

5.2.3 By gently tilting, spread specimen over the bottom of the aluminum dish.

5.2.4 Heat in oven at $140 \pm 2^{\circ}\text{C}$ for 2 hours.

5.2.5 Remove from oven, cool in desiccator and weigh the dish.

5.3 CALCULATION

$$S = \frac{C - A}{B - A} \times 100$$

where S = Non-volatile content, percent

A = Mass of aluminum dish, g

B = Mass of aluminum dish and wet latex specimen, g

C = Mass of aluminum dish and dried specimen after heating, g

5.4 REPORTING OF RESULTS

The report shall include the non-volatile content of the latex admixture to the nearest 0.1 percent.

6. CURING COMPOUNDS

6.1 APPARATUS

6.1.1 Syringe without needle, 10 mL

6.1.2 Aluminum dishes, approximately 60 mm in diameter, 15 mm in depth, 2 g or less in mass, and disposable.

6.1.3 Oven-ventilated, $105 \pm 2^{\circ}\text{C}$, forced circulation type or one with provision for free access of air.

6.1.4 Desiccator

6.1.5 Balance - Accurate to 0.001 g

6.2 PROCEDURE

6.2.1 Weigh each of three aluminum dishes to nearest 0.001 g.

6.2.2 Thoroughly mix sample by stirring in closed container. Avoid trapping air in sample.

6.2.3 Place representative sample in a 10 mL syringe without needle and discharge $1.2 \text{ g} \pm 0.1 \text{ g}$ into each of the aluminum dishes.

Note 1: To control evaporation loss weigh syringe each time after discharge and record.

6.2.4 By gently tilting, spread specimen over the bottom of the aluminum dish.

6.2.5 Heat in oven at $105 \pm 2^{\circ}\text{C}$ for 3 hours.

6.2.6 Remove from oven, cool in desiccator, and weigh the dish.

Note 2: Three specimens constitute a test.

Note 3: If necessary, a piece of stout wire can be included in the tare of the dish and used at intervals to break up skins by stirring during the heating period.

6.3 CALCULATION

$$S = \frac{C - A}{B - A} \times 100$$

where S = Non-volatile content, percent

A = Mass of aluminum dish, g

B = Mass of aluminum dish and wet curing compound specimen, g

C = Mass of aluminum dish and dried specimen, after heating, g.

6.4 REPORTING OF RESULTS

The report shall include the non-volatile content of the curing compound to the nearest 0.1 percent.

METHOD OF TEST FOR RELATIVE DENSITY OF CHEMICAL ADMIXTURES, AIR ENTRAINING ADMIXTURES, LATEX ADMIXTURES AND CURING COMPOUNDS

1. SCOPE

1.1 This method covers the determination of the relative density of concrete chemical admixtures (liquid), air entraining admixtures (liquid), latex admixtures or curing compounds.

2. RELEVANT DOCUMENTS

2.1 ASTM C 494, 18.4

2.2 ASTM D 244

3. PROCEDURE

3.1 CHEMICAL, AIR ENTRAINING AND LATEX ADMIXTURES: Procedure of ASTM C 494, Clause 18.4 shall be followed.

3.2 CURING COMPOUNDS: Procedure of ASTM D 244 shall be followed except as noted.

3.2.1 Volume of the stainless steel measure is recommended to be 100 mL.

3.2.2 Sample shall be stirred to produce a homogeneous mix in such a manner as to avoid trapping air.

METHOD OF TEST FOR pH OF AQUEOUS SOLUTIONS BY GLASS ELECTRODE

1. SCOPE

1.1 This method covers the determination of the pH of concrete air entraining admixtures and latex admixtures using the glass electrode.

2. RELEVANT DOCUMENTS

2.1 ASTM E 70

3. PROCEDURE

3.1 Procedure of ASTM E 70 shall be followed.

METHOD OF TEST FOR SETTLING RATE - CURING COMPOUND

1. SCOPE

1.1 This method covers the determination of settling rate of white pigmented Type 2 curing compounds over a 24 hour period.

2. RELEVANT DOCUMENTS

2.1 OPSS 1315

3. APPARATUS

3.1 Thermometer ($23 \pm 1.5^{\circ}\text{C}$)

3.2 Graduated Cylinders - (2) Kimax 250 mL or equivalent with 250 mL capacity

3.3 Stoppered Tops

3.4 Stirring Rod

4. PROCEDURE

4.1 Obtain uniform sample by stirring. Avoid trapping air in the sample.

4.2 Pour sample into each of the two graduated cylinders to the 150 mL mark.

4.3 Stopper the cylinders and leave undisturbed at $23 \pm 1.5^{\circ}\text{C}$ for 24 hours from initial time.

4.4 Observe the uniform white portion as visible to the eye and record the settling at 2 hours and 24 hours to the nearest mL.

5. REPORTING OF RESULTS

5.1 The report shall include the following:

5.1.1 The settling to the nearest mL at 2 hours and 24 hours as determined by taking the average of the two duplicate cylinders.

METHOD OF TEST FOR DETERMINATION OF TOTAL CHLORIDE ION IN CONCRETE - (ACID SOLUBLE)

1. SCOPE

1.1 This method covers procedure for the determination of the total chloride ion content of concrete cores. The method is limited to materials that do not contain sulfides, but the extraction procedure. Section 7 may be used for all such materials.

2. RELEVANT DOCUMENTS

2.1 "Standard Methods of Chemical Analysis", Volume III A, 6th Edition, Edited by Frank J. Welcher.

2.2 Clear, K. C., "Evaluation of Portland Cement Concrete for Permanent Bridge Deck Repair", Federal Highway Administration, Report FHWA-RD-74-5, February 1974, National Technical Information Services PB232-604/AS.

3. DEFINITION

3.1 The total chloride ion content in concrete is the one determined as described in this method and expressed in percent by mass of the concrete.

4. APPARATUS

4.1 CONCRETE SAW.

4.2 CONCRETE PULVERIZER.

4.3 SIEVE: 300 μ m.

4.4 ELECTRODE: Solid state or liquid filled chloride-ion or silver/sulfide ion-selective and manufacturer recommended filling solutions.

Note 1: Suggested electrodes are the Orion 96-17 Combination Chloride Electrode or the solid state Orion 96-17A. MTO uses the chloride ion-selective electrode together with a standard calomel electrode filled with saturated Na_2SO_4 instead of KCl.

4.5 MILLIVOLTMETER: Compatible with the ion electrode.

Note 2: Suggested millivoltmeter is the Orion Model 701A Digital Ph/mV meter or any equivalent with a digital readout.

4.6 STIRRER: Teflon-coated magnetic stirring bars.

4.7 BURETTE: With 0.05 mL graduations.

4.8 BALANCE: Sensitive to 0.0001 g with minimum capacity of 100 g.

- 4.9 HOT PLATE: 250 to 400°C heating surface temperature.
- 4.10 GLASSWARE: 250 and 400 mL beakers, filter funnels, stirring rods, watch glasses, dropper, mortar and pestle, wash bottles.
- 4.11 FILTER PAPER: Whatman No. 54 (or equivalent).

5. REAGENTS

- 5.1 DILUTE HNO_3 : (1:16, conc HNO_3 : water by vol.).
- 5.2 SODIUM CHLORIDE: NaCl , reagent grade (primary standard).
- 5.3 STANDARD 0.025 N NaCl SOLUTION.
 - 5.3.1 Dry reagent grade NaCl in an oven at 105°C. Cool in a desiccator, weigh out 1.4610 g, dissolve in distilled water, and transfer to a 1-litre volumetric flask. Make up to the one litre mark with distilled water and mix.
- 5.4 STANDARD 0.025N AgNO_3 .
 - 5.4.1 Weigh 4.247 g of reagent grade AgNO_3 , dissolve in distilled water filter into a 1-litre brown glass bottle, fill, and mix thoroughly. Standardize against 25.00 mL of the NaCl solution by the titration method described in Section 7.5.
- 5.5 DISTILLED WATER.
- 5.6 METHYL ORANGE INDICATOR.
- 5.7 ETHYL ALCOHOL: Technical grade.

6. SAMPLE PREPARATION

Unless instructed otherwise, each core shall be cut into 10 mm thick (including saw cut) horizontal sections as shown in Figure 1.

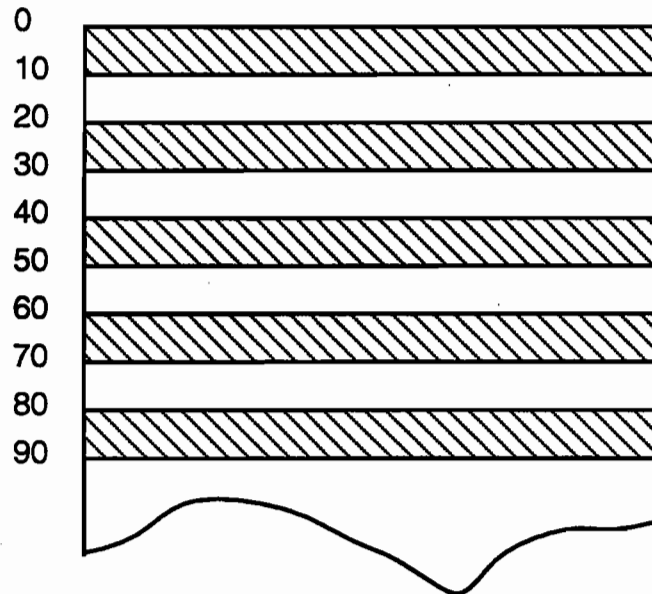


FIGURE 1 LOCATION OF SAW CUTS

- 6.1 As each section is saw cut, it shall be immediately marked to show its identification number.
- 6.2 Section 0 - 10 mm, 20-30 mm, 40-50 mm, 60-70 mm and 80-90 mm shall be dried to a constant weight in a 105°C oven, then crushed and pulverized so that the entire section passes the 300 µm sieve. Care shall be taken to avoid loss of material.
- 6.3 After each section is crushed and pulverized, the sieve and all the pulverizing tools shall be washed with ethyl alcohol or distilled water and shall be dry before use with each separate sample (section).
- 6.4 As each section has been pulverized, the material shall be placed in a suitable container and the container shall immediately be marked with the section's identification number.
- 6.5 The other sections (10-20 mm, 30-40 mm, 50-60 mm, and 70-80 mm) shall be placed in plastic bags and retained for at least six months for contingency tests.

7. PROCEDURE

- 7.1 Weigh, to the nearest milligram, a 5 g powdered sample representative of the material under test.

Note 3: Running of blank determinations is recommended to allow correction for any extraneous sources of chloride ion. Such corrections indicate sources of contamination which should be eliminated.

7.2 Transfer the sample quantitatively to a 250 mL beaker; add 120 mL of diluted HNO_3 , stirring with a glass rod until the sample is thoroughly dispersed.

7.3 Cover with a watch glass, keeping the stirring rod in the beaker, and boil the slurry for 5 minutes on a hot plate. Remove the beaker from the hot plate and filter the slurry through Whatman No. 54 filter paper into a 400 mL beaker, first decanting the clear supernatant liquid, then washing over the residue using hot distilled water. Wash the stirring rod and the inside of the beaker into the filter. Repeat until all residue has been transferred. Wash the filter paper with hot distilled water 6 times until free of chlorides. Lift the filter paper carefully from the funnel, and wash the outside of the paper with hot distilled water. Set aside the paper, and wash the interior of the funnel and its tip with hot distilled water a minimum of three times.

7.4 Cool the filtrate to $23 \pm 2^\circ\text{C}$, immersing the beaker in an ice bath if necessary. Add 1 to 2 drops of methyl orange indicator to the 400 mL beaker; then, if necessary, add concentrated HNO_3 drop wise with continuous stirring until a permanent pink to red colour is obtained. Add distilled water to bring the volume up to 250 mL.

7.5 Prepare the Cl electrode as recommended by the manufacturer and plug it into the millivoltmeter. Determine the approximate equivalence point by immersing the electrode in a beaker of distilled water and noting the approximate millivoltmeter reading (which may be unsteady in water). Remove the beaker of distilled water from the electrode, wipe the electrode with absorbent paper, and immerse the electrode in the sample solution. Place the entire beaker-electrode assembly on a magnetic stirrer and begin gentle stirring. If the millivoltmeter reading is 40 mV or more below the approximate equivalence point determined with distilled water, proceed as directed in 7.7. If the reading is less than 40 mV below the equivalence point, proceed as directed in 7.6.

7.6 Pipette 5.00 mL of 0.025 N NaCl into the sample and mix thoroughly. Remove the beaker of distilled water, wipe the electrode and immerse it in the sample solution. Place the entire beaker/electrode assembly on a magnetic stirrer and begin stirring. Using a calibrated burette, add gradually and record the amount of standard 0.025 N AgNO_3 solution necessary to bring the millivoltmeter reading to -40 mV of the equivalence point determined in distilled water. Then continue titrating as outlined in 7.7.

7.7 Add standard 0.025 N AgNO_3 solution in 0.25 mL increments recording the millivoltmeter reading after each addition. As the equivalence point is approached, the equal additions of AgNO_3 solution will cause larger and larger changes in the millivoltmeter reading. Past the equivalence point, the changes per unit volume will again decrease. Continue the titration until the millivoltmeter reading is at least 40 mV past the approximate equivalence point.

The end point of the titration usually is near the approximate equivalence point in distilled water. It shall be determined by following the method listed in "Standard Methods of Chemical Analysis" (Volume III A, 6th Edition, edited by Frank J. Welcher). Following this method, the titration end point is computed as the volume of AgNO_3 solution added up to the point where $\Delta^2E/\Delta V^2$ becomes zero. An illustration is given in Table 17-1 of page 288 of the above mentioned "Standard Methods of Chemical Analysis". A slightly modified version is as follows:

Vol. in mL	E in mV	$\Delta E/\Delta V$ in mV/0.25 mL	$\Delta^2E/\Delta V^2$
10.00	620		
		5	
10.25	625		+7
		12	
10.50	637		+20
		32	
10.75	669		+74
		106	
11.00	775		-36
		70	
11.25	845		-20
		50	
11.50	895		

$$V \text{ (at } \Delta^2E/\Delta V^2 = 0) = 10.75 + 0.25 \frac{74}{74 + 36} \text{ mL}$$

8. CALCULATIONS

8.1 Determine the end point of the titration as described in Section 7.7. Calculate the percent of chloride ion from the equation.

$$\% \text{ Cl}^- = 3.5453 \frac{V_1 N_1 - V_2 N_2}{W}$$

where: V_1 = end point in mL

V_2 = Volume of NaCl solution added in mL

N_1 = Normality of AgNO_3

N_2 = Normality of NaCl solution

W = mass of original concrete sample in g

8.2 The percent chloride may be converted to kilograms of Cl^- per cubic metre of concrete as follows:

$$\text{kg Cl}^-/\text{m}^3 = \frac{(\% \text{ Cl}^-)(UW)}{100}$$

where: UW = Density of concrete in kg/m^3

Note 4: A density of $2375 \text{ kg}/\text{m}^3$ is often assumed for normal structural mass concrete when the actual density is unknown.

METHOD OF TEST FOR EVALUATION OF LATEX MODIFIERS FOR USE IN CONCRETE

1. SCOPE

1.1 This method covers test requirements for evaluation of latex modifiers for use in concrete. It includes determination of air content, slump, compressive and flexural strength, slant shear composite strength, resistance to salt scaling and chloride permeability for latex modified concrete.

2. RELEVANT DOCUMENTS

- 2.1 OPSS 1002, 1301, 1302, 1303, 1312
- 2.2 MTO Test Methods LS-401, 402, 403, 404, 405, 407, 408, 412
- 2.3 CSA A23.2-2C
- 2.4 AASHTO T260

3. DEFINITION

3.1 Latex modifier is a dispersion of polymeric particles in water which, when added to concrete, decreases its permeability without significantly adversely affecting its other properties.

4. PREPARATION OF SAMPLES

- 4.1 CEMENT: The cement shall be Type 10 complying with the requirements of OPSS 1301.
- 4.2 FINE AGGREGATE: The fine aggregate shall be natural sand having a fineness modulus of 2.6 to 2.9 and shall comply with the requirements of OPSS 1002.
- 4.3 COARSE AGGREGATE: The coarse aggregate shall be crushed rock of 13.2 mm nominal maximum size and shall comply with the requirements of OPSS 1002.
- 4.4 WATER: Water shall comply with the requirements of OPSS 1302.
- 4.5 AIR ENTRAINING ADMIXTURE: The air entraining admixture shall comply with the requirements of OPSS 1303.
- 4.6 LATEX EMULSION: The test latex shall be as provided by manufacturer.
- 4.7 MIX PROPORTIONS: The mix proportions shall be as shown in Table I.

Table 1

PARAMETER	LATEX MODIFIED CONCRETE	REFERENCE CONCRETE
Cement, kg/m ³	390	390
Air, %	max. 9.0	6.0 ± 1.0
Fine to Total Aggregate Ratio by Absolute Volumes	0.46	0.46
Latex Solids % by Mass of Cement	15	----
Air Entraining Admixture	----	Sufficient amount to produce the specified air content
Water, Including Water in the Latex Emulsion, kg	Sufficient amount to produce a slump of 130 ± 20 mm	Sufficient amount to produce a slump of 80 ± 10 mm

4.7 BATCHING AND MIXING: The fine and coarse aggregate shall be saturated in accordance with CSA Test Method A23.2-2C.

The batch size shall be 50 L in all cases and the mixer shall be "battered" as described in LS-401.

A laboratory pan type or rotary drum mixer shall be used for mixing the concrete using the following procedure:

4.7.1 Latex Modified Concrete:

Add coarse aggregate and latex, mix 0.5 min., add fine aggregate and cement, mix 1.0 min., add remaining water, mix 2.5 min.

4.7.2 Reference Concrete:

Add coarse aggregate and about one half of the water containing the entire amount of the air entraining admixture, mix 0.5 min., add fine aggregate and cement, mix 1.0 min., add remaining water, mix 2.5 min.

The mixed concrete shall be covered with damp burlap between completion of the mixing and testing of the concrete.

5. TESTING PLASTIC CONCRETE

5.1 Two batches of the latex modified concrete shall be prepared. Room temperature shall be controlled at $23 \pm 2^{\circ}\text{C}$ and relative humidity at $50 \pm 5\%$ for the duration of the test.

5.2 The slump and air content of each batch of concrete shall be measured 4 minutes after completion of mixing. The concrete used for determination of the slump and air content shall be discarded.

5.3 Following determination of the initial (4 minute) slump and air content the batch of concrete shall be discharged into a non-absorptive pan whose size is such that the surface area of concrete exposed to laboratory air shall be approximately 0.5 m^2 . No other agitation will be performed except that required to remove samples for slump tests.

5.4 Fresh concrete shall be removed from the pan at 15 minute intervals to determine the slump. The concrete used in each slump test shall be discarded. The testing shall be continued until all the concrete is used or the slump is 25 % of the initial value determined 4 minutes after completion of mixing.

5.5 A plot of slumps versus the various times for each batch shall be produced. The times to reach a 50 % slump loss shall be averaged. The initial slump and air content for each batch, the slump versus time curve for each batch and the average time to reach the 50 % slump loss shall be reported.

6. COMPRESSIVE AND FLEXURAL STRENGTH

6.1 One batch of the latex modified concrete and one batch of the reference concrete shall be made. Each batch shall be tested for slump, air content and density 4 minutes after completion of mixing and then the specimens shall be made in accordance with LS-401.

6.2 The compressive specimens shall be 100 mm diameter by 200 mm long cylinders and the flexural specimens shall be 75 x 100 x 400 mm beams. A minimum of three specimens per test age shall be made for each batch of concrete. The test ages and curing procedures shall be as detailed in Table II.

6.3 The compressive and the flexural strength shall be determined in accordance with LS-407 and LS-408.

6.4 The mean strength of the latex modified concrete at 24 h and 28 d shall be reported as a percentage of that of the reference concrete of equal age for both the compressive and flexural tests. The mean decrease in compressive and flexural strength of the latex modified concrete between 28 d and 42 d shall also be reported.

7. SLANT SHEAR COMPOSITE STRENGTH

7.1 The specimens shall be:

- 1) 100 mm diameter and 200 mm long composite cylinders consisting of a base of hardened reference concrete and an upper portion of latex concrete, and
- 2) 100 mm diameter and 200 mm long cylinders of the latex modified concrete.

7.2 A minimum of five composite and five latex specimens shall be tested at each age of 24 h, 28 d and 42 d (note age measured in terms of latex modified concrete for composite cylinders). The cylinders shall be tested at the specified ages in accordance with LS-407 and LS-408. With preparation of the composite specimens, a batch of reference concrete shall be prepared. The composite cylinders shall be fabricated by first making concrete cylinders with the reference concrete in accordance with LS-401. These cylinders shall be cured 1 d under wet burlap, demoulded and then stored in a moisture room until needed but not less than 27 d. The cylinders shall then be cut to the shape shown in Fig. 1. The top half of each cylinder shall be discarded and the bottom half shall be returned to the moisture room until needed.

Table 2

CURING PROCEDURE		
TEST AGE	LATEX CONCRETE	REFERENCE CONCRETE
1 d	1 d wet burlap	1 d wet burlap
28 d	1 d wet burlap 27 d lab. air	1 d wet burlap 27 d moisture room
42 d	1 d wet burlap 27 d lab. air 14 d lime saturated water	1 d wet burlap 27 d moisture room 14 d lime saturated water
1 d wet burlap	- cure for 24 ± 1 h in moulds covered with wet burlap at $23 \pm 2^{\circ}\text{C}$	
27 d lab. air	- storage of demoulded specimens at $23 \pm 2^{\circ}\text{C}$ and $50 \pm 5\%$ RH	
27 d moisture room	- storage of demoulded specimens at $23 \pm 2^{\circ}\text{C}$ and at least 95 % RH	
14 d lime saturated water	- completely immersed in $23 \pm 2^{\circ}\text{C}$ water containing 2 g/L or more $\text{Ca}(\text{OH})_2$ in solution	

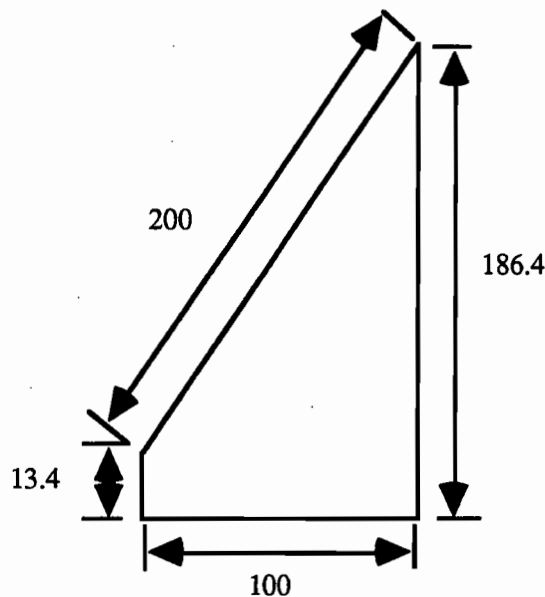


Figure 1

Base for slant shear composite specimen
Note: All dimensions in millimetres

7.4 Within 24 hours of cutting the cylinders, a batch of latex modified concrete shall be prepared. The reference concrete bases shall be removed from the moisture room and dried to a saturated surface dry condition, then a bond coat of the latex concrete shall be applied by brushing it into the cut surface. The bases shall then be put in 100 x 200 mm cylinder moulds. This shall be followed immediately by placing the upper half of the composite cylinders using the latex concrete. The monolithic latex concrete cylinders shall be made at this time as well, in accordance with LS-401. The latex concrete for both types of cylinders shall be from the same batch. Curing procedures for both the composite and the latex cylinders shall be as detailed for latex concrete in Table II.

