ranged from 27 to 67 kN (6,000 to 15,000 lbf.) and deflections were normalized at 40 kN (9,000 lbs.). The sensor spacing was set at: 0, 200, 300, 800, 1200, 1600 and 2000 mm from the center of the load plate. Tests were performed every 50 meters in each lane in the shoulder-side wheelpath.

The FWD/HWD-generated load-deflection data was used to estimate pavement layer modulus using available mechanistic tools for pavement analysis. The software package used for analysis was the Dynatest ELMOD4.5.

1.2.3.1 FWD Deflections

FWD deflections obtained at D0 (sensor at the load plate) and normalized for an impulse load of 40 kN are presented in Figure 8 for before and after the recycling process. Table 2 summarizes average and standard deviation D0 deflections for the entire project. Included in Table 2 are asphalt concrete temperatures estimated from air temperatures (recorded with the FWD system) using Bell's equation.

Table 2 Summary of FWD D0 Deflections

Testing Stage	Lane							
	South Bound				North Bound			
	Mean µm	Standard Deviation µm	Coefficient of Variance %	AC Temp. ºC	Mean µm	Standard Deviation µm	Coefficient of Variance %	AC Temp. ºC
Before Recycling	697.9	138.0	19.8	30.7	777.3	147.2	18.9	42.7
After Recycling	355.9	56.1	15.8	15.6	451.8	80.6	17.8	20.7

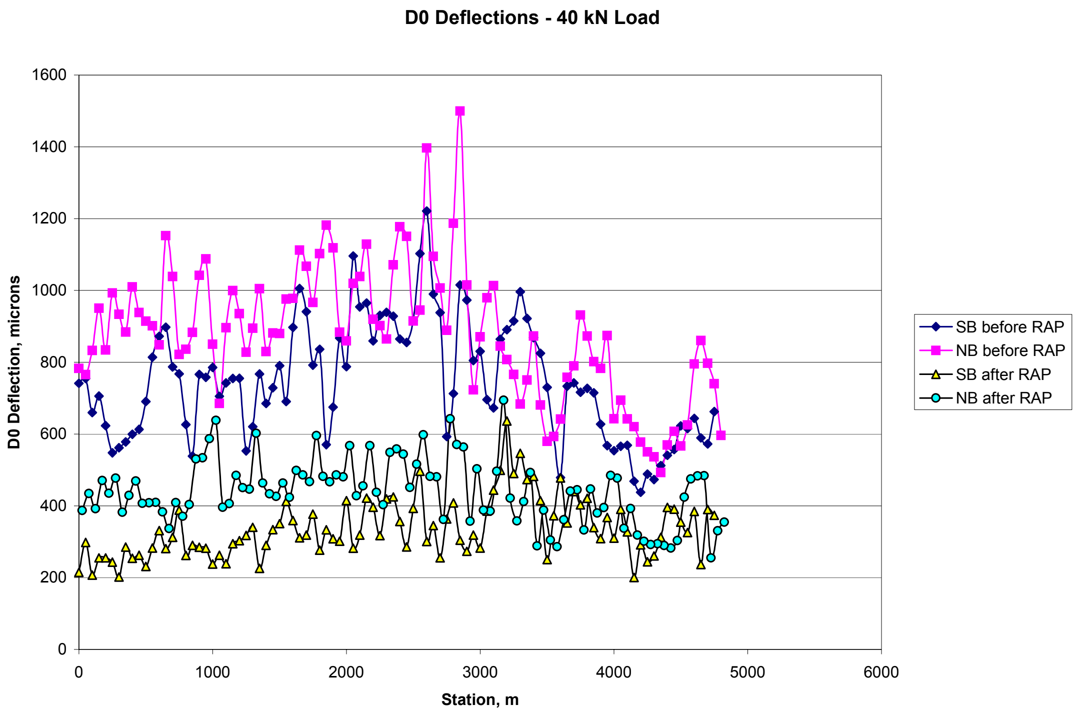

Figure 8. D0 deflections normalized at a 40-kN load.

The data indicate a decrease in D0 deflections after the recycling process. The decrease was by 49 and 42 percent for the southbound and northbound lanes, respectively. However, the reduction in deflections is not only due to the new recycled pavement but also to the low temperatures in the asphalt concrete at the time of testing. Average pavement temperatures at the time of testing before the recycling process (June, 2001) were about 15 to 20ºC higher than when the pavement was tested after the recycling process (September, 2001). Testing in the portion of the project that was not subjected to the recycling process between stations 3200 and 4800 m indicates that this temperature difference would decrease the deflections on the pavement only by about 30 percent. Therefore, the data still indicate a reduction in deflections with the recycled base material of about 12 to 17 percent with the adjustment for temperature difference.

