Report No. CDOT-DTD-R-2005-17
Final Report

REVIEW OF F AND t TEST RESULTS 2000 THROUGH 2004

Eric Chavez, CDOT Pavement Design Unit

October 2005

COLORADO DEPARTMENT OF TRANSPORTATION

The contents of this report reflect the views of the author(s), who is(are) responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views of the Colorado Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
CDOT-DTD-R-2005-17		

4. Title and Subtitle	5. Report Date
REVIEW OF F AND t TEST RESULTS 2000 THROUGH 2004	October 2005
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Eric Chavez	CDOT-DTD-R-2005-17
9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
Colorado Department of Transportation 4201 E. Arkansas Ave. Denver, Colorado 80222	11. Contract or Grant No.
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
Colorado Department of Transportation - Research 4201 E. Arkansas Ave. Denver, CO 80222	14. Sponsoring Agency Code

15. Supplementary Notes

Prepared in cooperation with the US Department of Transportation, Federal Highway Administration

16. Abstract

The Colorado Department of Transportation (CDOT) uses the F test and t test to determine if two sets of test data are from the same population. The comparison is usually between the Contractor's quality control tests and the Department's verification tests. The F test and t test are calculated in accordance with standard statistical procedures to make the comparisons. The F test analyzes the differences in the standard deviations of the data sets. The t test analyzes differences in the means of the data sets. Starting in 1988 the first projects were awarded under pilot specifications which contained the requirement for F and t test analysis. Analysis was conducted between the Contractor's and the Department's flexural strength tests on these first projects. The specification was released as a standard specification on February 11, 2000 titled: *Revision of Sections 105, 106, and 412, Quality of Portland Cement Concrete Pavement (Alternative Strength Criteria).* This report analyzes the F and t test results from 2000 through 2004. Eight of the projects evaluated in this report contain the alternative strength specification. Two projects included in this report contained modified specifications: ten year warranty PCCP & ten year warranty HMA. Analysis on ten projects is included in this report. On two of the projects the F and t test analysis was designated as being for informational purposes only by the engineer. Irregardless of the outcome of the F and t tests, the Contractor's tests results were used on one of these projects. CDOT's test results were used on the other. On both of these projects the F and t test passed on all processes. Of the ten projects evaluated five passed both tests on all processes. Three projects had at least one failing test in the t test. Two projects failed both tests on all processes. Twenty-two processes were established for the material being evaluated. The F tests passed in all but two of the processes. The variation of the data between the Contractor and the Department was within allowable differences 91% of the time. The t test failed on 7 of the processes, 32% of the time. There was a consistent difference between the two sets of test results on these processes. CDOT's test results were used instead of the Contractor's for the calculation of I/DPs on four processes because of failing F and t test results.

17. Keywords	18. Distribution Statement
F test, t test, mean, standard deviation, variance	No restrictions. This document is available to the public through the National Technical Information Service Springfield, VA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	35	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

Review of F and t Test Results 2000 Through 2004

by

Eric Chavez

Report No. CDOT-DTD-R-2005-17

Prepared by
Colorado Department of Transportation
Research Branch

Sponsored by the
Colorado Department of Transportation
In Cooperation with the
U.S. Department of Transportation
Federal Highway Administration

October 2005

Colorado Department of Transportation
Research Branch
4201 E. Arkansas Ave.
Denver, CO 80222
(303) 757-9266

TABLE OF CONTENTS

1.0 **INTRODUCTION AND COMMENTS** 1

2.0 **SPECIFICATIONS** 2

3.0 **DEFINITIONS** 3

4.0 **OVERVIEW OF THE F & t TEST** 5

5.0 **DISCUSSION OF DATA** 9

5.1 **Projects Evaluated** 9

5.2 **Review of F and t Calculations** 9

5.3 **Review of the Calculations by Project** 10

5.4 **Test Results Used for Incentive/Disincentive Calculations** 10

5.5 **Results for the HMA Project** 11

6.0 **SUMMARY** 12

7.0 **UPDATES AND CONTACT** 12

REFERENCES 13

Appendix A F and t Tests, Detailed Results.

Appendix B *Revision of Sections 105, 106, and 412, Quality of Portland Cement Concrete Pavement (Alternative Strength Criteria).*

Appendix C Test Data Used in Figures 1, 2, & 3.

1.0 INTRODUCTION AND COMMENTS

The Colorado Department of Transportation (CDOT) uses the F test and t test to determine if two sets of test data are from the same population. Comparisons between the Contractor's quality control tests and the Department's verification tests have been specified on selected projects. The F test and t test are calculated in accordance with standard statistical procedures to make the comparisons. The F test analyzes the differences in the standard deviations of the data sets. The t test analyzes differences in the means of the data sets.

A pilot specification, Revision of Sections 105, 106 and 412, Quality of Portland Cement Concrete Pavement (QC for Pay) was used on five projects beginning in 1998. Under the specification the contractor chooses between compressive strength and flexural strength criteria. If flexural strength is chosen analysis of the Department's verification tests of flexural strength and the Contractor's quality control tests of flexural strength shall be completed. The specification was released as a standard special provision on February 11, 2000 titled: Revision of Sections 105, 106 and 412, Quality of Portland Cement Concrete Pavement (Alternative Strength Criteria). Under this specification if flexural strength is chosen by the contractor analysis of the test results using F test and t test will be conducted between the Contractor's and Department's flexural strength tests.

One project was awarded in 2001 which contained the pilot specification: *Revision of Sections 105 and 106, Quality of Warranted Portland Cement Concrete Pavement*. This project contains a 10 year warranty. The specification's testing criteria and analysis is similar to the Alternative Strength Criteria specification except that no incentive payments were to be calculated.

One project was awarded in 2004 which contained a pilot specification for hot mixed asphalt (HMA) titled: Revision of Sections 105 and 106, Quality of Warranted Hot Bituminous Pavement System. Under this pilot specification analysis between the

Department's verification tests of in-place density and the Contractor's quality control tests of in-place density is required.

This report analyzes the F & t test data on projects from 2000 through 2004.

2.0 SPECIFICATIONS

Standard Special Provision: *Revision of Sections 105, 106, and 412, Quality of Portland Cement Concrete Pavement (Alternative Strength Criteria).* This specification, used on nine of the projects, contains the requirements for analysis of the Department's verification tests and the Contractor's quality control tests using the F & t test calculations. The specification allows for the use of the Contractor's quality control tests in the calculation of incentive/disincentive payments (I/DPs) as long as there is not a significant difference in the two sets of tests when analyzed by the F and t test calculations. The Department's test data shall be used for determining I/DPs if there is significant difference.

One of the projects evaluated contained the specification: *Revision of Sections 105 and 106, Quality of Warranted Portland Cement Concrete Pavement*. The testing criteria and analysis is similar to the Alternative Strength Criteria specification except that no incentive payments were to be calculated. The Contractor's quality control and the Department's verification tests are analyzed using the F and t test calculations. Use of the Contractor's quality control tests were to be used for the calculation of disincentive payments if no significant difference was found. The Department's test data shall be used for determining disincentive payments if there are significant differences.

The single hot mixed asphalt project contained in this report had the pilot specification: *Revision of Sections 105 and 106, Quality of Warranted Hot Bituminous Pavement System.* This specification is similar to the Warranted PCCP specification in that no incentive payments are calculated. Analysis of the Contractor's density quality control and the Department's density verification tests is to be completed using the using the F

& t test calculations. The Department's test data shall be used for determining disincentive payments if there are significant differences.

3.0 DEFINITIONS

Alpha – Level of significance (probability level) or critical region. This is the probability of incorrectly deciding the two data sets are different when they actually come from the same population. Alpha is the risk of rejecting good material.

Bid Date – The date the project was awarded to contract.

Calculated Value – Result obtained from running either the F test or t test calculations.

Critical Value – Level at which the two data sets become significantly dissimilar. The critical value is calculated based on the number of test results in the data sets and the assigned alpha value.

F Test – Comparison of the differences in the variances, standard deviation squared, of the two data sets.