7.5 The individual specimen strength at each age and the mean compressive strength of each type of cylinder at each age shall be reported. Using the means, the strength of the composite cylinders shall be reported as a percentage of that of the monolithic latex modified concrete cylinders of equal age. The mean percentage change in the compressive strength of the composite cylinders between 28 d and 42 d shall also be reported.

8. RESISTANCE TO SALT SCALING

8.1 The specimens shall be 300 x 300 x 75 mm slabs of the latex modified concrete fabricated in accordance with LS-412 with the exception of the curing. Curing shall be 1 d under wet burlap, 27 d in normal laboratory air and 14 d in a lime saturated water. The specimens shall be sandblasted prior to 28 d of age to remove 2 to 4 mm of each slab surface and then dyked.

8.2 Testing shall be in accordance with LS-412, except that the test will start at an age of 42 d. A graph showing the average cumulative mass loss in kg/m^2 versus the number of cycles shall be prepared. The loss of mass shall be reported to the nearest 0.1 kg/m^2 .

9. CHLORIDE PERMEABILITY

9.1 Four 300 x 300 x 50 mm slabs of the reference concrete shall be fabricated by placing the concrete in one layer (slightly over-filling the moulds) and compacting the concrete by rodding with a standard tamping rod (as per LS-412) 144 times. The mould shall be tapped to close any voids and around the periphery the concrete shall be spaded with a flat trowel. The surface shall then be levelled with several passes of a wood float. The slabs shall be cured for 1 d under wet burlap and a minimum of 13 d in a moisture room.

9.2 The slabs shall be overlaid with a 30 mm layer of the latex modified concrete, which is to be prepared as directed in section 4, Preparation of Samples. The overlay shall be compacted and finished in the same manner as the base slabs. The overlay shall be cured 1 d under wet burlap and then 41 d in normal laboratory air. Prior to 28 d of age, the slabs shall be sandblasted to remove 2 to 4 mm of each slab surface and dykes then installed or cast around three of the specimens as described in LS-412.

9.3 The undyked slab shall be stored in normal laboratory air. On the 43rd day of overlay age, the three dyked slabs shall be subjected to continuous ponding to a 13 mm depth with a 3 % sodium chloride solution for 90 d. Glass plates shall be placed over the specimens to retard the evaporation of the solution, although the surface of the slab shall not be sealed from the surrounding atmosphere. Additional solution shall be added as needed to maintain the 13 mm depth. After 90 d of ponding the solution shall be removed from the slabs, the slabs shall be allowed to dry and then the surfaces shall be wire brushed until all salt crystal build-up is completely removed.

9.4 Four cores, 50 mm diameter x 50 mm deep, (wet coring allowed) shall be obtained from each of the ponded and the unponded slabs. Each core shall be sawed (wet sawing allowed) to obtain discs representing the 2 to 13 mm and 13 to 25 mm depths. Each entire disc shall be crushed and pulverized and the total chloride content for each disc determined in accordance with AASHTO T 260.

9.5 The baseline chloride ion content shall be calculated as the mean total chloride ion content of the eight discs obtained from the unponded slab (B). The absorbed chloride ion content of each disc (X_i) from the ponded slabs shall be the difference between the total chloride ion content for that

disc (A_i) and the baseline chloride ion content (B). Chloride ion content shall be expressed as percent Cl^- by mass of concrete.

$$X_i = A_i - B$$

The average absorbed chloride ion content ($\bar{X}$), the standard deviation (σ) and the 95 percent absorbed chloride (X_{95}) in percent by mass of concrete for each depth within the ponded slabs shall be calculated using the following formulae:

$$\bar{X} = \sum_{i=1}^n \frac{X_i}{n}$$

$$\sigma = \sqrt{\frac{\sum X_i^2 - n\bar{X}^2}{n-1}}$$

$$X_{95} = \bar{X} + 1.645\sigma$$

The 95 percent absorbed chloride levels for the latex modified concrete shall be reported to the nearest 0.001 percent Cl^- at both the 2 to 13 mm depth and the 13 to 25 mm depth.

10. LATEX MODIFIER REQUIREMENTS

The latex modified concrete shall comply with the requirements of Table III.

Table 3

TESTS	REQUIREMENTS
Plastic Concrete	The air content of each latex modified batch shall not be higher than 9.0 %. The mean time to 50 % slump loss for the latex modified concrete shall be at least 50 minutes.
Compressive Strength	The mean compressive strength of the latex modified concrete at 24 h and 28 d shall be at least 50 and 75 %, respectively, of the mean compressive strength of the reference concrete of equal age. The mean decrease in compressive strength of the latex modified concrete between 28 d and 42 d shall not exceed 25 %.
Flexural Strength	The mean flexural strength of the latex modified concrete of 24 h and 28 d shall be at least 60 and 90 %, respectively, of that of the reference concrete of equal age. The mean decrease in the strength of the latex modified concrete between 28 d and 42 d shall not exceed 25 %.
Slant Shear Composite Strength	The mean compressive strength of the composite cylinders at each age shall be at least 45 % of that of the monolithic latex modified concrete cylinders of equal age. The mean decrease in the compressive strength of the composite cylinders between 28 d and 42 d shall not exceed 20 %.
Resistance to Salt Scaling	The mean cumulative surface mass loss shall not be higher than 0.8 kg/m ² .
Chloride Permeability	The 95 percent absorbed chloride levels for the latex modified concrete shall be less than 0.320 % Cl ⁻ at 2 to 13 mm depth and less than 0.064 % Cl ⁻ at 13 to 25 mm depth.

METHOD OF TEST FOR DETERMINATION OF CATHODIC DISBONDMENT OF EPOXY-COATED REINFORCING BARS

1. SCOPE

1.1 This test method determines the resistance to cathodic disbonding of an epoxy coating system applied to reinforcing bars, after the coated bars, each with a damage site, are placed in a 3% NaCl solution at 23°C and the polarized potential of the steel is maintained at -1.5 V for 168 hours.

2. RELEVANT DOCUMENTS

- 2.1 British Standard 3900: Part F10
- 2.2 British Standard 3900: Part F11
- 2.3 ASTM A775M 96: G 8 Test Method

3. APPARATUS

- 3.1 POWER SUPPLY: Filtered D.C. power supply, with a controlled voltage output of between 0 V and 12 V and a current capacity of 200 mA.
- 3.2 VOLTMETER: Voltmeter with minimum input impedance of 10 megohms and capable of measuring in the range of 0 V to 2 V to the nearest 1 mV.
- 3.3 SHUNT RESISTOR: 10 ohm shunt resistor (0.5 watt, 1% tolerance).
- 3.4 REFERENCE ELECTRODE: Calomel reference electrode.
- 3.5 ANODE: 150 mm in length, of solid platinum (1.6 mm nominal diameter), platinized wire (3.2 mm nominal diameter), or graphite (Stackpole Grade 6229, or equivalent, 13 mm nominal diameter).
- 3.6 ELECTROLYTE: 3% NaCl by mass dissolved in distilled water.
- 3.7 GLASS BEAKER: 1-litre glass beaker with Plexiglas cover.
- 3.8 THERMOMETER: Thermometer which can be submerged in water.
- 3.9 UTILITY KNIFE: Utility knife with sharp blade.

4. PREPARATION OF TEST SAMPLE

- 4.1 Specimens, each 200 mm in length, and free from holidays and bare areas, shall be cut from production coated bars.
- 4.2 On each bar, drill a 3 mm diameter hole approximately 50 mm from one end. The hole shall be centred between deformations and just deep enough to expose the steel. Seal the end of the bar closest to the hole completely with silicone. Drill a 3 mm hole and attach a self-tapping screw to the other end of the bar for the ground connection.

5. PROCEDURE

- 5.1 Perform the cathodic disbondment test using the equipment arrangement shown in Figure 1.
- 5.2 Add approximately 500 mL electrolyte to the beaker. Place the Plexiglas cover on the beaker.
- 5.3 Insert a bar into the beaker, with the sealed end of the bar resting on the bottom of the beaker. Add the electrolyte until 100 mm of the bar length is submerged. Connect the negative lead from the D.C. power supply to the grounding screw of the bar.
- 5.4 Insert 75 mm of the anode into the electrolyte (If a platinized wire anode is used, the end of the wire submerged in the electrolyte must be sealed completely with silicon to prevent damage to the copper core). Connect the shunt resistor to the anode and the positive lead from the power supply in series.
- 5.5 Insert the calomel reference electrode into the electrolyte. Place the porous tip of the electrode within 10 mm of the drilled hole in the coating. Connect the positive lead of the voltmeter to the calomel electrode and the negative lead to the bar.
- 5.6 Turn on the power supply. Adjust the power supply until the polarized potential of the steel is stabilized at -1500 ± 20 mV with respect to the calomel electrode. Measure the voltage drop across the shunt resistor using the voltmeter and calculate the current flow. Record the time as the start time.
- 5.7 The bar shall remain in the electrolyte, which shall be maintained at a temperature of $23 \pm 2^{\circ}\text{C}$, for a period of 168 ± 2 h. At intervals of 2 h, record the potential reading and adjust the voltage to correct any drift from -1500 ± 20 mV during the first 8 h. Check the potential reading again at 24 h and at least twice every 24 h thereafter; adjust the voltage if necessary. Measure the voltage drop across the shunt resistor at each potential measurement and calculate the current flow.
- 5.8 The calomel electrode shall be removed after each potential measurement to avoid the danger of contamination of the electrode. The calibration of the electrode shall be verified after each cathodic disbondment test.
- 5.9 Remove the bar from the beaker and store the bar in air at $23 \pm 3^{\circ}\text{C}$ for 1 h before preparing it for adhesion testing.
- 5.10 Using a new blade, make 4 cuts through the coating at each damage site, extending outward from the site at 0° , 90° , 180° , and 270° , providing 4 sections of coating for adhesion testing, as shown in Figure 2. Ensure that the cuts extend through the coating such that the metal is visible. Replace the knife blade if it becomes dull or damaged. The length of each cut shall be not less than 5 mm or the distance between adjacent deformations.

5.11 Perform the adhesion test as follows:

Insert a new blade in the knife. Position the knife vertically on the bar so that the point of the blade touches the edge of a section of coating and the plane of the blade aligned midway between the cut lines; rotate the knife so that it makes a shallow (approximately 30°) angle with the bar while maintaining the tip of the blade in contact with the bar as shown in Figures 3 and 4, but without applying force to the coating. Determine the adhesion of the coating by inserting the blade slowly and applying steady force equivalent to approximately 2 kg until the coating resists the insertion. Maintain the force for at least 5 seconds. Do not apply force such that the coating is cut. Use a lever action on the blade to remove any coating which has been disbonded as a result of inserting the blade under the coating.

5.12 Measure the diameter of the disbonded area from the 0° to 180° coating edges and the 90° to 270° coating edges, and average the two values. Subtract the diameter of the original damage site from this average to obtain the test value.

6. REPORT

6.1 The report shall include the following information for each test bar:

- (a) date of testing
- (b) epoxy powder description
- (c) primer description (if any)
- (d) bar batch number
- (e) potential and current measurements at different time intervals
- (f) disbondment radius in mm

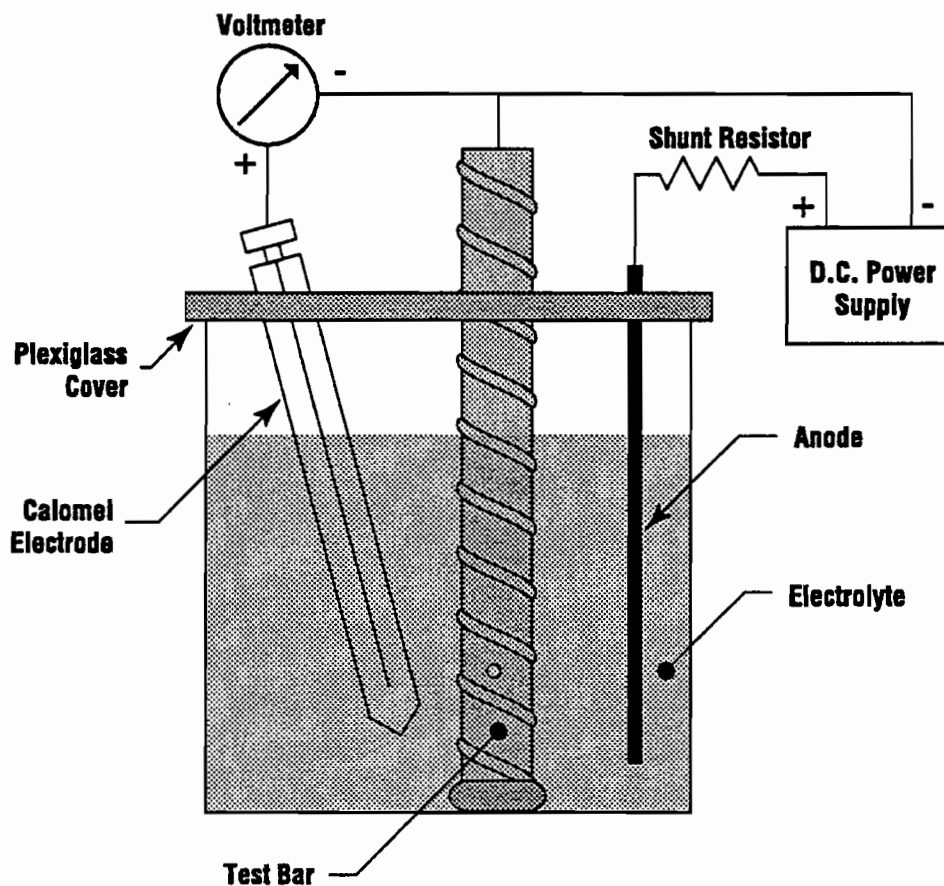


FIGURE 1
ARRANGEMENT FOR CATHODIC DISBONDMENT TEST

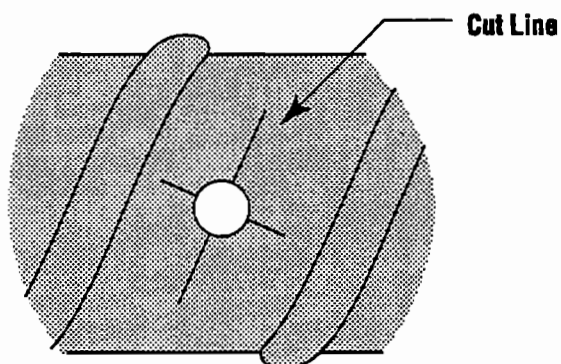


FIGURE 2
PREPARATION OF CUT LINES AT DAMAGE SITE FOR ADHESION TESTING

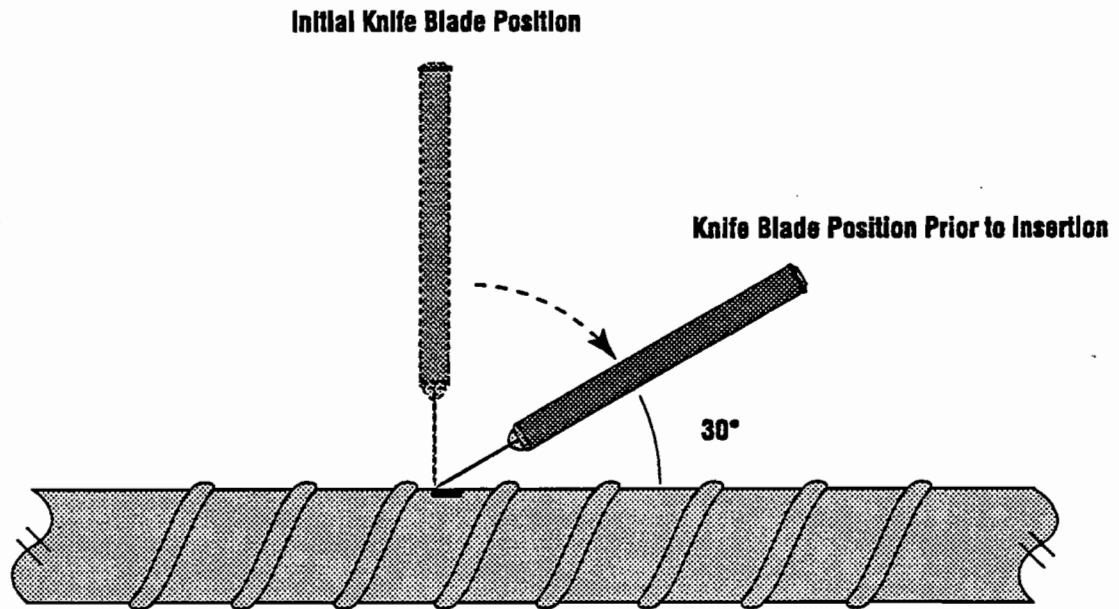


FIGURE 3
KNIFE BLADE - INITIAL PLACEMENT

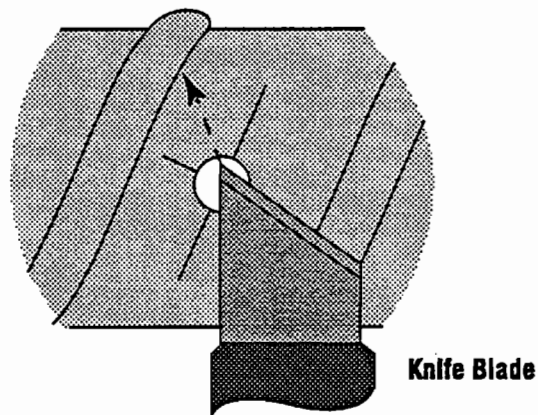


FIGURE 4
KNIFE BLADE - ORIENTATION PRIOR TO INSERTION

METHOD OF TEST FOR SALT SPRAY OF EPOXY-COATED REINFORCING BARS

1. SCOPE

1.1 This test method determines the resistance to disbonding of an epoxy coating system applied to reinforcing bars, after the coated bars, each with six damage sites on the coating, are exposed to water spray containing 5% NaCl at 35°C for 800 hours. The sampling frequency and acceptance requirements are described.

2. RELEVANT DOCUMENTS

- 2.1 ASTM A 775M 96: ANNEX A1.2.3 Salt Spray Resistance
- 2.2 ASTM B 117

3. APPARATUS

- 3.1 SALT SPRAY CABINET: Salt spray cabinet, as described in ASTM B 117.
- 3.2 SALT SOLUTION: 5% NaCl by mass dissolved in distilled water.
- 3.3 UTILITY KNIFE: Utility knife with sharp blades.

4. PREPARATION OF TEST SAMPLE

- 4.1 Specimens, each 200 mm in length, and free from holidays and bare areas, shall be cut from production coated bars. Both ends of each bar shall be completely sealed with silicone or plastic coating.
- 4.2 On each bar, drill six 3 mm diameter holes, as shown in Figure 1. Three of the holes shall be on the top of the bar, and three on the bottom. The first hole on each side shall be drilled approximately 50 mm from one end of the bar, the second hole drilled approximately 50 mm from the other end, and the third hole drilled approximately half-way in between. Each hole shall be centred between deformations and just deep enough to expose the steel.

5. PROCEDURE

- 5.1 Place the bars with the damage sites facing to the side in the salt spray cabinet for 800 ± 10 h at $35 \pm 2^\circ\text{C}$. The bars shall not be stacked and shall be placed at one level.
- 5.2 After 800 ± 10 h, remove the bars from the salt spray cabinet and rinse them in distilled water. Store the bars in air at $23 \pm 3^\circ\text{C}$ for 24 ± 2 h before preparing them for adhesion testing.

5.3 At each damage site and its adjacent area, scrape the surface gently with the front side of the utility knife to remove the corrosion products which have loosely deposited on the surface. Do not apply force such that the coating is damaged.

5.4 Using a new blade, make 4 cuts through the coating at each damage site, extending outward from the site at 0°, 90°, 180°, and 270°, providing 4 sections of coating for adhesion testing, as shown in Figure 2. Ensure that the cuts extend through the coating such that the metal is visible. Replace the knife blade if it becomes dull or damaged. The length of each cut shall be not less than 5 mm or the distance between adjacent deformations.

5.5 Perform the adhesion test as follows:

Insert a new blade in the knife. Position the knife vertically on the bar so that the point of the blade touches the edge of a section of coating and the plane of the blade aligned midway between the cut lines; rotate the knife so that it makes a shallow (approximately 30°) angle with the bar while maintaining the tip of the blade in contact with the bar as shown in Figures 3 and 4, but without applying force to the coating. Determine the adhesion of the coating by inserting the blade slowly and applying steady force equivalent to approximately 2 kg until the coating resists the insertion. Maintain the force for at least 5 seconds. Do not apply force such that the coating is cut. Use a lever action on the blade to remove any coating which has been disbonded as a result of inserting the blade under the coating.

5.6 Measure the diameter of the disbonded area from the 0° to 180° coating edges and the 90° to 270° coating edges, and average the two values. Subtract the diameter of the original damage site from this average to obtain the test value.

