

The 2013 CANADIAN ASPHALT MIX EXCHANGE PROGRAM (CAMEP)

2013 Detailed Report (August 2013)

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ABSTRACT

Thirty seven Canadian engineering organizations participated in the 2013 CANADIAN ASPHALT MIX EXCHANGE PROGRAM. The exchange provides an opportunity for participants to compare their test results to those of other laboratories. It provides a mechanism for review and refinement of existing test methods and equipment. The exchange evaluates the volumetric and mechanical properties of an asphalt-aggregate mixture using Marshall mix design procedures, the gyratory compactor, and the ignition oven.

This report documents the test results for the year 2013 CANADIAN ASPHALT MIX EXCHANGE PROGRAM.

The complete report is available on the internet at the following address:

<http://www.etsmtl.ca/Unites-de-recherche/LCMB/CAMEP-CAEP>

1 INTRODUCTION

The Canadian Asphalt Mix Exchange Program (CAMEP) is part of the Canadian Asphalt and Mix Program (CAMP). The Asphalt Mix Exchange Program is operated by a steering committee under the umbrella of the Canadian User Producer Group for Asphalt (CUPGA).

In 2013, Thirty two laboratories from across Canada obtained samples for the 2013 Canadian Asphalt and Mix Program. These laboratories represent 7 government/municipal agencies and 25 private/consulting firms.

There are three parts to the 2012 Canadian Asphalt Mix Exchange Program:

- Marshall Mix Design Procedures,
- SHRP Gyratory Compactor,
- Ignition Oven.

Thirty two labs participated in the Marshall Mix Design Procedures (7 government/municipal and 25 private/consulting). Seventeen laboratories participated in the Gyratory Compactor part of the exchange program (5 government/municipal and 12 private/consulting). Thirty laboratories participated in the Ignition Oven testing (7 government/municipal and 23 private/consulting).

Participation in the exchange program is voluntary. The results cannot be used for pre-qualification or specification purposes as previously indicated in this report. Laboratory results are confidential and are presented using a randomly assigned laboratory number that is known by the particular laboratory and the co-ordinating agency only. The order of the participating laboratories shown in Tables 12, 13, and 14 is not related to the laboratory numbers used in the other tables contained in this report.

The exchange program is operated on an annual basis. Samples are shipped to participants in March. Test results are returned to the co-ordinating agency in April and the final report is made available in July/august.

For 2013, each laboratory paid a participation fee of \$420 for the first part and \$125 for every part thereafter. The cost to participate in all three parts is \$670. The participation fee is used to cover the costs associated with operating the asphalt mix exchange program. The participation fee is reviewed at the CAMP annual meeting that is held in conjunction with the Canadian Technical Asphalt Association annual conference. Mix exchange packages are shipped collect to the participating laboratories.

École de technologie supérieure is the co-ordinating agency for the mix exchange program. The responsibilities include:

- developing participant lists
- providing instructions for handling and testing of the materials
- supplying data collection forms
- arranging and co-ordinating material suppliers
- preparing, packaging and shipping aggregate and asphalt samples
- collecting and compiling the test data
- preparing a final report that is available to all participants
- preparing a final report for the CTAA (Canadian Technical Asphalt Association) Annual Proceedings.

2 INSTRUCTIONS TO PARTICIPANTS (MARSHALL MIX)

Each asphalt mix exchange participant package contains seventeen prepared aggregate samples and two litres of asphalt cement. The aggregate samples are prepared by splitting raw aggregate samples on each of the sieves shown in Table 1. The weight of each individual sieve size, to be combined for the exchange aggregate samples, is established through a trial and error process. Each aggregate test sample is prepared by weighing the individual size components and recombining them.

The following samples are distributed:

- Seventeen (17) aggregate samples
- Two (2) asphalt cement samples

The aggregate samples are to be used as follows:

- Eight (8) 1,200.0 gram samples for Marshall briquettes.
- Three (3) 2,000.0 gram samples for Asphalt Mix Maximum Theoretical Density.
- Three (3) 2,000.0 gram samples for Coarse Aggregate Relative Density.
- Three (3) 1,000.0 gram samples for Fine Aggregate Relative Density.

NOTE:

- **The filler relative density is 2.700.**
- **Asphalt Cement**
Two litres of PG64-34 have been provided. To ensure consistency, the following values should be used:
 - Specific gravity 1.016
 - Mixing temperature 168°C
 - Compaction temperature 152°C

Aggregate samples are ready for use with the following exceptions:

- a) The coarse aggregate relative density samples must be washed and sieved on the 5.0 mm sieve as specified by ASTM C127 Standard Test Method for Specific Gravity and Absorption of Coarse Aggregate.
- b) The fine aggregate relative density samples shall be tested according to ASTM C128 Standard Test Method for Specific Gravity and Absorption of Fine Aggregate. They must be washed on the 75 µm sieve.
- c) Aggregate Sieve Analysis.

Table 1: Aggregate Sieve Analysis

Sieve	Percent Passing
14.0 mm	100.0
10.0 mm	100.0
5.0 mm	55
2.5 mm	35
1.25 mm	30
630 µm	25
315 µm	15
160 µm	10
80µm	7

2.1 Aggregate Relative Density and Water Absorption

Three determinations are made on each of the individual pre-weighed coarse and fine aggregate samples. The coarse aggregate density is obtained by following ASTM C127 Standard Test Method for DENSITY, RELATIVE DENSITY (SPECIFIC GRAVITY), AND ABSORPTION OF COARSE AGGREGATE. The fine aggregate density is determined by following ASTM C128 Standard Test Method for DENSITY, RELATIVE DENSITY (SPECIFIC GRAVITY) AND ABSORPTION OF FINE AGGREGATE. Both aggregate densities are reported to four (4) significant figures.

The following interpretative revisions to ASTM C128 were agreed to at the 1989 Canadian Asphalt Mix Exchange meeting. All participants are to incorporate the following into their procedures:

1. The fine aggregate should again be washed after the 24 hour immersion period.
2. For the cone test, do not refill the cone after each tamping.

During the May 29, 1989 General Technical Meeting, most agencies indicated that a fan is used to dry aggregate when determining the aggregate specific gravity (as allowed by ASTM). This procedure is to be incorporated by all participants.

The water absorption for the two aggregates is determined during the aggregate relative density testing in accordance with the respective ASTM procedures. The combined percentage water absorption is based on a blend of 45 % of the average held on the 5.0 mm sieve and 55 % of the average passing the 5.0 mm sieve.

2.2 Maximum Theoretical Density

Aggregate for the eight Marshall compaction briquettes have been labelled, "1".

The aggregate samples have been pre-weighed to 1,200.0 grams. 63.0 grams of asphalt cement will be added to the aggregate samples to prepare the Marshall compaction briquettes. (5.25% asphalt content based on dry weight of aggregate or 5.0% asphalt content on a total mix basis).

Aggregate for the Maximum Theoretical Density (MTD) samples has been pre-weighed to 2,000.0 grams to which 105.0 grams of asphalt cement will be added to achieve an asphalt content of 5.60% based on the dry weight of aggregate. The test for MTD shall follow AASHTO T 209 Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixtures. **The only deviations from AASHTO T 209 are:**

- the 2000 g aggregate samples provided shall be mixed at 150°C, and

- the mix samples shall be conditioned for four hours at the compaction temperature of 135°C.

The results for this Theoretical Maximum Specific Gravity and Density test shall be used for determining the air voids of the Marshall briquettes and the percent asphalt absorption.

NOTE:

- If for some reason the aggregate mass varies from that specified, the asphalt cement mass should be calculated based on the new aggregate mass to achieve an asphalt cement content of 5.60% by weight of dry aggregate.

2.3 Aggregate Relative Density and Water Absorption

Three determinations are to be made on each of the coarse and fine aggregates using the individual pre-weighed samples. The coarse relative density shall follow ASTM C127. The fine relative density shall follow ASTM C128. Aggregate relative density is to be reported to four (4) significant figures.

The following interpretative revisions to ASTM C128 were agreed to at the 1989 Asphalt Mix Exchange. All participants should incorporate the following into their procedures:

1. The fine aggregate should again be washed after the 24 hour immersion period.
2. For the Cone Test, do not refill the cone after each tamping.

NOTE:

- **During the May 29, 1989 General Technical Meeting, most agencies indicated that a fan is being used to dry aggregate for determining bulk specific gravity, as allowed by ASTM.**

The following interpretative revisions to ASTM C128 were agreed to at the 1989 Asphalt Mix Exchange. All participants should incorporate the following into their procedures:

- The water absorption for the two aggregates shall be determined during the relative density testing in accordance with the respective ASTM procedures and reported.
- The combined percentage water absorption is based on a blend of 54% of the average held on the 5.0 mm sieve and 46 % of the average passing the 5.00 mm sieve.

Asphalt absorption determination shall follow ASTM D4469 Standard Test Method for Calculating Percent Asphalt Absorption by the Aggregate in an Asphalt Pavement Mixture.

2.4 Asphalt Absorption

Asphalt absorption determination shall follow ASTM D4469 Standard Test Method for Calculating Percent Asphalt Absorption by the Aggregate in an Asphalt Pavement Mixture.

2.5 Asphalt Cement Content and Asphalt Mix Sample Preparation

Eight (8) briquettes with an asphalt cement content of 5.25% (by weight of dry aggregate basis) are to be prepared separately by adding 63 g of asphalt cement.

Three MTD samples with an asphalt cement content of 5.25% (by weight of dry aggregate basis) are to be prepared by adding 105 g of asphalt cement.

The following procedures are to be followed to ensure uniformity in preparation of the asphalt mix samples:

Mixing

1. Aggregates shall be heated for 12 hours minimum at a temperature of 110°C ± 5°C prior to adding asphalt.

2. Mixing should be done at 168°C using a "**buttered**" mixing pan. The mixing pan should not be totally clean but should contain the residue from previous mixing that is left after scraping with a spoon and/or spatula.
3. The asphalt cement added should be the percentage specified and no allowance should be made for asphalt cement that is left sticking to the sides of the mixing pan.
4. All mixing is to be done by hand using a spoon and a spatula.

Compaction

A total of eight (8) briquettes will be manufactured: four (4) by hand compaction and four by (4) mechanical compaction.

Hand compaction shall be **75 BLOWS** to each face at 152°C. Mechanical compaction should be based on the equivalent blow count to each face that your laboratory correlates to 75 blows of the hand hammer at 152°C.

1. The compaction pedestal shall follow specifications from AASHTO T245 Standard Test Method for Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus and shall be secured to a solid concrete slab.
2. For a bevelled compaction hammer, the thickest part of the compaction foot shall be placed toward the chain of the mechanical compactor at the start of compaction.
3. Briquettes are manufactured one at a time. Do not combine samples.
4. Manufactured briquettes will be air cooled for one hour before they are removed from the mould.
5. The briquettes shall not be removed from the mould by applying blows to the face but rather by a constant applied pressure.

Marshall Mix Design Characteristics

1. Bulk specific gravity and density determination for briquettes shall be as specified in ASTM D2726 Standard Test Method for Bulk Specific Gravity and Density of Non-Absorptive Compacted Bituminous Mixtures.
2. Marshall stability and flow determination for briquettes shall be as specified in AASHTO T245.
3. Bulk specific gravity, Marshall stability and flow testing shall be performed 24 hours after the briquettes have been compacted.

Flow shall be measured using flow meters on each guide rod. The average flow value is recorded if hand flow meters are used. Please specify if some other method is being used.