I/DP – Incentive/Disincentive Payment. The amount of increase or decrease paid for a quantity of material within a test element.

Mean ($\overline{x}$) – Or Average, the sum of all test values divided by the number of tests.

Process Quantities – Processes group like material or construction techniques together. All material that has been determined to have the same characteristics will be added to the same process. If a change to the material or the construction technique occurs then a new process will be created, see the specification for details.

Std. Dev. (Standard Deviation) - Definition, see variance.

equation: $SD = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n-1}}$

Where: $\sum$ = summation

x_i = individual test value

$\overline{x}$ = mean

n = number of samples

Subaccount – A unique five digit numeric identifier for a project.

t Test – Comparison of the differences in the means of the two data sets.

Variance - A measure of the average distance between each of a set of data points and their mean value; equal to the sum of the squares of the deviation from the mean value. The square root of the variance is the standard deviation.

equation: $\sigma = SD^2 = \frac{\sum (x_i - \bar{x})^2}{n-1}$

Where: $\sum$ = summation

x_i = individual test value

$\overline{x}$ = mean

n = number of samples

4.0 OVERVIEW OF THE F & t TESTS

The F test and t test are calculated in accordance with standard statistical procedures to make the comparisons. This analysis is required by the project specifications to provide a method of comparing two different data sets of multiple test results to determine if the materials tested come from the same population. It is assumed that the two populations are normally distributed in order to be evaluated by comparing the standard deviations and means. The analysis is done by calculating and comparing the variances (standard deviation squared) and population means (arithmetic averages) of the two data sets. The F test compares the population variances while the t test compares the population means. The calculated value for the F or t test is determined by running the appropriate equation. The calculated value is then compared against the critical value as determined for the data sets. The critical value is assigned based on the number of test results in the data sets and the assigned alpha value. If the calculated values are below the critical values for the data sets the two sets of data are assumed to come from the same population. If the calculated values exceed the critical values the data sets are not from the same population.

Figure 1 shows an example of passing results for both the F and t tests. Each of the data sets is represented by its normal curve. The standard deviation for the data set is indicated by how "tall and narrow" or "short and fat" the curve is. Smaller standard deviations will have a taller and narrower curve. This data is more tightly grouped and covers a smaller range of values across the bottom of the graph. As the standard deviation increases, a wider range of values is covered across the bottom of the graph. The curve now becomes shorter and fatter. The two curves in Figure 1 have a similar shape, standard deviations that are similar to each other. The standard deviations are within acceptable limits and pass the F test. The means for the data sets, located at the highest point of each curve, are relatively close to each other. The difference between the means is within acceptable limits and the t test passes.

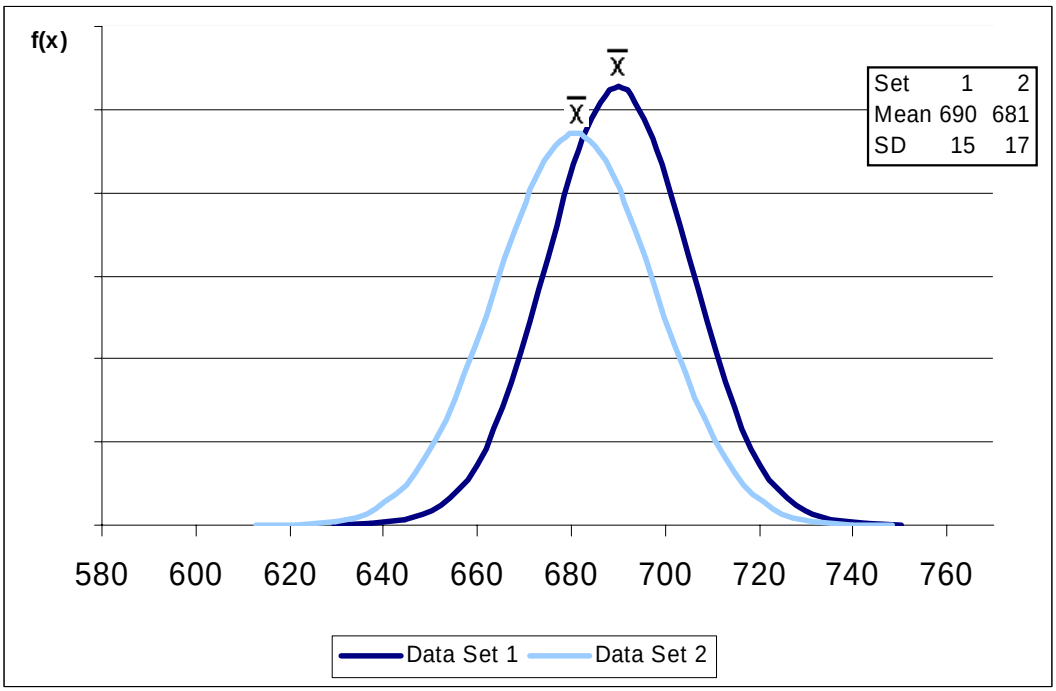

Figure 1. Example: Passing Results for both the F and t Tests.

Figure 2 shows a failure of the F test, significant difference in the standard deviations of two sets of data. The shape of a curve relates directly to its standard deviation. The two curves are not very similar in shape and indicate a high difference in the standard deviations. The standard deviations exceed the allowable limits in this case and the F test fails. The means for the two data sets in Figure 2 are fairly close to each other and within acceptable limits for the t test. The t test passes.

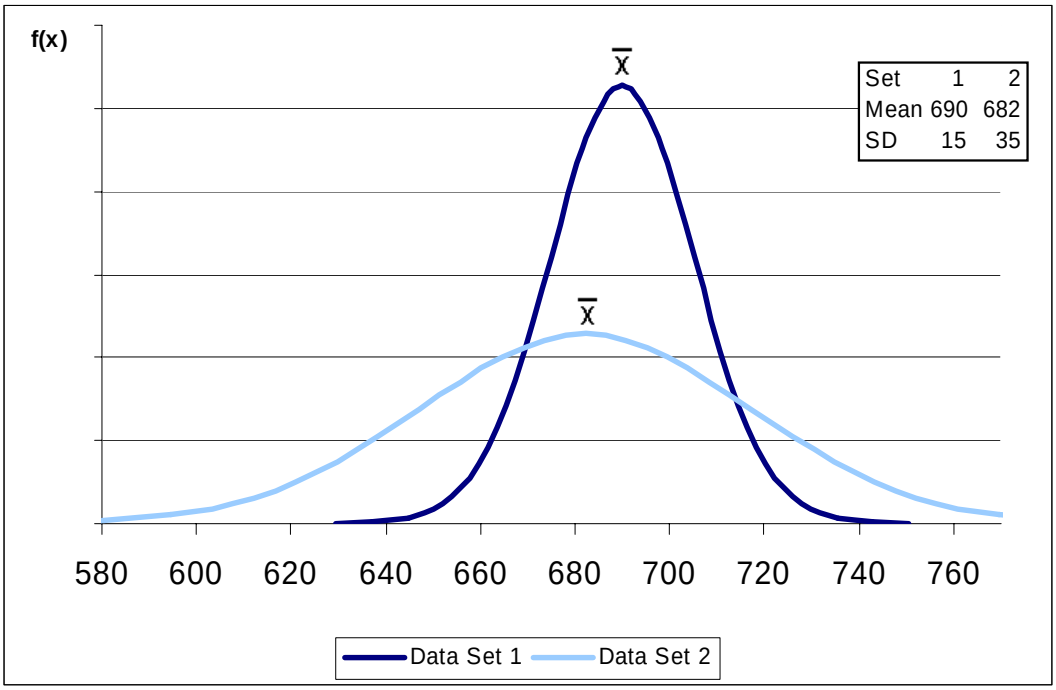

Figure 2. Example: F Test Showing Significant Difference, Standard Deviations

Figure 3 shows a failure of the t test, significant difference in the sample means. The curves have a similar look, similar standard deviations. However, the means for the curves exceed acceptable limits from each other, too far apart, and result in a failure of the t test. The F test does pass in this example.