6. REPORT

6.1 The report shall include the following information for each test bar:

- (a) date of testing
- (b) epoxy powder description
- (c) primer description (if any)
- (d) bar batch number
- (e) disbondment radius for each of the six test locations

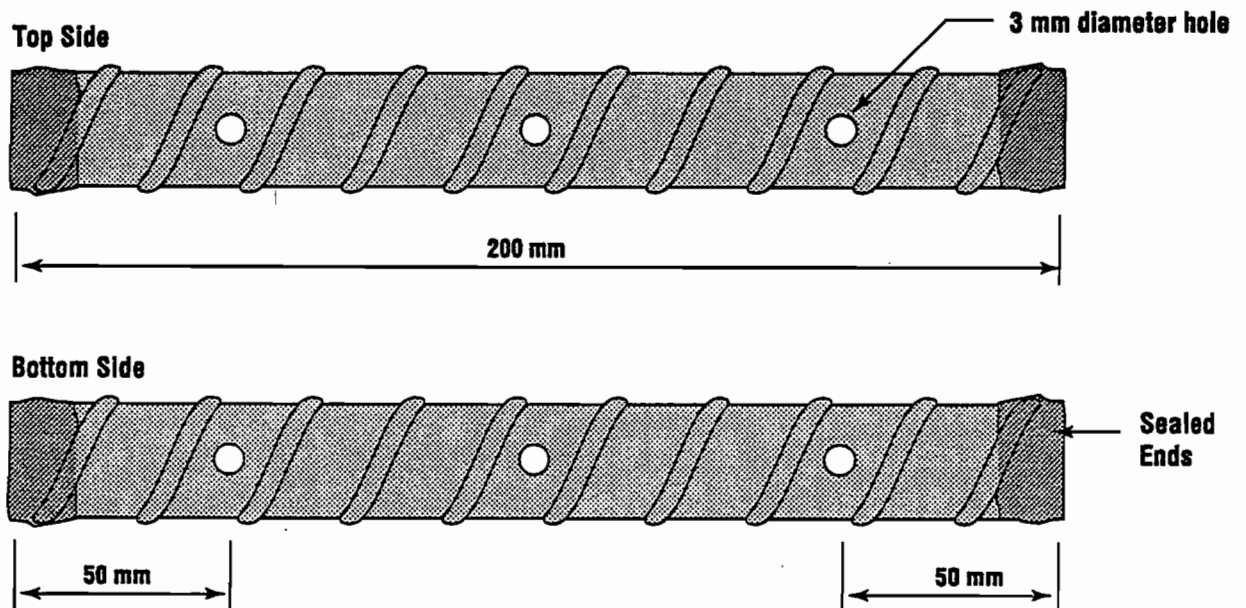


FIGURE 1
TEST LOCATIONS ON BAR

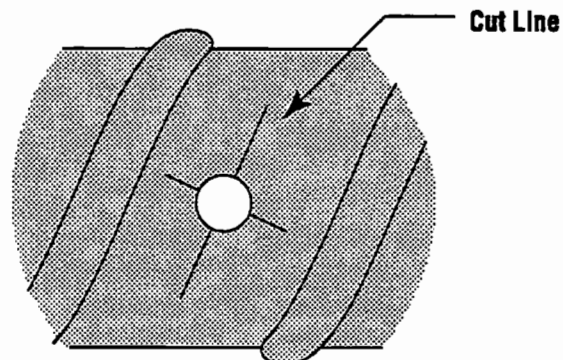


FIGURE 2
PREPARATION OF CUT LINES AT DAMAGE SITE FOR ADHESION TESTING

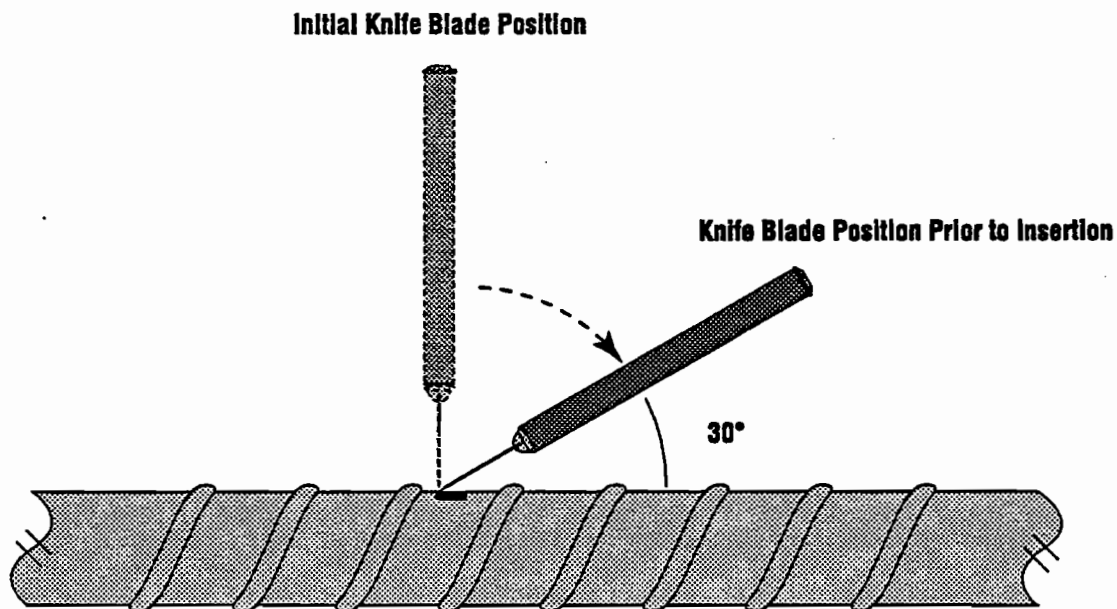


FIGURE 3
KNIFE BLADE - INITIAL PLACEMENT

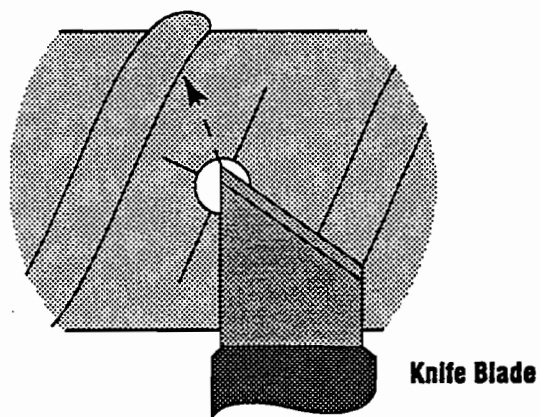


FIGURE 4
KNIFE BLADE - ORIENTATION PRIOR TO INSERTION

METHOD OF TEST FOR EVALUATION OF AIR ENTRAINING ADMIXTURES FOR CONCRETE

1. SCOPE

1.1 This method covers test requirements for evaluation of air entraining admixtures for concrete. These tests are based on arbitrary stipulations that make possible highly standardized testing in the laboratory and are not intended to simulate actual job conditions.

Note 1: This test method is based on CSA CAN3-A266.1-M78, Air Entraining Admixtures for Concrete which is not currently in existence as a CSA specification.

2. RELEVANT DOCUMENTS

- 2.1 MTO Test Methods LS-401, LS-407, LS-481
- 2.2 CSA Standards A5, A23.1, A23.2-4C, A23.2-5C, A23.2-6C
- 2.3 ASTM C 157
- 2.4 ASTM C 403
- 2.5 ASTM C 457
- 2.6 ASTM C 666
- 2.7 ACI Standard Practice 211.1

3. DEFINITIONS

- 3.1 Air entraining admixture is a material that, when used in concrete, entrains minute air voids.

4. PHYSICAL REQUIREMENTS

4.1 The admixture shall be evaluated by comparing the properties of a test concrete containing the admixture with the properties of a reference concrete containing a reference admixture. When prepared and tested in accordance with this test method, the test concrete shall meet the requirements specified in Table 1.

Table 1
Physical Requirements

Property	Performance Requirement	Calculation
Initial Set Minimum, hours:min. Maximum, hours:min.	-1:00 +1:00	T - R
Compressive Strength Minimum, % 3 days 7 days 28 days 6 months 1 year	100 100 100 100 100	T/R x 100 x 1.05
Length Change	If R exceeds 0.030 %, T/R shall not exceed 1.20. If R is not more than 0.030 %, T-R shall not exceed 0.006 %	
Air-Void Spacing Factor Maximum, mm	0.20	
Relative Durability Factor Minimum, %	100	T/R x 100 x 1.10

5. CONCRETE MATERIALS

The materials used for the preparation of concrete shall be uniform in quality, properly blended where required and prepared in sufficient quantity so that one lot of material is used for the entire test program.

5.1 CEMENT: Cement shall meet the requirements of CSA Standard A5, Portland Cements, and shall be a blend of equal parts of Normal Portland Cement (Type 10) from three different mills, St. Lawrence, Mississauga, Ontario, St. Marys Cement Company, St. Marys, Ontario, and Essroc Italcementi Group, Picton. Ontario. When the blend of cements is tested for early stiffening in accordance with CSA Standard A5 (Appendix A), the penetration shall be at least 50 %.

5.2 WATER: The water used in the preparation of mixes shall be drinkable water approved by the Ministry of Health.

5.3 AGGREGATE: All aggregate used in the preparation of concrete mixes shall meet the requirements of CSA Standard A23.1, except as specified herein. Aggregate shall meet the grading requirements of Table 2 and shall be batched in a water saturated condition which shall be attained by soaking the aggregate, completely submerged, for 24 hours in water. To meet the grading requirements specified, it is necessary to sieve the coarse aggregate through the 26.5, 19.0, 13.2, 9.5 and 4.75 mm sieves and recombine the material to the specified grading.

Table 2
Aggregate Grading Requirements

Type	Sieve Size	Percent Passing	(Alternative)
Fine Aggregate	4.75 mm	95 -100	
	1.18 mm	65 - 80	
	300 µm	10 - 30	
	150 µm	2 - 10	
Coarse Aggregate	26.5 mm	100	(100)
	19.0 mm	80	(75)
	13.2 mm	50	(50)
	9.5 mm	30	(25)
	4.75 mm	0	(0)

5.4 REFERENCE ADMIXTURE: The reference admixture shall be neutralized vinsol resin.

6. CONCRETE MIX PROPORTIONS

6.1 The same mix proportions shall be used in all batches of both test and reference concrete. MTO Laboratory Test Method LS-481, Selecting Proportions for MTO Structural and Pavement Concrete (ACI Standard 211.1, Recommended Practice for Selecting Proportions for Normal and Heavyweight Concrete) shall be used as a proportioning guide.

6.2 Both the reference concrete and the test concrete shall have a cement content of 305 ± 5 kg/m³. The slump of the reference and test concrete shall fall in the range of 80 - 100 mm and the slump of the test concrete shall be within 10 mm of that of the reference concrete.

6.3 The air content of the reference and test concrete shall be in the range of 5 - 7 % and the air content of the test concrete shall be within 0.5 % of that of the reference concrete.

7. MIXING OF CONCRETE

The following mixing procedure shall be followed.

7.1 Ensure that the mixer is buttered either by mixing a butter batch similar to the reference concrete or through having discharged another test batch just previously;

7.2 Prior to starting the mixer, place about 1/2 the mixing water, the saturated coarse aggregate, the air entraining admixture solution, the saturated fine aggregate and the cement in the mixer in that order. The air entraining admixture shall be diluted with part of the mixing water;

7.3 Start the mixer and mix for 1/2 minute;

7.4 Continue mixing for a further 3-1/2 minutes while adding the remainder of the mixing water;

Note 2: An experienced operator may add water incrementally during mixing to adjust to the desired slump.

7.5 Stop the mixer for 3 minutes. During this rest period cover the mixer with damp burlap or other suitable material to prevent evaporation; and

7.6 Mix for 1 minute.

The total mixing time shall be 5 minutes plus 3 minutes rest period.

8. TEST PROGRAM

8.1 Each of the properties listed in Table 1, except the air-void spacing factor, shall be determined from each round of at least three rounds of tests made on different days. The air-void spacing factor shall be determined from one round only. A round of tests shall consist of sufficient batches to provide the required number of test and reference specimens. Reference and test mixes for comparison purposes shall always be made on the same day. Where it is apparent that the

reproducibility within three rounds of tests is poor, repeat tests shall be carried out until satisfactory reproducibility is obtained.

8.2 The values for compressive strength, time of initial set, length change, and relative durability factor shall be those obtained by averaging the results from three consecutive rounds of tests and applying the appropriate correction factors (see Table 1).

9. TEST PROCEDURE

9.1 FRESH CONCRETE

9.1.1 Slump

The slump shall be determined for each batch in accordance with CSA Test Method A23.2-5C, Slump of Concrete . The test shall be performed within 3 to 5 minutes after completion of mixing. The same time interval shall be used when determining the slump of reference and test concrete in the same round of testing.

9.1.2 Air content

The air content of the freshly mixed concrete shall be determined for each batch in accordance with CSA Test Method A23.2-4C, Air Content of Plastic Concrete by the Pressure Method . Meters designed to provide air content measurements as a function of pressure change shall have dials with each division representing not more than 0.1 percent air content in the range of 5 - 7 percent and shall be accurately calibrated by positive displacement methods in this range.

9.1.3 Density

The density shall be determined in accordance with CSA Test Method A23.2-6C, Density, Yield and Cement Factor of Plastic Concrete . The volume of concrete tested shall be not less than 14 L.

9.1.4 Time of initial set

The time of initial set shall be determined in accordance with ASTM Standard C403, Time of Setting of Concrete Mixtures by Penetration Resistance. The test shall be conducted at $23 \pm 2^{\circ}\text{C}$ and the penetration resistance apparatus used shall be of the bench or floor mounted hydraulic or spring reaction type, having a frame of sufficient stiffness to prevent lateral movement of the needle during penetration.

9.2 HARDENED CONCRETE

9.2.1 Compressive strength

Compressive strength specimens shall be 150 mm in diameter and shall be prepared and cured in accordance with MTO Method LS-401, Method of Making and Curing Concrete Compression and Flexure Test Specimens in the Laboratory. The specimens shall be tested in accordance with MTO Method LS-407, Method of Test for Compressive Strength of Moulded Concrete Cylinders. One test shall consist of two cylinders from each round for each age specified in Table 1.

9.2.2 Air-void spacing factor

The air-void spacing factor shall be determined in accordance with ASTM Standard C457 at a minimum magnification factor of 100. Either the Linear Traverse (Rosiwal) Method or Modified Point-Count Method may be used and the paste content may be either measured or calculated. A test shall consist of one sample prepared from a 100 mm x 200 mm test cylinder cast from any batch of test concrete. The specimen shall be prepared from a longitudinal slice sawn from the centre of the cylinder.

9.2.3 Relative Durability Factor

The relative durability factor shall be determined using Procedure A (Freeze in Water, Thaw in Water) of ASTM Standard C666, Resistance of Concrete to Rapid Freezing and Thawing. The relative durability factor (RDF) shall be calculated as follows:

$$T \text{ (or R)} = PN / 300$$

$$RDF = (T / R) \times 100 \times 1.10$$

where:

T = durability factor of the concrete containing the admixture under test

R = durability factor of concrete containing the reference admixture

P = relative dynamic modulus of elasticity in percentage of the dynamic modulus of elasticity at zero cycles (values of P will be 60 or greater)

N = number of cycles at which P reaches 60 percent, or 300 if P does not reach 60 percent prior to the end of the test (300 cycles)

A test shall consist of two specimens each of reference and test concrete from each round.

9.2.4 Length Change

The determination of length change shall be made in accordance with ASTM Standard C157, Length Change of Hardened Cement Mortar and Concrete. The moist curing period, including the period in the moulds shall be 14 days. The drying period shall also be 14 days. The drying shrinkage shall be considered to be the length change during the drying period based on initial measurement at the time of removal of the specimen from the mould. It shall be expressed as a percent, to the nearest 0.001 percent based on the specimen gauge length.

METHOD OF TEST FOR EVALUATION OF CHEMICAL ADMIXTURES FOR CONCRETE

1. SCOPE

This method covers physical requirements and qualification tests for chemical admixtures. It applies to water reducing, strength increasing, set retarding, and accelerating admixtures.

These tests are based on arbitrary stipulations that make possible highly standardized testing in the laboratory and are not intended to simulate actual job conditions.

Note 1: This test method is based on CSA - A266.2-M78, Chemical Admixtures for Concrete which is not currently in existence as a CSA specification.

2. RELEVANT DOCUMENTS

- 2.1 MTO Test Methods LS-401, LS-407, LS-481
- 2.2 CSA Standards A5, A 23.1, A 23.2-12A, A 23.2-4C, A 23.2-5C, A 23.2-6C
- 2.3 ASTM C 157
- 2.4 ASTM C 359
- 2.5 ASTM C 403
- 2.6 ASTM C 457
- 2.7 ASTM C 494
- 2.8 ASTM C 666
- 2.9 ACI Standard Practice 211.1

3. DEFINITIONS

3.1 WATER REDUCING ADMIXTURES

3.1.1 Type WN - An admixture that increases the strength of concrete primarily as a result of reducing the water required for a given consistency and does not significantly affect the initial set. (Equivalent to ASTM Type A admixture).

3.1.2 Type WR - An admixture that increases the strength of concrete primarily as a result of reducing the water required for a given consistency and retards the initial set of concrete. (Equivalent to ASTM Type D admixture).

3.2 STRENGTH INCREASING ADMIXTURES

3.2.1 Type SN - An admixture that increases the strength of concrete without substantially affecting the water requirement for a given consistency and does not significantly affect the initial set (no ASTM equivalent).

3.2.2 Type SR - An admixture that increases the strength of concrete without substantially affecting the water requirement for a given consistency and retards the initial set of concrete (no ASTM equivalent).

3.3 SET RETARDING ADMIXTURES

3.3.1 Type R - An admixture that moderately retards the initial set of concrete. (Included under ASTM Type B admixtures).

3.3.2 Type RX - An admixture that produces extended retardation of the initial set of concrete. (Included under ASTM Type B admixtures).

3.4 ACCELERATING ADMIXTURES

Type AC - an admixture that accelerates the initial set and early strength development of concrete. (Equivalent to ASTM Type C admixtures).

4. PHYSICAL REQUIREMENTS

4.1 The admixture shall be evaluated by comparing the properties of a test concrete containing the admixture with the properties of a reference concrete containing similar materials without the admixture. The test concrete and the reference concrete shall be air entrained. When prepared and tested in accordance with this test method, the test concrete shall meet the requirements specified in Table 1.

Table 1
Physical Requirements

Property	Calculation	Types						
		WN	WR	SN	SR	R	RX	AC
Water Content Maximum, %	$T/R \times 100$	95	95	97	98	97	97	100
Initial Set Minimum, hours:min. Maximum, hours:min.	T - R	-1:20 +1:20	+1:00 +3:00	-1:20 +1:20	+1:00 +3:00	+1:00 +3:00	+5:00 -----	-1:00 -3:00
Compressive Strength Minimum, % 3 days 7 days 28 days 6 months 1 year	$T/R \times 100 \times 1.05$	 115 115 115 100 100	 115 115 115 100 100	 120 120 120 100 100	 120 120 120 100 100	 110 110 110 100 100	 100 110 110 100 100	 125 110 105 100 100
Length Change	If R exceeds 0.030 %, T/R shall not exceed 1.35. If R is not more than 0.030 %, T-R shall not exceed 0.010 %							
Air-Void Spacing Factor Maximum, mm	T	0.23	0.23	0.21	0.21	0.21	0.21	0.21
Relative Durability Factor Minimum, %	$T/R \times 100 \times 1.10$	100	100	100	100	100	100	100

5. CONCRETE MATERIALS

The materials used for the preparation of concrete shall be uniform in quality, properly blended where required and prepared in sufficient quantity so that one lot of material is used for the entire test program.

5.1 CEMENT: Cement shall meet the requirements of CSA Standard A5, Portland Cements, and shall be a blend of equal parts of Normal Portland Cement (Type 10) from three different mills, St. Lawrence, Mississauga, Ontario, St. Marys Cement Company, St. Marys, Ontario, and Essroc Italcementi Group, Picton, Ontario. When the blend of cements is tested for early stiffening in accordance with CSA Standard A5 (Appendix A), the penetration shall be at least 50 %.

5.2 WATER: The water used in the preparation of mixes shall be drinkable water approved by the Ministry of Health.

5.3 AGGREGATE : All aggregate used in the preparation of concrete mixes shall meet the requirements of CSA Standard A23.1, except as specified herein.

Aggregate shall meet the grading requirements of Table 2 and shall be batched in a water saturated condition which shall be attained by soaking the aggregate, completely submerged, for 24 hours in water. To meet the grading requirements specified, it is necessary to sieve the coarse aggregate through the 26.5, 19.0, 13.2, 9.5 and 4.75 mm sieves and recombine the material to the specified grading.

Table 2
Aggregate Grading Requirements

Type	Sieve Size	Percent Passing	(Alternative)
Fine Aggregate	4.75 mm	95 - 100	
	1.18 mm	65 - 80	
	300 µm	10 - 30	
	150 µm	2 - 10	
Coarse Aggregate	26.5 mm	100	(100)
	19.0 mm	80	(75)
	13.2 mm	50	(50)
	9.5 mm	30	(25)
	4.75 mm	0	(0)

5.4 Air Entraining Admixture

The air entraining admixture shall be neutralized vinsol resin.

6. CONCRETE MIX PROPORTIONS

The same mix proportions shall be used in all batches of both test and reference concrete. MTO Laboratory Test Method LS-481, Selecting Proportions for MTO Structural and Pavement Concrete (ACI Standard 211.1, Recommended Practice for Selecting Proportions for Normal and Heavyweight Concrete) shall be used as a proportioning guide.

Both the reference concrete and the test concrete shall have a cement content of $305 \pm 5 \text{ kg/m}^3$. The slump of the reference and test concrete shall fall in the range of 80 - 100 mm and the slump of the test concrete shall be within 10 mm of that of the reference concrete.

The air content of the reference and test concrete shall be in the range of 5 - 7 % and the air content of the test concrete shall be within 0.5 % of that of the reference concrete.

7. MIXING OF CONCRETE

The following mixing procedure shall be followed:

7.1 Ensure that the mixer is buttered either by mixing a butter batch similar to the reference concrete or through having discharged another test batch just previously;

7.2 Prior to starting the mixer, place about 1/2 the mixing water, the saturated coarse aggregate, the solutions of air entraining and chemical admixtures when required, the saturated fine aggregate, and the cement in the mixer in that order. The admixture solutions shall be diluted with part of the mixing water;

7.3 Start the mixer and mix for 1/2 minute;

7.4 Continue mixing for a further 3-1/2 minutes while adding the remainder of the mixing water

Note 2: An experienced operator may add water incrementally during mixing to adjust to the desired slump.

