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Lottman Repeatability:

Variablility in the Indirect Tensile Stripping Test
Colorado Procedure L-5109

Within-Laboratory and
Between-Laboratory Variations

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16. Abstract

Four investigations were conducted to determine the amount of variability in the indirect tensile strength ratio as determined by Colorado Procedure L-5109 (CPL-5109). Within-laboratory variation was investigated by having one operator perform the test ten times on one mix using the same sources of aggregate, asphalt cement, and anti-stripping additive, over a five week period. Next, an investigation was made of the between-laboratory variation in test results obtained by fifteen laboratories testing the same material. Two more investigations were conducted to determine the between-laboratory variations for seven CDOT laboratories.

The within-laboratory standard deviation (1s) of the tensile strength ratio was 0.040 for the ten tests (using three sample pairs as called for in CPL-5109). The first between-laboratory investigation found a standard deviation of the tensile strength ratio of 0.161 while two follow up investigations found standard deviations of 0.126 and 0.113 for the seven CDOT laboratories. All of the between-laboratory investigations found standard deviations in the test results which were higher than the 0.080 reported in ASTM D 4867.

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Table of Contents

List of Tables

List of Figures

1.0 INTRODUCTION

A modified Lottman indirect tensile stripping test has been used by the Colorado Department of Transportation (CDOT) for the last ten years as the standard test for the moisture susceptibility of asphalt mixes. The test has been defined by AASHTO T 283, ASTM D 4867 and Colorado Procedure L-5109 (CPL-5109) (*1*). The use of CPL-5109 in specifications is relatively new to Colorado and the repeatability of the results using Colorado aggregates has not been extensively examined. In addition, contractors in Colorado have questioned the repeatability and accuracy of the test.

This report investigates the repeatability of the Colorado Procedure L-5109 for within-laboratory testing and between-laboratory testing.

2.0 METHOD

Four investigations of the indirect tensile stripping test as specified by CPL-5109 were conducted. One investigation examined the within-laboratory variability of the results obtained by a single operator. Three between-laboratory variability investigations were also conducted. The first between-laboratory investigation examined the variability in the results reported by fifteen laboratories, both CDOT and private. The second and third between-laboratory investigations concentrated on CDOT laboratory results only.

2.1 Definitions

Some terms used in this study have been defined in ASTM C 670 and ASTM C 802.

Variations in test results occur within a laboratory. Within-laboratory precision provides an estimate of the difference that may be expected between duplicate measurements made on the same material in the same laboratory by the same operator using the same apparatus over a period of time. Within-laboratory variation is also referred to as single-operator, replicate, or repeatability variation.

Variations in test results can also occur between various laboratories. Between-laboratory precision provides an estimate of the differences that can be expected between measurements made on the same material in two different laboratories. Between-laboratory variation is also referred to as multilaboratory, interlaboratory or reproducibility variation.

The one-sigma limit (1s) is the standard deviation of a population of measurements. It is an indication of the variability of a large group of individual test results obtained under similar conditions.

The difference two-sigma limit (d2s) is the difference between two individual test results that would be equaled or exceeded in only 1 case in 20 in the normal and correct operation of the method. The limit is calculated by multiplying the appropriate standard deviation (1s) by $1.96\sqrt{2}$. This equation is given in ASTM C 670.

Materials which pass the mix design process and then have failing field production test results are of concern. Since CDOT specifies a TSR of 0.80 for material during a mix design and a TSR of 0.70 for field produced material, only a negative difference of 0.10 between the first and second TSR test results is of interest.

The d2s precision statement given in ASTM C 670 calculates a difference between two test results which would be expected with a probability of 0.05. Repeated differences between two test results will be normally distributed. The differences in test results are evenly divided between each end of the normal distribution curve. The second test result will be more than d2s above the first test result with a probability of 0.025 and more than d2s below the first test result with a probability of 0.025. When the case where the second test result is higher than the first test result is excluded, the appropriate one-sided d2s limit is found by finding the limit which accounts for an area of 0.05 on only one end of the normal distribution curve. This limit is the negative difference that would be equaled or exceeded in 1 case in 20. It is calculated by multiplying the appropriate standard deviation (1s) by $1.65\sqrt{2}$.

2.2 Test Procedure

2.2.1 Colorado Procedure CPL-5109

CPL-5109, a modified Lottman procedure, is an indirect tensile stripping test which measures the effects of saturation, freezing, and accelerated water conditioning of compacted bituminous mixtures.

The test is also specified in AASHTO T 283 and ASTM D 4867. The three procedures are summarized in Table 1.

The indirect tensile strength test specification given in the Colorado Laboratory Manual of Test Procedures (1988) CPL-5109 (*1*) was used to perform all of the tests.

Under CPL-5109, six samples are compacted for each test. The samples are then sorted into two sets of three samples each so that the average air void contents of the two sets is approximately equal.

TABLE 1 Comparison Between CPL-5109, AASHTO T 283, and ASTM D 4867

Procedure	CPL-5109	AASHTO T 283	ASTM D 4867
Short-Term Aging	Loose Mix: 16-24 Hrs. @ 140°F Compacted Samples: 72-96 Hrs. @ Room Temp.	Loose Mix: 16 Hrs. @ 140°F Compacted Samples: 72-96 Hrs. @ Room Temp.	None
Method of Compaction	Texas Gyratory Compactor	Marshall Hammer Cal. Kneading Compactor Corps of Eng. Gyratory Comp.	Marshall Hammer Cal. Kneading Compactor Corps of Eng. Gyratory Comp.
Air Voids	6% to 8%	6% to 8%	6% to 8%
Sample Grouping	Equal Average Air Voids	Equal Average Air Voids	Equal Average Air Voids
Saturation	55% to 80%	55% to 80%	55% to 80%
Freeze	Min. 16 Hours @ 0°F	Optional: Min. 16 Hours @ 0°F	Optional: Min. 15 Hours @ 0°F
Hot Water Soak	24 Hours @ 140°F	24 Hours @ 140°F	24 Hours @ 140°F
Dry Subset Storage	77°F Cabinet	Room Temp.	Room Temp.
Pre Loading Treatment	77°F Cabinet	Wrapped in Plastic 2 Hours in 77°F Water Bath	Unwrapped 20 Minutes in 77°F Water Bath
Loading Rate	0.2" / Min.	2.0" / Min.	2.0" / Min.