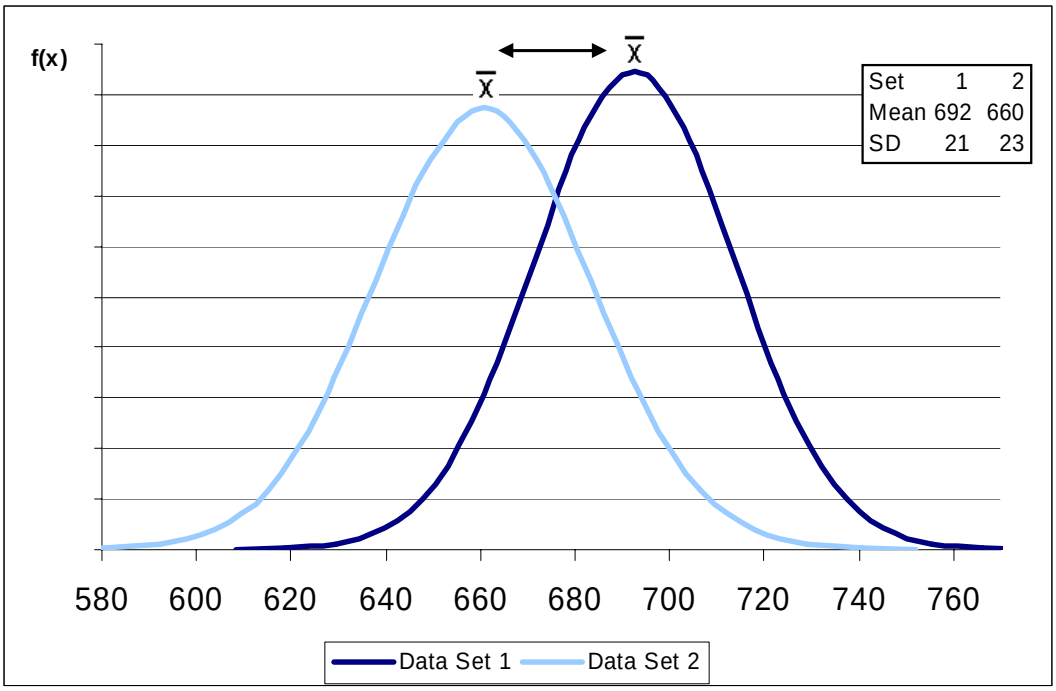

Figure 3. Example: t Test Showing Significant Difference, Sample Means

To review the data sets used in Figures 1, 2, & 3 see Appendix C.

The Department has created computer programs for completing the F and t test calculations.

5.0 DISCUSSION OF THE DATA

5.1 Projects Evaluated, 2000 Through 2004

Eleven projects were identified that contained a specification requiring analysis by performing the F and t tests. The F and t test analysis was not completed on one of these projects. Nine of the projects contained portland cement concrete paving. Eight of these contained the Standard Special Provision: *Revision of Sections 105, 106, and 412, Quality of Portland Cement Concrete Pavement (Alternative Strength Criteria),* flexural strength being chosen as the testing criteria. Project IM 0705-070 contained a modified specification, 10 year warranty PCCP. Project NH 0243-068 was the single HMA project awarded under the pilot specification: *Revision of Sections 105 and 106, Quality of Warranted Hot Bituminous Pavement System* which contained the requirement of F and t analysis. The F and t analysis was completed for informational purposes on two of the projects, the first being project IM 0705-070, the 10 year warranted PCCP specification. On this project the Contractor's results were used in any disincentive calculations. The test results from this project resulted in no disincentives being assigned. The second project was C 0405-023. CDOT's test results were used in the I/DP calculations as designated by the engineer.

5.2 Review of F and t Calculations

Analysis was completed on ten of the projects. The material was grouped into 22 processes. Each project would have at least one defined process. A new process is created whenever the material being evaluated changes. Only similar material is grouped together for the evaluations.

Twenty of the 22 processes passed the F test. The variation in the standard deviations between the Contractor's quality control tests and the Department's verification tests exceeded the acceptable limits only twice. The failing processes were in two different projects.

Fifteen of the 22 processes passed the t test. The variation in the sample means between the Contractor's quality control tests and the Department's verification tests

exceeded the acceptable limits 7 times, 32% of the time. Five projects had a failing process in the t test. One of the projects had three failing processes in the t test.

The variability of the test results between the Contractor and the Department is at a reasonable level, 9% of the projects failing the F test. The mean difference between the two sets of test results is high at 32% failure of the t test. In some of the projects there is a consistent difference between the report values of the Contractor as compared to the Department, shown in the mean values of the processes.

5.3 Review of the Calculations by Project

Five of the ten projects evaluated, 50%, passed both the F test and the t test on all of the process. Good correlation of the test results between the Contractor and the Department was reported on these projects. Three of the projects, 30%, had all processes pass the F tests but showed at least one process failure in the t test. One of these projects had all processes fail the t test. The remaining two projects did not pass the F test nor the t test on all processes. Significant differences were reported on both the standard deviations and means in the comparison of the test results.

5.4 Test Results Used for Incentive/Disincentive Payment Calculations

Eight of the projects evaluated contained the Standard Special Provision, Revision of Sections 105, 106, & 412, Alternative Strength Criteria. Both of the warranty projects contained pilot specifications, one PCCP and one HMA. A review of the results for the projects is presented in Table 1.

In 15 of 22 processes the Contractor's quality control tests were used in the calculation of I/DPs. The Contractor's tests were used in one process which failed the t test. In another process the Contractor's tests were used even though both tests had failed. The F and t testing was performed for informational purposes only on project C 0405-023 as designated by the engineer. CDOT's test results were used in the calculations for I/DP even though both processes passed both the F and t test. CDOT's test results were used instead of the Contractor's on four processes which did not pass the F or t

test. Each of these processes had failed on the t test. These processes were in two projects. One of the projects failed the t test on all processes. For detailed results see Appendix A.

Table 1. Review of F and t Results

Subacct.	Project Code	Process	Alpha	F Test	t Test	Info Only	Results Used
11849	IM 0704-184	1	0.10	Pass	Pass	No	Contractor
		2	0.10	Pass	Pass	No	Contractor
		3	0.10	Pass	Pass	No	Contractor
		4	0.10	Pass	Pass	No	Contractor
11925	IM 0253-151	1	0.05	Pass	Pass	No	Contractor
		2	0.05	Pass	Pass	No	Contractor
		3	0.05	Pass	Pass	No	Contractor
		4	0.05	Pass	Pass	No	Contractor
		5	0.05	Pass	Fail	No	Contractor
11985	STA C370-004	1	0.05	Pass	Fail	No	CDOT
		2	0.05	Pass	Pass	No	Contractor
12489	C 0405-023	1	0.05	Pass	Pass	Yes	CDOT
		2	0.05	Pass	Pass	Yes	CDOT
12635 ①	IM 0705-070	1	0.05	Pass	Pass	Yes	Contractor
12636	IM 0252-324	1	0.10	Pass	Fail	No	CDOT
		2	0.10	Pass	Fail	No	CDOT
		3	0.10	Pass	Fail	No	CDOT
13529	STU 1192-011	1	0.05	Fail	Fail	No	CDOT
13831	IM 0761-184	1	0.05	Fail	Fail	No	Contractor
13897	NH 0852-088	1	0.05	Pass	Pass	No	Contractor
14822 ②	NH 0243-068	1	0.05	Pass	Pass	No	Contractor
		2	0.05	Pass	Pass	No	Contractor
①	Pilot specification 10 year warranty PCCP project						
②	Pilot specification 10 year warranty HMA project						

5.5 Results for the HMA Project

One project included in this evaluation contained HMA. This project was constructed using a pilot specification: *Revision of Sections 105 and 106, Quality of Warranted Hot Bituminous Pavement System.* In the density element, the Contractor's quality control

tests and CDOT's verification tests were analyzed using the F and t tests. Both processes passed both the F and t test.