7.5 Stop mixer for 3 minutes. During this rest period cover the mixer with damp burlap or other suitable material to prevent evaporation;

7.6 Mix for 1 minute. Stop the mixer and let the concrete rest for 2 minutes before removing any concrete for testing. During this period cover the mixer as during the previous rest period.

Note 3: An experienced operator may add water incrementally during mixing to adjust to the desired slump.

The total mixing time shall be 5 minutes plus 5 minutes rest period.

8. TEST PROGRAM

8.1 Each of the properties listed in Table 1, except the air-void spacing factor, shall be determined from each round of at least three rounds of tests made on different days. The air-void spacing factor shall be determined from one round only. A round of tests shall consist of sufficient batches to provide the required number of test and reference specimens. Reference and test mixes for comparison purposes shall always be made on the same day. Where it is apparent that the reproducibility within three rounds of tests is poor, repeat tests shall be carried out until satisfactory reproducibility is obtained.

8.2 The values for compressive strength, time of initial set, length change, and relative durability factor shall be those obtained by averaging the results from three consecutive rounds of tests and applying the appropriate correction factors (see Table 1).

9. TEST PROCEDURE

9.1 FRESH CONCRETE

9.1.1 Water Content

The water content shall be defined as the total effective water and shall include added water, surface moisture on aggregate and any water contained in the admixtures. It shall be calculated according to the following equation for each batch:

$$W_T \text{ (or } W_R) = W_A + W_B + W_C - W_D (1+A/100) - W_E (1+B/100)$$

where:

W_T = water content for test concrete

W_R = water content for reference concrete

W_A = batch mass of saturated aggregate

W_B = batch mass of added water

W_C = mass of water contained in all admixtures

W_D = oven dry mass of coarse aggregate

W_E = oven dry mass of fine aggregate

A = absorption percent of coarse aggregate as defined in CSA Test Method A23.2-12A

B = absorption percent of fine aggregate defined in CSA Test Method A23.2-6C

9.1.2 Slump

The slump shall be determined for each batch in accordance with CSA Test Method A23.2-5C, Slump of Concrete. The test shall be performed within 3 to 5 minutes after completion of mixing. The same time interval shall be used when determining the slump of reference and test concrete in the same round of testing.

9.1.3 Air Content

The air content of the freshly mixed concrete shall be determined for each batch concurrently with the slump test in accordance with CSA Test Method A23.2-4C, Air Content of Plastic Concrete by the Pressure Method. Meters designed to provide air content measurements as a function of pressure change shall have dials with each division representing not more than 0.1 percent air content in the range of 5 - 7 percent and shall be accurately calibrated by positive displacement methods in this range.

9.1.4 Density

The density shall be determined in accordance with CSA Test Method A23.2-6C, Density, Yield and Cement Factor of Plastic Concrete, except that the volume of concrete tested shall not be less than 14 L.

9.1.5 Time of Initial Set

The time of initial set shall be determined in accordance with ASTM Standard C403, Time of Setting of Concrete Mixtures by Penetration Resistance. The test shall be conducted at $23 \pm 2^{\circ}\text{C}$ and the penetration resistance apparatus used shall be of the bench or floor mounted hydraulic or spring reaction type, having a frame of sufficient stiffness to prevent lateral movement of the needle during penetration.

9.2 HARDENED CONCRETE

9.2.1 Compressive Strength

Compressive strength specimens shall be 150 mm in diameter and shall be prepared and cured in accordance with MTO Method LS-401, Method of Making and Curing Concrete Compression and Flexure Test Specimens in the Laboratory. The specimens shall be tested in accordance with MTO Method LS-407, Method of Test for Compressive Strength of Moulded Concrete Cylinders. One test shall consist of two cylinders from each round for each age specified in Table 1.

9.2.2 Air-Void Spacing Factor

The air-void spacing factor shall be determined in accordance with ASTM Standard C457 at a minimum magnification factor of 100. Either the Linear Traverse (Rosiwal) Method or Modified Point-Count Method may be used and the paste content may be either measured or calculated. A test shall consist of one sample prepared from a 100 mm x 200 mm test cylinder cast from any batch of test concrete. The specimen shall be prepared from a longitudinal slice sawn from the centre of the cylinder.

9.2.3 Relative Durability Factor

The relative durability factor shall be determined using Procedure A (Freeze in Water, Thaw in Water) of ASTM Standard C666, Resistance of Concrete to Rapid Freezing and Thawing. The relative durability factor (RDF) shall be calculated as follows:

$$T \text{ (or } R) = PN / 300$$

$$RDF = (T / R) \times 100 \times 1.10$$

where:

T = durability factor of the concrete containing the admixture under test

R = durability factor of concrete containing the reference admixture

P = relative dynamic modulus of elasticity in percentage of the dynamic modulus of elasticity at zero cycles (values of P will be 60 or greater)

N = number of cycles at which P reaches 60 percent, or 300 if P does not reach 60 percent prior to the end of the test (300 cycles)

A test shall consist of two specimens each of reference and test concrete from each round.

9.2.4 Length Change

The determination of length change shall be made in accordance with ASTM Standard C157, Length Change of Hardened Cement Mortar and Concrete. The moist curing period, including the period in the moulds shall be 14 days. The drying period shall also be 14 days. The drying shrinkage shall be considered to be the length change during the drying period based on initial measurement at the time of removal of the specimen from the mould. It shall be expressed as a percent, to the nearest 0.001 percent based on the specimen gauge length.

METHOD OF TEST FOR EVALUATION OF SUPERPLASTICIZING ADMIXTURES FOR CONCRETE

1. SCOPE

This method covers physical requirements and qualification tests for superplasticizing admixtures used for:

- 1.1 High range water reduction and strength increase; and
- 1.2 Production of flowing concrete.
- 1.3 These tests are based on arbitrary stipulations that make possible highly standardized testing in the laboratory and are not intended to simulate actual job conditions.

Note 1: This method is based on CSA A266.6-M 85, Superplasticizing admixtures for Concrete which is not currently in existence as a CSA specification.

2. RELEVANT DOCUMENTS

- 2.1 MTO Test Methods LS-401, LS-407, LS-422, LS-481
- 2.2 CSA Standards A5, A23.1, A23.2-12A, A23.2-4C, A23.2-5C, A23.2-6C
- 2.3 ASTM C 157
- 2.4 ASTM C 403
- 2.5 ASTM C 457
- 2.6 ASTM C 666
- 2.7 ACI Standard Practice 211.1

3. DEFINITIONS

- 3.1 Non-flowing concrete: Concrete of slump 20 to 180 mm
- 3.2 Flowing concrete: Concrete of slump greater than 180 mm
- 3.3 Type SPN superplasticizers: Superplasticizing admixtures with normal setting characteristics.
- 3.4 Type SPR superplasticizers: Superplasticizing admixtures with set retarding characteristics.

4. PHYSICAL REQUIREMENTS

- 4.1 The admixture shall be evaluated by comparing the properties of a test concrete containing the admixture with the properties of a reference concrete containing similar materials without the admixture. The test concrete and the reference concrete shall be air entrained. When prepared and

tested in accordance with this test method, the test concrete shall meet the requirements for nonflowing concrete or flowing concrete, or both, as specified in Table 1.

Table 1
Physical Requirements

Property	Calculation	Nonflowing concrete		Flowing Concrete	
		SPN type	SPR type	SPN type	SPR type
Water Content Maximum, %	$T/R \times 100$	88	88	NA	NA
Slump retention of test mix after 20 min	$T_{\text{final}} / T_{\text{initial}} \times 100$	Final slump of the test mix shall be at least 50 % of initial slump			
Initial Set Minimum, hours:min. Maximum, hours:min.	$T - R$	-1:20 +1:20	+1:00 +3:00	-1:20 +1:20	+1:00 +3:00
Compressive Strength Minimum, % 1 day 3 days 7 days 28 days 6 months 1 year	$T/R \times 100 \times 1.05$	150 130 125 120 100 100	130 130 125 120 100 100	100 100 100 100 100 100	100 100 100 100 100 100
Length Change	If R exceeds 0.030 %, T/R shall not exceed 1.35. If R is not more than 0.030 %, T-R shall not exceed 0.010 %				
Air-Void Spacing Factor Maximum, mm	T	0.23	0.23	0.23	0.23
Relative Durability Factor Minimum, %	$T/R \times 100 \times 1.10$	100	100	100	100

5. CONCRETE MATERIALS

The materials used for the preparation of concrete shall be uniform in quality, properly blended where required and prepared in sufficient quantity so that one lot of material is used for the entire test program.

5.1 CEMENT: Cement shall meet the requirements of CSA Standard A5, Portland Cements, and shall be a blend of equal parts of Normal Portland Cement (Type 10) from three different mills, St. Lawrence, Mississauga, Ontario, St. Marys Cement Company, St. Marys, Ontario, and Essroc Italcementi Group, Picton, Ontario. When the blend of cements is tested for early stiffening in accordance with CSA Standard A5 (Appendix A), the penetration shall be at least 50 %.

5.2 WATER: The water used in the preparation of mixes shall be drinkable water approved by the Ministry of Health.

5.3 AGGREGATE: All aggregate used in the preparation of concrete mixes shall meet the requirements of CSA Standard A23.1, except as specified herein.

Aggregate shall meet the grading requirements of Table 2 and shall be batched in a water saturated condition which shall be attained by soaking the aggregate, completely submerged, for 24 hours in water. To meet the grading requirements specified, it is necessary to sieve the coarse aggregate through the 26.5, 19.0, 13.2, 9.5 and 4.75 mm sieves and recombine the material to the specified grading.

Table 2
Aggregate Grading Requirements

Type	Sieve Size	Percent Passing	(Alternative)
Fine Aggregate	4.75 mm	95 -100	
	1.18 mm	65 - 80	
	300 µm	10 - 30	
	150 µm	2 - 10	
Coarse Aggregate	26.5 mm	100	(100)
	19.0 mm	80	(75)
	13.2 mm	50	(50)
	9.5 mm	30	(25)
	4.75 mm	0	(0)

5.4 AIR ENTRAINING ADMIXTURE: The air entraining admixture shall conform to the requirements of MTO Laboratory Test Method LS-422, Method of Test for Evaluation of Air Entraining Admixtures for Concrete.

5.5 MIXTURE TEMPERATURE: The materials shall be conditioned so as to ensure a uniform concrete temperature in the range of 17 - 22°C.

6. CONCRETE MIX PROPORTIONS

6.1 PROPORTIONING: The same mix proportions shall be used in all batches of both test and reference concrete. MTO Laboratory Test Method LS-481, Selecting Proportions for MTO Structural

and Pavement Concrete (ACI Standard 211.1, Recommended Practice for Selecting Proportions for Normal and Heavyweight Concrete) shall be used as a proportioning guide.

6.2 NONFLOWING CONCRETE: The water content of the reference concrete shall be that which produces a slump in the range of 80 - 100 mm. The water content of the test concrete shall be not more than 88 % of the water content of the reference concrete, and the slump of the test concrete after addition of the superplasticizing admixture shall equal or exceed the slump of the reference concrete, but shall not exceed 180 mm.

6.3 FLOWING CONCRETE: The water content of the reference concrete shall be that which produces a slump in the range of 80 - 100 mm. The test concrete shall have the same water content as the reference concrete and, after addition of the superplasticizing admixture, its slump shall be in the range of 180 - 240 mm. If these proportions result in segregation of the test concrete, the fine aggregate content shall be progressively increased until a satisfactory mix is obtained. This mix becomes the test concrete and the proportions of the reference concrete remain unchanged.

6.4 AIR CONTENT: The air content range shall be 5 - 7 %, and the air contents of the test and reference concretes shall not differ by more than 0.5 %. The admixture under test shall be added in the amount necessary to comply with the applicable requirements for water reduction, initial set, and slump.

7. MIXING OF CONCRETE

The following mixing procedure shall be followed:

7.1 Ensure that the mixer is buttered either by mixing a butter batch similar to the reference concrete or through having discharged another test batch just previously.

7.2 Prior to starting the mixer, place about 1/2 the mixing water, the saturated coarse aggregate, the solution of air entraining admixture (but not the superplasticizing admixture), the saturated fine aggregate, and the cement in the mixer in that order. The air entraining admixture shall be diluted with part of the mixing water.

7.3 Start the mixer and mix for 30 ± 3 seconds.

7.4 During the next 90 ± 3 seconds mixing shall be continued, while, in the case of reference or flowing test concrete, the remainder of the mixing water is being added (see note). For a nonflowing, water-reduced test concrete, water shall be added to bring the total amount to about 70 % of the total used for the reference concrete. If this fails to achieve complete wetting of the cement, which is essential to the proper functioning of a superplasticizing admixture, the amount of water shall be increased gradually until the cement is wetted to the point where all the ingredients can properly mix.

Note 2: In the case of reference concrete, an experienced operator may add water incrementally during mixing to adjust to the desired slump.

7.3 The superplasticizing admixture shall be added to the test concrete over a period of 10 to 20 s and mixing continued for a further 120 ± 3 seconds.

7.4 The mixer shall then be stopped for 180 ± 3 seconds. During this rest period the mixer shall be covered with damp burlap or other suitable material to minimize evaporation.

7.5 Mixing shall be resumed for 60 ± 3 seconds.

7.6 The mixer shall then be stopped and the concrete left undisturbed for 120 ± 3 seconds before removing any for testing. During this period the mixer shall be covered as during the previous rest period. The total mixing time shall be 5 minutes, with 2 rest periods totalling approximately 5 minutes.

8. TEST PROGRAM

8.1 Each of the properties listed in Table 1, except the air-void spacing factor, shall be determined from each round of at least three rounds of tests. A round of tests shall consist of sufficient batches to provide the required number of test and reference specimens. Reference and test mixes for comparison purposes shall always be made on the same day. When the repeatability within a round of tests or the reproducibility over three consecutive rounds of tests is judged unsatisfactory, additional rounds of tests shall be performed until satisfactory repeatability and reproducibility are obtained.

8.2 The values for water content, compressive strength, time of initial set, length change, and relative durability factor shall be those obtained by averaging the results from three consecutive rounds of tests and applying the appropriate correction factors.

9. TEST PROCEDURE

9.1 FRESH CONCRETE

9.1.1 Water content: The water content shall be defined as the total effective water and shall include added water, surface moisture on aggregate and any water contained in the admixtures. It shall be calculated according to the following equation for each batch:

$$W_T \text{ (or } W_R) = W_A + W_B + W_C - W_D (1+A/100) - W_E (1+B/100)$$

where:

W_T = water content for test concrete

W_R = water content for reference concrete

W_A = batch mass of saturated aggregate

W_B = batch mass of added water

W_C = mass of water contained in all admixtures

W_D = oven dry mass of coarse aggregate

W_E = oven dry mass of fine aggregate

A = absorption percent of coarse aggregate as defined in CSA Test Method A23.2-12A

B = absorption percent of fine aggregate defined in CSA Test Method A23.2-6C

9.1.2 Slump: The initial and final slump shall be determined for each batch of reference or test concretes in accordance with CSA Test Method A23.2-5C, Slump of Concrete. Initial slump shall be determined not sooner than 3 minutes nor later than 5 minutes after the final rest period following mixing of the concrete. After the concrete has been allowed to remain undisturbed for 20 minutes with the ambient air temperature in the range of $23 \pm 2^\circ\text{C}$, the concrete shall be remixed to ensure uniformity and the final slump determined. The moulding of test specimens shall commence only after the final slump has been determined.

9.1.3 Air content: The air content of the concrete shall be determined for each batch concurrently with the final slump test in accordance with CSA Test Method A23.2-4C, Air Content of Plastic Concrete by the Pressure Method. Meters designed to provide air content measurements as a function of pressure change shall have dials with each division representing not more than 0.1 % air content in the range of 5 - 7 %, and shall be accurately calibrated by positive displacement methods in this range.

9.1.4 Density: The density shall be determined in accordance with CSA Test Method A23.2-6C, Density, Yield and Cement Factor of Plastic Concrete. The volume of concrete tested shall be not less than 14 L.

9.1.5 Time of initial set: The time of initial set shall be determined in accordance with ASTM Standard C403, Time of Setting of Concrete Mixtures by Penetration Resistance. The test shall be conducted at $23 \pm 2^\circ\text{C}$ and the penetration resistance apparatus used shall be of the bench or floor mounted hydraulic or spring reaction type, having a frame of sufficient stiffness to prevent lateral movement of the needle during penetration.

9.2 HARDENED CONCRETE

9.2.1 Compressive strength: Compressive strength specimens shall be 150 mm in diameter and shall be prepared and cured in accordance with MTO Method LS-401, Method of Making and Curing Concrete Compression and Flexure Test Specimens in the Laboratory. The specimens shall be tested in accordance with MTO Method LS-407, Method of Test for Compressive Strength of Moulded Concrete Cylinders. One test shall consist of two cylinders from each round for each age specified in Table 1.

9.2.2 Air-void spacing factor: The air-void spacing factor shall be determined in accordance with ASTM Standard C457 at a minimum magnification factor of 100. Either the Linear Traverse

(Rosiwal) Method or Modified Point-Count Method may be used and the paste content may be either measured or calculated. A test shall consist of one sample prepared from a 100 mm x 200 mm test. The specimen shall be prepared from a longitudinal slice sawn from the centre of the cylinder.

9.2.3 Relative durability factor: The relative durability factor shall be determined using Procedure A (Freeze in Water, Thaw in Water) of ASTM Standard C666, Resistance of Concrete to Rapid Freezing and Thawing. The relative durability factor (RDF) shall be calculated as follows:

$$D_T \text{ (or } D_R) = PN/300$$

$$RDF = (D_T / D_R) \times 100 \times 1.10$$

where:

D_T = durability factor of the concrete containing the admixture under test

D_R = durability factor of concrete containing the reference admixture

P = relative dynamic modulus of elasticity in percentage of the dynamic modulus of elasticity at zero cycles (values of P will be 60 or greater)

N = number of cycles at which P reaches 60 percent, or 300 if P does not reach 60 percent prior to the end of the test (300 cycles)

A test shall consist of two specimens each of reference and test concrete from each round.

9.2.4 Length change : The determination of length change shall be made in accordance with ASTM Standard C157, Length Change of Hardened Cement Mortar and Concrete. The moist curing period, including the period in the moulds shall be 14 days. The drying period shall also be 14 days. The drying shrinkage shall be considered to be the length change during the drying period based on initial measurement at the time of removal of the specimen from the mould. It shall be expressed as a percent, to the nearest 0.001 percent based on the specimen gauge length.

METHOD OF TEST FOR GLASS BEAD APPLICATION RATE AND DRY FILM THICKNESS FOR SPRAY APPLIED PAVEMENT MARKINGS

1. SCOPE

- 1.1 This method covers the determination of glass bead rate and dry film thickness for spray applied pavement markings.

2. DEFINITIONS

- 2.1 Unbeaded - No overlay of glass beads is applied to the pavement marking coating.
- 2.2 Beaded - An overlay of glass bead is applied to the pavement marking coating.

3. APPARATUS

- 3.1 **BALANCE:** A weighing device having a capacity of 1.0 kg or more, sensitive and readable to 0.1 g or less and accurate within 0.1% of the test load at any point within the range of use for this test.
- 3.2 **TEST PANELS:** Steel Q panels measuring not less than 152 mm wide, 305 mm in length and of a minimum thickness of 0.8 mm shall be used.
- 3.3 **DRY FILM THICKNESS GAUGE:** Magnetic Type 2 – Constant Pressure Probe Gauge. The gauge must have a minimum capacity of 1250 μm and an accuracy at least within 10%.

4. PROCEDURE

- 4.1 Bare steel Q panels are weighed and the mass recorded. The panels are used as the substrate for both the glass bead application rate and the dry film thickness measurement.
- 4.2 Two panels are obtained per test site (one unbeaded and one beaded). The panels are placed on the pavement surface so that the short side of the panel is parallel with the direction of the pavement marking striping operation. The panels should be placed between 2 and 3 m apart. The unbeaded panel is obtained by momentarily turning off the glass bead application gun on the striping equipment.

- 4.3 The coated panels are removed from the roadway surface and permitted to dry or cure on a flat, level surface. For paints, a minimum of 24 hours is required before conducting tests. For spray field reacted materials please refer to the coating manufacturer's product data sheets for minimum cure times.
- 4.4 In order to obtain accurate measurements the coated panels must be kept free from dirt grease and any other foreign matter.
- 4.5 The panels are re-weighed and the mass recorded. All weight determinations should be made to the nearest 0.1 g.

5. CALCULATION OF GLASS BEAD APPLICATION RATE

- 5.1 The Glass Bead Application Rate is calculated as follows:

A= Weight of unbeaded panel (grams)

B= Weight of coated unbeaded panel (grams)

C= Weight of beaded panel (grams)

D= Weight of coated beaded panel (grams)

E=B-A

F=D-C

where E= Weight of coating on unbeaded panel (grams)

where F= Weight of coating & beads on beaded panel (grams)

Glass Bead Application Rate = $(G \cdot H \cdot (F - E)) / (E \cdot 100)$

where G= Coating Density (kg/l)

where H= Weight Solids of Coating (%)

- 5.2 Both the Coating Density and Weight Solids of the Coating can be obtained from the coating manufacturer's product data sheet or the manufacturer.
- 5.3 Glass Bead Application Rate shall be expressed in kg/l of pavement marking material.

6. MEASUREMENT OF DRY FILM THICKNESS

- 6.1 Calibration and Verification: Type 2 – Constant Pressure Probe Gauges

6.1.1 Different manufacturers of Type 2 gauges follow different methods of calibration or adjustment. Calibrate the gauge according to manufacturer's instructions.

6.1.2 Magnetic gauges are sensitive to geometrical discontinuities of the steel such as holes, corners or edges. The sensitivity to edge effects and discontinuities varies from gauge to gauge. Measurements should not be made closer than 1.5 cm from the panel and paint edges.

6.2 Measurement of Dry Film Thickness

6.2.1 With a properly calibrated gauge, measure the dry film thickness as specified below.

6.2.2 Make five separate spot measurements spaced randomly over the panel. Take the average of the five spot measurements. The dry film thickness shall be expressed in μm (micrometers).

6.2.3 A spot measurement is as follows: A minimum of three gauge readings shall be made for each spot measurement. For each new gauge reading move the probe to a new location within 4 cm-diameter circle defining the spot. Discard any unusually high or low gauge reading that cannot be repeated consistently.