0°F = -18°C
77°F = 25°C
140°F = 60°C

0.2" per minute = 5.1 mm per minute
2.0" per minute = 50.8 mm per minute

The "dry" three-sample set is stored in a temperature controlled 77°F (25°C) dry cabinet until testing. The "conditioned" three-sample set has vacuum applied to immersed samples until between 55% and 80% of the air voids are filled with water. The conditioned samples are then wrapped in plastic film to retain the water, frozen for a minimum of 16 hours at 0°F (-17.7°C), unwrapped, and immersed in a 140°F (60.0°C) water bath for 24 hours. The conditioned samples are then immersed in a 77°F (25.0°C) water bath for at least 2 hours immediately before testing while the dry samples are removed from the 77°F (25.0°C) cabinet and tested immediately.

During the mix design process only, all samples are also placed in a 140°F (60.0°C) oven for 16 to 24 hours after they have been mixed and all mix design samples are also stored at room temperature for 72 to 96 hours before vacuum saturation.

The tensile strength ratio (TSR) is calculated by dividing the maximum load applied to the conditioned sample by the maximum load applied to the dry sample. The average TSR value of the three replicates in one test is reported.

2.2.2 CPL-5109 vs. AASHTO T 283 and ASTM D 4867

CPL-5109 is similar to the AASHTO T 283 test and ASTM D 4867 with the exceptions of the loading head speed, short-term aging, the method used to bring samples to 77°F (25°C) before testing, and the method of compaction.

CPL-5109 uses a loading head speed of 0.2 inches per minute (5.1 mm per minute) while both AASHTO T 283 and ASTM D 4867 specify a loading head speed of 2.0 inches per minute (50.8 mm per minute). The difference in the loading head speed results in significantly lower tensile strengths for samples but the tensile strength ratio remains comparable to those from the AASHTO and ASTM procedures, as shown by Maupin (*2*).

For samples mixed in the laboratory, both the Colorado Procedure CPL-5109 and AASHTO T 283 specify short-term aging of 16 hours at 140°F (60°C) before compaction and another short-term aging period of 72 to 96 hours at room temperature after samples are compacted. ASTM D 4867 does not specify the short-term aging of samples.

CPL-5109 specifies that the dry samples be taken directly from a 77°F (25°C) incubator and tested. Both AASHTO and ASTM put the dry samples into the same water bath as the conditioned samples to allow the dry samples to come to the same temperature as the conditioned samples. AASHTO specifies that the dry samples are wrapped in plastic and immersed for 2 hours while ASTM specifies that the dry samples are immersed for 20 minutes without wrapping.

Both AASHTO and ASTM have optional freeze-thaw cycles while the freeze-thaw cycle is mandatory in CPL-5109.

CPL-5109 specifies that a Texas gyratory compactor be used to compact samples to an air void content of 7±1 percent. AASHTO and ASTM allow many different compaction machines but do not include the Texas gyratory compactor in their lists of allowable compactors. However, the end result of CPL-5109 and both the AASHTO and ASTM procedures are the same since they all specify sample air void contents of 7±1 percent.

2.3 Causes of Testing Variation

2.3.1 Testing Head Speed

The rate of movement of the testing machine head during the application of the diametrical load to the sample has a large effect on the maximum load which the sample will support. As the rate of movement increases, the maximum load that the sample will support increases. This makes it critical that the rate of movement of the testing machine head is well controlled.

2.3.2 Sample Temperature

The temperature of the sample at the time of testing has an effect on the maximum load that the sample can support. Since the strength of samples which are stored in a water bath is being compared to the strength of samples which are stored in a dry, temperature controlled cabinet, it is essential that the temperatures of the water bath and the temperature controlled cabinet are monitored to ensure that they are the same.

2.3.3 Sample Air Void Contents

Dukatz (3) has shown a correlation between the air void contents of samples and their tensile strengths. The tensile strength vs. air voids data for the conditioned samples are shown in Figure 1. Using the within-laboratory data for the tensile strength vs. air voids of conditioned samples, the hypothesis that the slope of the regression line is equal to zero was tested. The ratio of the regression mean square divided by the residual mean square gives an indication of whether the variables are related. In this case, the ratio F is 7.762 with 1 and 28 degrees of freedom. This indicates that there is less than 1% chance that the variables are not correlated. The coefficient of determination, $r^2 = 0.22$ which indicates that approximately 22% of the variation in conditioned sample tensile strength can be explained by the variation in sample air voids.

By choosing sets of samples with similar average air void contents, a correction is made for any effect that air voids may have on the strength of individual samples.