2.6 Calculated Data

For the four (4) hand compacted and four (4) mechanically compacted briquettes, each lab uses their determination of the aggregate bulk density, the bulk density of the compacted mixture and the maximum theoretical density of the asphalt-aggregate mixture to compute:

- percent voids in the mineral aggregate (*VMA*)
- percent air voids (*AV*)
- percent voids filled (*VF*)

The void characteristics are calculated using the following formulae:

Percent Voids in the Mineral Aggregate (*VMA*)

$$VMA = 100 - \left(\frac{G_{mb}}{G_{sb}} \times \frac{100}{100 + P_b} \right) \times 100$$

Percent Air Voids (*AV*)

$$AV = 100 \times \left(1 - \frac{G_{mb}}{G_{mm}} \right)$$

Percent Voids Filled with Asphalt (*VF*)

$$VF = \left(\frac{VMA - AV}{VMA} \right) \times 100$$

Percent Water Absorption (*WA*)

$$WA = \left(\frac{B - A}{A} \right) \times 100$$

Where:

Units

G_{mb}	= bulk density of the compacted mixture	(g/cm ³)
G_{sb}	= bulk density of the aggregate	(g/cm ³)
P_b	= asphalt content of the mix (% by weight of dry aggregate)	(%)
G_{mm}	= maximum theoretical density of the asphalt-aggregate mixture	(g/cm ³)
B	= weight of saturated surface dry aggregate	(g)
A	= dry weight of aggregate	(g)

2.7 Mechanical Compaction Equipment Data

Each laboratory must provide a description of the mechanical compaction equipment used. This required information includes:

- number of blows,
- mass of the compaction hammer (kg),
- drop of the hammer (mm),
- type of spring in the hammer,
- thickness of the compaction foot (mm),
- the high and low thickness (if the compaction foot is bevelled),
- type of base (rotating or stationary),
- type and trade name of the mechanical compactor (e.g., home-made, Soil test, Pine Instrument, double acting, etc.).

3 INSTRUCTIONS TO PARTICIPANTS (GYRATORY COMPACTOR)

Please note that at the November 2008 CAMP technical meeting, it was agreed that only the determination of the Bulk Density at $N_{design} = 75$ gyrations is required for this part of the proficiency exchange.

3.1 Mix Ingredients

The mix, consisting of processed aggregates, is a standard surface mix for Transport Quebec. The aggregates and the asphalt cement were provided by Transport Quebec.

3.2 Guidelines for Gyratory Compaction

- a) Mixing Temperature = 151°C
- b) Compaction Temperature = 135°C
- c) $N_{\text{Design}} = 75$ gyrations
- d) Asphalt Content = 5.0% by total weight of mix (258 grams to be added to each sample)
- e) If for some reason the aggregate mass varied from that specified, the labs are to adjust the asphalt mass so that the desired asphalt content is maintained.

3.3 Sample Container

Your Gyratory Compactor asphalt mix exchange participant package consists of the following materials:

- aggregate samples
- 1 asphalt cement sample

The aggregate samples are to be used as follows: Three (3) 4,900.0 gram samples for the Gyratory Compactor testing.

3.4 Preparation of Aggregate

Place the pan containing the aggregate in an oven set approximately 15°C higher than the mixing temperature. Two to four hours are required for the aggregate to reach the mixing temperature. While aggregate is heating, heat all mixing implements such as spatulas, mixing bowl and other tools.

Heat the asphalt binder to the desired mixing temperature. The time required for this step varies depending on the amount of asphalt and the heating method. Preheat a forced draft oven to 135°C to use for short term aging of the test specimens immediately after mixing.

3.5 Preparation of Mixture

Place the hot mixing bowl on a scale and zero the scale. Charge the mixing bowl with the heated aggregates and dry mix thoroughly.

Form a crater in the blended aggregate and weigh the required asphalt into the mixture to achieve the desired batch weight.

Remove the mixing bowl from the scale and mix the asphalt and aggregate. Mix the specimen until the aggregate is thoroughly coated. Place the mix in a flat shallow pan at an even thickness of 21 – 22 kg/m² and place the pan in the forced draft oven at 135°C. Short term age the specimen for 2 hours in accordance with AASHTO R30.

Repeat this procedure until the desired number of specimens is produced. Proper timing of the gyratory compaction steps can be achieved by spacing approximately 20 minutes between mixing each specimen and proceeding with compaction.

3.6 Compaction of Specimens

The compaction of the specimens and the determination of the bulk density will be conducted in accordance with AASHTO T312 and AASHTO R35.

3.7 Preparation Instructions

Complete instructions and a data sheet are included in the package to ensure uniformity between the labs. Three specimens are prepared and tested.

Aggregate Preparation

The following procedures are used to prepare the aggregate:

1. The aggregate is placed in a pan and heated in an oven for two to four hours until the mixing temperature is reached. The oven temperature is set approximately 15 °C higher than the mixing temperature. All the mixing implements are heated at the same time.
2. The asphalt binder is heated to the desired mixing temperature.
3. A forced draft mixing oven is preheated to 135 °C for use in short term aging of the test specimens.

Mixture Preparation

The following procedures are used to prepare the mixture:

1. Place the hot mixing bowl on a scale and zero the scale.
2. Charge the mixing bowl with the heated aggregates and dry mix thoroughly.
3. Form a crater in the blended aggregate and weigh the required asphalt into the mixture to achieve the desired batch weight.
4. Remove the mixing bowl from the scale and mix the asphalt and the aggregate until the aggregate is thoroughly coated.
5. Place the mixture in a flat shallow pan to an even thickness of 21-22 kg/m² and put the pan in the forced draft oven at 135 °C.
6. Short term age the specimen for 2 hours in accordance with AASHTO R30.
7. Repeat this process for each specimen.
8. Proper timing of the gyratory compaction steps can be achieved by spacing approximately 20 minutes between mixing each specimen and proceeding with compaction.

3.8 Compaction of Specimens

The compaction of the specimens and the determination of the bulk density will be conducted in accordance with AASHTO T312 and AASHTO R35.

3.9 Gyratory Compactor Characteristics

The bulk density at 75 gyrations is determined after the specimens are compacted with the gyratory compactor.

4 PARTICIPANT SAMPLE PACKAGES (IGNITION OVEN)

Each ignition oven participant package contains three 1,500 gram aggregate samples, three asphalt mix samples and one asphalt cement sample. The three aggregate samples are used to calibrate the ignition oven; the three asphalt mix samples are used for the ignition oven tests.

5 INSTRUCTIONS TO PARTICIPANTS (IGNITION OVEN)

5.1 Calibration

Calibration testing is to be completed on the three 1,500.0 gram samples supplied for the Ignition Oven calibration.

The aggregate samples have been pre-weighed to 1,500.0 grams. The Ignition Oven calibration testing is to be completed at an asphalt content of 5.2% based on the dry weight of aggregate (4.93% asphalt

content based on a total mix basis).

Three samples are to be prepared separately by adding 78.0 grams of asphalt to the aggregate in order to obtain the desired asphalt content of 5.2% based on the dry weight of the aggregate.

Three determinations will be made to establish a calibration factor.

Note:

- **If for some reason the aggregate mass varies from that specified, the asphalt cement mass should be calculated based on the new aggregate mass to achieve an asphalt cement content of 5.2% by weight of dry aggregate.**

Mixing

4. Aggregates shall be heated for 12 hours minimum at a temperature of $110^{\circ}\text{C} \pm 5^{\circ}\text{C}$ prior to adding asphalt.
5. Mixing should be done at 150°C using a "buttered" mixing pan. The mixing pan should not be totally clean but should contain the residue from previous mixing that is left after scraping with a spoon and/or spatula.
6. The asphalt cement added should be the percentage specified and no allowance should be made for asphalt cement that is left sticking to the sides of the mixing pan.
7. All mixing is to be done by hand using a spoon and a spatula.
8. After the sample is mixed, record the mass of the total mixture to the nearest 0.1 gram as M_{PC1} .
9. Repeat the process for the other two samples and record the mass of the total mixture to the nearest 0.1 gram as M_{PC2} and M_{PC3} .

Testing

7. After the samples are prepared, the asphalt content should be determined using:

ASTM D6307 Standard Test Method for Asphalt Content of Hot-Mix Asphalt by Ignition Method.

8. After the asphalt is burned off in the ignition oven, determine the mass of the remaining sample to the nearest 0.1 gram and record it as M_{AC1} , M_{AC2} and M_{AC3} .

Note:

- **Ensure that the mass recorded as M_{AC1} , M_{AC2} and M_{AC3} are from the same samples as the masses recorded for M_{PC1} , M_{PC2} and M_{PC3} respectively.**

Calculations

10. Calculate the measured percent mass loss (C_{sx}) for each sample using the equation in ASTM D 6307:

$$C_{sx} = \left(\frac{M_{PCx} - M_{ACx}}{M_{PCx}} \times 100 \right) - \% AC$$

C_{sx} = Measured mass loss of the calibration sample

x = Calibration sample number, where $x = 1$ or $x = 2$ or $x = 3$.

M_{PCx} = Total mass of the mixture calibration sample prior to ignition.

M_{ACx} = Total mass of the mixture calibration sample after ignition.

$\%AC$ = Percentage of the actual asphalt cement in the mix by **mass of the total mix** expressed as a percentage (e.g. 5%).

11. Record the measured mass loss of the calibration sample for each sample on the test result sheet, in the “Data Collection and Submission Forms” section of these instructions.
12. Calculate the average calibration factor (C_F) using the following equation:

$$C_F = \frac{C_{S1} + C_{S2} + C_{S3}}{3}$$

Where:

C_F = Average measured mass loss of the calibration samples expressed as a percentage

C_{S1} = Measured mass loss of calibration sample 1

C_{S2} = Measured mass loss of calibration sample 2

C_{S3} = Measured mass loss of calibration sample 3

13. Compute and record the average calibration factor on the test result sheet in the “Data Collection and Submission Forms” section of these instructions.

Testing

The following process was used to ensure uniformity in ignition oven testing:

1. After the samples are prepared, the asphalt content will be determined using:
 - ASTM D6307 STANDARD TEST METHOD FOR ASPHALT CONTENT OF HOT-MIX ASPHALT BY IGNITION METHOD.
2. After the asphalt is burned off in the ignition oven, determine the mass of the remaining sample to 0.1 gram and record it as M_{AC1} , M_{AC2} , and M_{AC3} . The masses recorded as M_{AC1} , M_{AC2} , and M_{AC3} should correspond to the samples that have masses of M_{PC1} , M_{PC2} , and M_{PC3} respectively.

Calculations

A correction factor for the calibration samples is determined.

1. Calculate the measured percent mass loss (C_{Sx}) for each sample using the equation in ASTM D6307:

$$C_{Sx} = \left(\frac{M_{PCx} - M_{ACx}}{M_{PCx}} \times 100 \right) - \%AC$$

Where:	Units
C_{Sx} = Measured mass loss of the calibration sample.	(%)
x = Calibration sample number, where $x = 1$ or $x = 2$ or $x = 3$.	
M_{PCx} = Total mass of the mixture calibration sample prior to ignition.	(g)
M_{ACx} = Total mass of the mixture calibration sample after ignition.	(g)
$\%AC$ = Percentage of the actual asphalt cement in the mix by mass of the total mix.	(%)

- Calculate the average calibration factor (CF) using the following equation:

$$C_F = \frac{C_{S1} + C_{S2} + C_{S3}}{3}$$

Where:	Units
C_F = Average measured mass loss of the calibration sample expressed as a (%) percentage.	
C_{S1} = Measured mass loss of calibration sample 1.	(%)
C_{S2} = Measured mass loss of calibration sample 2.	(%)
C_{S3} = Measured mass loss of calibration sample 3.	(%)

5.2 Testing of premixed asphalt samples

After the correction factor is determined, ignition oven testing is completed on the other three premixed asphalt mix samples. The asphalt mix samples have been pre-mixed with a predetermined amount of asphalt that is known only to the coordinating agency.