6.0 SUMMARY

The F and t test calculations are useful in comparing the test results between the Contractor's quality control and the Department's verification tests. Eight of the projects evaluated in this report contained the same specification: *Revision of Sections 105, 106, and 412, Quality of Portland Cement Concrete Pavement (Alternative Strength Criteria).* Two projects were evaluated which contained modified specifications, ten year warranty PCCP & ten year warranty HMA. On two of the projects the F and t test analysis was designated as being for informational purposes only by the engineer. Irregardless of the outcome of the F and t tests, the Contractor's tests results were used on one of these projects. CDOT's test results were used on the other. On both of these projects the F and t test passed on each process. Five of the ten projects passed both tests on all processes. Three projects had at least one failing test in the t test. Two projects failed both tests on all processes. Twenty-two processes were established for the material being evaluated. The F tests passed in all but two of the processes. The variation of the data between the Contractor and the Department was within allowable differences 91% of the time. The t test failed on 7 of the processes, 32% of the time. There was a consistent difference between the two sets of test results on these processes. CDOT's test results were used instead of the Contractor's for the calculation of I/DPs on four processes because of failing F and t test results.

7.0 UPDATES AND CONTACT

The database used will be updated as additional project data is received. If you have any questions concerning this report please contact Eric Chavez at 303 757-9308, Eric.Chavez@dot.state.co.us. If you find any errors in the project data please report them to Eric Chavez.

REFERENCES

1. Colorado Procedure 14-03, Standard Practice for F and t-test Statistical Method for HBP Voids Acceptance.

Appendix A

F and t Tests, Detailed Results

Sub. 11849 **IM 0704-184** **Peoria - East** **Test: Flexural Str** **Bid Date: 05/04/00**

	Tests			F Test: Standard Deviations				t Test: Sample Means						
Proc. No.	Con.	Ver.	Alpha	Crit.	Calc.	Diff.	Result	Crit.	Calc.	Diff.	Result	Info Only	Results Used	Comment:
1	8	2	0.10	236.8	2.8	233.9	Pass	1.9	1.2	0.7	Pass	No	Contractor	Alpha 0.10
2	2	2	0.10	161.4	1.4	160.1	Pass	2.9	0.1	2.8	Pass	No	Contractor	Alpha 0.10
3	11	2	0.10	241.9	3.0	238.9	Pass	1.8	1.3	0.5	Pass	No	Contractor	Alpha 0.10
4	32	9	0.10	2.3	1.0	1.3	Pass	1.7	0.6	1.1	Pass	No	Contractor	Alpha 0.10

Sub. 11925 **IM 0253-151** **I-25, Weld Co Rd 8 Interchange** **Test: Flexural Str** **Bid Date: 08/30/01**

	Tests			F Test: Standard Deviations				t Test: Sample Means						
Proc. No.	Con.	Ver.	Alpha	Crit.	Calc.	Diff.	Result	Crit.	Calc.	Diff.	Result	Info Only	Results Used	Comment:
1	99	31	0.05	1.9	1.0	0.8	Pass	2.0	0.4	1.6	Pass	No	Contractor	CMO #9
2	50	13	0.05	2.9	2.2	0.7	Pass	2.0	0.7	1.3	Pass	No	Contractor	MD 2002112
3	12	2	0.05	6.7	2.1	4.6	Pass	2.2	0.4	1.8	Pass	No	Contractor	MD 2002113
4	68	23	0.05	1.9	1.0	0.9	Pass	2.0	0.0	2.0	Pass	No	Contractor	MD 2003321
5	38	14	0.05	2.8	1.1	1.7	Pass	2.0	2.7	-0.7	Fail	No	Contractor	MD 2004015

Sub. 11985 **STA C370-004** **SH 6, Phillips Co** **Test: Flexural Str** **Bid Date: 11/30/00**

	Tests			F Test: Standard Deviations				t Test: Sample Means						
Proc. No.	Con.	Ver.	Alpha	Crit.	Calc.	Diff.	Result	Crit.	Calc.	Diff.	Result	Info Only	Results Used	Comment:
1	114	29	0.05	1.7	1.4	0.3	Pass	2.0	3.6	-1.6	Fail	No	CDOT	Need detailed report.
2	10	3	0.05	39.4	1.1	38.3	Pass	2.2	0.2	2.0	Pass	No	Contractor	

Sub. 12489 **C 0405-023** **Jct SH 94 E & W** **Test: Flexural Str** **Bid Date: 05/24/01**

	Tests			F Test: Standard Deviations				t Test: Sample Means						
Proc. No.	Con.	Ver.	Alpha	Crit.	Calc.	Diff.	Result	Crit.	Calc.	Diff.	Result	Info Only	Results Used	Comment:
1	92	24	0.05	1.8	1.1	0.7	Pass	2.0	0.7	1.3	Pass	Yes	CDOT	CDOT's Tests Used
2	7	3	0.05	7.3	1.4	5.8	Pass	2.3	0.6	1.8	Pass	Yes	CDOT	CDOT's Tests Used

Sub. 12635 **IM 0705-070** **I-70 Reconstruction, Stratton** **Test: Flexural Str** **Bid Date: 08/23/01**

	Tests			F Test: Standard Deviations				t Test: Sample Means						
Proc. No.	Con.	Ver.	Alpha	Crit.	Calc.	Diff.	Result	Crit.	Calc.	Diff.	Result	Info Only	Results Used	Comment:
1	152	39	0.05	1.6	1.5	0.1	Pass	2.0	0.5	1.5	Pass	Yes	Contractor	10 yr warranty project

Sub. 12636 **IM 0252-324** **Widening I-25 Climb Ln. Phase** **Test: Flexural Str** **Bid Date: 06/15/00**

	Tests			F Test: Standard Deviations				t Test: Sample Means						
Proc. No.	Con.	Ver.	Alpha	Crit.	Calc.	Diff.	Result	Crit.	Calc.	Diff.	Result	Info Only	Results Used	Comment:
1	30	5	0.10	2.7	1.3	1.4	Pass	1.7	2.5	-0.8	Fail	No	CDOT	Alpha 0.10
2	8	7	0.10	3.9	2.1	1.8	Pass	1.8	2.9	-1.1	Fail	No	CDOT	Alpha 0.10
3	55	20	0.10	2.0	1.1	0.9	Pass	1.7	3.3	-1.6	Fail	No	CDOT	Alpha 0.10

Sub. 13529 **STU 1192-011** **SH 119 & US 287** **Test: Flexural Str** **Bid Date: 07/25/02**

	Tests			F Test: Standard Deviations				t Test: Sample Means						
Proc. No.	Con.	Ver.	Alpha	Crit.	Calc.	Diff.	Result	Crit.	Calc.	Diff.	Result	Info Only	Results Used	Comment:
1	69	19	0.05	2.3	2.6	-0.3	Fail	2.0	2.3	-0.3	Fail	No	CDOT	

Sub. 13831 **IM 0761-184** **I-76 @ 88th Ave** **Test: Flexural Str** **Bid Date: 10/10/02**

	Tests			F Test: Standard Deviations				t Test: Sample Means						
Proc. No.	Con.	Ver.	Alpha	Crit.	Calc.	Diff.	Result	Crit.	Calc.	Diff.	Result	Info Only	Results Used	Comment:
1	45	13	0.05	2.9	3.2	-0.3	Fail	2.0	2.5	-0.5	Fail	No	Contractor	Failed both tests. Used contr

Sub. 13897 **NH 0852-088** **SH 85 Sedalia** **Test: Flexural Str** **Bid Date: 02/27/03**

	Tests			F Test: Standard Deviations				t Test: Sample Means						
Proc. No.	Con.	Ver.	Alpha	Crit.	Calc.	Diff.	Result	Crit.	Calc.	Diff.	Result	Info Only	Results Used	Comment:
1	12	3	0.05	39.4	1.3	38.1	Pass	2.2	1.4	0.7	Pass	No	Contractor	SB data only, NB not availabl

Sub. 14822 **NH 0243-068** **US 24 Constitution to Garrett** **Test: HMA Density** **Bid Date: 08/12/04**