2.3.4 Aging of Asphalt Samples

It is possible that the amount of time that a sample has aged

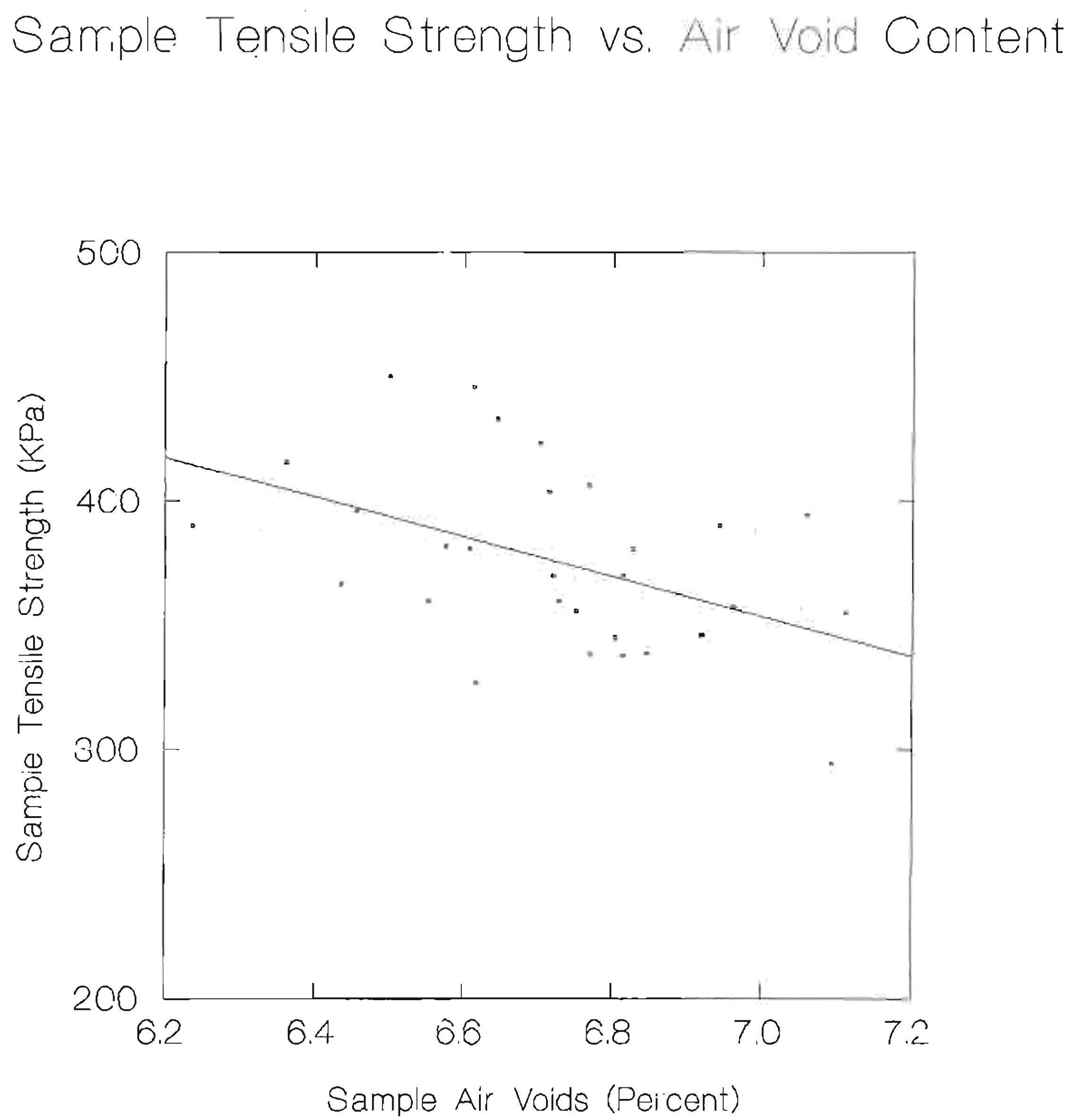

FIGURE 1 The Effect of Sample Air Voids on the Sample Strength.

before it is tested can affect the tensile strengths of the material. Stuart (4) noticed age hardening resulting in higher tensile strengths of samples stored for a period of about 1 year. A change in tensile strength may or may not produce a change in TSR since both the dry and the conditioned tensile strengths will be affected.

3.0 WITHIN-LABORATORY TEST VARIABILITY - EXPERIMENT

3.1 Test Procedure and Equipment

To determine the within-laboratory variability of TSR test results, a single CDOT Grading C mix was used. Two TSR tests involving batching, mixing and testing of samples were performed each week for five weeks. The same source of aggregate, asphalt cement, and additive were used for all of the mixes.

The testing machine used to test the samples for the within-laboratory investigation was a Tinius Olsen Super "L" Hydraulic Testing Machine with a Model 290 digital indicating system which displays the measured speed of the testing head and allows the operator to keep the head speed within a range of 0.19" per minute (4.8 mm per minute) to 0.21" per minute (5.3 mm per minute).

3.2 Materials and Mixes

A mix meeting the Colorado Grading C specification was used (Table 2). The nominal maximum size of the aggregate was ¾" (19.1 mm) and the mix was dense graded. The gradation chart is shown in Figure 2. The aggregate contained 11% recycled asphalt pavement (RAP) by weight of aggregate. The asphalt cement was Frontier AC-10 and an anti-stripping additive, Pave Bond Special, was used. The mix contained 4.8% asphalt cement by weight of mix and 0.5% anti-stripping additive by weight of the asphalt cement.

TABLE 2 Mix Properties and Materials Used for Within-Laboratory Testing

Grading of mix	CDOT Grading C
Source of aggregate	11% recycled asphalt pavement by weight of aggregate 89% McIntyre - Ralston material
Source of asphalt cement	Frontier AC-10
Asphalt cement content	4.8% by weight of mix
Anti-stripping additive	Pave Bond Special - 0.5% by weight of asphalt cement

3.3 Results

This investigation of the variability of the CPL-5109 test found a within-laboratory standard deviation (1s) of 0.040 for TSR. This investigation found a within-laboratory standard deviation (1s) for the tensile strength of 5.3 psi for conditioned samples and 5.0 psi for dry samples.