1.2.3.2 BackCalculculated Modulus

The Dynatest program ELMOD 4.5 was used to back-calculate modulus for a three-layer system. The three-layer system is comprised of an asphalt concrete layer (AC), an unbound base layer (AB), and the subgrade (SG). Thicknesses for the asphalt concrete and base layers were obtained from extracted cores and DCP testing, respectively (see Sections 1.2.1 and 1.2.2). Back-calculated moduli were obtained for the materials at the temperatures recorded during FWD testing and then adjusted for an asphalt concrete temperature of 25°C. Figures 9 and 10 present estimated moduli for an asphalt concrete temperature of 25°C before and after the recycling process, respectively. Table 3 summarizes moduli of the layers before and after the recycling process.

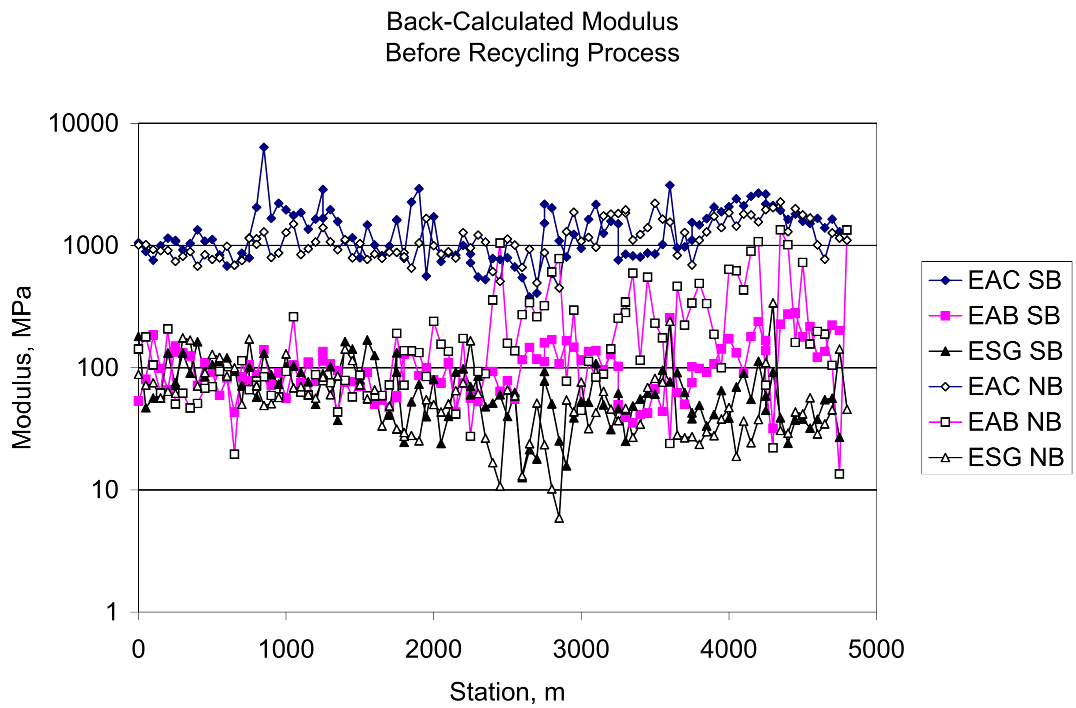

Figure 9. Estimated moduli of pavement layers before recycling process.