Preparation of asphalt mix samples

- In accordance with AASHTO T308 or ASTM D6307, oven dry each hot mix sample at a temperature of $105^{\circ}\text{C} \pm 5^{\circ}\text{C}$ to constant mass.
- Record the mass of the total mixture to the nearest 0.1 gram as M_{PT1} .
- Ensure the sample has been softened enough to distribute evenly in the sample basket.
- Repeat the process for the other two samples and record the mass of the total mixture to the nearest 0.1 gram as of the total mixture to the nearest 0.1 gram as M_{PT2} and M_{PT3} .

Testing

The following process is used to ensure uniformity in the ignition oven testing:

- After the samples are prepared, the asphalt content will be determined using AASHTO T308 or ASTM D6307.
- After the asphalt is burned off in the ignition oven, determine the mass of the remaining samples to 0.1 gram and record it as M_{AT1} , M_{AT2} , and M_{AT3} . The masses recorded as M_{AT1} , M_{AT2} , and M_{AT3} should correspond to the samples that have masses of M_{PT1} , M_{PT2} , and M_{PT3} respectively.

Calculations

- Calculate the corrected asphalt content ($\%AC_x$) using the equation in ASTM D6307:

$$\%AC_x = \left(\frac{M_{PTX} - M_{ATX}}{M_{PTX}} \times 100 \right) - C_F$$

Where:

Units

$\%AC_x$	= Measured percent asphalt content by mass of the oven-dry HMA sample.	(%)
C_F	= Calibration factor as determined above, expressed as a percentage.	(%)
x	= Testing sample number (1, 2 or 3).	
M_{PTX}	= Total mass of the mixture testing sample prior to ignition.	(g)
M_{ATX}	= Total mass of the aggregate remaining after ignition.	(g)

2. Calculate the asphalt content percent ($\%AC_x$) by mass of the oven dry HMA for each sample and record on the result sheet.
3. Compute and record the asphalt content ($\%AC_x$) by dry weight of aggregate for each sample and record on the test result sheet. Use the following equation:

$$\%AC_{\text{DRY WEIGHT AGGREGATE}} = \frac{\%AC_{\text{OVEN DRY}}}{1 - \left(\frac{\%AC_{\text{OVEN DRY}}}{100} \right)}$$

The results shown in Table 11.1 provide asphalt content by mass of oven-dry HMA samples.

6 SUMMARY OF TEST RESULTS

6.1 Background

The 2013 asphalt mix exchange test results are analysed using ASTM test procedure E691, Standard Practice for Conducting an Inter-laboratory Study to Determine the Precision of a Test Method.

The repeatability standard deviation, s_r , is a measure of the variability that can be expected within-laboratory under repeatability conditions. It usually refers to the single operator variability that can be expected when the operator, equipment, equipment calibration, and environment (temperature, humidity, etc.) have a minimal effect on the variability of test results within a lab.

The reproducibility standard deviation, s_R , is a measure of between-laboratory variability. It refers to the variability that can be expected when the operator, equipment, equipment calibration, and environment (temperature, humidity, etc.) have a significant effect on the variability of test results between different labs.

The k consistency statistic is used to examine the consistency of test results within a laboratory. This value indicates how a lab's within-laboratory variability (under repeatability conditions on a particular material) compares with the within-laboratory variability of all the other laboratories combined. The k consistency statistic is calculated for each lab and then compared to a critical value, k_{crit} . If a lab's k consistency statistic exceeds the critical value, then it is likely that they are having problems repeating test results in their laboratory. The critical value is determined using a statistical calculation based on an F-Test at a 0.5% level

of significance. The critical value is a function of the level of significance, the number of labs involved in the testing and the number of replicate samples.

The h consistency statistic is used to examine the consistency of test results between laboratories. This value indicates how a lab's average test result (under repeatability conditions on a particular material) compares to the average obtained by all of the other laboratories involved in the testing program. The h consistency statistic is calculated for each lab and compared to a critical value, h_{crit} . If a lab's h consistency statistics exceeds the critical value, then it is likely that they are having problems correlating test results with other laboratories. The critical value is determined using a statistical calculation based on a Student's t-Test at a 0.5% level of significance. The critical value is a function of the level of significance and the number of labs involved in the testing.

The level of significance is the probability of incorrectly deciding that two data sets are different when in fact they are the same. At a 0.5% level of significance, only 1 in every 200 times will a lab be identified as having some type of testing problem; when in fact they do not. ASTM E691 Standard Practice for Conducting an Inter-laboratory Study to Determine the Precision of a Test Method suggests that a 0.5% level of significance is appropriate for this type of analysis.

6.2 Test Results

A summary of the results for each test procedure used in the Marshall Mix, Gyratory Compactor, and Ignition Oven parts of the exchange is presented in Table 15. The following information is provided:

- The average value
- The repeatability and reproducibility standard deviations
- The 95% confidence limits for repeatability and reproducibility
- The labs that exceed or are close to the critical h or k statistics.

As an example, for the Bulk Density of the Coarse Aggregate in Table 15, the average value reported by all of the laboratories is 2.7258. The repeatability standard deviation, s_r , is 0.0079 and reproducibility standard deviation, s_R , is 0.0142.

The 95% confidence limit for repeatability is computed with the following equation:

$$95\% \text{ Repeatability Confidence Limit} = 1.96 * \sqrt{2} * s_r$$

The 95% confidence limit for repeatability means that approximately 95% of all pairs of test results on a given material from within a laboratory can be expected to differ in absolute value by $1.96 * \sqrt{2} * s_r$. For example, the Bulk Density of the Coarse Aggregate 95% Confidence Limit for Repeatability is computed to be $1.96 * \sqrt{2} * 0.0079 = 0.022$. This means that approximately 95% of all pairs of test results on a given material from within a laboratory can be expected to differ in absolute value by 0.022. In other words, two test results from the same lab on the same material will be considered suspect if they differ in absolute value by more than 0.022.

The 95% confidence limit for reproducibility is computed with the following equation:

$$95\% \text{ Reproducibility Confidence Limit} = 1.96 * \sqrt{2} * s_R$$

The 95% confidence limit for reproducibility means that approximately 95% of all pairs of test results on a given material from between laboratories can be expected to differ in absolute value by $1.96 * \sqrt{2} * s_R$. For example, the Bulk Density of the Coarse Aggregate 95% Confidence Limit for Reproducibility is computed to be $1.96 * \sqrt{2} * 0.0126 = 0.0393$. This means that approximately 95% of all pairs of test results on a given material from between two laboratories can be expected to differ in absolute value by 0.0393. In other words, two test results from different labs on the same material will be considered suspect if they differ in absolute value by more than 0.0393.

Table 15 indicates which labs have between-laboratory consistency statistics (h consistency statistic) that exceed (Labs Out h -stat) or are close (Labs Close h -stat) to the critical between-laboratory consistency statistic, h_{crit} . This table also shows the laboratories that have within-laboratory consistency statistics (k consistency statistic) that exceed (Labs Out k -stat) or are close (Labs Close k -stat) to the critical within-laboratory consistency statistic, k_{crit} .

If a lab has a between-laboratory consistency statistic (h consistency statistic) that exceeds the critical between-laboratory consistency statistic, h_{crit} , then its average test result is significantly different from the average obtained by the other laboratories. It may have difficulty correlating to other laboratories and should investigate its testing equipment and procedures.

Using Bulk Density of Coarse Aggregate from Table 1.2 as an example, lab 10 has a between-laboratory consistency statistics (h consistency statistic) that exceeds the critical consistency statistic, h_{crit} . The laboratory average test results are significantly different from the average obtained by the other laboratories. They may have difficulty correlating to other laboratories and should investigate their testing equipment and procedures.

If a lab has a between-laboratory consistency statistic (h consistency statistic) that is close to the critical between-laboratory consistency statistic, h_{crit} , then its average test result is not significantly different from the average obtained by the other laboratories. However, the lab may want to consider taking precautions to ensure that there are not any problems with its testing procedures and equipment.

If a lab has a within-laboratory consistency statistic (k consistency statistic) that exceeds the critical within-laboratory consistency statistic, k_{crit} , then its within-laboratory standard deviation is significantly different from that obtained by all of the laboratories combined. The laboratory is having problems repeating test results in its own laboratory and should investigate its testing procedures and equipment.

Using Bulk Density of Fine Aggregate from Table 1.1 as an example, lab 29 has a within-laboratory consistency statistic (k consistency statistic) that exceeds the critical consistency statistic, k_{crit} . The within-laboratory standard deviation is significantly different from that obtained by all of the laboratories combined. They may have problems repeating the test results in their own lab and should investigate their testing procedures and equipment.

If a lab has a within-laboratory consistency statistic (k consistency statistic) that is close to the critical within-laboratory consistency statistic, k_{crit} , then its within-laboratory standard deviation is not significantly different from that obtained by all of the laboratories combined. However, the lab may want to consider taking precautions to ensure that there are not any problems with its testing procedures and equipment.

7 ADDITIONAL INFORMATION

The complete set of test results is presented in Appendix A (Tables 1.1 – 11.1). Graphs representing the k-consistency statistic, for within laboratory variability, and the h-consistency statistic, for between laboratory variability, are also included in Appendix A.

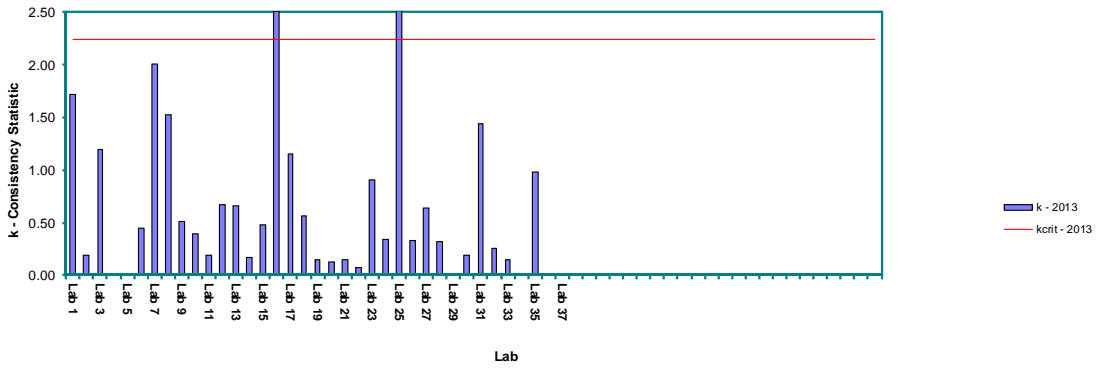
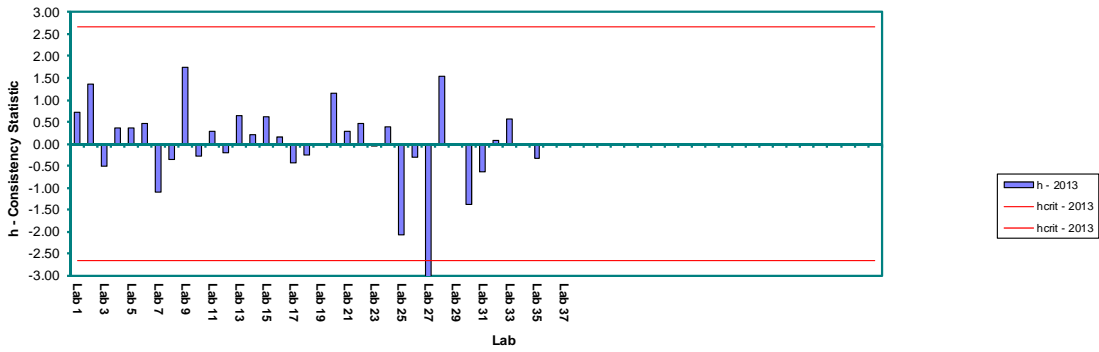
The definitions and formulae for the statistical equations used in the analysis of the test results are included in Appendix B. Additional elaboration on the statistical analysis can be found in ASTM E691 Standard Practice for Conducting an Inter-laboratory Study to Determine the Precision of a Test Method.