	Tests			F Test: Standard Deviations				t Test: Sample Means						
Proc. No.	Con.	Ver.	Alpha	Crit.	Calc.	Diff.	Result	Crit.	Calc.	Diff.	Result	Info Only	Results Used	Comment:
1	28	7	0.05	2.9	1.2	1.8	Pass	2.0	0.3	1.7	Pass	No	Contractor	HMA 10 yr warranty
2	32	8	0.05	2.7	1.8	1.0	Pass	2.0	0.2	1.8	Pass	No	Contractor	HMA 10 yr warranty

Results:

Projects: 10

Info Only:

3 **Processes**

F Test: Standard Deviations	t Test: Sample Means	F and t Test	Results Used
Processes: 22	**Processes:** 22	**Processes:**	**Processes:** 22
Pass: 20	**Pass:** 15	**Pass Both:** 15	**Contractor:** 15
Fail: 2	**Fail:** 7	**Fail Both:** 2	**CDOT:** 7

Appendix B

REVISION OF SECTIONS 105, 106 AND 412
QUALITY OF PORTLAND CEMENT CONCRETE PAVEMENT (ALTERNATIVE STRENGTH CRITERIA)

Sections 105, 106 and 412 of the Standard Specifications are hereby revised for this project as follows:

Subsection 105.03 shall include the following:

Conformity to the Contract of all Portland Cement Concrete Pavement, Item 412, will be determined in accordance with the following:

When the Engineer finds that the materials furnished, the work performed, or the finished product does not conform with the Contract, or the Pay Factor (PF) for an element's process is less than 0.75 but that reasonably acceptable work has been produced, the Engineer will determine the extent of the work that will be accepted and remain in place. The Engineer will use a Contract Modification Order to document the justification for allowing the work to remain in place and the price adjustment that will be applied.

When the Engineer finds the materials furnished, work performed, or the finished product is not in conformity with the Contract, or the PF for an element's process is less than 0.75 and has resulted in an inferior or unsatisfactory product, the work or material shall be removed and replaced or otherwise corrected by and at the expense of the Contractor. When the PF for any process is 0.75 or greater, the finished quantity of work represented by the process will be accepted at the calculated pay factor.

Materials will be sampled and tested by the Contractor and the Department in accordance with Section 106 and with procedures contained in the Department's Field Materials Manual. The approximate quantity represented by each sample will be as set forth in Section 106, Tables 106-3 and 106-4. Additional samples may be selected and tested at the Engineer's discretion.

(a) Incentive/Disincentive Payments (I/DP) will be made based on a statistical analysis that yields Pay Factors (PF) and Quality Levels (QL). The PF and QL will be made based on test results for the three elements of compressive strength, sand equivalent, and pavement thickness (compressive strength criteria) or the two elements of flexural strength and pavement thickness (flexural strength criteria). The Contractor shall choose whether compressive strength or flexural strength criteria will be used and indicate the choice in writing to the Engineer when the initial proposed mix design is submitted to the Engineer. Once the selection of acceptance criteria is made, they shall remain the acceptance criteria for all processes for the duration of the project.

Incentive/ Disincentive payment will not be made for thickness of concrete pavement furnished by the Contractor and placed by others.

If the Contractor chooses compressive strength criteria then the QL will be calculated for the elements of compressive strength, sand equivalent and pavement thickness on a process basis. If the Contractor chooses flexural strength criteria, then the QL will be calculated for the elements of flexural strength and pavement thickness on a process basis. A separate process will be established for an element when a change in the process affects that element. A process will consist of the test results from a series of random samples. Test results determined to have sampling or testing errors will not be used. All materials produced will be assigned to a process. A change in process is defined as a change that affects the element involved. Changes in mix design, material source, design pavement thickness, or the method being utilized to place the pavement are considered changes in process. The following is provided to clarify changes in processes for each element:

1. Construction of mainline pavement, including the shoulders if placed with the mainline, is a single process, providing there are no changes in process as described above.
2. Construction of ramps, acceleration and deceleration lanes, shoulders placed separately and areas requiring hand work are considered separate processes.

3. A change in the mix design is a process change for the compressive strength element or the flexural strength element, but is not a process change for the pavement thickness element.

(b) When it is necessary to represent material by one or two tests, each individual test shall have a PF computed in accordance with the following:

If the value of the test is at or above the lower tolerance limit, then PF = 1.000. If the value of the test is below the lower tolerance limit, then:

$PF = 1.00 – [0.25(T_L - T_0)/V]$

where: PF = pay factor.
V= V factor from Tables 105-6 and 105-7.
T_0 = the individual test value.
T_L= lower tolerance limit.

(c) The following procedures will be used to compute Incentive/Disincentive Payments (I/DP), quality levels (QL), and pay factors (PF) for processes represented by three or more tests:

1. Quality Level (QL) will be calculated according to CP-71.
2. Compute the PF for the process. When the process has been completed, the number of tests (Pn) it includes shall determine the formula to be used to compute the final pay factor in accordance with the following:

A. For compressive strength and pavement thickness:
When 3 ≤ Pn ≤ 5
If QL ≥ 85, then PF = 1.00 + (QL - 85)0.001333
If QL < 85, then PF = 1.00 + (QL - 85)0.005208

When 6 ≤ Pn ≤ 9
If QL ≥ 90, then PF = 1.00 + (QL - 90)0.002000
If QL < 90, then PF = 1.00 + (QL - 90)0.005682

When 10 ≤ Pn ≤ 25
If QL ≥ 93, then PF = 1.00 + (QL - 93)0.002857
If QL < 93, then PF = 1.00 + (QL - 93)0.006098

When Pn ≥ 26
If QL ≥ 95, then PF = 1.00 + (QL - 95)0.004000
If QL < 95, then PF = 1.00 + (QL - 95)0.006757

B. For flexural strength:
When 3 ≤ Pn ≤ 5
If QL ≥ 85, then PF = 1.00 + (QL - 85)0.002000
If QL < 85, then PF = 1.00 + (QL - 85)0.005208

When 6 ≤ Pn ≤ 9
If QL ≥ 90, then PF = 1.00 + (QL - 90)0.003000
If QL < 90, then PF = 1.00 + (QL - 90)0.005682

When 10 ≤ Pn ≤ 25
If QL ≥ 93, then PF = 1.00 + (QL - 93)0.004286
If QL < 93, then PF = 1.00 + (QL - 93)0.006098

When Pn ≥ 26
If QL ≥ 95, then PF = 1.00 + (QL - 95)0.006000
If QL < 95, then PF = 1.00 + (QL - 95)0.006757

C. For sand equivalent:
When $3 \leq Pn \leq 5$
If $QL \geq 85$, then $PF = 1.00 + (QL - 85)0.000667$
If $QL < 85$, then $PF = 1.00 + (QL - 85)0.005208$

When $6 \leq Pn \leq 9$
If $QL \geq 90$, then $PF = 1.00 + (QL - 90)0.001000$
If $QL < 90$, then $PF = 1.00 + (QL - 90)0.005682$

When $10 \leq Pn \leq 25$
If $QL \geq 93$, then $PF = 1.00 + (QL - 93)0.001429$
If $QL < 93$, then $PF = 1.00 + (QL - 93)0.006098$

When $Pn \geq 26$
If $QL \geq 95$, then $PF = 1.00 + (QL - 95)0.002000$
If $QL < 95$, then $PF = 1.00 + (QL - 95)0.006757$

3. Compute the I/DP for the process:

$I/DP = (PF-1)(QR)(UP)$

where: QR = Quantity Represented by the process.
UP = Unit Price bid for the Item.

The total I/DP for an element shall be computed by accumulating the individual I/DP for each process of that element.

(d) As acceptance test results become available, they will be used to calculate accumulated QL and Incentive/Disincentive Payments (I/DP) for each element and for the item. The Contractor's test results and the accumulated calculations shall be made available to the Engineer upon request. The Engineer's test results and the calculations will be made available to the Contractor as early as reasonably practical. Numbers from the calculations shall be carried to significant figures and rounded according to AASHTO Standard Recommended Practice R-11, Rounding Method.