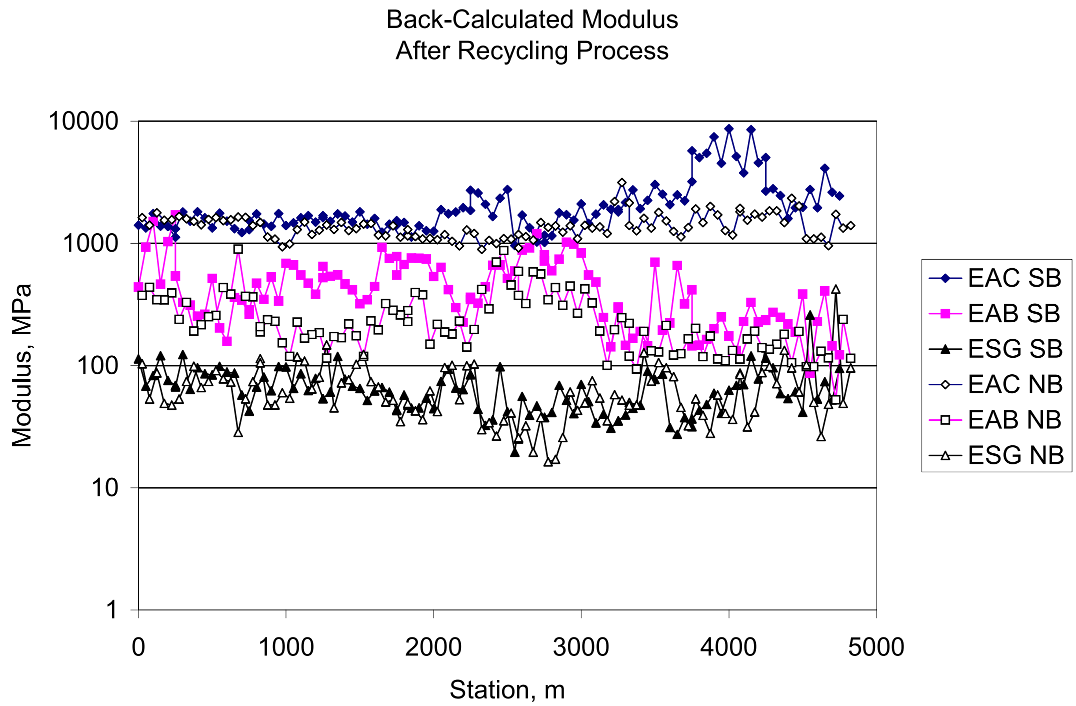

Figure 10. Estimated moduli of pavement layers after recycling process.

Table 3 Summary of Estimated Modulus

Layer	Southbound Lane			Northbound Lane		
	Modulus, MPa	**Standard Deviation, MPa**	**Coefficient of Variance**	**Modulus, MPa**	**Standard Deviation, MPa**	**Coefficient of Variance**
	Before Recycling Process					
AC	1294.4	831.8	64.3	963.4	274.6	28.5
Aggregate Base	95.7	34.1	35.6	146.9	170.1	115.8
Subgrade	78.2	38.5	49.2	65.9	39.2	59.5
	After Recycling Process					
AC	1590.9	358.4	22.5	1302.1	216.5	16.6
Aggregate Base	579.1	290.1	50.1	310.5	160.8	51.8
Subgrade	65.5	23.0	35.1	62.6	29.5	47.1

The data indicate higher base moduli for the recycled asphalt concrete material than with the existing aggregate material before the recycling process. Increased moduli may be due to improved compaction and/or a better base material produced by the recycling process. The benefit of a higher modulus is better performance of a flexible pavement. In general, the high modulus base would reduce elastic deflections that produce fatigue cracking in the asphalt concrete and reduce stresses that cause permanent deformation (rutting) in the underlying layers.

1.3 Laboratory Testing Program

Laboratory testing was conducted to characterize the recycled asphalt concrete material and two Caltrans aggregate base class 2 materials using standard and repeated loading tests. The laboratory results were then compared to establish the relative response and performance of the recycled asphalt concrete material to standard California bases.

1.3.1 Materials

The three materials used for laboratory testing were as follows:

1. RAP = the recycled asphalt concrete material produced by the recycling process on I-395 and sent to the Pavement Research Center (PRC) by Caltrans District 2.
2. D2 AB Cl 2 = an aggregate base class 2 material sent to PRC by Caltrans District 2.
3. D4 AB Cl 2 = an aggregate base class 2 material used in Caltrans District 4 and used in the accelerated pavement test sections at the University of California Berkeley Pavement Research Center.

1.3.1.1 Particle Size Distribution

Mechanical sieving was conducted following ASTM 136 (dry sieving) for the recycled asphalt concrete material, and ASTM 117 (wet sieving) and 136 for the two aggregate base class 2 materials to determine the particle size distributions. ASTM 117 could not be performed on the recycled material because the material bonds during the oven drying process due to the fact that it contains asphalt from the recycled asphalt concrete.

The results of the particle-size distributions are presented in Figure 11 for the recycled asphalt concrete material, the two California aggregate base class 2 materials, and the Caltrans specification for a 19-mm aggregate base class 2 material. The data indicate that the recycled material met the Caltrans specification for a 19-mm Aggregate Base Class 2 material.