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GRADATION CHART

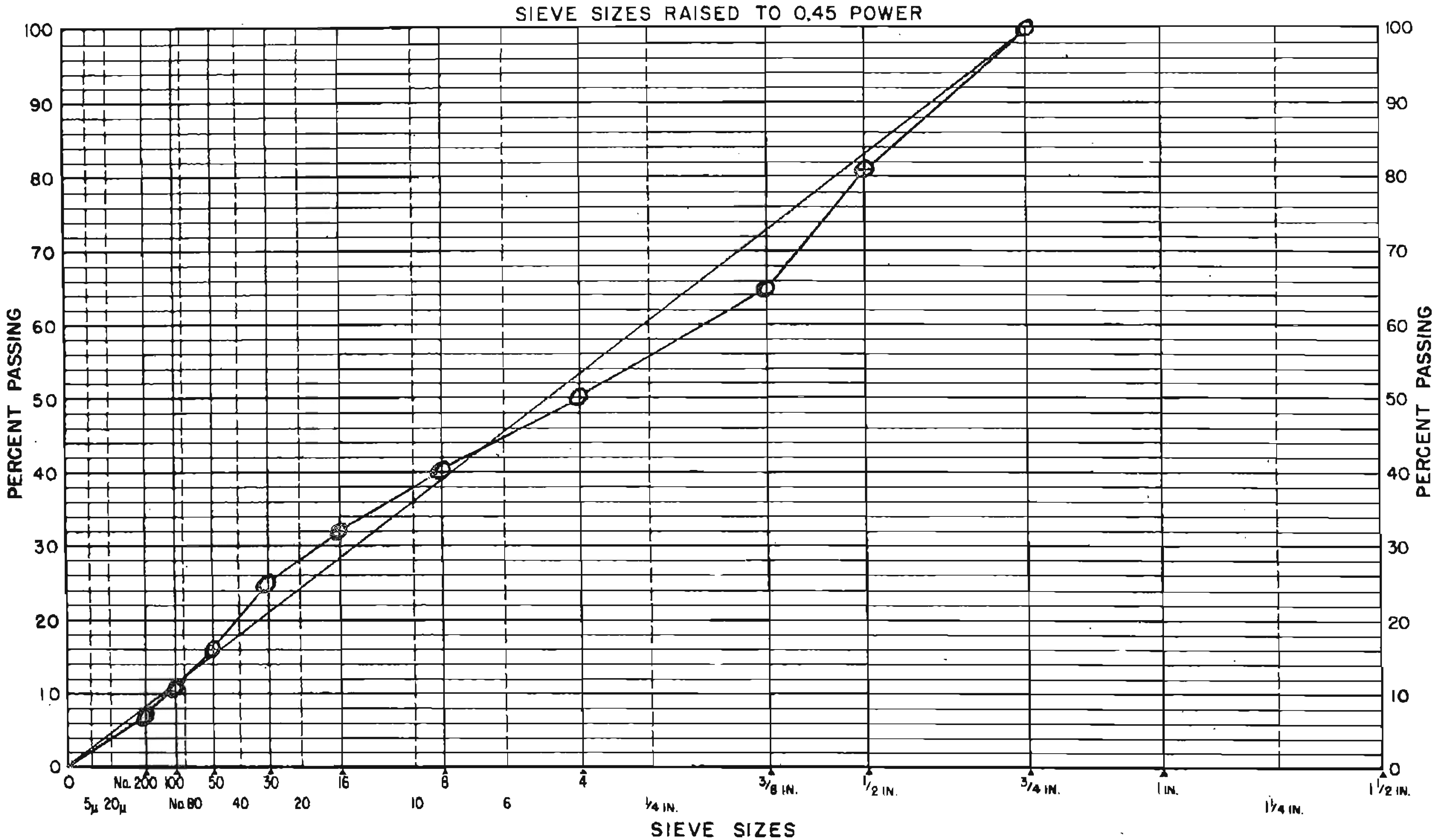

FIGURE 2 Mix Gradation Used for the Within-Laboratory TSR Study.

The within-laboratory variability which this study measured compares closely to figures given by the Virginia DOT (*5*), which found a standard deviation for TSR of 0.035 for a procedure lacking the freeze-thaw cycle specified in CPL-5109. Lottman (*6*) found a within-laboratory standard deviation of 0.100 for TSR which is quite a bit higher than the variation found in this study. The test results and the standard deviations of three variables are shown in Table 3. A comparison of within-laboratory variabilities of TSR and tensile strength as determined by various studies is summarized in Table 4.

TABLE 3 Variation in the Within-Laboratory Tensile Strength Ratio Test

Test Number	Tensile Strength, psi (kPa)		TSR
	Conditioned	Dry	
1	54.0 (372)	75.6 (521)	0.72
2	62.0 (428)	77.7 (536)	0.80
3	52.7 (363)	74.7 (515)	0.71
4	58.3 (402)	77.0 (531)	0.76
5	51.1 (352)	74.0 (510)	0.69
6	56.1 (387)	73.9 (510)	0.76
7	47.1 (325)	67.0 (462)	0.70
8	49.7 (343)	70.7 (487)	0.71
9	56.8 (392)	71.6 (494)	0.79
10	53.4 (368)	69.4 (478)	0.77
Mean	54.1 (373)	73.2 (505)	0.74
Standard Dev.	4.4 (30)	3.4 (23)	0.04

TABLE 4 Comparison of Reported Within-Laboratory TSR Variations

Source	Date Reported	Variable Measured	Standard Deviation (1s)
Colorado	1993	TSR	0.040
Virginia	1991	TSR	0.035
Lottman	1982	TSR	0.10
Colorado	1993	Tensile Strength	5.3 psi (37 kPa)
ASTM D 4867	1988	Tensile Strength	8.0 psi (55 kPa)

The within-laboratory standard deviation (1s) of the tensile strength of 5.3 psi (37 kPa) for conditioned samples and 5.0 psi (35 kPa) for dry samples measured by this investigation compares favorably to the figure of 8.0 psi (55 kPa) given in ASTM D 4867 for either dry or conditioned samples.

3.4 Analysis of Results

3.4.1 Variability in the TSR Test Results

The state of Colorado has two different specifications for the TSR of a mix, one which is applied to the mix design and a lower one applied to the field produced material. A mix design sample must have a TSR of at least 0.80 while a field production sample must have a TSR of at least 0.70, giving a margin for testing variability of 0.10.

The standard deviation (1s) of TSR test results of 0.040 are encouraging. The maximum decrease in TSR test results which would be expected one time in twenty is approximately 0.094. The calculation is shown in section 2.1.

If the same material which met the TSR specification of 0.80 during the mix design process is submitted as a field sample, the chances that it will fail the field sample TSR test specification of 0.70 due to within-laboratory variation are low (less than 5%). More probable causes of field sample TSR test failures include non-uniformity in the mix production process and non-uniformity in the addition of lime or anti-stripping additive to the mix.

3.4.2 Effect of a Reduction in the Number of Samples per Test

Three dry samples and three conditioned samples are currently tested for one TSR test. If two-sample sets were to be tested, the accuracy of the test results would be reduced in two ways.