The entire report is available for viewing and/ or printing from the following Internet address:
<http://www.etsmtl.ca/Unites-de-recherche/LCMB/CAMEP-CAEP>

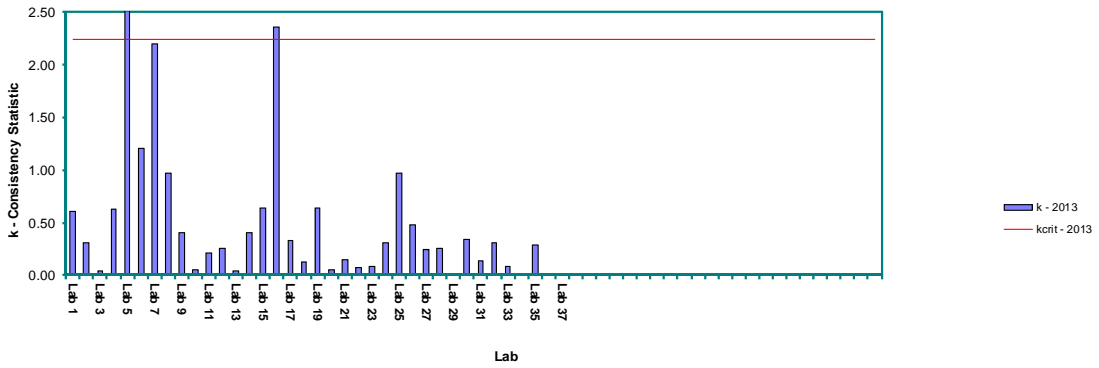
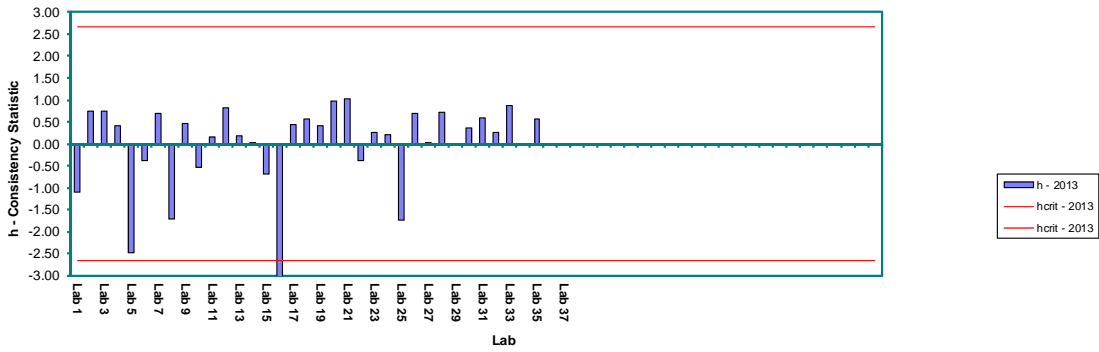
Questions pertaining to the Canadian Asphalt Mix Exchange Program can be directed to:

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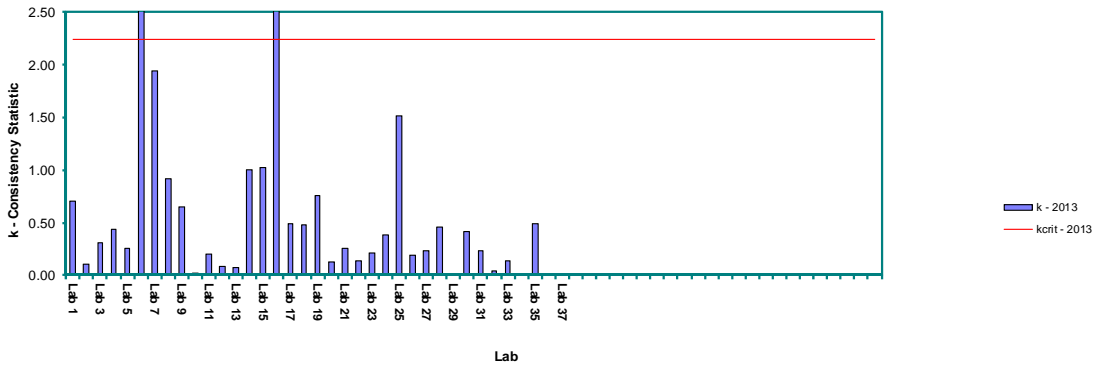
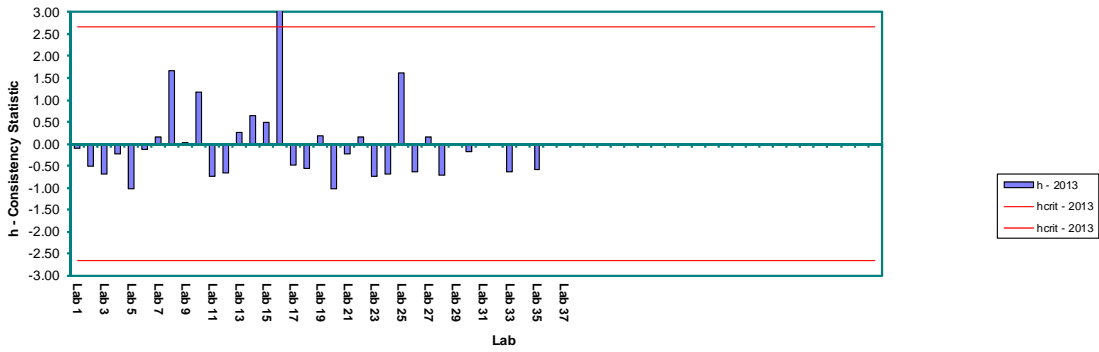
Appendix A



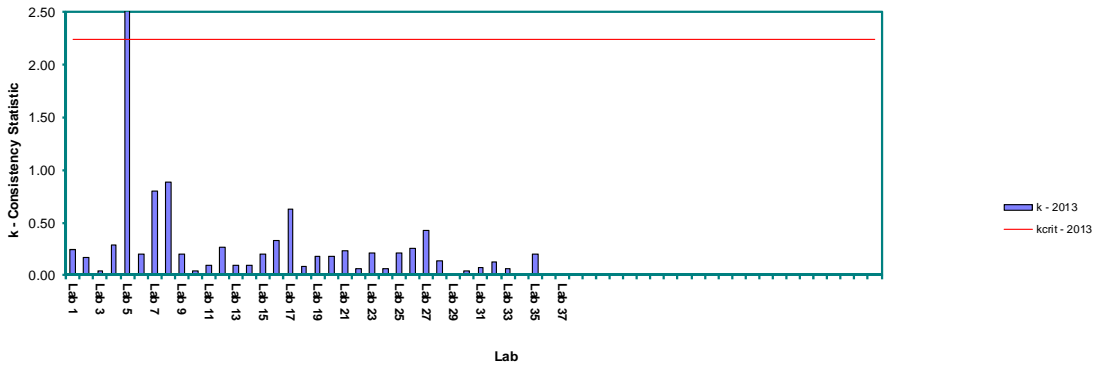
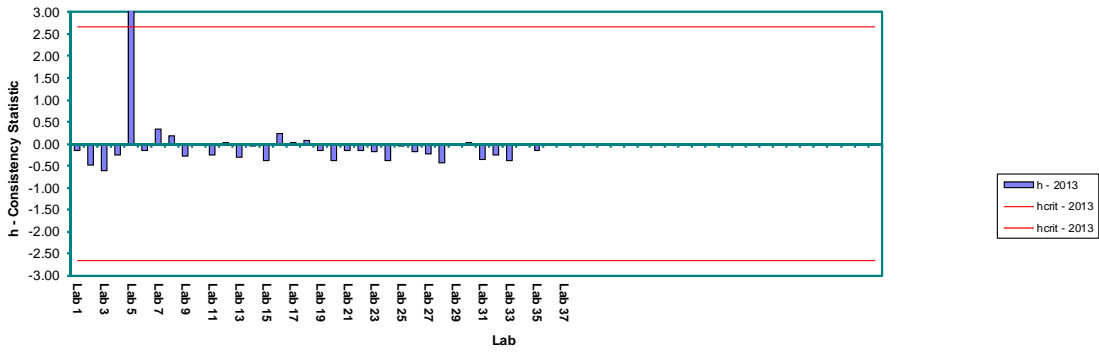
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\bar{X}_{ave} = Cell Average	$s_{(ave)}$ = Standard Deviation of Cell Averages	
n = Number of Test Results per Cell	s_r = Repeatability Standard Deviation	
s = Cell Standard Deviation	s_{Ri} = Interim Reproducibility Standard Deviation	
d = Cell Deviation ($X_{ave} - (\bar{X}_{ave})_{ave}$)	s_R = Reproducibility Standard Deviation (Larger of s_r and s_{Ri})	
s^2 = Cell Variation	h = Between Laboratory Consistency Statistic	
p = Number of Laboratories	k = Within Laboratory Consistency Statistic	
h_{crit} = Critical Between Laboratory Consistency Statistic	r = 95% Confidence Limit for Repeatability	
k_{crit} = Critical Within Laboratory Consistency Statistic	R = 95% Confidence Limit for Reproducibility	