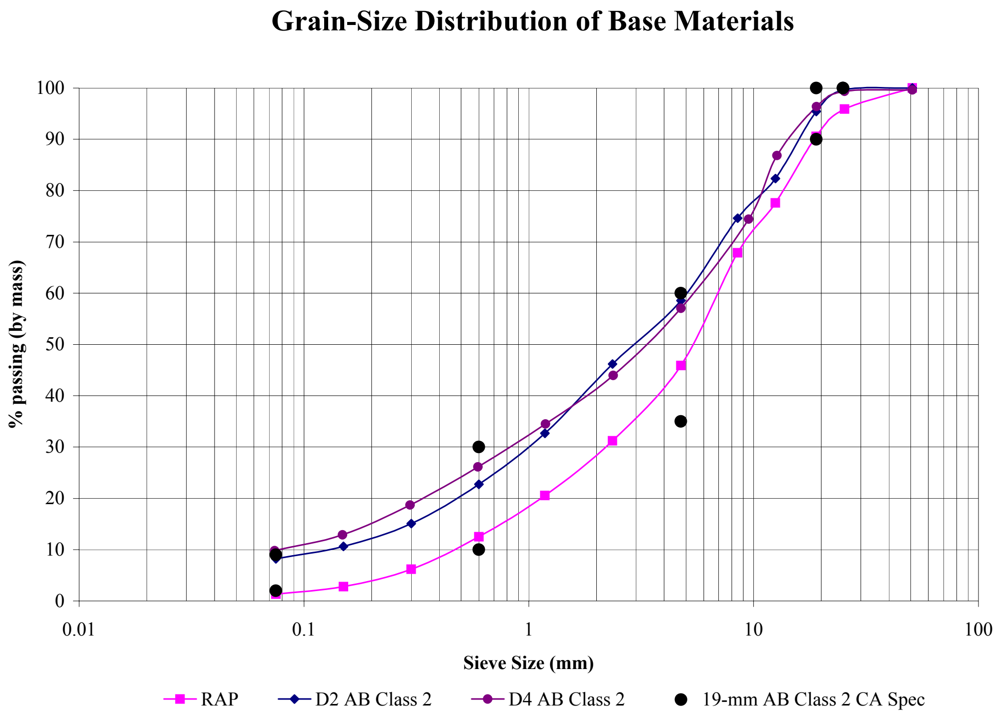

Figure 11. Grain size distribution of base materials.

1.3.1.2 Moisture Density Relationship

Compaction tests were conducted following California Test Method (CTM) 216. The results of the compaction test are presented in Figure 12 for the three base materials. Figure 12 shows that the recycled asphalt concrete material has lower wet density than the aggregate base materials. Table 4 summarizes maximum wet densities and optimum moisture contents based on CTM-216 for the base materials. These compaction values were used to prepared material specimens for triaxial testing.

Table 4 Summary of Compaction Tests

Base Material	**Maximum Wet Density ,kg/m^3**	**Optimum Moisture Content, %**
Recycled Asphalt Concrete	2460	5.5
District 2 AB Class 2	2380	6.5
District 4 AB Class 2	2210	6.5