I/DP will be made to the Contractor in accordance with subsection 412.24(a). During production, interim I/DP will be computed for information only. The Pn will change as production continues and test results accumulate. The Pn at the time an I/DP is computed shall determine the formula to be used. After all portland cement concrete pavements have been placed according to the contract, the final I/DP will be computed.

(e) The Contractor will not have the option of accepting a price reduction or disincentive in lieu of producing specification material. Continued production of non-specification material will not be permitted. Material which is obviously defective may be isolated and rejected without regard to sampling sequence or location within a process.

Table 105-6
"V" FACTORS AND INCENTIVE PAYMENTS
COMPRESSIVE STRENGTH CRITERIA

Element	V factor	Maximum Incentive Payment	Lower Tolerance Limit, T_L
Compressive Strength	2760 kPa (400 psi)	2.00%	28 day strength, Table 601-1
Pavement Thickness	10 mm (0.4 inch)	2.00%	Plan Thickness –10 mm (-0.4")
Sand Equivalent	4%	1.00%	80%

Table 105-7
"V" FACTORS AND INCENTIVE PAYMENTS
FLEXURAL STRENGTH CRITERIA

Element	V factor	Maximum Incentive Payment	Lower Tolerance Limit, T_L
Flexural Strength	345 kPa (50 psi)	3.00%	3930 kPa (570 psi)
Pavement Thickness	10 mm (0.4 inch)	2.00%	Plan Thickness –10 mm (-0.4")

Subsection 106.03 shall include the following:

All Portland Cement Concrete Pavement, Item 412, shall be tested in accordance with the following process control and acceptance testing procedures:

(a) Process Control Testing. The Contractor shall be responsible for process control testing of all elements listed in Table 106-3 or 106-4. Process control testing shall be performed at the expense of the Contractor. If the Contractor chooses flexural strength criteria, then the Quality Control testing for flexural strength shall be performed at the expense of the Contractor. The Contractor shall develop a quality control plan (QCP) in accordance with the following:

1. Quality Control Plan. For each element listed in Tables 106-3 or 106-4, the QCP must provide adequate details to ensure that the Contractor will perform process control. The Contractor shall submit the QCP to the Engineer at the preconstruction conference. The Contractor shall not start any work on the project until the Engineer has approved the QCP in writing.

   A. Frequency of Tests or Measurements. The QCP shall indicate a random sampling frequency, which shall not be less than that shown in Table 106-3 or 106-4. The process control tests shall be independent of acceptance tests.

   B. Test Result Chart. Each process control test result, the appropriate area, volume and the tolerance limits shall be plotted. The chart shall be posted daily at a location convenient for viewing by the Engineer.

   C. Quality Level Chart. The QL for each element in Table 106-3 or 106-4 shall be plotted. The QL will be calculated in accordance with the procedure in CP 71 for Determining Quality Level. The QL will be calculated on tests 1 through 3, then tests 1 through 4, then tests 1 through 5, then thereafter the last five consecutive test results. The area of material represented by the last test result shall correspond to the QL.

D. F-test and t-test Charts. If the Contractor chooses flexural strength criteria, then the results of F-test and t-test analysis between the Department's verification tests of flexural strength and the Contractor's quality control tests of flexural strength shall be shown on charts. The F-test and t-test will be calculated in accordance with standard statistical procedures using all verification tests and quality control tests completed to date. When a verification test is completed, the F-test and t-test calculations will be redone. The area of material represented by the last test result shall correspond to the F-test and t-test. A warning value of 5% and an alert value of 1% shall be shown on each chart. The chart shall be posted daily at a location convenient for viewing by the Engineer.

2. Point of Sampling. The material for process control testing shall be sampled by the Contractor using approved procedures. Acceptable procedures are Colorado Procedures, AASHTO and ASTM. The order of precedence is Colorado Procedures, AASHTO procedures and then ASTM procedures. The location where material samples will be taken shall be indicated in the QCP.

3. Testing Standards. The QCP shall indicate which testing standards will be followed. Acceptable standards are Colorado Procedures, AASHTO and ASTM. The order of precedence is Colorado Procedures, AASHTO procedures and then ASTM procedures.

   The compressive strength test for process control will be the average strength of two test cylinders cast in plastic molds from a single sample of concrete, cured under standard laboratory conditions, and tested three to seven days after molding. The trial mix proposed and conducted by the Contractor for mix design approval shall include compressive strength data including the curing time for compressive strength process control tests. CDOT may participate in the process control testing for compressive strength at a frequency determined by the Engineer.

4. Testing Supervisor Qualifications. The person in charge of and responsible for the process control testing shall be identified in the QCP. This person shall be present on the project and possess one or more of the following qualifications:
   A. Registration as a Professional Engineer in the State of Colorado.
   B. Registration as an Engineer in Training in the State of Colorado with two years of paving experience.
   C. A Bachelor of Science in Civil Engineering or Civil Engineering Technology with three years of paving experience.
   D. National Institute for Certification in Engineering (NICET) certification at level III or higher in the subfields of Transportation Engineering Technology, Highway Materials or Construction Materials Testing Engineering Technology, Concrete and four years of paving experience.

5. Technician Qualifications. Technicians performing tests, if other than the person in responsible charge, must have a minimum of two years concrete testing experience and possess an American Concrete Institute (ACI) Laboratory Testing Technician Grade 1 certification.

6. Testing Equipment. All of the testing equipment used to conduct process control testing shall conform to the standards specified in the test procedures and be in good working order. If the Contractor chooses flexural strength criteria, then the Contractor shall provide the following equipment and supplies which will not be paid for separately but shall be included in the work:

   A. A separate, temperature controlled facility of at least 28 m^2 (300 square feet) usable space. This facility shall be used exclusively for the molding, storage and testing of concrete test specimens as required. This facility shall be provided in addition to other facilities required in Section 620. The storage facility shall have sufficient water storage capacity for curing all required test specimens. The storage facility shall provide separate storage tanks for each type of required testing. Each storage tank shall have a continuously recording thermometer and sufficient blank charts for the project. Temperatures of each storage tank shall be recorded for the duration of the project.

B. A machine for testing flexural strength of concrete specimens. The machine shall be used only for flexural strength tests. The machine shall be model number F-250F manufactured by Forney with a DFM/IV digital monitor or an approved equal. Both the Contractor and the Engineer will use this machine for testing concrete specimens. The machine and the flexural strength assembly shall be of a rigid construction. The applied vertical load shall be uniformly distributed to the third points and uniformly across the width of the beam (transverse distribution). Uniform distribution of the load is defined as less than a 3 percent variation in the load between each of the nine strain gages placed in the middle third section of the tension face for loads from 4450 to 44 500 N (1,000 to 10,000 pounds). One firm that can evaluate and assess the ability of the machine to distribute the load evenly is Construction Technology Laboratories, Skokie Illinois (847)965-7500 (Paul Okamoto), other firms may be capable of evaluating and assessing the load distribution of the machine. The Engineer must approve the firm prior to assessing the machine. The machine shall be ready for use and calibration two days before paving begins. After the machine has been calibrated and accepted by the Engineer it shall not be moved until all portland cement concrete paving and flexural strength acceptance tests have been completed.

C. Beam molds for molding all test specimens required. This shall include all testing described in subsection 106.03.

7. Reporting and Record Keeping. The Contractor shall report the results of the tests to the Engineer in writing at least once per day. The Contractor shall make provisions such that the Engineer can inspect quality control work in progress, including sampling, testing, plants, documentation and the Contractor's testing facilities at any time.

(b) Acceptance Testing. Acceptance testing frequencies shall be in accordance with Table 106-3 or Table 106-4. Except for flexural strength, acceptance tests will be conducted by and at the expense of the Department. Acceptance sampling and testing procedures will be in accordance with the Department's Field Materials Manual with the following exceptions and inclusions:

A split sample from an acceptance test shall not be used for a process quality control test. The Engineer shall designate the location where samples are to be taken. Samples shall be taken by the Contractor. The Engineer will be present during the sampling and take possession of all acceptance samples. Samples transported in different containers will be combined and mixed before molding specimens. All materials are subject to inspection and testing at all times.