6.2.4 Take the average of the acceptable gauge readings as the spot measurement.

APPENDIX

Example of Glass Bead Application Rate

Weight of bare steel panel for unbeaded sample 293.2 g

Weight of bare steel panel for beaded panel sample 295.6 g

Weight of coated unbeaded panel 301.6 g

Weight of coated beaded panel 310.9 g

Coating Density 1.52 kg/l

Weight Solids 52.2%

$$E=B-A$$

$$E=301.6-293.2= 8.4 \text{ g}$$

$$F=D-C$$

$$F=310.9-295.6=15.3 \text{ g}$$

$$\text{Glass Bead Application Rate} = (1.52 \times 52.2 \times (15.3 - 8.4)) / (8.4 \times 100)$$

$$\text{Glass Bead Application Rate} = 0.652 \text{ kg/l}$$

METHOD OF TESTING COMPRESSIVE STRENGTH OF HIGH PERFORMANCE CONCRETE CYLINDERS

1. SCOPE

1.1 This method covers apparatus, materials and procedures for testing compressive strength of high performance concrete with $\downarrow$ 100 x 200mm cylinders.

2. RELEVANT DOCUMENTS

2.1 CSA Standard A23.2-9C

2.2 ASTM C39

3. PROCEDURE

3.1 Procedures of CSA Standard A23.2-9C shall be followed, except as noted below.

4. EXCEPTIONS

4.1 APPARATUS

4.1.1 Calibration of compression testing machine: The compression testing machine for testing high performance concrete shall be calibrated at a 6 month interval.

4.1.2 The bearing faces of blocks used for compression testing of concrete must have a Rockwell hardness of not less than 55 HRC.

4.2 MATERIALS

4.2.1 Capping materials: The capping materials must have a compressive strength of not less than 70 MPa. Capping materials shall not be recycled for high performance concrete testing.

4.3 PROCEDURES

4.3.1 Receiving, Demolding and Examining Cylinders

4.3.1.1 Each set of cylinders shall consist of three cylinders. A sample sheet should accompany the cylinders.

4.3.1.2. Sample identification shall be clearly recorded on the cylinders after demolding.

4.3.1.3. The cylinders shall be visually examined for defects or any other unusual conditions and observations should be recorded.

4.3.1.4. The mass of cylinders shall be measured to the nearest 0.05 kg and recorded.

4.3.1.5. The diameter of each cylinder shall be determined with two measurements at right angles to each other at about midheight of the cylinder and recorded to the nearest 0.1 mm. The two measurements shall then be averaged to the nearest 0.5 mm. The

average diameter of each cylinder shall be recorded and used for calculating the cross-sectional area of the cylinder.

4.3.1.6. If the two diameter measurements on a cylinder differ by more than 2 % of the smaller reading, the cylinder shall not be tested.

4.3.2 Cylinder Ends Preparation

Cylinder ends shall be prepared by either grinding or capping. The cylinders shall be kept moist after end preparation. If the cylinder ends are prepared more than 3 hours prior to the scheduled testing time, the cylinders shall be kept in a curing facility after the completion of end preparation until the time of testing.

4.3.2.1 Specimen Tolerances

The planeness and perpendicularity of both prepared ends of every cylinder shall be measured and recorded.

Planeness: The surface of prepared ends of cylinders shall not depart from a plane by more than 0.025 mm.

Perpendicularity: Either prepared end of a cylinder shall not depart from the perpendicularity to the axis by more than 0.5°. (Approximately equivalent to 2 mm in 200 mm)

4.3.2.2 Prepare Cylinder Ends by Grinding

The grinding operation shall be carried out when the concrete has adequate strength to sustain the operation.

4.3.2.3 Prepare Cylinder Ends by Capping:

Each laboratory shall establish the time-strength development relation curve or table for its capping material up to 72 hours at least once every three months or once per batch of capping material whichever is more frequent.

Capping shall be done between 2 to 72 hours prior to testing, at such time that the capping material will have enough time to reach 70 MPa prior to testing cylinders according to the time-strength development curve or table for the material. (For example, if capping material ABC can reach 70 MPa at 24 hours, the cylinders must be capped at least 24 hours prior to testing.)

Each day high performance concrete cylinders are capped, three 50x50x50 mm cubes of the capping material shall be made as per CSA A23.2-9C at the same time as the cylinders are capped.

Each day high performance concrete cylinders are tested, the strength of capping material cubes shall be tested prior to the cylinder test.

4.3.3 Testing Compressive Strength

All cylinders shall be tested to complete failure. The type of failure shall be recorded according to ASTM C39 (Section 9.1.6 and Figure 2.).

4.3.4 Calculation of Compressive Strength

4.3.4.1 Calculate the compressive strength of each cylinder and the mean compressive strength of the three cylinders. The 0.95 correction factor shall not be used.

4.3.4.2 Calculate the difference in compressive strength between individual cylinders and the mean and record the difference in the form of percentage of the mean.

4.3.4.3 If none of the three results differs more than 15% (of the mean) from the mean, the mean is considered valid and shall be recorded as the compressive strength of this set.

4.3.4.4 If one or more of the three individual results differs more than 15% from the mean, the lowest result should be discarded. The mean of the remaining two cylinders shall be calculated. If the two individual results differ less than 15% (of the mean of the two) from the mean of the two, the result is valid and the mean of the two remaining cylinders shall be recorded as the compressive strength of the set. If the two individual results still differ more than 15% from the mean of the two, the results of this set of cylinder are invalid and the three individual results shall be reported for reference.

4.3.4.5 Examples of Calculation

Example A:

The results of the three cylinders are: 54.0, 60.0 and 63.0 MPa.

The mean of the three = $(54.0 + 60.0 + 63.0) / 3 = 59.0$

The differences between each individual and the mean are:

$$(54.0 - 59.0) / 59.0 \times 100\% = -8\%$$

$$(60.0 - 59.0) / 59.0 \times 100\% = 2\%$$

$$(63.0 - 59.0) / 59.0 \times 100\% = 7\%$$

None of the three is more than 15%, therefore, the result of this set should be: 59.0 MPa

Example B:

The results of the three cylinders are: 51.0, 70.0 and 80.0 MPa.

The mean of the three = $(51.0 + 70.0 + 80.0) / 3 = 67.0$

The differences between each individual and the mean are:

$$(51.0 - 67.0) / 67.0 \times 100\% = -24\%$$

$$(70.0 - 67.0) / 67.0 \times 100\% = 4\%$$

$$(80.0 - 67.0) / 67.0 \times 100\% = 19\%$$

The first and the third cylinders are more than 15% apart from the mean, therefore, the lowest result, 51.0 MPa, is discarded.

The mean of the remaining two = $(70.0 + 80.0) / 2 = 75.0$ MPa

The differences between each individual and the mean of the two are:

$$(70.0 - 75.0) / 75.0 \times 100\% = -7\%$$

$$(80.0 - 75.0) / 75.0 \times 100\% = 7\%$$

None of the two are more than 15% apart from the mean, therefore, the result of this set should be: 75.0 MPa

Example C:

The results of the three cylinders are: 40.0, 43.0 and 70.0 MPa.

The mean of the three = $(40.0 + 43.0 + 70.0) / 3 = 51.0$

The differences between each individual and the mean are:

$$(40.0 - 51.0) / 51.0 \times 100\% = -22\%$$

$$(43.0 - 51.0) / 51.0 \times 100\% = -16\%$$

$$(70.0 - 51.0) / 51.0 \times 100\% = 37\%$$

All of three cylinders are more than 15% from the mean, therefore, the lowest result, 40.0 MPa, is discarded.

The mean of the remaining two = $(43.0 + 70.0) / 2 = 56.5$ MPa

The differences between each individual and the mean of the two are:

$$(43.0 - 56.5) / 56.5 \times 100\% = -24\%$$

$$(70.0 - 56.5) / 56.5 \times 100\% = 24\%$$

Both cylinders are more than 15% apart from the mean of the two, therefore, report the results of this set as invalid and provide the three individual results.

4.3.5 Reporting of Results

The report shall include:

- a. Diameter of each cylinder to the nearest 0.5 millimeters.
- b. Cross-sectional area of each cylinder in square millimeters
- c. Mass of each cylinder, to the nearest 0.05 kilograms.
- d. Maximum load in Newton.
- e. Compressive strength of each cylinder calculated to the nearest 0.1 MPa.
- f. Mean compressive strength of the set calculated according to the above instructions, to the nearest 0.1 MPa.
- g. Deviation of result of each cylinder from the mean in percentage of the mean.
- h. The type of fracture (according to ASTM C39 Section 9.1.6 and Figure 2)
- i. Method of end preparation, i.e. capping or grinding.

- j. If the cylinders are capped, the compressive strength of the capping material to the nearest 0.1 MPa and testing time in hours after casting.
- k. The planeness and perpendicularity measurements of both ends of each cylinder.

METHOD OF TEST FOR COMPRESSIVE DEFORMATION OF PLAIN BEARINGS

1. SCOPE

- 1.1 This test method covers the test procedures for determining the compressive deformation characteristics of plain bearings.

2. RELEVANT DOCUMENT

- 2.1 OPSS 1202 - Material Specification for Bearings - Elastomeric Plain and Steel Laminated

3. DEFINITION

- 3.1 The compressive deformation of plain bearings is the deformation at the Maximum Average Pressure expressed as a percentage of the effective elastomer thickness.

4. APPARATUS

- 4.1 *Compression Testing Machine* - A compression testing machine conforming to the requirements of ASTM E 4, Standard Practices for Force Verification of Testing Machines. The machine shall be of sufficient capacity to fully load the bearing by applying force gently and without impact.
- 4.2 *Displacement Gauge* - The deformation shall be read on a digital or dial gauge graduated in hundredths of millimetres.
- 4.3 *Measuring Tape* - The dimensions of the specimen should be measured using a measuring tape graduated to the nearest millimetre.
- 4.4 *Load Distribution Plate* - Rigid machined plates (top & bottom) that can withstand the compressive stresses without bending.

5. TEST SPECIMENS

- 5.1 Test specimens shall be according to OPSS 1202 and Contract Documents.

6. PREPARATION OF SPECIMENS

- 6.1 Upon delivery, the specimens shall be stored and left undisturbed for at least 24 hours at a temperature of $23^{\circ}\text{C} \pm 2^{\circ}\text{C}$ prior to testing.
- 6.2 No adjustments or modifications shall be made to the specimen except that the surfaces of the specimen that will contact the platens of the testing machine shall be cleaned of any dust, bloom, grease, or other foreign material.

7. NATURE OF TEST

- 7.1 Compressive forces are applied and removed in three successive cycles. The first two cycles are for conditioning the specimen.

8. CALCULATION (BEFORE TESTING)

- 8.1 Calculate the surface area and perimeter using the measured dimensions.
- 8.2 Calculate the area free to bulge.
- 8.3 Calculate the shape factor.
- 8.4 Calculate the loading rate.
- 8.5 Calculate the Maximum Average Pressure.
- 8.6 Calculate the stress levels at which the displacement gauge readings are recorded.
- 8.7 Calculate the corresponding loads for each stress level determined in step 8.6.

9. EXAMPLE OF CALCULATION (BEFORE TESTING)

9.1 Measured Dimensions of Bearing :

Length = 300 mm

Width = 200 mm

Thickness = 21 mm

9.2 From measured bearing dimensions calculate the following:

a. Measured Area (area of loaded face) = 60,000 mm²

b. Perimeter = 1,000 mm

Effective Elastomer Thickness (T_e) is the actual measured pad thickness
= 21 mm

9.3 Calculate area of bearing free to bulge (area of sides).

Area free to bulge = perimeter x thickness

$$1,000 \text{ mm} \times 21 \text{ mm} = 21,000 \text{ mm}^2$$

9.4 Calculate the Shape Factor.

Shape Factor = (area of the loaded face divided by the area free to bulge).

$$60,000 \text{ mm}^2 / 21,000 \text{ mm}^2 = 2.86$$

9.5 Calculate the loading rate corresponding to 1.5 MPa/minute.

$$\text{Loading Rate} = 1.5 \text{ N/mm}^2/\text{minute} \times 60,000 \text{ mm}^2 = 90.0 \text{ kN/min.}$$

9.6 Calculate the Maximum Average Pressure.

Maximum Average Pressure = $0.22 \times (\text{Shape Factor})^2$.

$$= 0.22 \times (2.86)^2$$

$$= 1.80 \text{ MPa}$$

9.7 Calculate the stress levels at which the displacement gauge readings are recorded.

Readings start at a level equal to 20% of the Maximum Average Pressure and continue at intervals equal to 20% of the Maximum Average Pressure until reaching 110% of the Maximum Average Pressure.

9.8 Calculate the load for each stress level.

$$\text{Load} = \text{Stress} \times \text{Area} = (0.36 \text{ N/mm}^2) \times (60,000 \text{ mm}^2) = 22 \text{ kN}$$

Stress	Load	Gauge # 1	Gauge # 2	Average	Deformation
MPa	kN	mm	mm	mm	mm
0.36	22	-	-	-	-
0.72	43	-	-	-	-
1.08	65	-	-	-	-
1.44	86	-	-	-	-
1.80	108	-	-	-	-
1.98	119	-	-	-	-

10. TEST PROCEDURE

- 10.1 Centre the specimen between the platens of the testing machine. If load distribution plates are used, the plates shall be centred under the platens and the specimen centred under the plates. Plates or platens in contact with the specimen shall be at least 25 mm greater than the test specimen in both plan dimensions.
- 10.2 At least two displacement gauges shall be positioned at the centre of opposite sides in the long dimension of the specimen to measure deformation.
- 10.3 The specimen shall be initially loaded to 20% of the Maximum Average Pressure. The displacement gauge readings shall be recorded at this point.
- 10.4 The bearing shall be loaded to 110% of the Maximum Average Pressure at the rate of 1.5 MPa/minute. The displacement gauge reading shall be recorded at this point.
- 10.5 The bearing shall be unloaded at the same rate until the pressure of the bearing returns to 20% of the Maximum Average Pressure. The displacement gauge readings shall be recorded at this point.
- 10.6 The pressure on the bearing shall be maintained at 20% Maximum Average Pressure for 15 minutes. The displacement gauge reading at the end of this 15 minute period shall be recorded.

- 10.7 The bearing shall be subjected to a 2nd cycle by repeating steps 10.4, 10.5 and 10.6.
- 10.8 In the 3rd cycle, the bearing shall be reloaded to 110% of the Maximum Average Pressure in the same manner as step 10.4 except the displacement gauge readings shall be recorded at intervals equal to 20% of the Maximum Average Pressure.
- 10.9 The data recorded during the 3rd cycle shall be plotted on a graph of stress versus deformation. A 'best-fit' straight line using the least-squares method shall be constructed through the data points. The line shall start at the point corresponding to 20% Maximum Average Pressure and zero deformation.

11. CALCULATION (AFTER TESTING)

- 11.1 Determine the deformation (d) at the Maximum Average Pressure from the stress/deformation graph and calculate the percent compressive deformation (A) using the effective elastomer thickness (T_e). Express the result to the nearest 0.1 %.

$$A = (d / T_e) \times 100$$

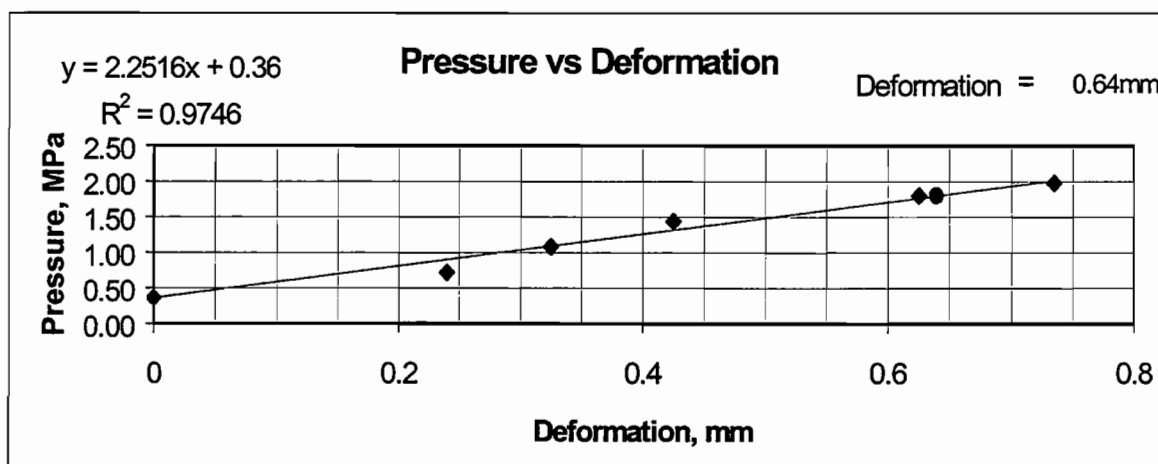
12. EXAMPLE OF CALCULATION (AFTER TESTING)

- 12.1 The deformation is determined by subtracting the average gauge reading at the stress level of 20% of the Maximum Average Pressure from each average gauge reading. For example, the deformation at 0.72 MPa is 3.18 mm – 2.94 mm = 0.24 mm.

Stress	Load	Gauge # 1	Gauge # 2	Average	Deformation
MPa	kN	mm	mm	mm	mm
0.36	22	2.36	3.51	2.94	0.00
0.72	43	2.70	3.65	3.18	0.24
1.08	65	2.75	3.77	3.26	0.32
1.44	86	2.84	3.88	3.36	0.42
1.80	108	3.05	4.07	3.56	0.62
1.98	119	3.16	4.18	3.67	0.73

- 12.2 Determine the deformation at 1.80 MPa (Maximum Average Pressure) from Pressure/Deformation graph

Deformation = 0.64



- 12.3 Compressive Deformation = (Deformation at Max. Avg. Pressure/ T_e) $\times$ 100
Compressive Deformation = (0.64/21) $\times$ 100 = 3.0%

METHOD OF TEST FOR COMPRESSIVE DEFORMATION OF LAMINATED BEARINGS

1. SCOPE

- 1.1 This test method covers the test procedures for determining the compressive deformation characteristics of laminated bearings.

2. RELEVANT DOCUMENT

- 2.1 OPSS 1202 Material Specification for Bearings - Elastomeric Plain and Steel Laminated

3. DEFINITION

- 3.1 The compressive deformation of laminated bearings is the deformation at 7.0 MPa expressed as a percentage of the effective elastomer thickness.

4. APPARATUS

- 4.1 *Compression Testing Machine* - A compression testing machine conforming to the requirements of ASTM E 4, Standard Practices for Force Verification of Testing Machines. The machine shall be of sufficient capacity to fully load the bearing by applying force gently and without impact.
- 4.2 *Displacement Gauge* - The deformation shall be read on a digital or dial gauge graduated in hundredths of millimetres.
- 4.3 *Measuring Tape* - The dimensions of the specimen should be measured using a measuring tape graduated to the nearest millimetre.
- 4.4 *Load Distribution Plate* - Rigid machined plates (top & bottom) that can withstand the compressive stresses without bending.

5. TEST SPECIMENS

- 5.1 Test specimens shall be according to OPSS 1202 and Contract Documents.

6. PREPARATION OF SPECIMENS

- 6.1 Upon delivery, the specimens shall be stored and left undisturbed for at least 24 hours at a temperature of $23^{\circ}\text{C} \pm 2^{\circ}\text{C}$ prior to testing.
- 6.2 No adjustments or modifications shall be made to the specimen except that the surfaces of the specimen that will contact the platens of the testing machine shall be cleaned of any dust, bloom, grease, or other foreign material.

7. NATURE OF TEST

- 7.1 Compressive forces are applied and removed in three successive cycles. The first two cycles are for conditioning the specimen.

8. CALCULATION (BEFORE TESTING)

- 8.1 Calculate the surface area using the measured dimensions
- 8.2 Calculate the loading rate to cause a stress increase of 1.5 MPa / minute
- 8.3 Calculate the corresponding loads for each stress level from 1.5 MPa to 7.5 MPa at increments of 0.5 MPa

9. EXAMPLE OF CALCULATION (BEFORE TESTING)

- 9.1 Dimensions of Bearing (mm):

Length = 350

Width = 250

- 9.2 From bearing dimensions calculate the following:

a. Effective Elastomer Thickness $T_e = 49.36 \text{ mm}$ (determined by LS-429)

b. Measured Area $\text{Area} = 350 \times 250 = 87,500 \text{ mm}^2$

- 9.3 Load Rate = $1.5 \text{ N/mm}^2/\text{minute} \times 87,500 \text{ mm}^2 = 131.25 \text{ kN / minute}$

- 9.4 Calculate the load for each stress level

$\text{Load} = \text{Stress} \times \text{Area} = (2.0 \text{ N/mm}^2) \times (87,500 \text{ mm}^2) = 175 \text{ kN}$

Stress	Load	Gauge # 1	Gauge # 2	Average	Deformation
MPa	kN	mm	mm	mm	mm
1.5	131	-	-	-	-
2.0	175	-	-	-	-
2.5	219	-	-	-	-
3.0	263	-	-	-	-
3.5	306	-	-	-	-
4.0	350	-	-	-	-
4.5	394	-	-	-	-
5.0	438	-	-	-	-
5.5	481	-	-	-	-
6.0	525	-	-	-	-
6.5	569	-	-	-	-
7.0	613	-	-	-	-
7.5	656	-	-	-	-

10. TEST PROCEDURE

- 10.1 Centre the specimen between the platens of the testing machine. If load distribution plates are used, the plates shall be centred under the platens and the specimen centred under the plates. Plates or platens in contact with the specimen shall be at least 25 mm greater than the test specimen in both plan dimensions.
- 10.2 At least two displacement gauges shall be positioned at the centre of opposite sides in the long dimension of the specimen to measure deformation.
- 10.3 The specimen shall be initially loaded to cause a stress of 1.5 MPa. The displacement gauge readings shall be recorded at this point.
- 10.4 The loading shall be increased at a rate of 1.5 MPa / min until the specimen has attained a stress of 7.5 MPa. The displacement gauge reading shall be recorded at this point.

- 10.5 The bearing shall be unloaded at a rate of 1.5 MPa / min until the stress on the bearing returns to 1.5 MPa. The displacement gauge reading shall be recorded at this point.
- 10.6 The stress on the bearing shall be maintained at 1.5 MPa for 15 minutes. The displacement gauge reading at the end of this 15 minute period shall be recorded.
- 10.7 The bearing shall be subjected to a 2nd cycle by repeating steps 10.4, 10.5 and 10.6.
- 10.8 In the 3rd cycle, the bearing shall be reloaded to 7.5 MPa in the same manner as step 10.4 except the displacement gauge readings shall be recorded after each 0.5 MPa increment starting at 1.5 MPa.
- 10.9 The data recorded during the 3rd cycle shall be plotted on a graph of stress versus deformation. A 'best-fit' straight line using the least-squares method shall be constructed through the data points. The line shall start at the point corresponding to 1.5 MPa stress and zero deformation.