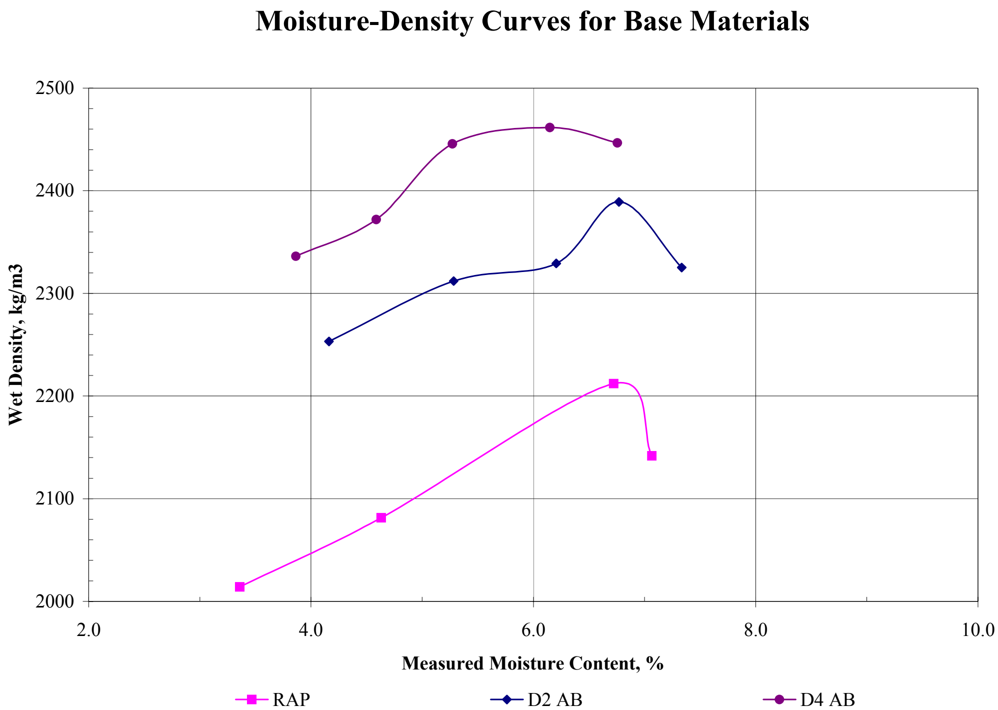

Figure 12. Moisture density curves from CTM 216 performed on three base materials.

1.3.2 Triaxial Tests

Static and repeated loading triaxial tests were conducted on prepared 152-mm diameter by 304-mm high cylindrical specimens. The specimens were tested on a closed-loop servo-hydraulic testing equipment capable of applying various sequences of stress levels. Linear Variable Displacement Transducers (LVDT) and load cells were used to monitor load, and displacement measurements. Measurements were recorded and processed using a high-speed data acquisition system. Figure 13 illustrates the system.

Static stress-strain triaxial tests and repeated loading tests (resilient modulus) were conducted on specimens compacted at optimum moisture content and at 95 and 100 percent maximum wet density according to CTM 216 (see Table 4).

Figure 13. University of California Berkeley Pavement Research Center triaxial testing system.

1.3.2.1 Stress-Deformation-Strength Characteristics

Displacement-controlled stress-strain triaxial tests were conducted on the specimens at confining pressures of 0, 35, 70, and 105 kPa. Typical stress-strain plots at a confining pressure of 105 kPa are presented in Figures 14 and 15 for specimens compacted at 95 and 100 percent maximum wet density according to CTM 216, respectively.

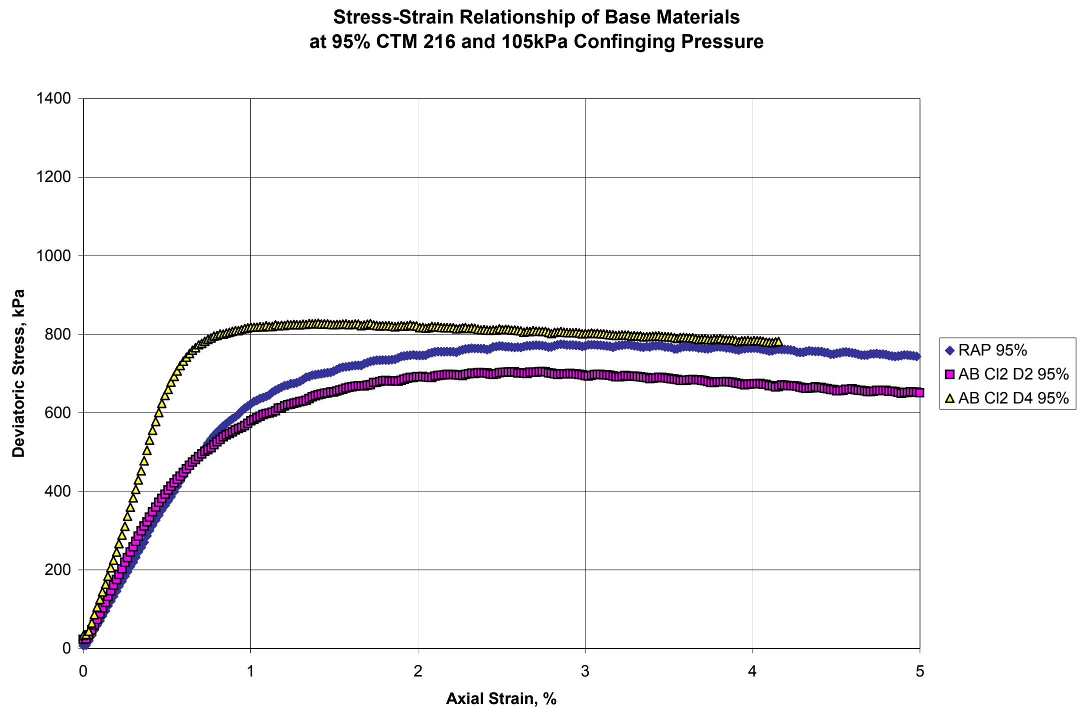

Figure 14. Drained triaxial test CTM 216 performed at 95 percent maximum wet density and 105 kPa confining pressure.