First, the standard deviation of the mean TSR of a two-sample set is larger than the standard deviation of the mean TSR of a three-sample set. The standard deviation of the mean of a three-sample set is 0.040 for a single operator. The standard deviation of the mean of a two-sample set is estimated by:

$$0.040\times\frac{\sqrt{3}}{\sqrt{2}}=0.049$$

This indicates that the expected standard deviation of the a two-sample set would increase to 0.049, about 23% greater then the variability expected from the mean of a three-sample set.

The second reduction in accuracy is more difficult to evaluate numerically. If the dry or wet strength for one sample in a three-sample set is different from the strength of the other two samples, it is possible to examine the data and remove the outlier. With a two-sample set, a third sample would be required to determine which results are accurate. Since the test requires about one week to complete, the reporting of results would be delayed.

4.0 BETWEEN-LABORATORY TEST VARIABILITY - EXPERIMENT

The six CDOT Region materials laboratories had been recently set up with new equipment and personnel when this study of the variation in the results from CPL-5109 was conducted.

For the first investigation, fifteen different laboratories in Colorado tested the same material from field samples.

After the first between-laboratory investigation was completed, efforts were made to improve the repeatability of the test results reported by the CDOT Region labs. In order to evaluate the success of these measures, second and third between-laboratory investigations were conducted by the six CDOT Region laboratories and the CDOT Central laboratory.

4.1 Test Procedure and Equipment

The laboratories involved in the between-laboratory investigation were asked to run the indirect tensile strength test as specified in CPL-5109, which is described in the "method" section.

The testing machine used to load the samples in the CDOT Central laboratory was the same as the testing machine used for the within-laboratory investigation. The testing machines used by the CDOT Region laboratories were Versa-Tester hydraulic testing machines produced by Soiltest. These machines are not fitted with devices to measure the rate of travel of the loading head. When dial gauges were fitted to the testing machines, it was discovered that the loading head speed varied greatly as the load applied to the samples varied during a test.

The loading head speeds of the testing machines used by private Colorado laboratories were not measured or evaluated during this investigation.

4.2 Materials, Mixes, and Equipment

For the first between-laboratory investigation, a Colorado Grading C specification mix was used (Table 5). The nominal maximum size of the aggregate was ½" (12.7 mm) and the mix was dense graded. The gradation chart is shown in Figure 3. The mix

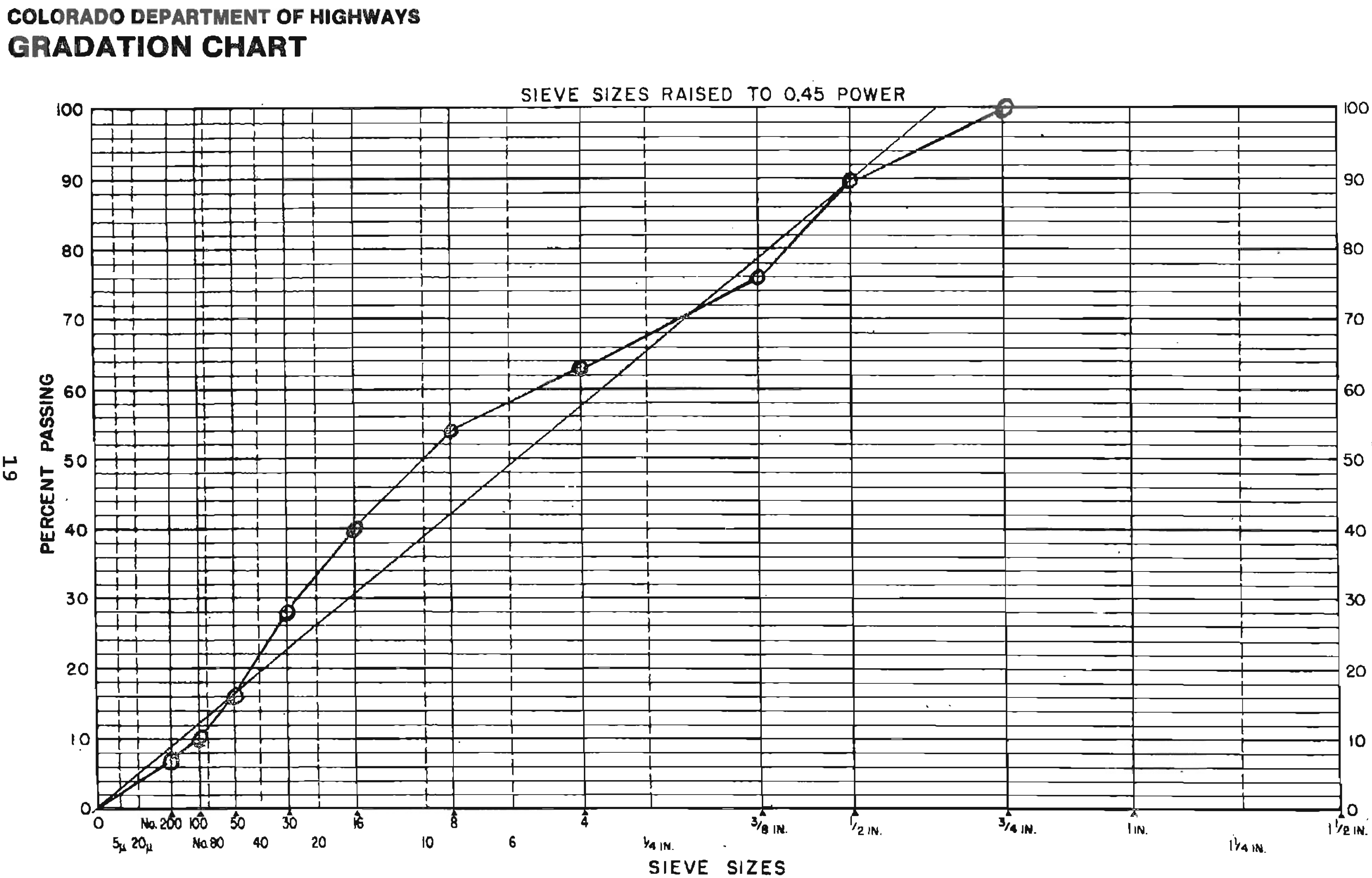

FIGURE 3 Mix Gradation Used for the First Between-Laboratory TSR Investigation.

contained 5.0% Conoco AC-10 asphalt cement by weight of mix and also contained 15% recycled asphalt pavement by weight of aggregate.