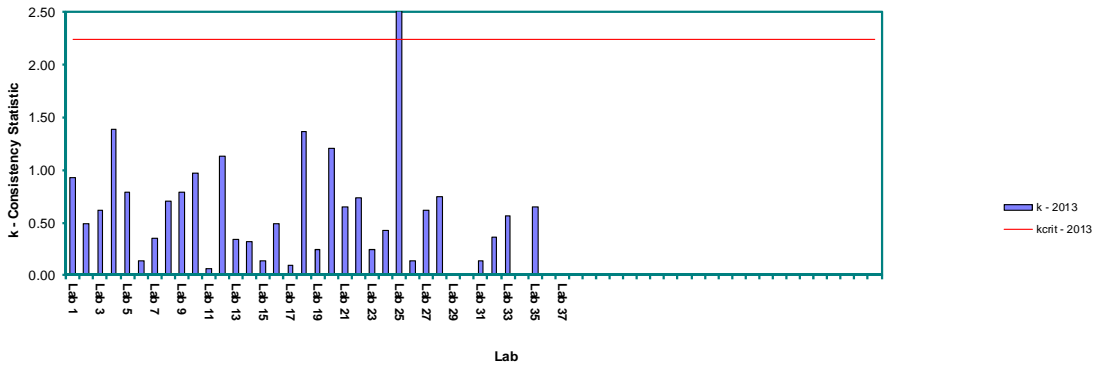
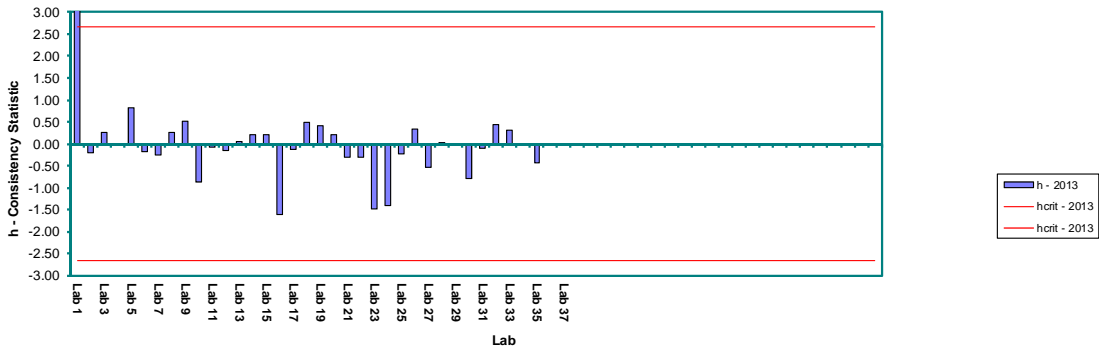
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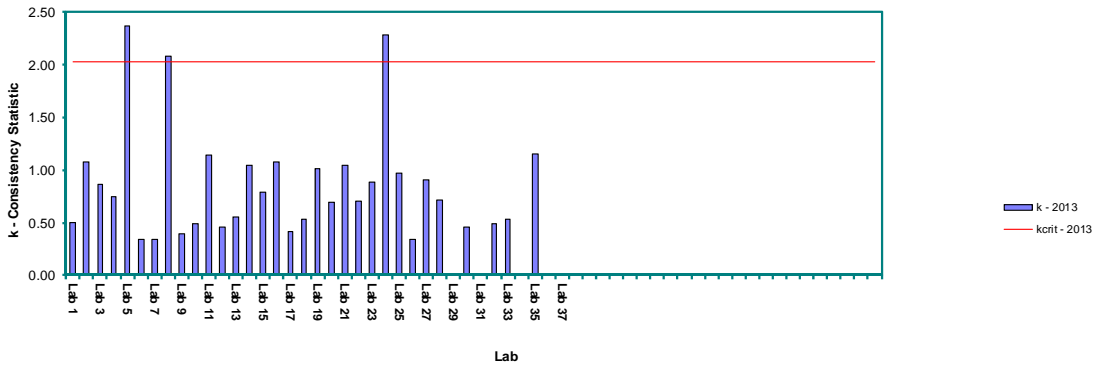
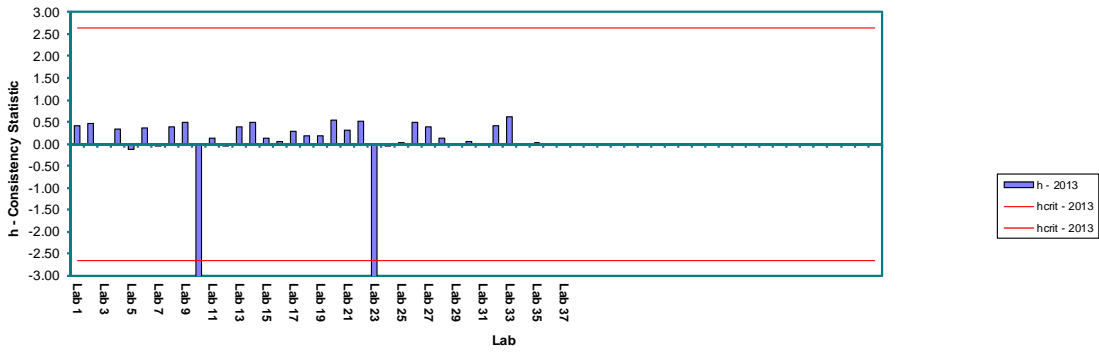
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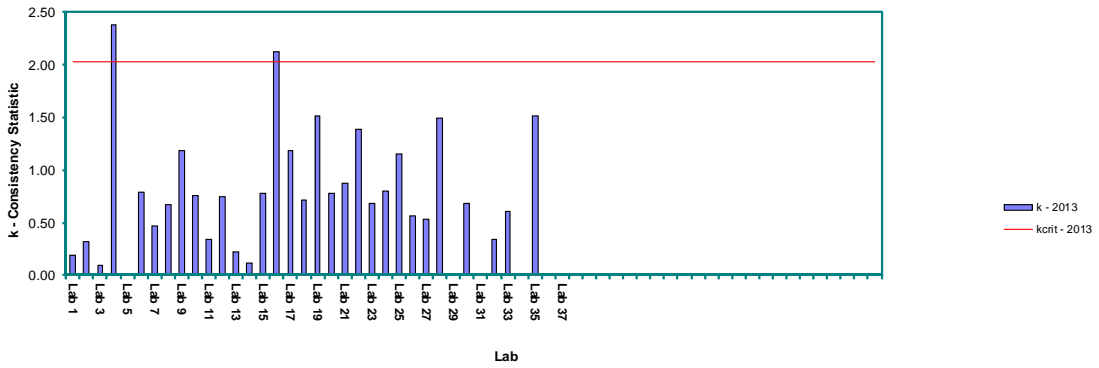
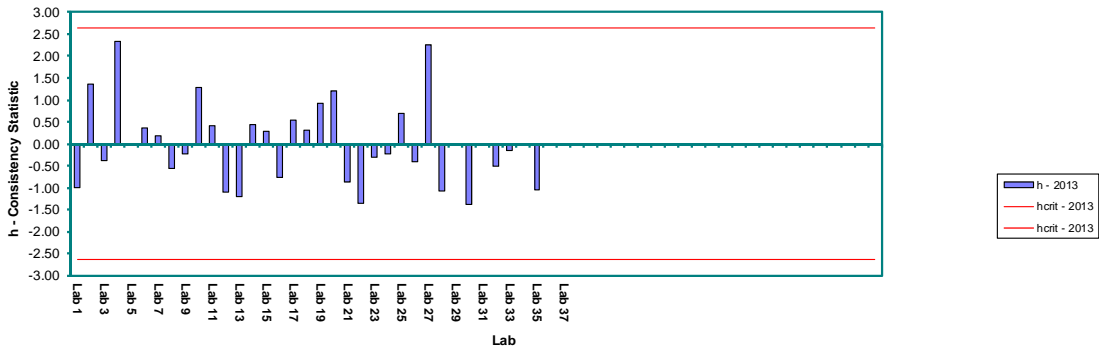
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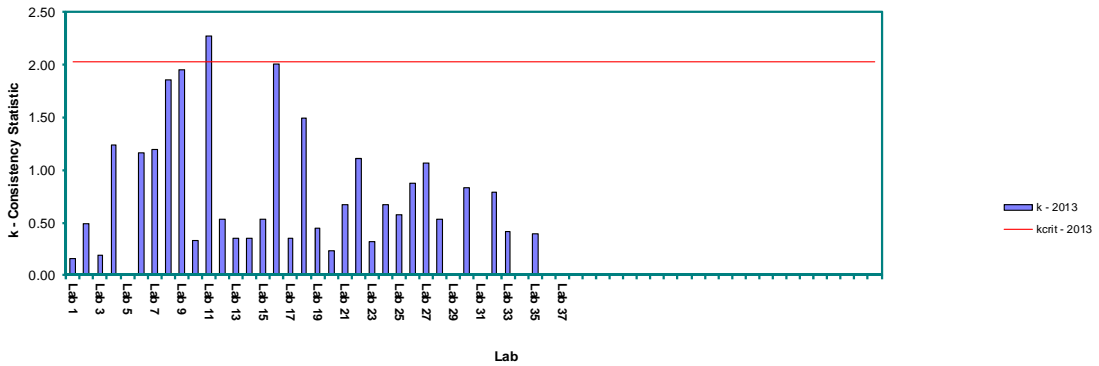
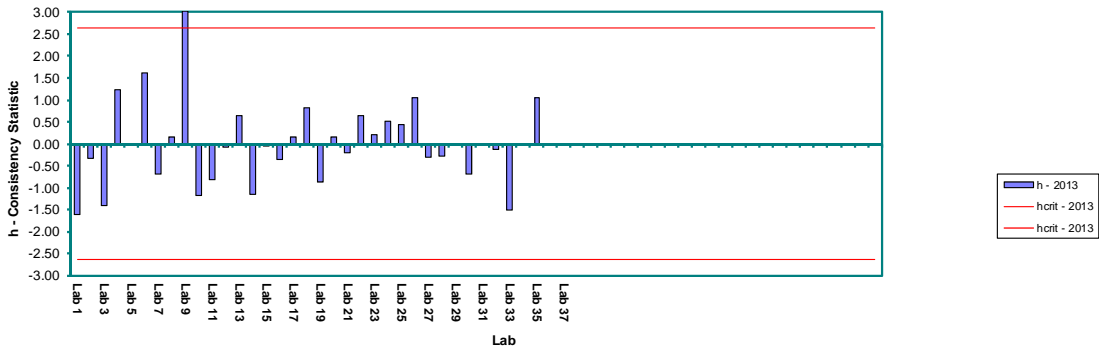
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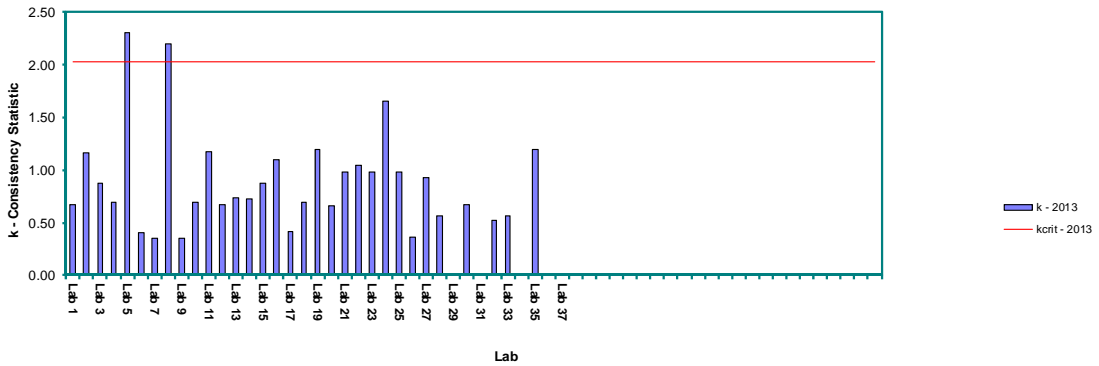
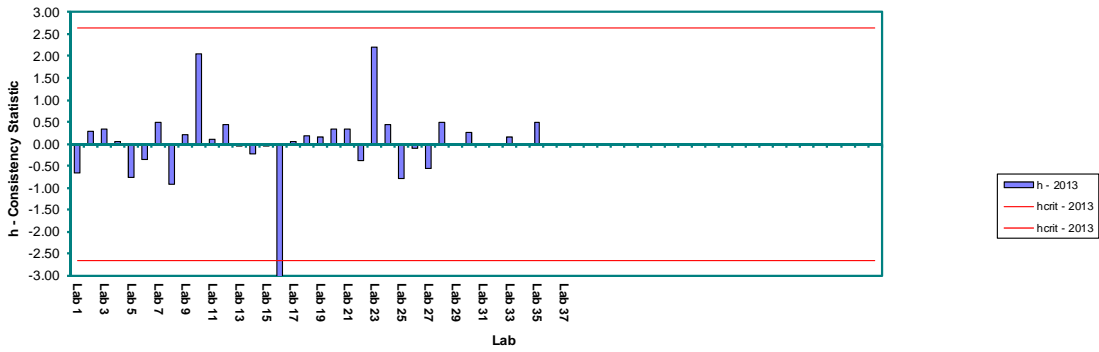
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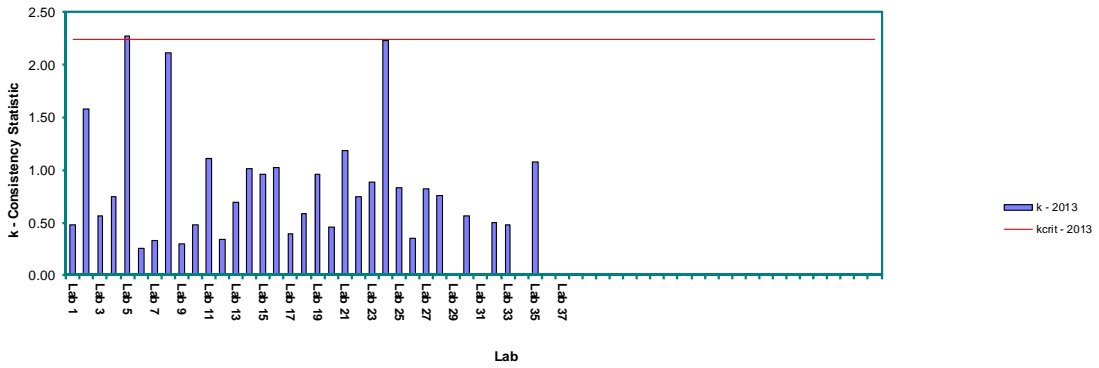
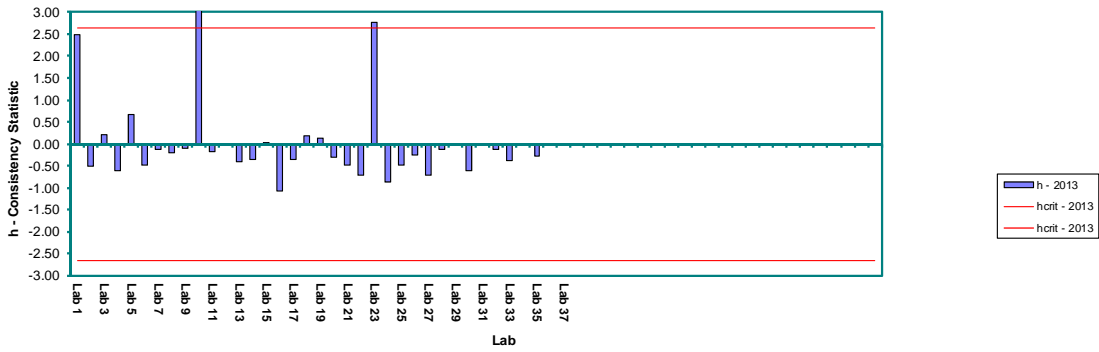
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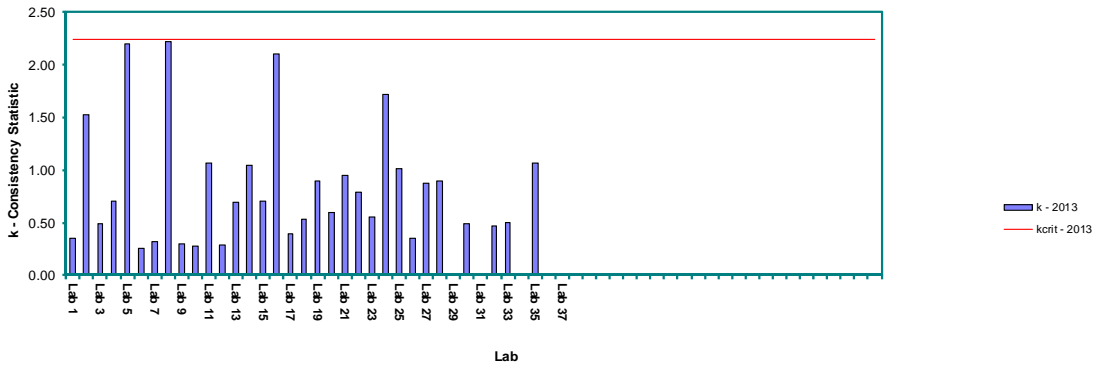
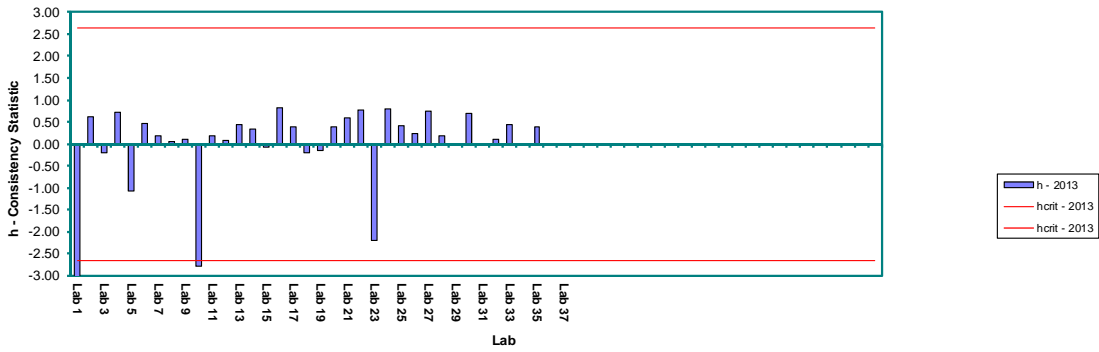
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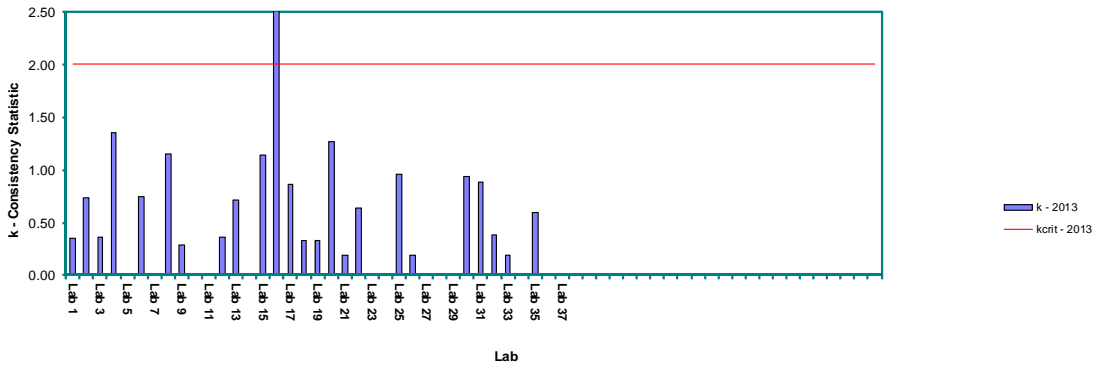
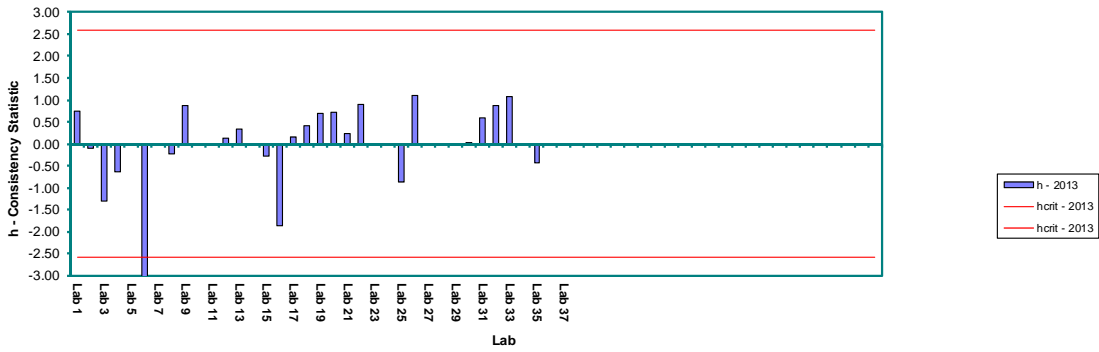
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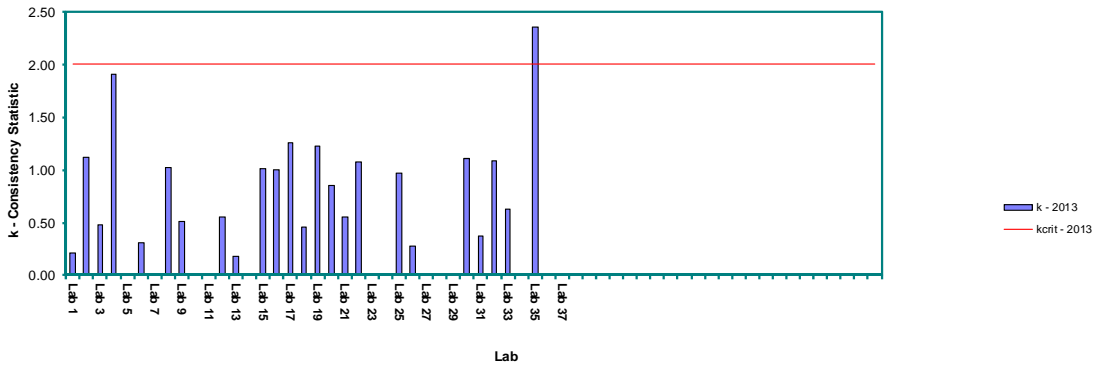
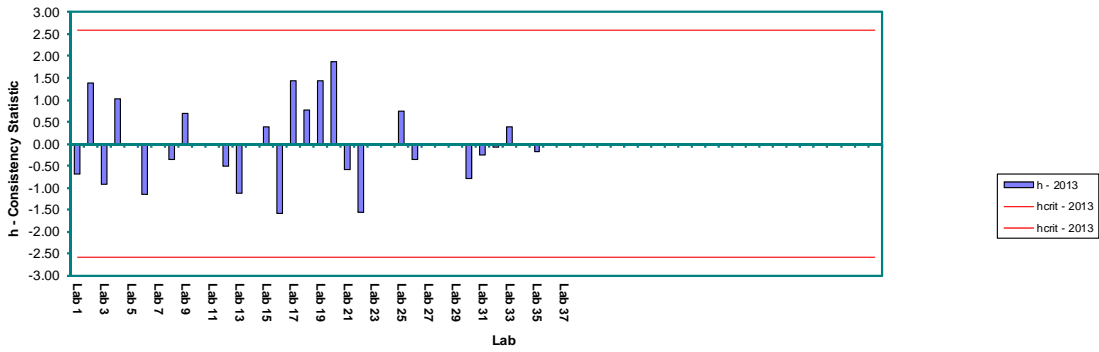