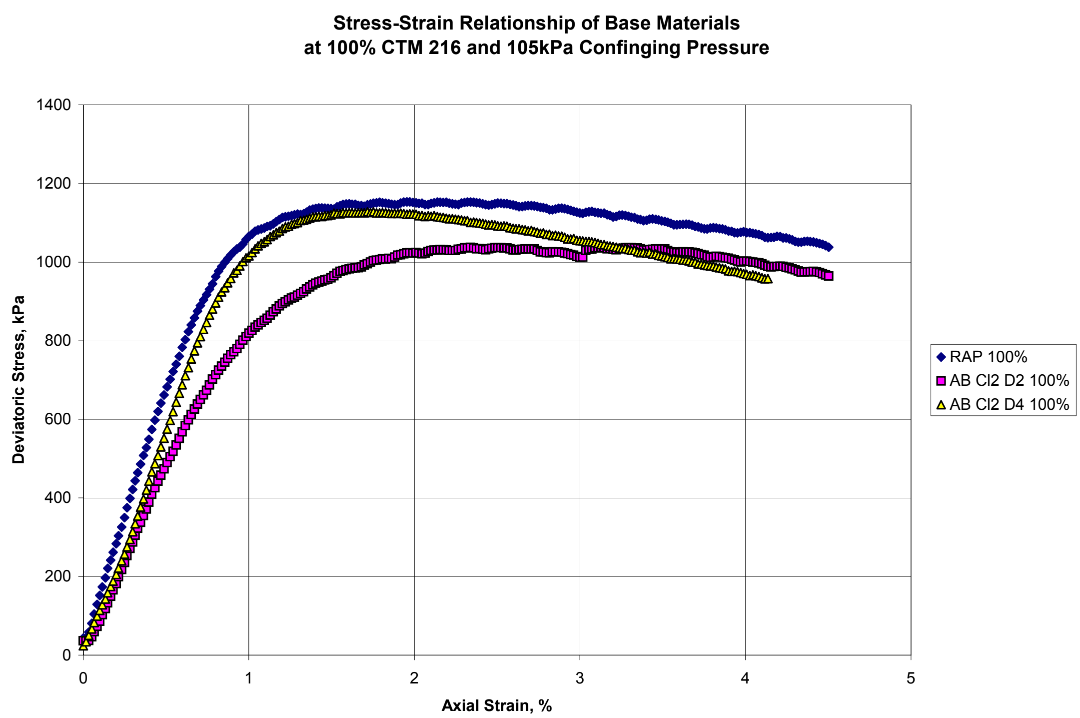

Figure 15. Drained triaxial testCTM 216 performed at 100 percent maximum wet density and 105 kPa confining presssure.

Stress-strain triaxial test results were used to define the shear strength of the materials using Mohr-Coulomb failure criteria. Mohr-Coulomb failure parameters are summarized in Table 5 for the two compaction levels considered.

Table 5 Mohr-Coulomb Failure Parameters

Base Material	**Compaction Level**			
	95% Maximum Wet Density		**100% Maximum Wet Density**	
	Cohesion Intercept, kPa	**Angle of Friction, φ**	**Cohesion Intercept, kPa**	**Angle of Friction, φ**
RAP	0	51.5	0	57.5
D2 AB Cl2	0	51.0	0	56.5
D4 AB Cl2	44.0	53.0	71.3	57.0

The data indicate that the RAP material has similar static shear strength than the two California aggregate base class 2 materials. The results also indicate the increase in shear strength of the materials when the compaction level is increased from 95 to 100 percent maximum wet density (CTM 216).

1.3.2.2 Resilient Modulus Tests

The resilient modulus (M_R) is an elastic modulus based on the recoverable strain under repeated loads. It is defined as

$$M_R = \sigma_d/\varepsilon_r$$

where σ_d is the applied deviatoric stress (σ_1 - σ_3) and ε_r is the recoverable strain.

A number of factors affect the M_R of a soil, some of which are moisture content, density, stress history, aggregate type, gradation, temperature, percent fines, and degree of saturation. The resilient modulus tests were conducted following the Strategic Highway Research Program (SHRP) test protocol P-46.