11. CALCULATION (AFTER TESTING)

- 11.1 If 'T_e' is zero, no further calculations are required and the specimen shall be reported as 'rejected'.
- 11.2 Determine the deformation (d) at 7.0 MPa from the Stress/Deformation graph and calculate the percent compressive deformation (A) using the effective elastomer thickness (T_e) determined by Test Method LS-429. Express the result to the nearest 0.1 %.

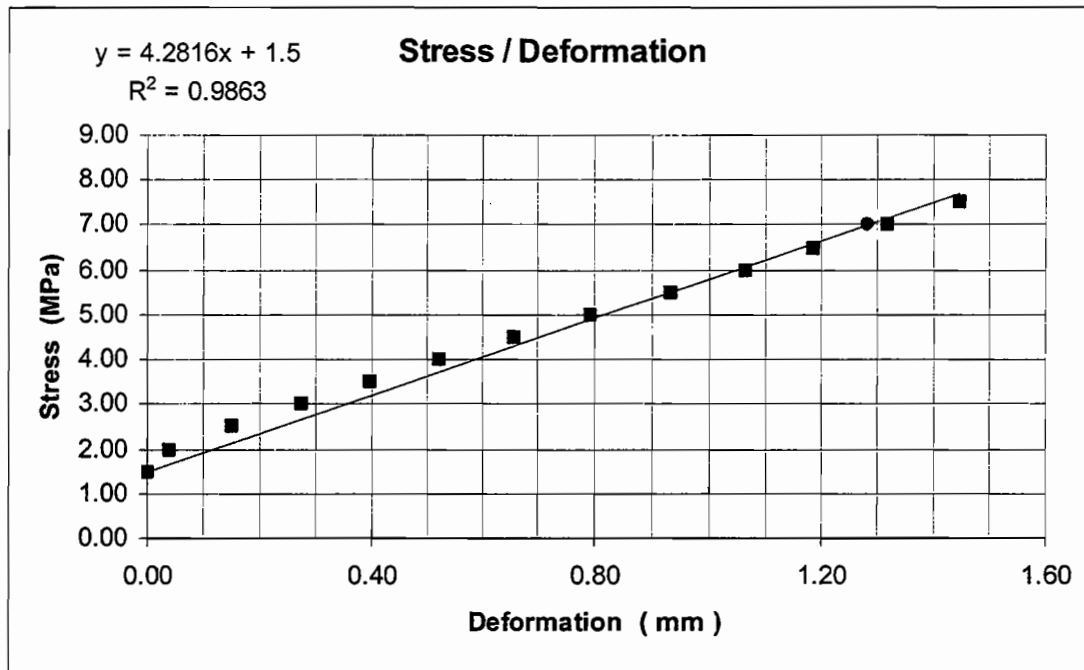
$$A = (d / T_e) \times 100$$

12. EXAMPLE OF CALCULATION (AFTER TESTING)

- 12.1 The deformation is determined by subtracting the average gauge reading at 1.5 MPa from each average gauge reading. For example, the deformation at 2.0 MPa is 0.53 mm – 0.49 mm = 0.04 mm

Stress	Load	Gauge # 1	Gauge # 2	Average	Deformation
MPa	kN	mm	mm	mm	mm
1.5	131	0.04	0.93	0.49	0.00
2.0	175	0.02	1.03	0.53	0.04
2.5	219	0.11	1.16	0.64	0.15
3.0	263	0.21	1.31	0.76	0.28
3.5	306	0.31	1.45	0.88	0.40
4.0	350	0.41	1.60	1.01	0.52
4.5	394	0.54	1.74	1.14	0.66
5.0	438	0.66	1.90	1.28	0.80
5.5	481	0.78	2.06	1.42	0.94
6.0	525	0.89	2.21	1.55	1.07
6.5	569	1.00	2.34	1.67	1.19
7.0	613	1.12	2.49	1.81	1.32
7.5	656	1.23	2.63	1.93	1.45

- 12.2 Determine the deformation at 7.0 MPa from the Stress/Deformation graph. Use the value determined from the best-fit line and not the actual measured value at 7.0 MPa.



Deformation at 7.0 MPa = 1.28 mm

12.3 Compressive Deformation = (Deformation at 7.0 MPa / T_e) $\times$ 100

Compressive Deformation = (1.28 / 49.36) $\times$ 100 = 2.6%

METHOD OF TEST FOR PARALLELISM OF STEEL LAMINATES OF LAMINATED BEARINGS

1. SCOPE

- 1.1 This test method is for determining parallelism of the steel laminates with respect to the surface of the bearing which includes calculating the effective elastomeric thickness and verifying fabrication tolerances.

2. RELEVANT DOCUMENT

- 2.1 OPSS 1202 Material Specification for Bearings - Elastomeric Plain and Steel Laminated

3. DEFINITION

- 3.1 Shape Factor means the area of the loaded face of an elastomeric layer divided by the area free to bulge.
- 3.2 Effective Elastomer Thickness is the sum of the thickness of all the layers of elastomer, excluding outer layers of cover.
- 3.3 The parallelism of the steel laminates is with respect to the surface of the bearing and expressed as a fraction of the effective elastomer thickness.

4. APPARATUS

- 4.1 *Saw Equipment* – rotating steel band saw capable of cutting full depth in one pass and providing clean square edges. The saw shall be equipped to continuously direct a soap-water solution to cool the saw blade during the entire cutting operation.
- 4.2 *Caliper* - digital or dial gauge graduated in hundredths of millimetres.
- 4.3 *Measuring Tape* - The dimensions of the specimen should be measured using a measuring tape graduated to the nearest millimetre.

5. TEST SPECIMENS

- 5.1 Test specimens shall be according to OPSS 1202 and Contract Documents.

6. PREPARATION OF SPECIMENS

6.1 Upon delivery, the specimens shall be stored and left undisturbed for at least 24 hours at a temperature of $23^{\circ}\text{C} \pm 2^{\circ}\text{C}$ prior to testing.

6.2 A 30-40 mm wide strip shall be removed from opposite ends by saw cutting full depth and square along the full length of the short dimension of the specimen to expose the steel laminates.

The cut faces of the remaining centre piece shall be examined for damage caused by improper cutting. If necessary, additional strips shall be cut until a satisfactory specimen is created.

6.3 The specimen shall be marked as follows:

- a) number the 4 corners consecutively
- b) mark a line from the top to bottom of the bearing on both cut faces at locations 10 mm measured from each corner

7. NATURE OF TEST

7.1 Measurement of the overall dimensions of the bearing, thickness of individual layers of elastomer, thickness of individual steel laminates and edge cover to determine adherence to fabrication tolerances, effective elastomer thickness and parallelism of steel laminates.

8. TEST PROCEDURE

8.1 The distance from the top of the bearing to the top of every steel laminate along the lines marked in Step 6.3b shall be measured and recorded.

8.2 The thickness of every steel laminate along the lines marked in Step 6.3b shall be measured and recorded.

8.3 The thickness of every layer of elastomer including the top and bottom cover along the lines marked in Step 6.3b shall be measured and recorded.

- 8.4 The thickness of the elastomer edge cover between the side of the bearing and edge of the steel laminates at the corners shall be measured and recorded.

9. CALCULATION

- 9.1 Determine the difference between the highest and lowest value of the 4 measurements taken for every steel laminate and recorded in Step 8.1.
- 9.2 Determine the cumulative total of the differences determined in Step 9.1.
- 9.3 Calculate the average thickness for every layer of elastomer by averaging the 4 readings taken in Step 8.3.
- 9.4 Calculate the Shape Factor for every layer of elastomer. Discontinue any further testing if any of the inner layers have a shape factor exceeding the specified value stated in the contract documents.
- 9.5 Determine the effective elastomer thickness (T_e) by totalling the thickness of each layer of elastomer. Do not include the top and bottom cover layers regardless of their shape factor values.
- 9.6 Calculate the parallelism of the steel laminates expressed as a fraction of the effective elastomer thickness by dividing the cumulative total value from Step 9.2 by T_e determined in Step 9.5.
- 9.7 Actual measurements for overall dimensions of the bearing, thickness of individual layers of elastomer, thickness of individual laminates and edge cover, shall be compared to the design drawings and checked against the allowable fabrication tolerances specified in the contract documents.

Record all non-conformities.

10. EXAMPLE OF CALCULATION

- 10.1 Difference between the highest and lowest value of the 4 measurements taken for each laminate in accordance with Step 8.1.

Steel Laminate Layer No	Measurement Location				Max. Difference (mm)
	1	2	3	4	
1	5.94	5.60	6.20	5.59	0.60
2	21.48	20.85	20.93	19.91	1.57
3	36.12	36.27	38.26	36.06	2.20
4	52.28	52.44	54.93	52.10	2.83
TOTAL :					7.20

- 10.2 Thickness of steel laminates.

Steel Laminate No.	Measurement Location				
	1	2	3	4	Avg.
1	3.07	3.00	3.09	3.06	3.06
2	3.03	3.04	3.06	3.05	3.05
3	3.08	3.07	3.08	3.09	3.08
4	3.07	3.06	3.00	3.08	3.05

- 10.3 Thickness of every inner layer of elastomer and corresponding shape factor.

Elastomer Layer No	Measurement Location				Avg. Thickness (mm)	*Shape Factor
	1	2	3	4		
1	12.26	12.16	11.6	11.05	11.77	9.5
2	11.59	12.61	13.69	12.92	12.71	8.8
3	12.91	13.07	13.49	13.14	13.15	8.5
Effective Elastomer Thickness (Te) = 37.63 mm						

*The bearing shall be considered unacceptable if any layer of elastomer has a shape factor exceeding the maximum allowable value specified in the contract documents.

Shape Factor = Area of Loaded Face / Area Free to Bulge

Measured Size:

Length = 504 mm,
Width = 402 mm,
Thickness = 11.77 mm

Area of Loaded Face = 504 mm x 402 mm = 202,608 mm²

Area Free to Bulge = Perimeter x Thickness

$$2 \times (504 + 402) \times 11.77 = 21,327 \text{ mm}^2$$

Shape Factor of Layer # 1 = 202,608 mm² / 21,327 mm² = 9.5

10.4 Thickness of edge cover and top/bottom elastomer over steel laminates.

	Measurement Location				Min. Cover (mm)	Max. Cover (mm)
	1	2	3	4		
Top	5.94	5.60	6.20	5.59	5.59	6.20
Bottom	6.19	6.37	5.52	7.16	5.52	7.16
Steel Laminate Layer No	Edge Measurement Location					
	1	2	3	4		
1	6.63	6.35	9.64	3.88	3.88	9.64
2	6.92	5.35	7.82	5.00		
3	5.67	5.84	7.65	4.18		
4	5.70	5.14	6.70	4.75		

10.5 Parallelism of steel laminates with respect to the surface of the bearings and expressed as a fraction of the effective elastomer thickness.

Total cumulative total of the differences from Step 9.1 is 7.20 mm.

Effective elastomer thickness from Step 9.4 is 37.63 mm

$$7.20 \text{ mm} / 37.63 \text{ mm} = 0.19$$

The total of the differences is approximately 19% of the effective elastomer thickness. Compare this value of 0.19 T_e with the maximum allowable value specified in the contract documents.

METHOD OF TEST FOR BOND STRENGTH BY TENSILE LOAD

1. SCOPE

1.1 This method covers the apparatus and procedure to determine the bond strength of toppings to existing concrete.

2. RELEVANT DOCUMENTS

2.1 CSA 23.2-6B

3. PROCEDURES

3.1 Procedures of CSA Standard A23.2-6B shall be followed, except as noted below.

4. EXCEPTIONS

4.1 APPARATUS

4.1.1 Load Indication Device: If the load indicator is a dial type device, the smallest increment on the graduated scale shall be no more than 0.5 kN of tensile load. The full scale load shall be no more than 25kN. If the load indicator is a digital type device, the numerical increment shall be no more than 0.1kN. Both types of load indicators shall be equipped with a suitable device indicating the maximum load applied until reset.

4.1.2 100N Equivalent Label for Loading Rate Control: If the load indication device does not show the load directly or not show the load in N or kN, a label or sticker showing what is equivalent to 100N shall be affixed close to the load indication device on the apparatus.

4.1.3 Accuracy: The accuracy of the testing apparatus shall be verified every 12 month. The percentage of error for the loads between 5% and 95% of the full scale shall not exceed $\pm 2\%$ of the indicated load.

4.2 PROCEDURE

4.2.1 When recording the load at failure, record the load to the nearest 0.1kN for digital type device or record the load to the nearest estimated 0.25kN for dial type device.

4.2.2 Retest, as specified by Section 5 Unsatisfactory Tests of CSA A23.2 6B, shall be performed by either re-attaching the plate to cleaned original core surface or recore within 30 cm of original core location.

4.2.3 If the type of failure is (d) "separation of the epoxy compound and the cap or the topping" and the calculated bond strength is higher than the specified strength, verify whether the depth of coring is 30mm into the underlying concrete by removing the core. If the coring is 30mm into the underlying concrete, record the calculated result. If the coring is not 30 mm into the underlying concrete or the coring depth cannot be verified, a retest shall be performed within 30 cm of original core location.

METHOD OF TEST FOR MICROSCOPICAL DETERMINATION OF AIR VOID SYSTEM PARAMETERS IN HARDENED CONCRETE, FOR CONFORMANCE TESTING

1. SCOPE

1.1 This method covers the apparatus and procedure to determine the air-void system parameters in hardened concrete for conformance testing purposes.

2. RELEVANT DOCUMENTS

2.1 ASTM C 457-98 "Standard Test Method for Microscopical Determination of Parameters of the Air-void System in Hardened Concrete"

3. PROCEDURES

3.1 Procedure B-Modified Point-Count Method of ASTM C 457-98 shall be followed, except as noted below.

4. EXCEPTIONS

4.1 APPARATUS

4.1.1 Stereoscopic Microscope: The magnification of the microscope shall be between 100x and 125x.

4.2 PROCEDURE

4.2.1 Minimum Area of Finished Surface for Microscopical Measurement: The total area to be tested shall be twice the size specified in Table 1 of ASTM C457-98 for the same Nominal Or Observed Maximum Size Of Aggregate In the Concrete. Table A provides examples for the minimum area requirements for the two Nominal Maximum Sizes of aggregate used in MTO contracts.

For specimens prepared by cutting cores lengthwise, if the total available area is larger than that specified above, test either the entire available area or an area of the specified size adjacent to the surface of the concrete structure or concrete component.

For specimens prepared from cores 100 mm in diameter and a minimum of 125mm in length, as specified by the contract, the total available area shall be tested.

4.2.2 Minimum Length of Traverse and Minimum Number of Points: The length of traverse and the number of points shall be twice those specified in Table 3 of ASTM C457-98. Table A provides examples for the minimum length of traverse and the minimum number of points for two Nominal Maximum Sizes of aggregates used in MTO contracts.

4.2.3 Calculation: Use the following equation to calculate the spacing factor.

If p/A is less than or equal to 4.342

$$\bar{L} = \frac{S_p \cdot I}{4N}$$

If p/A is greater than 4.342

$$\bar{L} = \frac{3I \cdot S_a}{4N} \left[1.4 \left(1 + \frac{S_p}{S_a} \right)^{1/3} - 1 \right]$$

Note 1: These equations are based on the equations in ASTM C457. These equations use the data recorded on the counters directly to avoid rounding the numbers in subsequent steps.

4.2.4 Report of results: Report the total air content in percentage to one decimal point and report spacing factor in micrometer with no decimal point.

Table A Examples Of Required Minimum Area To Be Traversed, Minimum Length Of Traverse And Minimum Number Of Points

Nominal Or Observed Maximum Size Of Aggregate In the Concrete (mm)	Minimum Area To Be Traversed (cm ²)	Minimum Length Of Traverse (mm)	Minimum Number Of Points
19	142	4572	2700
13.2	130	4064	2400

METHOD OF DRY PREPARATION OF AGGREGATES FOR THE DETERMINATION OF PHYSICAL CONSTANTS

1. SCOPE

1.1 This method covers the dry preparation of aggregate samples, as received from the field, for the required tests.

2. REFERENCES

- 2.1 LS-601, Method of Test for Material Finer than 75 μm Sieve in Mineral Aggregates by Washing
- 2.2 LS-602, Method of Test for Sieve Analysis of Fine and Coarse Aggregates
- 2.3 ASTM C 702
- 2.4 ASTM E 11 Standard Specification for Wire-Cloth Sieves for Testing Purposes
- 2.2 AASHTO T 248

3. APPARATUS

- 3.1 SIEVES: With square openings and of suitable sizes to separate the material into the sizes required for testing. The sieves shall conform to ASTM E 11.
- 3.2 SIEVE SHAKER: Any mechanical sieve shaker may be used which produces the thoroughness of sieving equivalent to the hand sieving described in LS-602.
- 3.3 OVEN: Of appropriate size and capable of maintaining a uniform temperature of $110 \pm 5^\circ\text{C}$.
- 3.4 BALANCE: Scale or balance accurate within 0.1 % of the test load at any point within the range of use.
- 3.5 CRUSHER: An aggregate crusher that is normally adjusted to produce material passing the 19.0 mm sieve. Oversize particles may be initially reduced in size by means of a sledgehammer to permit the material to be fed into the crusher.
- 3.6 SPLITTER: Any suitable means of obtaining a representative sample may be used. It is preferable, where practical, to use a mechanical splitter. Riffle type splitters shall have an even number of equal width chutes, but not less than a total of eight for coarse aggregate or twelve for fine aggregate, which discharge alternately to each side of the splitter. The minimum width of the individual chutes shall be approximately 50 per cent larger than the largest particles in the sample to be split. The splitter shall be equipped with two receptacles to hold the two halves of the sample following splitting. It shall also be equipped with a hopper or straight-edged pan that has a width equal to or slightly less than the over-all width of the assembly of chutes by which the sample may be

fed at a controlled rate to the chutes. The splitter and accessory equipment shall be so designed that the sample will flow smoothly without restriction or loss of material.

4. SAMPLE INFORMATION AND IDENTIFICATION

4.1 A laboratory sample number shall be allocated to each sample. This number shall accompany each portion of the sample throughout the processing and testing procedures.

4.2 Before processing the sample the following information shall be noted.

4.2.1 The number of bags of material in the sample.

4.2.2 The type of material, i.e., sand, stone, slag, etc.

4.2.3 Any peculiarities such as coatings, conglomerates, cementations, contaminants, etc.

5. SAMPLE DRYING

5.1 The sample shall be brought to a free flowing condition by drying at $110 \pm 5^{\circ}\text{C}$. It is permissible to prepare test samples by drying to a damp state, splitting and then drying at $110 \pm 5^{\circ}\text{C}$ to a free flowing condition.

Note: If asphalt coated particles are present, (i.e. reclaimed asphalt pavement), the sample shall be dried in an oven set at maximum 40°C or air-dried.

6. REMOVAL OF COATINGS FROM COARSE AGGREGATE AND PULVERIZATION OF CLODS

6.1 Samples containing coated coarse aggregate particles or hard clods shall be separated on the 4.75 mm sieve. The coatings shall be removed by such means as a stiff fibre or a steel wire brush and the hard clods broken up. The removed material that passes the 4.75 mm sieve shall be added to the original pass 4.75 mm sieve material and thoroughly mixed before test samples are prepared.

6.2 In the event of a dispute the total retained 4.75 mm sieve material shall be washed over a 75 μm sieve and if necessary soaked to soften any clods or coatings. The amount passing the 75 μm sieve shall be determined as outlined in LS-601. The total sample pass 75 μm material shall be the combined percentage of pass 75 μm material from the coarse aggregate by washing and from the fine aggregate by washing and sieving.

7. PREPARATION OF TEST SAMPLES

7.1 The quantities of materials required for various tests may be found in the respective test methods.

7.2 Before grading, split off any test samples as required such as LS-601 where the test may be affected by further handling.

7.3 Remove and grade all oversize, i.e., generally retained 19.0 mm sieve material by hand sieving. Grade the remaining material in a mechanical sieve shaker, record the mass retained on each screen and the total mass of pass 4.75 mm material. If there is not oversize to crush keep the masses retained on each screen in separate pans.

7.4 When the aggregate is going to be tested to predict its durability rather than to comply with specification requirements, the oversize material shall be crushed and combined with the uncrushed material to produce a laboratory crushed grading. The pass 4.75 mm sieve material from crushing shall be discarded unless advised otherwise.

7.5 The required test samples shall be combined from the separated sizes in proportion to the original or laboratory crushed grading.

7.6 After representative test portions have been prepared, sufficient of the remainder of the submitted sample should be saved for future tests or reruns.

8. GENERAL NOTES

8.1 All sieves must be frequently checked and any with broken wires, distortions, etc., replaced.

8.2 All mechanical shakers must be checked periodically to ensure conformance with hand sieving method.

8.3 Overloading of screens will produce improper sieving. Samples may be split, processed separately and then the individual sizes recombined to overcome this problem.

8.4 When possible, test portions should duplicate the condition of the original sample, for example, brittle, friable, very soft, etc., samples should receive as little handling as possible to maintain the test portions in the original state. Notes of any such conditions must be made to allow an accurate appraisal of the aggregate.

9. ASSOCIATED HAZARDS

9.1 When reducing the oversize by means of a sledgehammer the material must be placed in a canvas bag or protection provided to prevent flying rock chips.

9.2 Crushers must be provided with a cover and operated in such a fashion that there is no danger from flying stones and rock chips.

9.3 Artificial and waste materials must be checked before preparation to ensure that no hazard exists from noxious substances, used in the manufacturing process, when subjected to heat, handling, etc.

9.4 To minimize the hazards of improper lifting, dust, noise and equipment operations, the following steps must be taken.

9.4.1 All personnel must be instructed in the proper lifting techniques. Use of table height carts for moving materials is one method of reducing the amount of lifting.

9.4.2 The use of dust masks, dust evacuation systems and good housekeeping can effectively reduce the dust level in the work area.

9.4.3 The use of ear plugs, muffs and sound deadening enclosures can effectively reduce the noise level in the work area.