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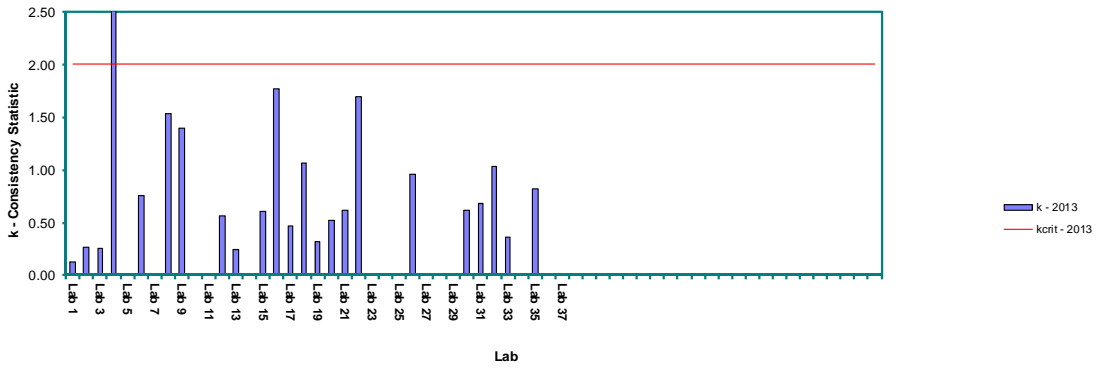
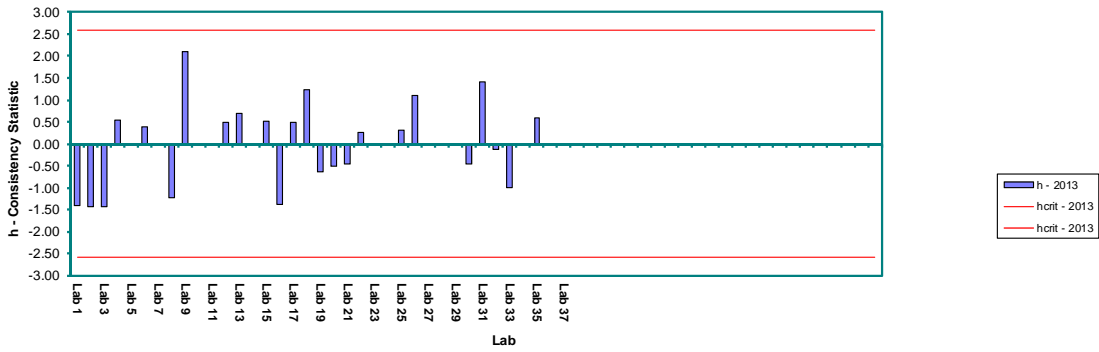
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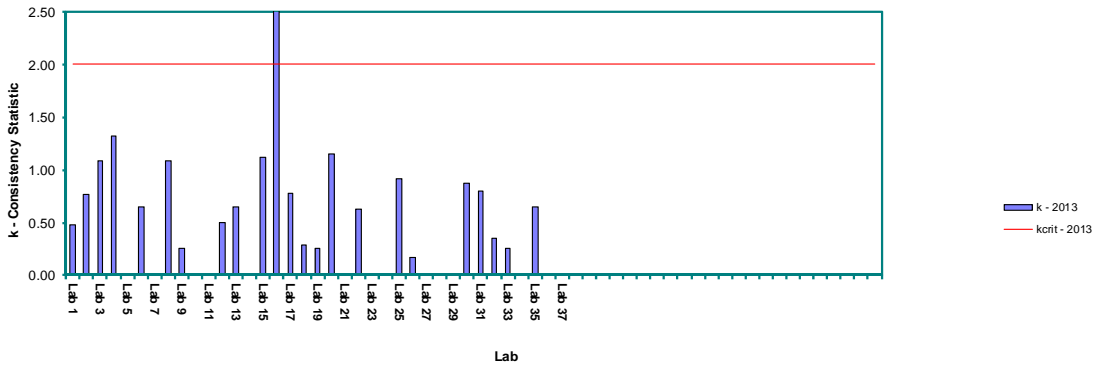
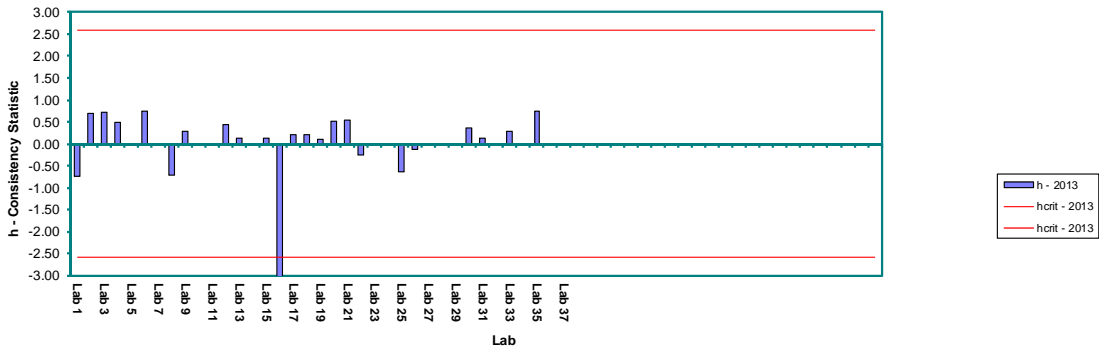
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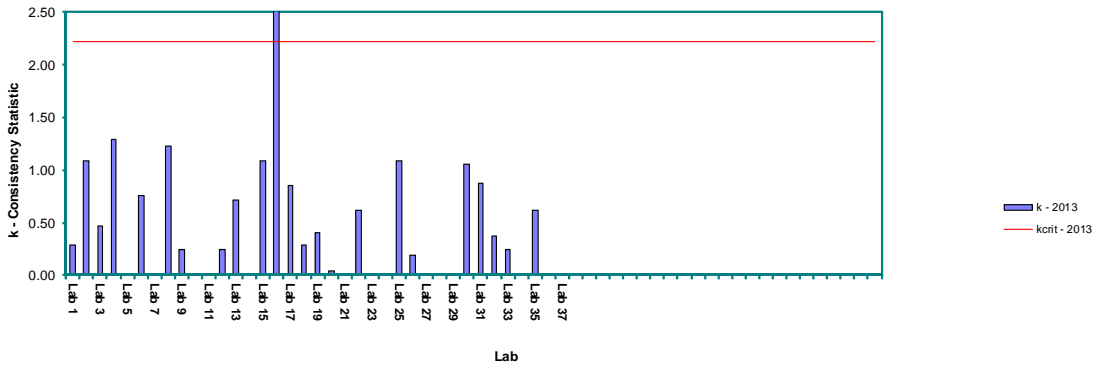
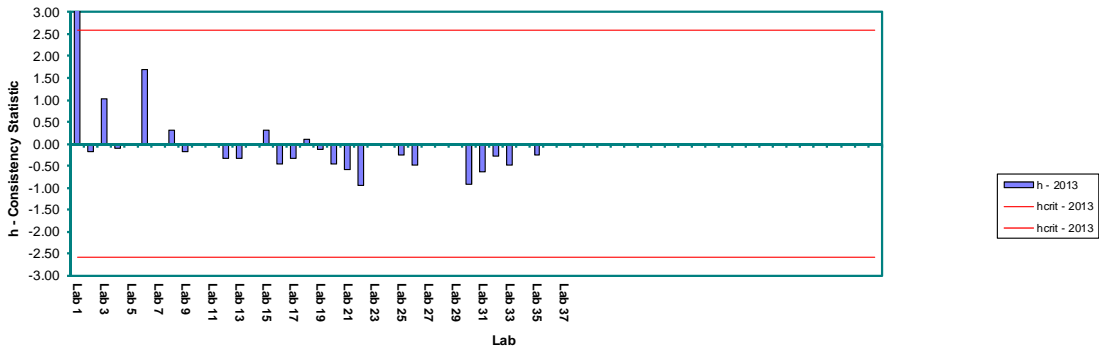
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$d =$	Cell Deviation $(X_{ave} - (\bar{X}_{ave})_{ave})$	$s_{Rc} =$	Reproducibility Standard Deviation (Larger of s_r and s_{Ri})
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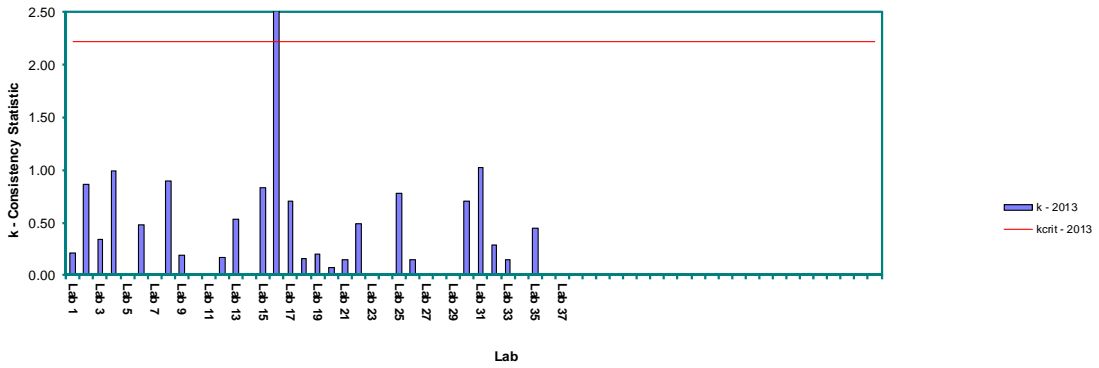
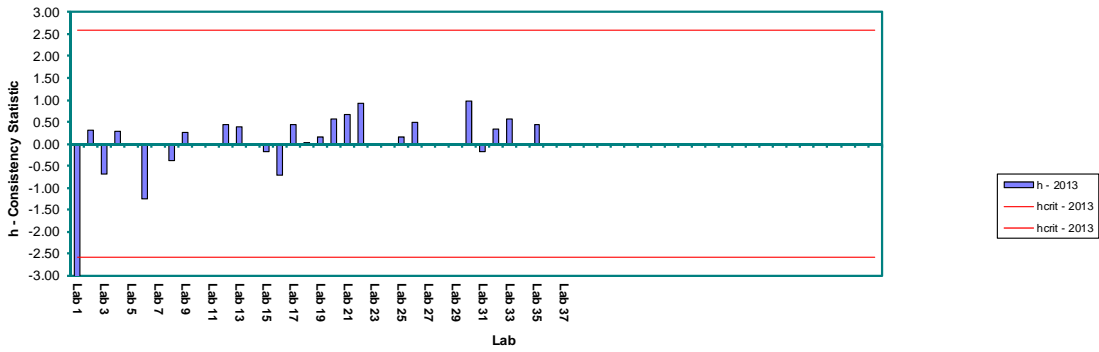
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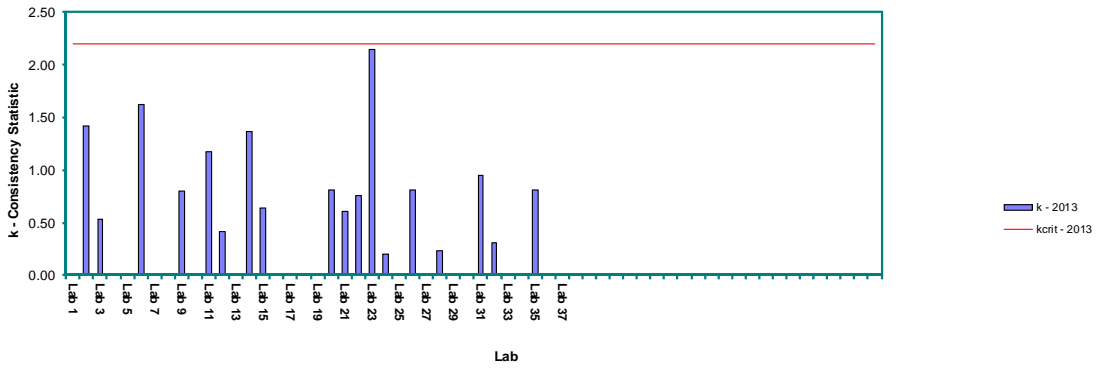
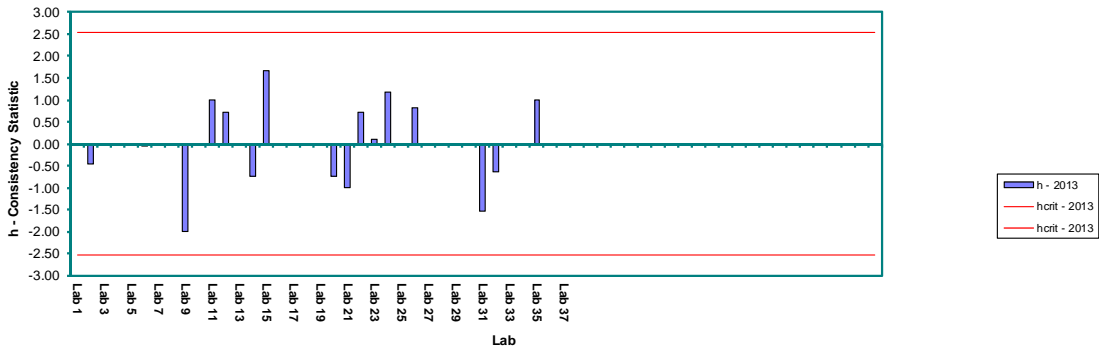
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$p =$	Number of Laboratories	$k =$	Within Laboratory Consistency Statistic
$h_{crit} =$	Critical Between Laboratory Consistency Statistic	$r =$	95% Confidence Limit for Repeatability
$k_{crit} =$	Critical Within Laboratory Consistency Statistic	$R =$	95% Confidence Limit for Reproducibility