Figure 16 and 17 present the results of the resilient modulus tests for the materials investigated in terms of Resilient Modulus versus Sum of Principal Stresses ($\sigma_1 + 2\sigma_3$). The data indicate that the recycled asphalt concrete material has higher resilient modulus than the two aggregate base materials. The resilient modulus is higher for the recycled material and the aggregate base material (obtained in District 4) when the compaction level is increased to 100 percent CTM 216 maximum density. The increase in compaction did not seem to have an effect on the resilient modulus of the aggregate base received from District 2.

The base modulus obtained in the laboratory seems to conform to those obtained from the deflection analysis (see Table 3). Laboratory moduli for the RAP material ranged from 300 to 450 MPa for 95 percent compaction and from 450 to 650 MPa for bulk stresses ranging from 200 kPa to 500 kPa. Field moduli for the RAP material ranged from 310 MPa to 580 MPa.

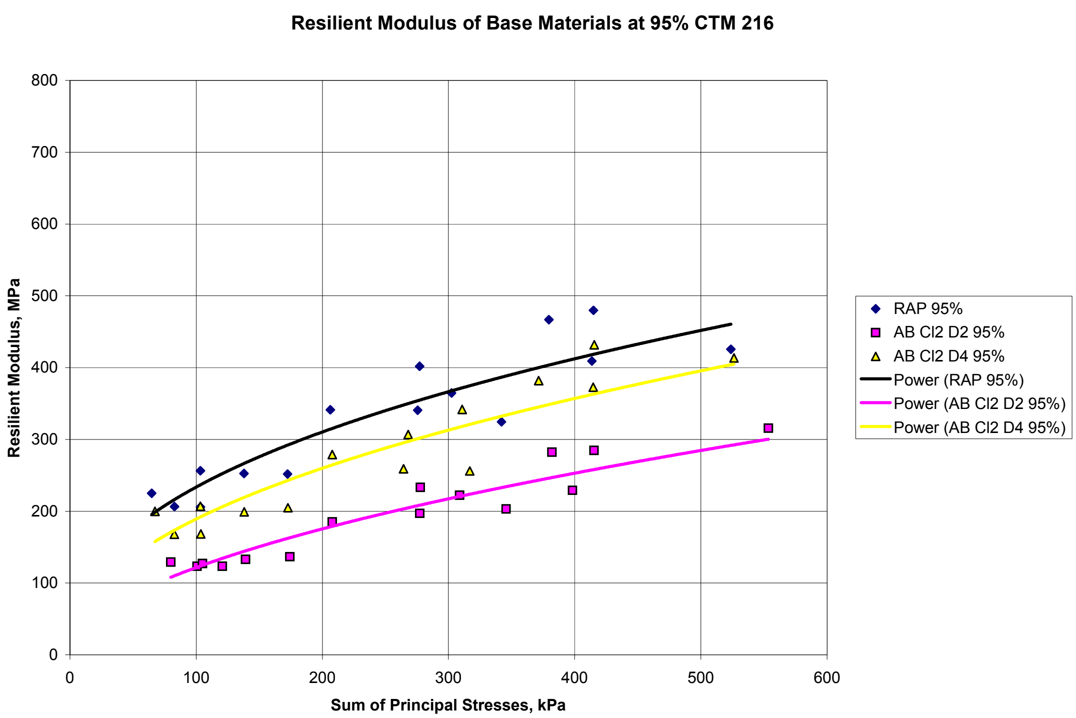

Figure 16. Resilient modulus characteristics of base materials, 95 percent maximum wet density, CTM 216.