9.4.4 All personnel must be instructed in the proper use of any machinery. Any moving parts, where possible and practical, should be provided with guards and electrical safety switches.

METHOD OF TEST FOR MATERIALS FINER THAN 75 μ m SIEVE IN MINERAL AGGREGATES BY WASHING

1. SCOPE

1.1 This method covers a procedure for determining, by washing, the amount of material finer than a 75 μ m sieve.

2. RELEVANT DOCUMENTS

2.1 ASTM C 117

2.2 AASHTO T 11

3. PROCEDURE

3.1 Procedures of ASTM Standard C 117 shall be followed, except as noted below, to determine the amount of material finer than a 75 μ m sieve in coarse aggregate.

3.2 Follow ASTM Standard C 117, Procedure B in cases where the aggregate has been contaminated with oil or organic solvents.

3.3 The use of the 1.18 mm protection sieve may be omitted when 100 % of the material passes the 4.75 mm sieve.

3.4 Sieves: The minimum diameter of the sieves shall be 200 mm.

4. USE OF LABORATORY CONTROL AGGREGATE

4.1 Every 10 samples, but at least every week in which a sample is tested, a sample of the standard reference aggregate shall also be tested. The material shall be taken from a stock supply maintained by the laboratory. Material shall be selected so as to have an average loss of 1.0 - 2.0 % (coarse aggregate) or 10 - 20 % (fine aggregate).

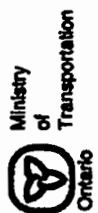
4.2 Control Chart Use: The percent loss of the last twenty samples of reference material shall be plotted on a control chart in order to demonstrate the performance of the laboratory.

5. REPORT

The report shall also include the following:

5.1 The percent loss of the reference sample, tested closest to the time at which the aggregate sample was tested, to two decimal places.

5.2 The percent loss of the last twenty samples of reference material on a control chart.



LOSS BY WASHING - COARSE AGGREGATE

[illegible]

PH-CC-373 78-06

DATE _____

OPERATOR -

COMPUTED BY:

Figure 1 Loss By Washing Data Card

METHOD OF TEST FOR SIEVE ANALYSIS OF AGGREGATES

1. SCOPE

1.1 This method covers the determination of the particle size distribution of fine and coarse aggregates by sieving.

2. REFERENCES

- 2.1 LS-600, Method of Dry Preparation of Aggregates for the Determination of Physical Constants
- 2.2 LS-601, Method of Test for Materials Finer than 75 μm Sieve in Mineral Aggregate by Washing.
- 2.3 LS-625, Guidelines for Sampling of Granular Materials
- 2.4 ASTM C 136 Standard Method for Sieve Analysis of Fine and Coarse Aggregates.
- 2.5 ASTM D 75 Standard Practice for Sampling Aggregates
- 2.6 ASTM E 11 Standard Specification for Wire-Cloth Sieves for Testing Purposes
- 2.7 ASTM Manual on Testing Sieving Methods - Publication STP 447B
- 2.8 CAN/CGSB, 8.1, Sieves, Testing, Woven Wire, Inch Series
- 2.9 OPSS 1010, Ontario Provincial Standard Specification for Granular A, Granular B, Granular M, and Select Subgrade Material (SSM)

3. APPARATUS

3.1 BALANCE:

3.1.1 Fine Aggregate: A balance or scale readable to 0.1 g and accurate to within 0.1% of the test load at any point within the range of use.

3.1.2 Coarse Aggregate or a mixture of Coarse and Fine Aggregates: A balance or scale accurate to within 0.1% of the test load at any point within the range of use.

3.2 SIEVES: With square openings and of suitable sizes to furnish the information required by the specification covering the material to be tested. The sieve cloth and frame shall conform to ASTM E11 or CAN/CGSB 8.1. Half height sieves shall not be used for sieving material coarser than 9.5 mm.

3.3 OVEN: Of appropriate size capable of maintaining a uniform temperature of $110 \pm 5^\circ\text{C}$.

3.4 SIEVE SHAKER: Any mechanical sieve shaker may be used which produces the thoroughness of sieving equivalent to the hand sieving described in para. 5.2.

3.5 SAMPLE SPLITTERS: For fine and coarse aggregates. (See Test Method LS-600, para. 3.6.)

4. PREPARATION OF TEST SAMPLE

4.1 Aggregate test samples for sieve analysis should be split from a larger field sample taken in accordance with LS-625, ASTM D75, or as otherwise specified. Where no sampling specification is given, the field sample should be at least four times the minimum test sample mass given in Table 1.

4.2 The sample of aggregate to be tested shall be, if necessary, thoroughly mixed and reduced by use of a sample splitter or by coning and then quartering to an amount suitable for testing. The sample to be tested shall be the end result of the reduction method used. No attempt shall be made to select samples of an exact predetermined mass.

4.3 Except for aggregate specifications included in OPSS 1010 as noted in para. 4.4 below, the minimum mass of the test sample is determined by the maximum nominal particle size as shown in Table 1.

Note 1: Maximum nominal particle size is defined as "the largest sieve in the applicable specification upon which any material is permitted to be retained".

Table 1

Nominal Maximum Size	Minimum Test Sample Mass, Kg
9.5 mm	1
13.2 mm	2
16.0 mm	3.5
19.0 mm	5
26.5 mm	10
37.5 mm	15
53.0 mm	20
63.0 mm	25
75.0 mm	45

4.4 For OPSS aggregate specifications, the minimum test sample mass for Granular A and M shall be 10 kg. For Granular B Type I, Granular B Type II and SSM, the minimum test sample

mass shall be determined by the smallest sieve in Table 1 that 100 per cent of the material passes.

Note 2: Because of the wide range of possible gradations within the Granular B and SSM specifications, test sample sizes need to vary with the material, rather than the specification. Examples include: for a Granular B, Type I, with 100% passing the 53.0 mm sieve (some material retained on the 37.5 mm sieve), the minimum test sample mass is 20 kg; for an SSM with 100% passing the 13.2 mm mm sieve, the minimum test sample mass 2 kg.

4.4 Fine aggregate portions (material passing 4.75 mm sieve) for testing should be reduced in size by splitting to 250 – 300 g. If the test sample is predominantly composed of fine sand, i.e., 100% passing 600 µm sieve, the sample size should be reduced to 125 - 150 g to prevent overloading on one or more sieves.

4.5 When greater precision is specified for testing fine aggregate, obtain 500 – 600 g of dried fine aggregate by use of a sample splitter or by quartering. Split this sample into two sub-samples of 250 – 300 g each.

5. TEST PROCEDURE

5.1 Dry the test sample to a constant mass using an oven operating at a temperature of $110 \pm 5^{\circ}\text{C}$. If the sample contains asphalt coated particles, i.e., reclaimed asphalt pavement, the sample shall be dried to constant mass in an oven set at maximum 40°C or by air drying. Allow the sample to cool to room temperature before proceeding.

Note 3: For control purposes, particularly where rapid results are desired, it is generally not necessary to dry coarse aggregate for the sieve analysis test. The results are little affected by the moisture content unless: (a) the nominal maximum size is smaller than about 13.2 mm; (b) the coarse aggregate contains appreciable material finer than 4.75 mm, or; (c) the coarse aggregate is highly absorptive, e.g, light-weight aggregate.

Note 4: Samples may be dried at higher temperatures associated with the use of hot plates without affecting results provided that steam is allowed to escape freely without generating pressures sufficient to fracture the particles, and that temperatures are not so great as to cause chemical alteration or physical breakdown of the aggregate.

5.2 Coarse Sieving Operation: Weigh and record the total mass of the dried test sample. Place the test sample in the uppermost of a progressive series of sieves selected according to the specification requirements or material characteristics and vibrate by means of a lateral and vertical motion of the sieve accompanied by a jarring motion so as to keep the sample moving continuously over the surface of the sieves. A satisfactory end point is considered to have been reached when an

additional 1 minute of sieving fails to change the mass on any of the sieves used by 1.0 per cent. In no case should the particles be turned or manipulated through the sieve by hand.

Note 5: ASTM suggests the following in order to test sieving sufficiency: Continue sieving for a sufficient period and in such manner that, after completion, not more than 1.0 weight % of the residue on any individual sieve will pass that sieve during 1 minute of continuous hand sieving performed as follows: Hold the individual sieve, provided with a snug-fitting pan and cover, in a slightly inclined position in one hand. Strike the side of the sieve sharply and with an upward motion against the heel of the other hand at the rate of about 150 times per minute, turn the sieve about one sixth of a revolution at intervals of about 25 strokes. In determining sufficiency of sieving for sizes larger than the 4.75 mm sieve, limit the material on the sieve to a single layer of particles. If the size of the mounted testing sieves makes the described sieving motion impractical, use 203 mm diameter sieves to verify the sufficiency of sieving.

5.3 To prevent overloading of individual sieves, additional sieves to those required by the specification should be inserted so as to distribute the fractions more evenly. Material retained on these sieves shall be added in cumulative weighing to the next smallest specification sieve

Note 6: To determine the maximum amount of material allowed on a given sieve, refer to the information given in ASTM C136 or the tables published in ASTM STP 447B - ASTM Manual on Test Sieving Methods.

5.4 On completion of the coarse sieving operation, separate the sieves, weigh and record the individual mass of the fraction retained on each sieve.

5.5 Weigh and record the mass which passes the 4.75 mm sieve (pan portion). Check the initial dry mass of the sample against the mass of the sample after sieving. This mass is obtained by adding the mass of material passing the 4.75 mm sieve in the pan to the cumulative mass retained on the 4.75 mm sieve. The difference between the initial mass and the mass after sieving shall be no more than 0.30%, otherwise, a re-test is required.

Note 7: There is a probability of particle loss during sieving, causing a testing error. This loss is usually in the form of fines. However, occasionally, it could be in the form of coarse particles.

5.6 Reduce the pan portion according to para. 4.4 or para. 4.5 to produce the fine aggregate test portion. Where the fine aggregate test portion is prepared according to para. 4.5, perform the test one each of the two sub-samples.

5.7 Fine Sieving Operations: Weigh and record the total mass of the prepared test sample. Wash the fine aggregate test portion according to the procedure given in LS-601. Dry the material

retained on the 75 µm sieve to constant mass as described in para. 5.1. Weigh and record the total mass of the dried test sample.

5.8 Sieve the remaining test portion through the required nest of fine aggregate sieves in the manner described in para. 5.2.

5.9 On completion of the sieving operation, separate the sieves and weigh and record, cumulatively, the mass of the fraction retained on each sieve. Record the mass of any portion which passes the smallest sieve size (pan portion).

5.10 For test portions consisting of two sub-samples, weigh and record the cumulative mass of the fraction retained on each sieve (and pan portion) for each sub-sample separately. Provided that the difference on any sieve between the two individual sub-samples is no greater than 5%, a combined grading is calculated from the sum of the cumulative masses for each sieve (and pan portion), otherwise a re-test is required.

6. CALCULATIONS

6.1 All determinations shall be made to the nearest 0.1% of the mass of the sample.

6.2 Calculate the percentage of coarse and fine aggregates in the sample as follows:

$$\text{Per cent coarse aggregate, } D = \frac{B}{A} \times 100$$

$$\text{Per cent fine aggregate, } E = \frac{C}{A} \times 100$$

6.3 Calculate the cumulative percentages on each sieve for the coarse aggregate portion and the fine aggregate portion of the test sample.

6.3.1 Coarse Aggregate Portion:

$$\text{Per cent retained} = \frac{X}{B} \times 100$$

$$\text{Per cent passing} = \frac{B - X}{B} \times 100$$

6.3.2 Fine Aggregate Portion:

$$\text{Per cent retained} = \frac{Y}{F} \times 100$$

$$\text{Per cent passing} = \frac{F - Y}{F} \times 100$$

6.4 Calculations to obtain the complete gradation of the sample.

6.4.1 To determine the percentage retained on each sieve:

$$\text{Per cent retained coarse aggregate sieves} = \frac{X}{A} \times 100$$

$$\text{Per cent retained fine aggregate sieves} = \frac{Y}{F} \times E + \% \text{ Ret. 4.75}$$

6.4.2 To determine the percentage passing on each sieve:

$$\text{Per cent passing coarse aggregate sieves} = \frac{A - X}{A} \times 100$$

$$\text{Per cent passing fine aggregate sieves} = \frac{F - Y}{F} \times E$$

where: A = Mass of total sample

B = Mass retained on the 4.75 mm sieve

C = Mass passing the 4.75 mm sieve, $C = A - B$

D = Per cent coarse aggregate

E = Per cent fine aggregate

F = Mass of fine aggregate test portion before washing

X = Cumulative mass retained on each sieve, coarse portion

Y = Cumulative mass retained on each sieve, fine portion

6.5 Calculate the fineness modulus, when required, by adding the total percentages of material in the sample that is coarser than each of the following sieves (cumulative percentages retained), and dividing the sum by 100 : 150 μm , 300 μm , 600 μm , 1.18 mm, 2.36 mm, 4.75 mm, 9.5 mm, 19.0 mm, 37.5 mm, and larger, increasing in the ratio of 2:1.

7. REPORTING RESULTS

7.1 The report shall include the following, as necessary:

7.1.1 Total percentages of coarse and fine aggregates.

7.1.2 Total percentage of material retained on or passing each coarse aggregate sieve based on the total mass of the oven-dry coarse aggregate portion.

7.1.3 Total percentage of material retained on or passing each fine aggregate sieve based on the total mass of the oven-dry test sample of the fine aggregate before washing.

7.1.4 Total percentage of material retained on or passing each sieve based on the total mass of the oven-dry total sample.

7.1.5 When two sub-samples of fine aggregate are tested, the mean of the results shall be reported as the final result.

7.1.6 Report the difference between the initial dry mass of the sample and the sum of the individual masses retained on each sieve as a percentage of the initial dry mass.

8. GENERAL NOTES

8.1 Figure 1 shows a laboratory worksheet that may be used to record test data and calculate results.

8.2 Check all sieves regularly to ensure that the mesh is not blinded, and is free from defects and distortion. Fine mesh sieves, if blinded by sand particles, can be cleaned using an ultrasonic bath. If this equipment is not available, a soft brass brush may be used for cleaning sieves coarser than the 150 μm and a nylon brush for finer sieves. This is done by brushing the underside of the wire cloth with a circular motion, taking care not to use too much pressure. The frame of the sieve may be gently tapped with the wooden handle of the brush. Under no circumstances should embedded particles be forced out of the openings with a pick or needle.

8.3 Small holes or breaks in fine mesh sieves may be repaired with an appropriate epoxy.

8.4 When emptying each of the sand sieves, brush the bottom of the inverted sieve gently, but firmly with the proper sieve brush, using a circular motion. This ensures that all sand particles are included with the sample, and that the sieve is kept clean, and its efficiency maintained.

8.5 In the case of Granular B (OPSS 1010). Sizes larger than 26.5 mm may be removed, and hand sieved through the larger specified sieves. It is permissible to determine the percentage passing the 75 mm and larger sieves without drying the test sample. Remove the fines from these larger particles, and return them to the test sample. The gradation of the passing 75 mm portion must be carried out after drying.

Figure 1. Gradation Computation Worksheet

Lab No:	Date:
Sample Description:	Specification:

Note: All masses are for dried aggregate.

Total Sample Mass [A] :	g	% Coarse Aggregate [D]:	%	% Fine Aggregate [E] :	%

Coarse Aggregate

Sieve	Individual Mass Retained (g)	Cumulative Mass Retained (g) [X]	(Coarse Aggregate Portion Only)		% Passing (Total Sample)
			% Retained	% Passing	
106 mm					
75 mm					
63 mm					
53 mm					
37.5 mm					
26.5 mm					
22.4 mm					
19.0 mm					
16.0 mm					
13.2 mm					
9.5 mm					
6.7 mm					
4.75 mm		[B]			
Pan		Pan + [B]	Mass passing 4.75 mm (g) [C = A - B]:		

Fine Aggregate

Sample mass before washing (g): [F]		Mass passing 75µm sieve by washing (g):		
Sample mass after washing (g)		Mass passing 75µm sieve by sieving (g):		
Sieve	Cumulative Mass Retained (g) [Y]	(Fine Aggregate Portion Only)		% Passing (Total Sample)
		% Retained	% Passing	
4.75 mm				
2.36 mm				
1.18 mm				
600 µm				
300 µm				
150 µm				
75 µm				
Pan		Total mass passing 75 µm sieve (g):		

Note: Space provided for sub-samples

Technician: _____

METHOD OF TEST FOR RESISTANCE TO DEGRADATION OF COARSE AGGREGATE BY ABRASION AND IMPACT IN THE LOS ANGELES ABRASION MACHINE

1. SCOPE

1.1 This method covers the determination of resistance to degradation of coarse aggregate by abrasion and impact using the Los Angeles testing machine.

2. RELEVANT DOCUMENTS

- 2.1 ASTM C 131
- 2.2 ASTM C 535
- 2.3 AASHTO T 96
- 2.4 CSA-A23.2-16A
- 2.5 CSA-A23.2-17A

3. PROCEDURE

3.1 Procedures of ASTM Standard C 131 and C 535 shall be followed, except as noted below, for the determination of degradation of coarse aggregate by abrasion and impact using the Los Angeles testing machine.

4. EXCEPTIONS

4.1 SIEVES: Conforming to ASTM Specification E11, except use 13.2 mm sieve size instead of 12.5 mm.

4.2 Replace ASTM Standard Clause 5.4.1, with Table 1 as follows:

The abrasive charge, depending upon the grading of the test sample as described in Table 2, shall be as follows:

Table 1

GRADING	# OF SPHERES	MASS, g
A	12	5000 ± 25
B	11	4580 ± 25
C	8	3330 ± 20
D	9	3740 ± 20

Table 2: Gradation of Test Samples

SIEVE SIZE		MASS OF INDICATED SIZES, g			
PASSING	RETAINED	A	B	C	D
37.5 mm	26.5 mm	1250 ± 25			
26.5 mm	19.0 mm	1250 ± 25			
*19.0 mm	13.2 mm	1250 ± 10	2500 ± 10	-	2500 ± 10
13.2 mm	9.5 mm	1250 ± 10	2500 ± 10	-	1250 ± 10
* 9.5 mm	4.75 mm	-	-	-	1250 ± 10
9.5 mm	6.7 mm	-	-	2500 ± 10	-
6.7 mm	4.75 mm	-	-	2500 ± 10	-
TOTAL		5000 ± 10	5000 ± 10	5000 ± 10	5000 ± 10

* Material previously separated into individual sizes shall be recombined in proportion to the original or laboratory crushed gradation.

5. USE OF LABORATORY CONTROL AGGREGATE

5.1 Every ten samples, but at least every week in which a sample is tested, a sample of a reference aggregate shall also be tested. The material shall be taken from a stock supply maintained by the laboratory. The material shall be selected so as to have an average loss of 20-30%.

Note: The material selected by the laboratory may be calibrated against a supply of Brechin stone. When prepared to an 11-B grading, the mean loss of the Brechin standard reference aggregate is 23.0% (MTO MI Report 175, 1997). Individual test data should not normally be greater than 24.8%, or less than 21.2%.

5.2 Control Chart Use: The percent loss of the last twenty samples of reference material shall be plotted on a control chart in order to monitor the performance of the laboratory.

6. REPORT

The report shall also include the following:

6.1 The percent loss of the reference sample, tested closest to the time at which the aggregate sample was tested, to one decimal place.

6.2 The percent loss of the last twenty samples of reference material on a control chart.

Figure 1 Los Angeles Abrasion Data Card

METHOD OF TEST FOR RELATIVE DENSITY AND ABSORPTION OF COARSE AGGREGATE

1. SCOPE

1.1 This method covers the determination of relative density (oven-dry and saturated-surface dry) and apparent relative density at 23°C and absorption of coarse aggregate.

2. RELEVANT DOCUMENTS

- 2.1 ASTM C 127
- 2.2 AASHTO T 85
- 2.3 CSA-A23.2-12A

3. PROCEDURE

3.1 Procedures of ASTM Standard C 127 shall be followed, except as noted below, for the determination of relative density and apparent relative density at 23°C and absorption of coarse aggregate.

4. EXCEPTIONS

- 4.1 Where greater precision is required, such as for asphalt mix design, obtain two 3 kg sub-samples and perform the test on each.
- 4.2 If duplicate tests of relative density differ by more than 0.020, the material shall be retested.
- 4.3 Absorption values shall be calculated to three decimal places. If duplicate tests of absorption differ by more than 0.20%, the material shall be retested.
- 4.4 Replace ASTM Standard C 127, Section 8. Procedure, with the following:
 - 4.4.1 Immerse the "prepared" sample in water at room temperature for 24 ± 4 h.
 - 4.4.2 Thoroughly wash the sample to remove dust or other coatings from the surface of the particles. Place the sample in the container and determine its mass in water at $23 \pm 1.7^\circ\text{C}$ having a density of $0.997 \pm 0.002 \text{ g/cm}^3$. Carefully remove all entrapped air before weighing by shaking the container while immersed. Record this and all subsequent masses to the nearest 0.5 g (Mass C).
 - 4.4.3 Remove the sample from the water and roll it in a large absorbent cloth until all visible films of water are removed. Wipe the larger particles individually. Take care to avoid evaporation of water from aggregate pores during the surface drying operation. Immediately weigh the sample in the saturated surface-dry condition (Mass B).
 - 4.4.4 Dry the sample to a constant mass at a temperature of $110 \pm 5^\circ\text{C}$, cool in air at room temperature to constant mass for 1 to 3 h and record the mass (Mass A).

4.4.5 Record all results on data card Figure 1.

5. USE OF LABORATORY CONTROL AGGREGATE

5.1 Every ten samples, but at least every week in which a sample is tested, a sample of the standard reference aggregate shall also be tested. Material shall be taken from a stock supply of Brechin Quarry No.2 stone maintained by the Soils & Aggregates Section, Ministry of Transportation, 1201 Wilson Avenue, Downsview, Ontario M3M 1J8, Fax (416) 235-4101. Only material retained 4.75 mm and coarser shall be tested. It is permissible to re-use the reference material provided it does not degrade due to multiple wetting and drying cycles.

5.2 Control Chart Use: The relative density and absorption of the last twenty samples of reference material shall be plotted on a control chart in order to monitor the performance of the laboratory.

5.3.1 The mean absorption of the Brechin Quarry No.2 standard reference aggregate is 0.68% (MERO-002 & 008, 2003 & 2004). Individual test data should not normally be greater than 0.81% or less than 0.55%.