Pavement thickness acceptance will be determined by cores.

The sand equivalent value will be measured according to AASHTO T 176, alternate method 1, using the average of three specimens per test.

The compressive strength test for acceptance will be the average compressive strength of three test cylinders cast in plastic molds from a single sample of concrete and cured under standard laboratory conditions prior to testing. If the compressive strength of any one specimen differs from the average by more than 10%, that specimen will be deleted and the average strength will be determined using the remaining two specimens. Each set of three cylinders will be tested at 28 days after molding.

Acceptance tests for flexural strength shall be the Contractor’s quality control tests. The flexural strength tests shall be the average flexural strength of four test beams. The test beams shall be prepared according to AASHTO T 23 with the following additional requirements: Specimens shall be consolidated by internal vibration without the vibrator being inserted in the center six inches of the specimen’s long dimension. After the initial curing, specimens shall be stored in a moist condition at 23 EC ± 2 EC (73.4 EF ± 3 EF). The flexural strength of each specimen shall be measured according to AASHTO T 97 with the following additional requirements: If the flexural strength of only one specimen differs from the average by more than 10%, that specimen shall be deleted and the average strength shall be determined using the remaining three specimens. If the flexural strength of more than one specimen differs from the average by more than 10%, the test value shall be the average of all four specimens. Each set of four beams shall be tested at 28 days after molding. Specimens shall be properly centered in the machine for

each test. Leather shims shall be used in each test. The loading rate shall remain constant after the initial loading of a maximum of 4450 N (1000 pounds) has been applied.

(c) Verification Testing. Verification testing will be used only when the Contractor chooses flexural strength criteria and is the responsibility of the Department. The Department will determine the locations where samples or measurements are to be taken. The maximum quantity of material represented by each test result and the minimum number of test results shall be in accordance with Table 106-4. The location of sampling shall be based on a stratified random procedure.

Verification sampling and testing procedures will be in accordance with Sections 105, 106, 412 and the Schedule for Minimum Materials Sampling, Testing and Inspection in the Department's Field Materials Manual, CP-13. Samples for verification and acceptance testing shall be taken by the Contractor in accordance with the designated method and shall be taken in the presence of the Engineer.

An analysis of test results will be performed after all test results are known using the t-test and F-test statistical methods using an alpha value set at 0.05. If either the above t-test and F-test analysis shows a significant difference then the following items shall be checked; comparison of beam fracture locations and types, computations and flexural testing machine outputs, curing tank temperature charts, slump and air contents, plant batch tickets for major changes, review of sampling, molding, testing procedures, along with IAT check tests and any other investigations that may clarify the significant differences. If after a review of the data no reasons can be determined for the significant difference, the Department's test data shall be used for determining Quality Levels and I/DP according to the methods in this Section.

(d) Check Testing. The Contractor and the Engineer shall conduct a check testing program (CTP) prior to the placement of any concrete pavement. The check testing program will include a conference directed by the Region Materials Engineer of the Contractor's testers and the Department's testers concerning methods, procedures and equipment for compressive or flexural strength testing. Check testing shall be completed before any portland cement concrete pavement is placed. A set of three cylinders or four beams will be molded by both the Contractor and the Department's project testers from a split sample. The specimens will be sampled, molded and cured for seven days and tested for compressive or flexural strength according to the procedures of Section 106. The Department's Independent Assurance Tester will also mold, cure and test a set of three cylinders or four beams, but the Independent Assurance Test results will not be entered in the check testing analysis. If the results of the check tests do not meet the following criteria, then the check testing will be repeated until the following criteria are met:

1. The average of the Contractor's test results and the average of the Department's test results shall be within 10% of the average of all test results.
2. Each specimen test result shall be within 15% of the average of all test results.

When the compressive strength criteria is chosen, a check test must also be conducted on the sand equivalent test. A set of 5 sand equivalents will be run by both the Contractor's and the Department's project tester, from a split sample. The average of the absolute differences between the process control and the acceptance testing personnel will be compared to the acceptable limits shown in Table 13-1 of CP-13. The CTP will be continued until the acceptance and process control test results are within the permissible ranges shown in Table 13-1 of CP-13.

During production, split samples of randomly selected acceptance tests will be compared to the permissible ranges shown in Table 13-1 of CP-13. The minimum frequency will be as shown in Table 106-3.

If production has been suspended and then resumed, the Engineer may order a CTP between process control and acceptance testing persons to assure the test results are within the permissible ranges shown in Table 106-5. Check test results shall not be included in process control testing. The Region Materials Engineer shall be called upon to resolve differences if a CTP shows unresolved differences beyond the ranges shown in Table 13-1 of CP-13.

(e) Independent Assurance Tests (IAT) for flexural strength will be performed at a frequency of 1/50 000 m^2 (1/50,000 sq. yds). The sample for the IAT will be a split sample of the Contractor's quality control test. The Department's representative performing verification tests shall also use a split sample of the Contractor's quality control test and participate in the IAT. The IAT for flexural strength will be the average flexural strength of four test beams prepared according to the requirements of Section 106 and cured for seven days.

(f) Testing Schedule. All samples used to determine I/DP by quality level formulas in accordance with Section 105, will be selected by a stratified random process.

TABLE 106-3
TESTING SCHEDULE - ITEM 412 PORTLAND CEMENT CONCRETE PAVEMENT, COMPRESSIVE STRENGTH CRITERIA

Element	Minimum Testing Frequency Contractor's Process Control	Minimum Testing Frequency CDOT Acceptance Testing
Aggregate Gradation and Fractured Faces	1/10 000 m^2 (1/10,000 sq. yds.) or one/day if less than 10 000 m^2 (10,000 sq. yds.) are placed in a day	None
Slump	First three loads each day, then as needed for control.	Witness by the Engineer.
Compressive Strength, Air Content, ' Yield and Sand Equivalent	1/2500 m^2 (1/2500 sq. yds.) or one/day if less than 2500 m^2 (2500 sq. yds.) are placed in a day.	Minimum of 1/day. If the project total < 50 000 m^2 (50,000 sq. yds.), then a minimum of ten tests. If the project total ≥50 000 m^2 (50,000 sq. yds.), then 1/5000 m^2 (1/5,000 sq. yds.).
Pavement Thickness	In accordance with subsection 412.21.	Minimum of 1/day. If the project total < 50 000 m^2 (50,000 sq. yds.), then a minimum of ten tests. If the project total ≥ 50 000 m^2 (50,000 sq. yds.), then 1/5000 m^2 (1/5000 sq. yds.).
Pull Test Joints	Minimum of six transverse and six longitudinal joint locations in each 760 m (2500 linear feet).	Witness by the Engineer.
Load Transfer Dowel Bar Placement	Minimum of six transverse joint locations in each each 760 m (2500 lineal feet).	Witness by the Engineer.
Tining Depth	1 per 160 m (528 linear feet) in each lane and shoulder wider than 2.4 m (8 feet).	Witness by the Engineer.

' Yield is for information only.