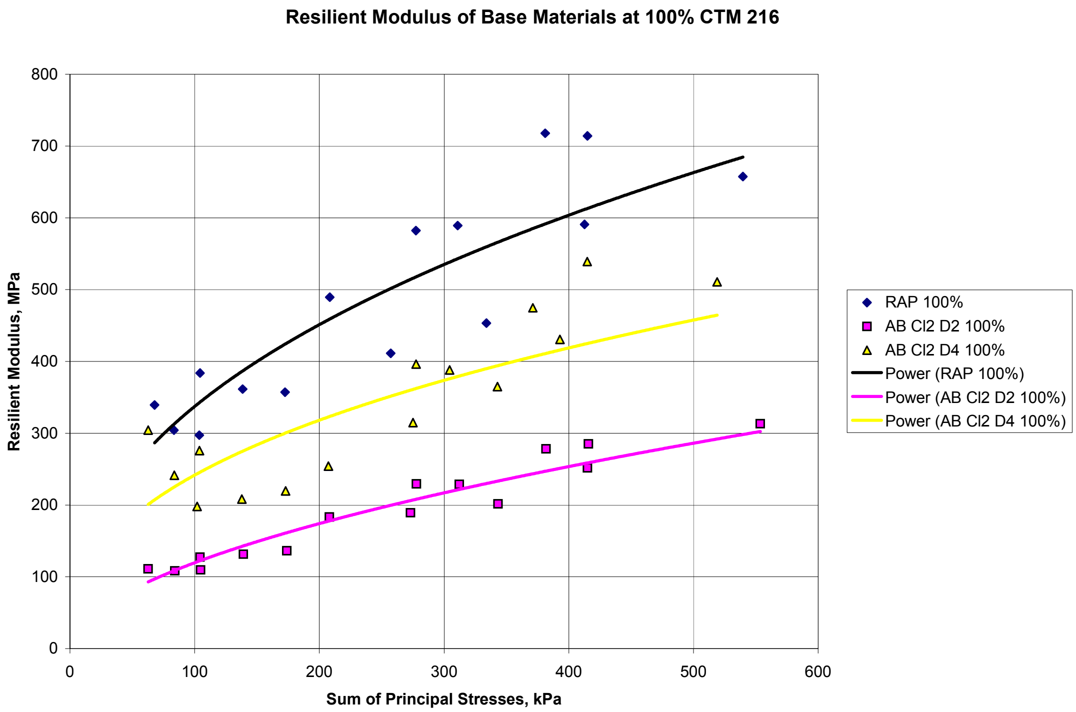

Figure 17. Resilient modulus characteristics of base materials, 100 percent maximum wet density, CTM 216.

1.3.2.3 Permanent Deformation Resistance

Permanent deformation tests are not included but will be conducted at a future date. However, researchers have shown that aggregate materials tested under stress-strain triaxial tests that reached a deviatoric stress of at least 620 kPa at 2 percent strain under a confining pressure of 103.5 kPa had a low potential for rutting. Lower permanent strains are obtained. Conversely, materials that did not reach a deviatoric stress of at least 620 kPa by 2 percent strain underwent a rapid accumulation of permanent deformation.

The stress-strain data shown in Figures 14 and 15 seem to indicate that the materials will not have a potential for rutting. Deviatoric stresses for the base materials reached values of between 650 kPa and 800 kPa at 2 percent strain for a compaction level of 95 percent CTM 216 maximum density. The data also indicate the reduction in the potential for rutting when the compaction level is increased from 95 percent to 100 percent CTM 216 maximum density. The materials reached deviatoric stresses from 1000 kPa to 1200 kPa at 2 percent strain for a compaction level of 100 percent CTM 216 maximum density.

1.4 Discussion of Results

A recycled asphalt concrete material was tested and characterized using field and laboratory testing and compared with two California aggregate base class 2 materials.

The field tests (DCP and FWD testing) indicate that the new recycled asphalt concrete base is stronger/stiffer than the base existing before the recycling process. A stronger/stiffer base reduces the elastic deflections in the pavement that cause fatigue cracking in the asphalt concrete and reduces the potential for rutting in the unbound layers.

The laboratory data indicate that the recycled material presents higher resilient modulus and slightly higher shear resistance than the two California aggregate class 2 base materials. The laboratory program also indicates that the response and performance of the recycled material can be significantly improved by increasing the compaction level in the field. Higher modulus and higher shear resistance are obtained at increased compaction levels.

1.5 Conclusions

An evaluation of the recycled asphalt concrete material was conducted based on field testing and laboratory testing. The following conclusions can be drawn from the data presented:

1. Based on the field testing, the results indicate that the recycling process produced a better pavement than the pavement that was present before the recycling process. Lower DCP penetration rates and higher moduli were observed in the new rehabilitated pavement.

2. Based on the laboratory testing, the results indicate that the recycled material received from Caltrans District 2 performs better than the two California aggregate base class 2 materials. Higher shear strength and resilient modulus were obtained for the recycled material.
3. Laboratory results indicate the benefits of increased compaction levels in the response and performance of unbound layers. Higher strength and resilient modulus are obtained at increased compaction levels, which would reduce the potential for fatigue cracking in the asphalt concrete layers and rutting in unbound materials.
4. The field and laboratory tests used in the evaluation of the recycled material properly indicated the response and performance of this new material.