Where: $x_1, \dots, x_n =$	Individual Test Result	Where: $(\bar{X}_{ave})_{ave} =$	Average of Cell Averages
$\bar{X}_{ave} =$	Cell Average	$s_{(ave)} =$	Standard Deviation of Cell Averages
$n =$	Number of Test Results per Cell	$s_r =$	Repeatability Standard Deviation
$s =$	Cell Standard Deviation	$s_{Ri} =$	Interim Reproducibility Standard Deviation
$d =$	Cell Deviation ($X_{ave} - (\bar{X}_{ave})_{ave}$)	$s_R =$	Reproducibility Standard Deviation (Larger of s_r and s_{Ri})
$s^2 =$	Cell Variation	$h =$	Between Laboratory Consistency Statistic
$p =$	Number of Laboratories	$k =$	Within Laboratory Consistency Statistic
$h_{crit} =$	Critical Between Laboratory Consistency Statistic	$r =$	95% Confidence Limit for Repeatability
$k_{crit} =$	Critical Within Laboratory Consistency Statistic	$R =$	95% Confidence Limit for Reproducibility



Where: x_1, \dots, x_n = Individual Test Result	Where: $(\bar{X}_{ave})_{ave}$ = Average of Cell Averages	
\bar{X}_{ave} = Cell Average	$s_{(ave)}$ = Standard Deviation of Cell Averages	
n = Number of Test Results per Cell	s_r = Repeatability Standard Deviation	
s = Cell Standard Deviation	s_{Ri} = Interim Reproducibility Standard Deviation	
d = Cell Deviation ($X_{ave} - (\bar{X}_{ave})_{ave}$)	s_{Rc} = Reproducibility Standard Deviation (Larger of s_r and s_{Ri})	
s^2 = Cell Variation	h = Between Laboratory Consistency Statistic	
p = Number of Laboratories	k = Within Laboratory Consistency Statistic	
h_{crit} = Critical Between Laboratory Consistency Statistic	r = 95% Confidence Limit for Repeatability	
k_{crit} = Critical Within Laboratory Consistency Statistic	R = 95% Confidence Limit for Reproducibility	