TABLE 106-4
TESTING SCHEDULE - ITEM 412 PORTLAND CEMENT CONCRETE PAVEMENT, FLEXURAL STRENGTH CRITERIA

Element	Minimum Testing Frequency Contractor's Process Control	Minimum Testing Frequency CDOT Acceptance Testing
Aggregate Gradation and Sand Equivalent	For the first five days, 1/10 000 m^2 (1/10,000 sq. yds.) or one/day if less than 10 000m^2 (10,000 sq. yds.) are placed in a day. After 5 days, 1/40 000 m^2 (1/40,000 sq. yds.).	None
Slump	First three loads each day, then as needed for control.	Witness by the Engineer.
Water Cement Ratio	First three loads each day, then 1/500 m^3 (1/500 cu. yds.).	First three loads each day, then 1/2000 m^3 (1/2000 cu. yds.).
Air Content and 'Yield	1/2500 m^2 (1/2500 sq. yds.) or one/day if less than 2500 m^2 2500 sq. yds. are placed in a day.	Minimum of 1/day. If the project total < 50 000 m^2 (50,000 sq. yds.), then a minimum of ten tests. If the project total ≥ 50 000 m^2 (50,000 sq. yds.), then 1/5000 m^2 (1/5000 sq. yds.).
Flexural Strength	1/2500 m^2 (1/2500 sq. yds.) or one/day if less than 2500 m^2 2500 sq. yds. are placed in a day.	One verification test per four quality control tests performed by the Contractor. (Approximately 1/10 000 m^2 [1/10,000 sq. yds.]).
Compressive Strength	1/10 000 m^2 (1/10,000 sq. yds.).	None
Pavement Thickness	In accordance with subsection 412.21.	Minimum of 1/day. If the project total < 50 000 m^2 (50,000 sq. yds.), then a minimum of ten tests. If the project total ≥ 50 000 m^2 (50,000 sq. yds.), then 1/5000 m^2 (1/5000 sq. yds.).
Pull Test Joints	Minimum of six transverse and six longitudinal joint locations in each 760 m (2500 linear feet).	Witness by the Engineer.
Load Transfer Dowel Bar Placement	Minimum of six transverse joint locations in each 760 m (2500 linear feet).	Witness by the Engineer.
Tining Depth	1 per 160 m (1 per 528 linear feet) in each lane and shoulder wider than 2.4 m (8 feet).	Witness by the Engineer.

'Yield is for information only.

In subsection 412.04 delete the second paragraph and replace with the following:

When the Contractor has chosen flexural strength criteria, the following requirements shall be incorporated in the mix design: The total mass (weight) of cement plus flyash shall not be less than 356 kg/m^3 (600 lbs./cu. Yd.). Cement shall be 80 percent and Class F flyash shall be 20 percent of the total mass (weight) of cement plus flyash. No concrete will be accepted with a water cement ratio greater than 0.44. The 28-day flexural strength of the laboratory trial mix shall not be less than 4482 kPa (650 psi).

In subsection 412.21, delete the fifth through tenth paragraphs and replace with the following:

The lower tolerance limit (T_L) for pavement thickness shall be Plan Thickness (PT) minus 10 mm (0.4 inches). This T_L shall be used in the formulas in Section 105 for Incentive/Disincentive Payments (I/DP), Quality Levels (QL) and Pay Factor (PF) determinations. Any pavement thickness test value that exceeds the PT by more than 25 mm (1.0 inch) shall be assigned a value of PT + 25 mm (1.0 inch) for the purpose of calculating the QL, PF and I/DP.

Coring frequency shall be in accordance with subsection 106.03. Core locations shall be determined by a random procedure so that each area has a randomly selected coring location. One core will be taken at each location.

Where the new portland cement concrete pavement overlays an existing roadway, cores for measuring pavement thickness shall be determined by a stratified random procedure in the longitudinal direction and by the point of minimum required thickness in the lateral direction as shown in the plans. If existing field conditions show a condition where the point of minimum thickness in the lateral direction as shown in the plans is not appropriate, the Contractor shall identify the location and extent of the area to the Engineer at least 24 hours before paving. The Engineer may exclude this area from pavement thickness measurements for incentive/disincentive payments.

Pavement thickness tests will be evaluated in accordance with subsection 105.03.

Additional cores will be taken at the direction of the Engineer as follows:

(1) One additional core at the location of each process control (PC) test that is less than T_L but greater than PT minus 25 mm (1.0 inch). If the length of the additional core is greater than T_L, no additional actions will be taken and the original randomly selected acceptance test core will be used to compute I/DP for the process that includes this material.

(2) If the additional core or any randomly selected core is less than T_L but greater than PT minus 25 mm (1.0 inch), the area represented by this core shall become a separate process and this core will not be used to compute an I/DP. Four additional randomly selected cores will be taken within the area represented by this core. The four additional cores will be used to compute an I/DP in accordance with Section 105. Cores taken at locations not randomly determined, such as process control cores will not be used to compute I/DP.

(3) When the measurement of any core is less than PT (Plan Thickness) minus 25 mm (1.0 inch), whether randomly located or not, the area represented by this core shall become a separate process and this core will not be used to compute an I/DP. The actual thickness of the pavement in this area will be determined by taking exploratory cores. Cores shall be taken at intervals of 4.6 m (15 feet) or less, parallel to the centerline in each direction from the affected location until two consecutive cores are found in each direction which are not less than PT minus 25 mm (1.0 inch).

Pavement areas found to be less than PT minus 25 mm (1.0 inch) shall be removed and replaced at the Contractor's expense. Exploratory cores taken at the Contractor's expense will be used to determine the extent of deficient pavement for pavement removal.

When the removal and replacement have been completed, four additional randomly selected cores will be taken within the area represented by this core. The four additional cores will be used to compute an I/DP in accordance with subsection 105.03. Exploratory cores will not be used to compute I/DP.

The Contractor shall repair all core holes by filling them with an approved non-shrink high strength grout.

Subsection 412.24(a) shall include the following:

Incentive/Disincentive Payments (I/DP) will not be made on interim estimates. I/DP will be made when the concrete pavement or a major phase of the concrete pavement has been completed and all the data for computing the I/DP is available.

Delete subsection 412.24(b) and replace with the following:

(b) Where the pavement thickness is more than Plan Thickness (PT) minus 25 mm (1.0 inch), I/DP for the element of pavement thickness will be applied to the contract unit price in accordance with subsections 105.03 and 412.21. I/DP for other elements will be applied to the contract unit in accordance with Sections 105 and 412.

Adjustments in payment because of deviations in air content will be in accordance with subsection 601.17 using \$131/m^3 (\$100.00 per cu. yd.) for the unit bid price.

Appendix C

Project Number:	F & t Test Report	Date:	November 10, 2005
Project Code (SA):			
Description:	Figure 1		
Region:			
Lot:			
Comments:	Example Only		

F Test alpha: 0.05

Compare Standard Deviations

F (calc) = 1.26

F (crit) = 5.12

No Significant Difference

Case 1

t Test alpha: 0.05

Compare Sample Means

t (calc) = 1.12

t (crit) = 2.16

No Significant Difference

Data Set 1

n =	8
mean =	690.000
St. Dev. =	15.119
Var. =	228.571

Test Results

710.00
670.00
675.00
680.00
685.00
695.00
710.00
695.00

Data Set 2

n =	7
mean =	680.714
St. Dev. =	16.938
Var. =	286.905

Test Results

680.00
700.00
660.00
690.00
660.00
675.00
700.00

Project Number: F & t Test Report
Project Code (SA):
Description: Figure 2
Region:
Lot:
Comments: Example Only

Date: November 10, 2005

F Test alpha: 0.05
Compare Standard Deviations
F (calc) = 5.35
F (crit) = 5.12

Yes Significant Difference

Case 2

t Test alpha: 0.05
Compare Sample Means
t (calc) = 0.55
t (crit) = 2.31

No Significant Difference

Data Set 1

n =	8
mean =	690.000
St. Dev. =	15.119
Var. =	228.571

Test Results

710.00
670.00
675.00
680.00
685.00
695.00
710.00
695.00

Data Set 2

n =	7
mean =	682.143
St. Dev. =	34.983
Var. =	1223.81

Test Results

725.00
720.00
670.00
710.00
645.00
655.00
650.00

Project Number: F & t Test Report
Project Code (SA):
Description: Figure 3
Region:
Lot:
Comments: Example Only

Date: November 10, 2005

F Test alpha: 0.05
Compare Standard Deviations
F (calc) = 1.17
F (crit) = 5.12

No Significant Difference

Case 1

t Test alpha: 0.05
Compare Sample Means
t (calc) = 2.81
t (crit) = 2.16

Yes Significant Difference

Data Set 1

n =	8
mean =	692.500
St. Dev. =	21.044
Var. =	442.857

Test Results

720.00
665.00
675.00
680.00
685.00
695.00
725.00
695.00

Data Set 2

n =	7
mean =	660.714
St. Dev. =	22.809
Var. =	520.238

Test Results

640.00
670.00
660.00
630.00
680.00
695.00
650.00