The second between-laboratory investigation used a CDOT Grading CX material with a nominal maximum aggregate size of ⅜" (9.5 mm). The gradation chart is shown in Figure 4. The mix contained 5.3% Conoco AC-20 asphalt cement by weight of mix.

TABLE 5 Mix Properties and Materials Used for the First Between-Laboratory Investigation

Grading of mix	CDOT Grading C
Source of aggregate	64% Lyons/Nelson pit 25% Adams pit 15% recycled asphalt pavement by weight of aggregate
Source of asphalt cement	Conoco AC-10
Asphalt cement content	5.0% by weight of mix
Anti-stripping additive	1% hydrated lime

The third between-laboratory investigation used a CDOT Grading C material with a nominal maximum aggregate size of ¾" (19.1 mm). The gradation chart is shown in Figure 5. The mix contained 4.8% Sinclair AC-10 asphalt cement by weight of mix.

4.3 Results From Three Between-Laboratory Evaluations

The TSR results from the three between-laboratory investigations showed more variability than the within-laboratory investigation. The results from the different laboratories are shown in Table 6.

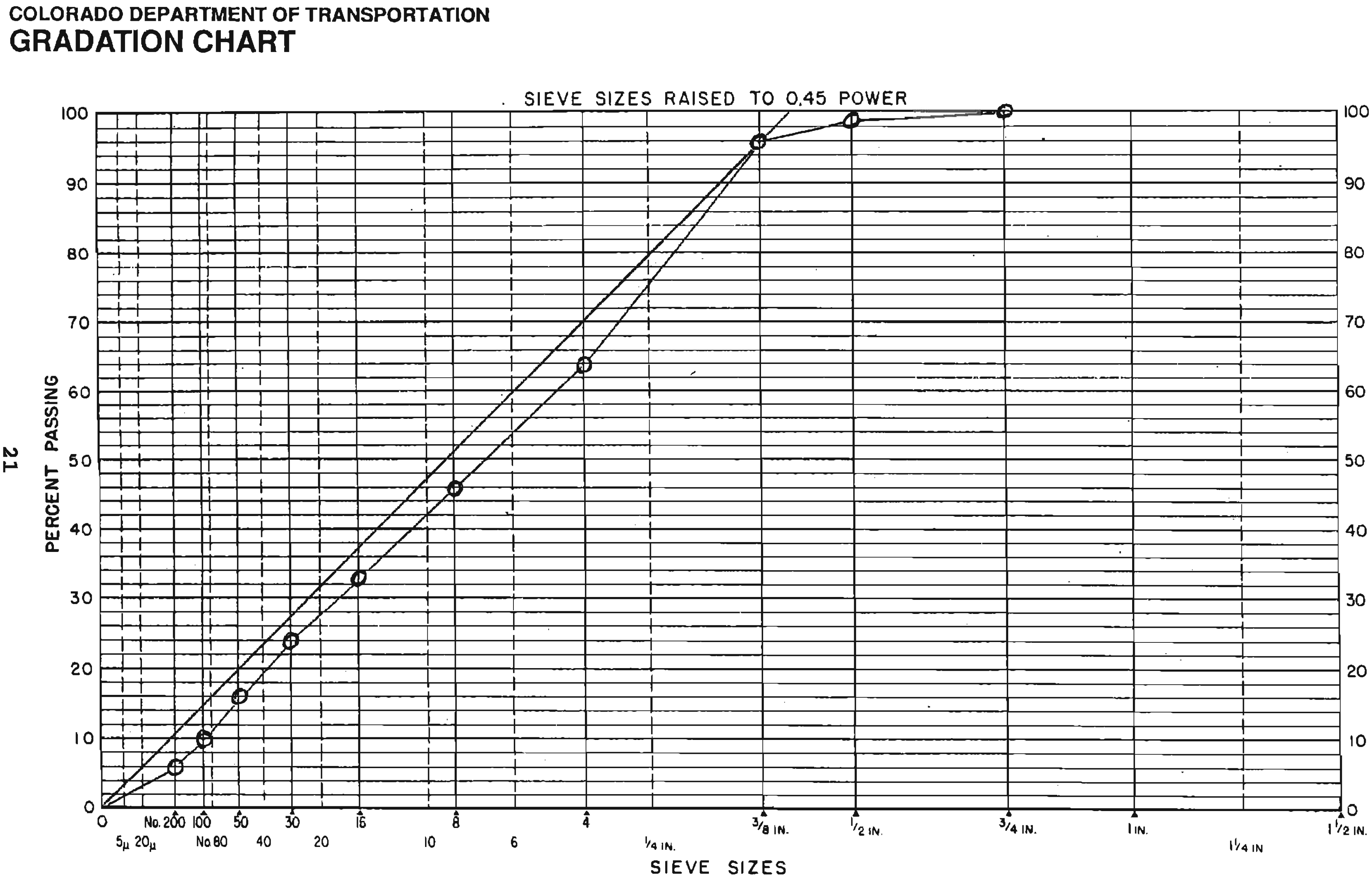

FIGURE 4 Mix Gradation Used for the Second Between-Laboratory TSR Investigation.