**Table 12 Participating Labs
CAMEP 2013 (Marshall Mix)**

Almor Testing Services Ltd	Calgary, AB	Golder Associates Ltd	Saskatoon, SK
AMEC Environment and Infrastructure	Saskatoon, SK	Golder Associates Ltd	Whitby, ON
AMEC Environment and Infrastructure	Dartmouth, NS	Government of Newfoundland and Labrador, Transportation and Works	St John's, NL
AMEC Environment and Infrastructure	Edmonton, AB	Hub City Paving - Division of Lafarge Canada	Nanaimo, BC
City of Edmonton	Edmonton, AB	Imperial Oil Limited	Sarnia, ON
City of Regina	Regina, SK	Levelton Consultants Ltd	Abbotsford, BC
Clifton Associates Ltd	North Battleford, SK	LVM	Toronto, ON
Clifton Associates Ltd	Lloydminster, AB	LVM/Maritime Testing Limited	Darmouth, NS
Clifton Associates Ltd	Regina, SK	Manitoba Infrastructure and Transportation, Materials Engineering Branch	Brandon, MB
Clifton Associates Ltd	Saskatoon, SK	Manitoba Infrastructure and Transportation, Materials Engineering Branch - Central lab	Winnipeg, MB
Clifton Associates Ltd	Edmonton, AB	MTQ	Québec, QC
Conquest Engineering Ltd.	Saint Hohn, NB	MTQ Laboratoire des chaussées	Québec, QC
EBA Engineering Consultants Ltd	Edmonton, AB	MTQ Service des matériaux d'infrastructure	Montreal, QC
EXP Services Inc	Saint John, NB	PEI Department of Transportation and Infrastructure Renewal	Mount Stewart, P.E.I.
Gecan	Acheson, AB	Peto MacCallum Ltd	Toronto, ON
Gemtec Ltd	Fredericton, NB	Thurber Engineering Ltd	Edmonton, AB
General Liquids Canada	Bedford, NS		

**Table 13 Participating Labs
CAMEP 2013 (Gyratory Compactor)**

City of Edmonton	Edmonton, AB	Levelton Consultants Ltd	Abbotsford, BC
Conquest Engineering Ltd.	Saint John, NB	LVM	Toronto, ON
EXP Services Inc	Saint John, NB	LVM/Maritime Testing Limited	Darmouth, NS
Gecan	Acheson, AB	Manitoba Infrastructure and Transportation, Materials Engineering Branch - Central lab	Winnipeg, MB
Gemtec Ltd	Fredericton, NB	MTQ	Québec, QC
General Liquids Canada	Bedford, NS	MTQ Laboratoire des chaussées	Québec, QC
Golder Associates Ltd	Whitby, ON	MTQ Service des matériaux d'infrastructure	Montreal, QC
Government of Newfoundland and Labrador, Transportation and Works	St John's, NL	PEI Department of Transportation and Infrastructure Renewal	Mount Stewart, P.E.I.
Imperial Oil Limited	Sarnia, ON	Peto MacCallum Ltd	Toronto, ON

**Table 14 Participating Labs
CAMEP 2013 (Ignition Oven)**

Almor Testing Services Ltd	Calgary, AB	Golder Associates Ltd	Whitby, ON
AMEC Environment and Infrastructure	Saskatoon, SK	Government of Newfoundland and Labrador, Transportation and Works	St John's, NL
AMEC Environment and Infrastructure	Dartmouth, NS	Hub City Paving - Division of Lafarge Canada	Nanaimo, BC
AMEC Environment and Infrastructure	Edmonton, AB	Imperial Oil Limited	Sarnia, ON
City of Edmonton	Edmonton, AB	Levelton Consultants Ltd	Abbotsford, BC
City of Regina	Regina, SK	LVM	Toronto, ON
Clifton Associates Ltd	Lloydminster, AB	LVM/Maritime Testing Limited	Darmouth, NS
Clifton Associates Ltd	Regina, SK	Manitoba Infrastructure and Transportation, Materials Engineering Branch	Brandon, MB
Clifton Associates Ltd	Saskatoon, SK	Manitoba Infrastructure and Transportation, Materials Engineering Branch - Central lab	Winnipeg, MB
Clifton Associates Ltd	Edmonton, AB	MTQ	Québec, QC
Conquest Engineering Ltd.	Saint Hohn, NB	MTQ Laboratoire des chaussées	Québec, QC
EXP Services Inc	Saint John, NB	MTQ Service des matériaux d'infrastructure	Montreal, QC
Gecan	Acheson, AB	PEI Department of Transportation and Infrastructure Renewal	Mount Stewart, P.E.I.
Gemtec Ltd	Fredericton, NB	Peto MacCallum Ltd	Toronto, ON
General Liquids Canada	Bedford, NS	Thurber Engineering Ltd	Edmonton, AB
Golder Associates Ltd	Saskatoon, SK		

Table 15 Summary of 2013 CAMEP Report

								Labs Out		Labs Close	
Test	Average	S _x	S _r	S _R	2.77S _r	2.77S _R	h-stat	k-stat	h-stat	k-stat	
Marshall Mix											
Bulk Density of Aggregates (g/cm ³)	Coarse Aggregate	2.7257	0.0124	0.0079	0.0140	0.0219	0.0388	1	2		
	Fine Aggregate	2.6804	0.0390	0.0242	0.0437	0.0670	0.1211	1	2		
Water Absorption (%)	Coarse Aggregate	0.624	0.363	0.174	0.390	0.482	1.080	1	1		
	Fine Aggregate	1.136	0.594	0.231	0.623	0.641	1.727	1	2		
Theor. Max. Specific Gravity & Density	Modified Rice	2.535	0.0163	0.0041	0.0166	0.0113	0.0461	1	1		
Bulk Density (g/cm ³)	Hand Compaction	2.500	0.025	0.0042	0.025	0.012	0.070	2	3		
	Mech. Compaction	2.502	0.011	0.005	0.012	0.014	0.032	1	1		
Marshall Stability (kN)	Hand Compaction	12.930	1.62	0.92	1.81	2.55	5.01		2		
	Mech. Compaction	12.599	1.60	0.79	1.74	2.19	4.82		1		
Flow (mm)	Hand Compaction	3.8	0.52	0.36	0.61	0.99	1.68	1	1		1
	Mech. Compaction	3.8	0.57	0.39	0.66	1.07	1.83		1		
VMA (%)	Hand Compaction	12.0	1.50	0.14	1.51	0.40	4.17	1	2		
	Mech. Compaction	11.9	1.27	0.20	1.28	0.55	3.55	1	1		
Air Voids (%)	Hand Compaction	1.4	0.97	0.17	0.98	0.47	2.73	2	1		1
	Mech. Compaction	1.4	0.64	0.20	0.66	0.57	1.83	1	1		
Voids Filled	Hand Compaction	88.8	6.9	1.3	7.0	3.7	19.5	2	1		2
With Asphalt (%)	Mech. Compaction	88.1	5.8	2.1	6.0	5.7	16.6	1	1		
Gyratory Compaction											
Bulk Density (g/cm ³)	75 Gyration	2.496	0.012	0.0050	0.013	0.014	0.036				
Ignition Oven											
Asphalt Content (%)	By Mass of Oven-Dry	5.0	0.159	0.069	0.168	0.192	0.467	2			

Legend:s_x = Standard Deviations_r = Repeatability Standard Deviations_R = Reproducibility Standard Deviation2.77s_r = 95% Confidence Limits for Repeatability (k-stat)2.77s_R = 95% Confidence Limits for Reproducibility (h-stat)

CAMEP = Canadian Asphalt Mix Exchange Program

VMA = Voids in Mineral Aggregate

MTD = Maximum Theoretical Density

Appendix B

Formulas Used in Calculating Precision Results

x = Individual test result

n = Number of test results per lab

p = Number of laboratories

$$\bar{x} = \text{Lab Average} = \frac{\sum^n x}{n}$$

$$x_a = \text{Average of lab averages} = \frac{\sum^p \bar{x}}{p}$$

$$s = \text{Lab standard deviation} = \sqrt{\frac{\sum^n (x - \bar{x})^2}{(n-1)}}$$

$$d = \text{Lab standard deviation} = \bar{x} - x_a$$

$$s_{X_{ave}} = \text{Standard deviation of lab averages} = \sqrt{\frac{\sum^p d^2}{(p-1)}}$$

$$s_r = \text{Repeatability standard deviation} = \sqrt{\frac{\sum^p s^2}{p}}$$

s_R = Reproducibility standard Deviation

$$= \text{the larger of } s_r \text{ and } \sqrt{(s_{X_{ave}})^2 + (s_r)^2} \times \frac{(n-1)}{n}$$

$$h = \text{The between-laboratory consistency statistic} = \frac{d}{s_{X_{ave}}}$$

$$k = \text{The within-laboratory consistency statistic} = \frac{s}{s_r}$$

Reference: ASTM E691, Standard Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method.