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GRADATION CHART

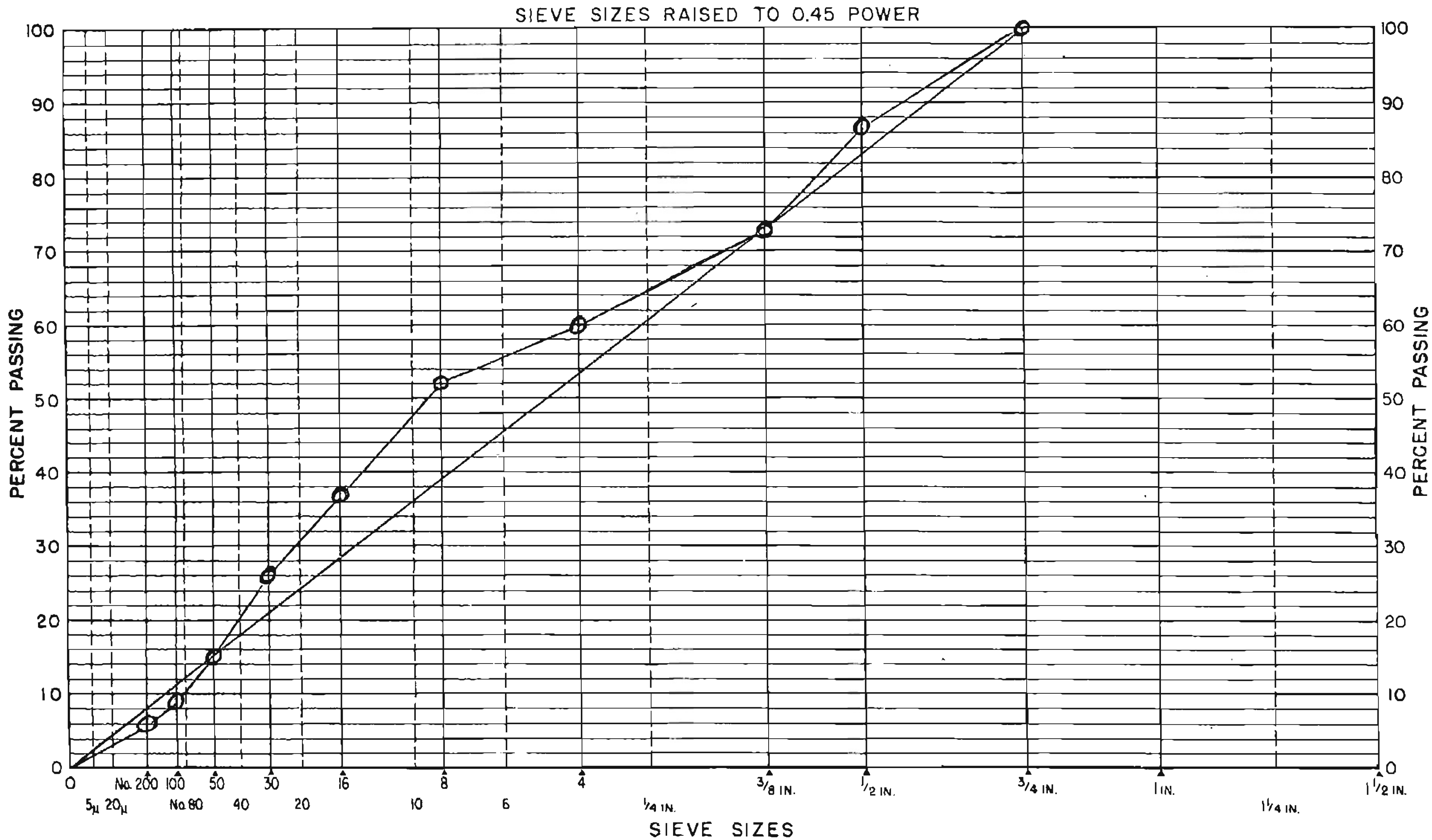

FIGURE 5 Mix Gradation Used for the Third Between-Laboratory TSR Investigation.

One result was removed from consideration since it was determined that the sample was not tested according to CPL-5109.

The standard deviation of the TSR results from the first between-laboratory investigation was 0.161. CDOT laboratory TSR data from the first between-laboratory experiment taken as a group had a standard deviation of 0.207. Based on these results, a program of test procedure standardization and training was begun within CDOT in an attempt to improve the repeatability of the test results produced by the CDOT materials testing laboratories. A second between-laboratory investigation was conducted which showed a standard deviation for the TSR of 0.126. All of the CDOT Region laboratories then purchased certified thermometers and other calibration instruments and checked their testing equipment. After this calibration effort, the third between-laboratory investigation was conducted which showed a standard deviation for the TSR of 0.113. The standard deviations for the three studies are shown in Table 7.

ASTM D 4867 gives a between-laboratory standard deviation of 0.080 which is lower than the standard deviation which was found in any of the three between-laboratory investigations conducted for this experiment.

TABLE 6 Average Dry Tensile Strength, Conditioned Tensile Strength, and Tensile Strength Retained, by Laboratory

Laboratory No.	Tensile Strength psi (kPa) Dry	Conditioned	TSR
1	45.4 (313)	43.5 (300)	0.96
2	23.7 (163)	31.1 (214)	1.31
3	40.7 (281)	51.1 (352)	1.26
9	50.6 (349)	50.2 (346)	0.99
4	71.5 (493)	59.7 (412)	0.83
11	74.7 (515)	75.5 (521)	1.01
23	46.7 (322)	45.9 (316)	0.98
27	62.0 (427)	51.6 (356)	0.83
31	50.6 (349)	41.1 (283)	0.81
8	46.4 (320)	38.0 (262)	0.82
51	44.9 (310)	38.1 (263)	0.85
32	42.3 (292)	42.3 (292)	1.00
24	74.0 (510)	55.6 (383)	0.75
15 (2.0" / min.)[1]	98.8 (681)[1]	113.7 (784)[1]	1.15[1]
15	60.8 (419)	55.7 (384)	0.92
22	53.1 (366)	44.3 (305)	0.84
Mean	52.5 (362)	48.2 (332)	0.94
Standard Deviation	14.0 (97)	10.8 (74)	0.161

[1] - results not included in calculations of mean or standard deviation. Loading head speed too high.

TABLE 7 Reduction in Between-Laboratory Test Result Variability

Source	Test Number	Number of Labs	Variable Measured	Standard Deviation (1s)
Colorado	1	15	TSR	0.161
Colorado	*[1]	8	TSR	0.207
Colorado	2	7	TSR	0.126
Colorado	3	7	TSR	0.113
ASTM D 4867			TSR	0.080

[1] Data from CDOT laboratories only.

4.4 Analysis of Results

One potential cause of variation in the TSR values reported by different laboratories could have been a lack of ability to measure or accurately control the loading head speed in some of the testing machines being used to run the test. Once the results were obtained from the first between-laboratory investigation, dial gauges were purchased for each testing machine to allow the operator to measure the testing head speed. The Versa-Tester hydraulic testing machines being used by the CDOT Region laboratories were found to be incapable of consistently producing a 0.2" per minute (5.1 mm per minute) loading head speed as specified by CPL-5109. The loading head speed of the testing machines will vary during the testing of a single sample at different loads as well as during the testing of multiple samples. Different testing machines have different loading head speed characteristics as samples are loaded but each machine has the same problem to some extent. As Maupin (*2*) showed, the tensile strength results are dependant on the loading head speed and this can cause variation in the reported TSR if there is a difference in the loading head speeds used for the dry and conditioned samples.

Another potential cause of differences in the between-laboratory results could be a difference between the temperatures of the incubator and the water bath which would cause the conditioned samples to be tested at a different temperature from the dry samples. Any difference in temperature between the conditioned and dry samples will cause a difference in the TSR reported for the material. One method which could be used to solve this problem would be to store the dry samples, either wrapped or unwrapped, in the same water bath as the conditioned samples for two hours before the testing is performed so that both sets of samples are at exactly the same temperature when they are tested.

The between-laboratory investigation of CPL-5109 showed the value of detailed, easy to follow test procedure instructions and periodic equipment calibration. A program to 1) standardize and clarify the test procedure, and 2) calibrate the laboratory equipment, is now being implemented by CDOT. This includes test method documentation, equipment calibration, operator training, and test result monitoring.

5.0 CONCLUSIONS

5.1 Within-Laboratory Investigation

This study found a within-laboratory standard deviation for TSR test results of 0.040. A study done by the Virginia DOT, of a test which did not include a freeze thaw cycle, found a standard deviation of 0.035 while Lottman (*6*) found a within-laboratory standard deviation of 0.100 for TSR values.

The loading machine which was used to obtain these results had precise loading head speed measurement and control capabilities.

The within-laboratory standard deviation of the tensile strength was found to be 5.3 psi (36 kPa) for conditioned samples and 5.0 psi (34 kPa) for dry samples. The within-laboratory standard deviation of the tensile strength for either dry or moisture conditioned samples is given in ASTM D 4867 as 8.0 psi (55 kPa).

This indicates that for a single operator, the indirect tensile stripping test CPL-5109 is as repeatable as both the less complicated Virginia stripping test and ASTM D 4867.

5.2 Between-Laboratory Investigation

This study of CPL-5109 found between-laboratory standard deviations of 0.161, 0.126 and 0.113 for the three investigations which were done. ASTM D 4867 gives a between-laboratory standard deviation of 0.080.

The high standard deviation of the TSR results indicate differences in the test procedures or the equipment being used by the various laboratories. The procedures and the equipment being used by the various Region laboratories should be examined and the causes of the differences in TSR results found and corrected.

The reduction of the standard deviation in test results over the three investigations which were performed for this experiment show the effectiveness of testing standardization efforts.

6.0 RECOMMENDATIONS

1) The documentation, training and monitoring program currently being implemented in CDOT laboratories is increasing the repeatability of test results. The between-laboratory standard deviation of the TSR results dropped each time the between-laboratory investigation was repeated. These results indicate that every laboratory performing the CPL-5109 test must take extreme care to make sure that they are using the same procedure as other laboratories and that their equipment is properly calibrated to ensure test results which are comparable to results from other laboratories. Further efforts will be necessary to bring the between-laboratory repeatability of the TSR test to the same level as the figure of 0.080 given in ASTM D 4867.

2) Raising the loading head speed from the 0.2" per minute (5.1 mm per minute) specified by CPL-5109 to the 2.0" per minute (50.8 mm per minute) specified by ASTM D 4867 and by AASHTO T 283 might reduce the effect on sample tensile strength caused by fluctuations in the speed of the loading heads of hydraulic testing machines. Before this proposal can be

carried out, a follow up study must determine whether it would reduce between-laboratory variability without causing any new problems. This proposal would also require changing the CDOT specification for the dry tensile strength of samples since a measured sample tensile strength is higher when the loading head speed is higher.

3) In the future, the type of testing machines purchased to perform CPL-5109 should be limited to testing machines which can maintain a constant, verifiable loading head speed at the low loads and low loading head speeds used in CPL-5109. Mechanical load application devices would provide a much more repeatable rate of loading than testing machines which use a hydraulic loading method. If hydraulic machines are used, the machine must be capable of constant loading head speeds without operator intervention and a method of constantly monitoring the load head speed must be included in the system.

4) Care must be taken to ensure that the temperatures at which the dry and conditioned samples are tested are the same. It is critical that these temperatures be monitored accurately for each test. Another way to ensure equal temperatures of the dry and conditioned samples would be to store the dry samples in the water bath with the conditioned samples for two hours before testing.

7.0 REFERENCES

1. "*Laboratory Manual of Test Procedures*", 1988, Denver, CO. Staff Materials, Colorado Department of Transportation

2. Maupin, G. W. (1979), "Implementation of Stripping Test for Asphaltic Concrete", Transportation Research Record 712, *Bituminous Materials and Skid Resistance*, Transportation Research Board, Washington, D.C., pp. 8-12.

3. Dukatz, E.K. (1987), "The Effect of Air Voids on Tensile Strength Ratio", *Proceedings of the Association of Asphalt Paving Technologists*, Vol. 56, pp. 517-554.

4. Stuart, K. D. (1992), "*Diametral Tests for Bituminous Mixtures*", Federal Highway Administration, McLean, VA, FHWA-RD-91-083. 143 pages.

5. Maupin, G. W. (1990), "*The Variability of the Indirect Tensile Stripping Test*", Virginia Transportation Research Council, Charlottesville, Virginia, FHWA/VA-91/5, 36 pages.

6. Lottman, R. P. (1982), "*Predicting Moisture Induced Damage to Asphaltic Concrete - Field Evaluation*", NCHRP Report 246, Transportation Research Board, Washington, D.C., 50 pages.