5.3.2 The mean relative density (oven-dry) of the Brechin standard reference aggregate is 2.670. Individual test data should not normally be greater than 2.682 or less than 2.658.

6. REPORT

The report shall include the following:

6.1 If duplicate tests of absorption and relative density are made, the mean of the results shall be reported as the final "test result".

6.2 The percent absorption to the nearest 0.01%, and relative densities to the nearest 0.001 of the reference sample, tested closest to the time at which the aggregate sample was tested.

6.3 The percent absorption and relative density of the last twenty samples of reference material on control charts.

[illegible]

PH-CC-331 90-01

DATE _____

OPERATOR

COMPUTED BY

Figure 1
Relative Density and Absorption – Coarse Aggregate Data Card

METHOD OF TEST FOR RELATIVE DENSITY AND ABSORPTION OF FINE AGGREGATE

1. SCOPE

1.1 This method covers the determination of relative density (oven-dry and saturated-surface-dry) and apparent relative density at 23°C and absorption of fine aggregate.

2. RELEVANT DOCUMENTS

- 2.1 MTO LS-601
- 2.2 ASTM C 128
- 2.3 AASHTO T 84
- 2.4 CSA-A23.2-6A

3. PROCEDURE

3.1 Procedures of ASTM Standard C 128 shall be followed, except as noted below, for the determination of relative density and apparent relative density at 23°C and absorption of fine aggregate.

4. EXCEPTIONS

4.1 Obtain approximately 2400 g of dried fine aggregate by use of a sample splitter or by quartering. Split this sample into two sub-samples of approximately 1200 g and perform the test on each sub-sample.

4.2 Wash the sample over a 75 µm sieve in accordance with MTO LS-601, Method Of Test For Material Finer Than 75 µm Sieve In Mineral Aggregates By Washing, until all material passing the 75 µm sieve is removed.

4.3 If duplicate tests of relative density differ by more than 0.030%, the material shall be retested.

4.4 If duplicate tests of absorption differ by more than 0.40%, the material shall be retested.

5. USE OF LABORATORY CONTROL AGGREGATE

5.1 Every ten samples, but at least every week in which a sample is tested, a sample of the standard reference aggregate shall also be tested. Material shall be taken from a stock supply of James Dick sand maintained by the Soils and Aggregates Section, Ministry of Transportation, 1201 Wilson Avenue, Downsview, Ontario M3M 1J8 (Fax: 416-235-4101).

5.2 Control Chart Use: The percent loss of the last twenty samples of reference material shall be plotted on a control chart in order to monitor the performance of the laboratory.

5.3 The mean absorption of the James Dick standard reference aggregate is 1.68%. Individual test data should not normally be greater than 2.05% or less than 1.31%.

5.4 The mean relative density (oven-dry) of the James Dick standard reference aggregate is 2.607. Individual test data should not normally be greater than 2.639 or less than 2.575.

6. REPORT

The report shall include the following:

6.1 Relative density values shall be calculated and reported to three decimal places and indicate the basis for relative density as either oven-dry (OD), saturated-surface dry (SSD) or apparent.

6.2 The mean of the results shall be reported as the final "test result".

6.3 The percent absorption to the nearest 0.01% and densities to the nearest 0.001 of the reference sample, tested closest to the time at which the aggregate sample was tested.

6.4 The percent absorption and relative density of the last twenty samples of reference material on control charts.

Ministry
of
Transportation
Ontario

[illegible]

PH-CC-332 78-06

DATE _____

OPERATOR

COMPUTED BY

Figure 1 Relative Density and Absorption – Fine Aggregate Data Card

METHOD OF TEST FOR SOUNDNESS OF AGGREGATES BY USE OF MAGNESIUM SULPHATE

1. SCOPE

1.1 This method covers the testing of aggregates to determine their resistance to disintegration in saturated solutions of magnesium sulphate. It furnishes information helpful in judging the soundness of aggregates subject to weathering action, particularly when adequate information is not available from service records.

2. RELEVANT DOCUMENTS

- 2.1 ASTM C 88
- 2.2 CSA-A23.2-9A

3. APPARATUS

3.1 SULPHATE TANK: A suitably constructed three-compartment tank, one compartment for solution make-up, one for the test solution, and the third for washing the completed test samples. The test solution compartment shall contain suitable refrigeration and heating units capable of controlling the temperature of the magnesium sulphate solution within $\pm 1.0^{\circ}\text{C}$ of the required temperature.

Note 1: Immersion type mercury contact thermo-regulators reading to 0.05°C controlling Jumo electronic relays are suitable for this purpose.

3.2 SIEVES: With square openings of the following sizes conforming to OPSS specifications, Table 1.

Table 1

Coarse Series	Fine Series
4.75 mm	300 μm
9.50 mm	600 μm
13.2 mm	1.18 mm
16.0 mm	2.36 mm
19.0 mm	4.75 mm

3.3 WIRE BASKETS: For immersing the samples of aggregates in the solution. The baskets shall bear a number or other means of identification. The baskets shall be made of copper wire and of appropriate mesh size for the aggregate under test (19 - 9.5 mm aggregate use sieve mesh 6.7 mm, 9.5 - 4.75 mm aggregate use sieve mesh 2.36 mm).

3.4 **BALANCES:** For fine aggregate, a balance or scale accurate within 0.1 g over the range required for this test; for coarse aggregate, a balance or scale accurate within 0.1% or 1 g, whichever is greater, over the range required for this test.

3.5 **MECHANICAL CONVECTION OVEN:** The oven shall be capable of being heated continuously at $110 \pm 5.0^{\circ}\text{C}$, and the rate of evaporation at this range of temperature shall be at least 25 g/h for 4 h, during which period the doors of the oven shall be kept closed. This rate shall be determined by the loss of water from one-litre Griffin low-form beakers, each initially containing 500 g of water at a temperature of $21 \pm 2.0^{\circ}\text{C}$, placed at each corner and the centre of each shelf of the oven. The evaporation requirement is to apply to all test locations when the oven is empty except for the beakers of water.

3.6 **HYDROMETER:** Capable of determining the relative density of the test solution, conforming to the requirements of ASTM E100 for ASTM Hydrometers.

3.7 **LABORATORY CONTROL AGGREGATE:** A supply of standard Brechin Quarry No. 2 coarse aggregate is available from the Soils and Aggregates Section, Ministry of Transportation, 1201 Wilson Avenue, Ontario M3M 1J8, Fax (416) 235-4101.

4. **PREPARATION OF SOLUTION**

4.1 Prepare a saturated solution of magnesium sulphate by dissolving a U.S.P. or equal grade of the salt in water at a temperature of $40 \pm 3.0^{\circ}\text{C}$. Add sufficient salt of either the anhydrous (MgSO_4) or the crystalline ($\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$, Epsom salt) form to ensure saturation and the presence of excess crystals when the solution is ready for use in the tests. Thoroughly stir the mixture during the addition of salt and stir the solution at frequent intervals until used. To reduce evaporation and prevent contamination, keep the solution covered at all times when access is not needed. Allow the solution to cool $21 \pm 1.0^{\circ}\text{C}$. Again stir and allow the solution to remain at the designated temperature for at least 48 h before use. Prior to each use, break up the salt cake, if any, in the container, stir the solution thoroughly and determine the relative density of the solution. When used, the solution shall have a relative density not less than 1.295 nor more than 1.308. Discard a discoloured solution or filter it and check for relative density.

Note 2: For the solution, 350 g of anhydrous salt or 1230 g of heptahydrate per litre of water are sufficient for saturation at 23°C . However, since these salts are not completely stable, with the heptahydrate being the more stable of the two, and since it is desirable that an excess of crystals be present, it is recommended that the heptahydrate be used and in an amount of not less than 1400 g/L of water.

Note 3: Freshly mixed sulphate solutions have low pH values which may result in a higher loss of material for aggregates containing carbonate minerals. When testing these types of materials, the pH

value of freshly mixed solutions should be checked for pH (with either a pH meter or pH paper, range 5 - 7) and neutralized by the addition of a suitable additive.

5. PREPARATION OF SAMPLE

5.1 FINE AGGREGATE: Fine aggregate for the test shall be passed through a 4.75 mm sieve. The test sample shall be obtained from the materials to be tested by use of a sample splitter or the method of quartering and shall weigh approximately 2500 g. The sample is then washed on a 300 µm sieve and dried to a constant mass. The sample is separated into the sizes shown in Table 2 by sieving in a mechanical sieve shaker for a period of 8 to 12 minutes. From the fractions obtained in this manner, select samples of sufficient size to yield 100 g after sieving to refusal (in general, a 110 to 120 g sample will be sufficient). The samples are then re-sieved to refusal on the same sieves using a mechanical sieve shaker for a period of 12 min. Weigh samples consisting of 100 ± 0.1 g from each of the separated fractions after final sieving and place in separate containers for the test.

Note 4: Sieving to 'refusal' means that no particles pass the sieve during 1 minute of continuous sieving. No hand manipulation of particles is allowed.

Table 2

Passing Sieve	Retained on Sieve
600 µm	300 µm
1.18 mm	600 µm
2.36 mm	1.18 mm
4.75 mm	2.36 mm

Should the sample have less than 30% retained on the 300 µm sieve, it is deemed to be too fine and no test is done on any fraction. If any fraction constitutes less than 5% of the sample, it shall not be tested.

5.2 COARSE AGGREGATE: Coarse aggregate for test shall consist of material from which sizes finer than the 4.75 mm sieve have been removed. Separate the sample into the different sizes shown in Table 3 by sieving to refusal. Weigh out quantities of the different sizes shown in Table 3. If any fraction constitutes less than 5% of the sample, it shall not be tested.

Table 3

Pass	Retained	Mass, g
9.5 mm	4.75 mm	300
19.0 mm	9.5 mm	1000
Consisting of:		
13.2 mm	9.5 mm	330
19.0 mm	13.2 mm	670
37.5 mm	19 mm	1500
Consisting of:		
26.5 mm	19 mm	500
37.5 mm	26.5 mm	1000
63 mm	37.5 mm	5000
Consisting of:		
53 mm	37.5 mm	2000
63 mm	53 mm	3000

6. PROCEDURE

6.1 FINE AGGREGATE: Place each fraction in a separate suitable wire basket.

6.2 COARSE AGGREGATE: Place the 9.5 mm to 4.75 mm fraction in a suitable wire basket. Place the combined 19.0 mm to 9.5 mm fraction in another wire basket. Place combined fractions larger than 19 mm in one or more baskets as required.

6.3 STORAGE OF SAMPLES IN SOLUTION: Immerse the samples in the prepared solution of magnesium sulphate for not less than 16 h or more than 18 h in such a manner that the solution covers them to a depth of at least 15 mm. Maintain the samples immersed in the solution at a temperature of $21 \pm 1.0^{\circ}\text{C}$ for the immersion period. The volume of solution shall be at least 20 times greater than the total sample volume.

6.4 DRYING SAMPLES AFTER IMMERSION: After the immersion period, remove the samples from the solution, drain for 30 ± 5 min. and place in drying oven. Dry at $110 \pm 5.0^{\circ}\text{C}$ until constant mass has been achieved, usually 6 to 8 h. Drying time may be established as follows: with oven containing the maximum sample load expected, check the loss in mass of samples by removing and weighing them in the baskets, without cooling, at intervals of 2 to 4 h. Make enough checks to establish required drying time for the least favourable oven location and sample condition. Constant mass will be considered to be achieved when the loss is less than 0.1% of sample mass in 4 h of drying. When constant mass is achieved, allow samples to cool to room temperature and immerse in solution.

Note 5: As the number of cycles progresses, the drying time required increases due to loss of drying efficiency because of the accumulation of salt adhering to particles, increase of surface area due to breakdown, and differences in surface area due to particle sizes.

6.5 NUMBER OF CYCLES: Repeat the process of alternate immersion and drying for 5 cycles.

7. QUANTITATIVE EXAMINATION

7.1 After completion of the final cycle, and after the sample has cooled, wash the sample free from the magnesium sulphate as determined by the reaction of the wash water with a 3% (by mass) barium chloride (BaCl_2). Wash by circulating hot tap water (about 50°C) in their containers. A continuous flow of fresh hot water shall be maintained throughout the washing period. In the washing operation, the sample shall not be subjected to impact or abrasion that may tend to break up particles. After the magnesium sulphate has been removed, dry the samples to a constant weight at $110 \pm 5.0^\circ\text{C}$.

7.2 FINE AGGREGATE: Sieve the fine aggregate over the same sieve on which it was retained before the test, nesting the sieves so that the finest is on the top and the coarsest is on the bottom. Sieve in a mechanical sieve shaker for a period of twelve minutes. Weigh the material retained on each sieve and record each amount on the Fine Aggregate Report Card (Figure 1).

7.3 COARSE AGGREGATE: Sieve material larger than 63 mm over the same sieve on which it was retained before the test. Sieve the sample of pass 63 mm retained 37.5 mm material over the 37.5 mm sieve. Sieve the sample of pass 37.5 mm retained 19 mm material over the 19 mm sieve. Sieve the sample of pass 19.0 mm retained 9.5 mm material over the 9.5 mm sieve. Sieve the sample of pass 9.5 mm retained 4.75 mm over the 4.75 mm sieve. Sieve only sufficiently to assure that all undersize material passes the sieves. Weigh the material retained on each sieve and record each amount on the Coarse Aggregate Report Card (Figure 2).

8. QUALITATIVE EXAMINATION

8.1 A qualitative examination may be done on coarse aggregate samples to determine the mode of breakdown, i.e. splitting, disintegration, crumbling, cracking, flaking, etc. This examination is not done routinely by MTO. Samples are held in storage for some time after the test. If there are conflicting or "surprising" results in this test, the samples may be recalled and examined in an effort to resolve problems of this nature.

9. CALCULATION

9.1 Calculate the percent loss for each fraction in the magnesium sulphate soundness test as follows:

$$\text{percent loss} = \frac{\text{original mass} - \text{mass retained after test}}{\text{original mass}} \times 100$$

9.1.1 Calculate the percent loss to one decimal place.

9.2 Calculate the percent loss for each fraction as the product of the percentage (based on the "as-received" coarse aggregate sample mass or "as-received" fine aggregate sample mass) of each fraction and the percent loss for that fraction.

9.2.1 Calculate the weighted average value of the as-received sample as the sum of the weighted average value for each fraction divided by 100.

9.2.2 For the purpose of calculating the weighted average, consider any sizes (not tested) that contain less than 5% of the as-received sample to have the same values as the average of the next smaller and the next larger size or if one of these sizes is missing, to have the same value as the next larger or smaller size, whichever is present. For fine aggregates, sizes smaller than the 300 µm sieve shall be assumed to have zero percent loss.

10. USE OF LABORATORY CONTROL AGGREGATE

10.1 Every ten samples, but at least every week in which a sample is tested, a sample of the standard reference aggregate shall also be tested. The material shall be tested on the 19.0 mm to the 9.5 mm and 9.5 mm to 4.75 mm gradings. For the purposes of calculating a weighted average loss, assume the 19.0 mm fraction constitutes 67% of the sample and the 9.5 mm to 4.75 mm fraction constitutes 33% of the sample.

10.2 Control Chart Use: The weighted average loss of the last twenty samples of reference material shall be plotted on a control chart in order to monitor the performance of the laboratory.

10.3 The mean loss of the Brechin Quarry No. 2 standard reference aggregate is 13.2% (MERO-002 & 008, 2003 & 2004). Individual test data should not normally be greater than 18.4% or less than 8.0%.

11. REPORT

The report shall include the following:

11.1 The weighted average loss of the reference sample, tested closest to the time at which the aggregate sample was tested, to one decimal place.

11.2 The weighted average loss of the last twenty samples of reference material on a control chart.

11.3 Report the loss in percent of each fraction of the sample tested to 0.1%.

11.4 Report the weighted loss in percent of the sample tested to the nearest 0.1%.

12. PRECAUTIONS

12.1 Wire baskets shall be examined after each test for defects in the mesh.

12.2 Extreme care must be taken when immersing the fine aggregate samples as often some of the particles float on the solution due to surface tension. Carefully, with the fingers, sink these particles into their baskets when this happens.



RUN NO.

[illegible]

REMARKS:

PH-CC-336 78-08

Figure 1 Fine Aggregate Data Card

RUN NO._____

[illegible]

PH-CC-338 88-08

Figure 2 Coarse Aggregate Data Card

METHOD OF TEST FOR DETERMINATION OF PERCENT CRUSHED PARTICLES IN PROCESSED COARSE AGGREGATE

1. SCOPE

- 1.1 This method covers the visual determination of the percent, by mass, of crushed particles in a processed coarse aggregate.
- 1.2 In conjunction, this method also covers the visual determination of the percent, by mass, of cementations in a coarse aggregate.
- 1.3 Two procedures are given. Method A is suitable for well-graded materials with equal representation from all particle sizes passing the 26.5 mm sieve, retained by the 4.75 mm sieve. Method B is suitable for materials that have an uneven distribution of particles across the various sieve fractions between the 26.5 mm and the 4.75 mm sieves, i.e., gap-graded or poorly graded materials, or where greater accuracy is required, e.g. referee testing

Note: This test method covers only the fractions of coarse aggregate passing 26.5 mm and retained on 4.75mm sieve.

2. REFERENCES

- 2.1 MI-134, Determination of Crushed Particles for Test Method LS-607, Engineering Materials Office, Ministry of Transportation.
- 2.2 LS-600, Method of Dry Preparation of Aggregates for the Determination of Physical Constants
- 2.3 LS-602, Method of Test for Sieve Analysis of Aggregates.
- 2.4 LS-621, Method of Test for Determination of Amount of Asphalt Coated Particles in Coarse Aggregate.

3. DEFINITION

- 3.1 A CRUSHED PARTICLE is defined as a piece of coarse aggregate with at least one well-defined face resulting from fracture. The area of the crushed face should be at least 20 percent of the total surface area and the edges should be sharp (Figures 1, 2 and 3). Particles with smooth faces and rounded edges, or with only small chips removed, are not considered crushed (Figures 4, 5 and 6).
- 3.2 A CEMENTATION is defined as a group of aggregate particles cemented together which may or may not include a host (dominant) particle.

4. APPARATUS

- 4.1 **BALANCE:** Of sufficient capacity and readable to 1 g or less and accurate to within 0.1% of the test load at any point within the range of use.

5. PREPARATION OF TEST SAMPLE

- 5.1 Prepare the coarse aggregate according to LS-600.
- 5.2 Dry the sample sufficiently to obtain a clean separation of particles on the 4.75 mm sieve.

Method A

- 5.3 Separate the sample into the following three fractions by sieving according to LS-602: (i) material retained on the 26.5 mm sieve; (ii) material passing the 26.5 mm sieve, retained on the 4.75 mm sieve, and (iii) material passing the 4.75 mm sieve.
- 5.4 Reduce the fraction passing the 26.5 mm sieve, retained on the 4.75 mm sieve by splitting or quartering to approximately the masses given in Table 1.

Note: The largest particle size is determined from the smallest sieve in Table 1 that 95% or more of the material passes.

Table 1 –Sample Preparation for Method A

Largest particle size (>95% passing sieve)	Mass (minimum), g
26.5 mm	1000
16.0 mm	850
13.2 mm	500
9.5 mm	200
6.7 mm	75

- 5.5 When the sample tested contains a mixture of natural aggregate, recovered crushed concrete and/or recovered asphaltic material, the size of test sample shall be increased so that the amount of natural aggregate in the test sample meets the requirements of Table 1.
- 5.6 Weigh and record the mass of material to the nearest 1 g.

Method B

- 5.7 Separate the sample by sieving according to LS-602 into one or more of the individual fractions indicated in Table 2.

- 5.8 Prepare the test sample from each coarse aggregate fraction representing at least 5 % or more of the submitted sample according to the minimum masses shown in Table 2.

Table 2 – Sample Preparation for Method B

Coarse Aggregate Fraction		Mass (minimum), g
Passing	Retained	
26.5 mm	19.0 mm	200 particles, minimum
19.0 mm	13.2 mm	1250
13.2 mm	9.5 mm	500
9.5 mm	6.7 mm	200
6.7 mm	4.75 mm	75

- 5.9 When the test sample contains a mixture of natural aggregate, recovered crushed concrete, recovered asphaltic material, glass and/or ceramic material, the size of test sample shall be increased so that the amount of natural aggregate and recovered crushed concrete in the test sample meets the requirements of Table 2.
- 5.10 Weigh and record the mass of material of each fraction to the nearest 1 g.

6. TEST PROCEDURE

- 6.1 Spread the test sample (Method A) or each fraction of the test sample (Method B) on a clean, flat surface large enough to permit individual particles to be visually inspected.
- 6.2 Separate any asphaltic, glass or ceramic material from test sample. Do not separate any asphalt stained particles as defined by LS-621.
- 6.3 Separate any crushed recovered concrete particles from the test sample and classify them as crushed particles.
- 6.4 Separate the natural aggregate particles into crushed and uncrushed portions. Separation of cemented particles shall be according to whether the host particle is crushed or uncrushed. When there is no host particle present, cemented particles shall be considered as uncrushed cementations.
- Note: If dirt or dust films make it difficult to determine if the particles have well-defined fractured faces, it is permissible to wash the particles. However, the sample should be dried before weighing*
- 6.5 Weigh and record the mass of each crushed, uncrushed and cementation portion of the sample or fraction to the nearest 1 g. Table 3 is a laboratory worksheet for recording test data and calculations.

7. CALCULATION

Method A

- 7.1 Calculate the percentage of crushed particles for the test sample (to one decimal place) using the following formula:

$$\% \text{ crushed particles} = \frac{A + B}{A + B + C + D} \times 100$$

where A = mass of crushed particles

B = mass of crushed cementations

C = mass of uncrushed particles

D = mass of uncrushed cementations

Method B

- 7.2 If the test sample was prepared according to Method B, calculate the percent of crushed natural aggregate particles for each fraction (to one decimal place), using the following formula:

$$\% \text{ crushed particles} = \frac{A + B}{A + B + C + D} \times 100$$

where A = mass of crushed particles

B = mass of crushed cementations

C = mass of uncrushed particles

D = mass of uncrushed cementations

- 7.2 Calculate the percent crushed particles weighted average value for each fraction as the product of the percentage (based on the as-received coarse aggregate sample mass) of each fraction and the percent crushed particles for that fraction.
- 7.3 Calculate the percent crushed particles weighted average value of the as-received sample as the sum of the weighted average value for each fraction divided by 100.
- 7.4 If the amount of cemented particles is required, use the following formula:

$$\% \text{ cemented particles} = \frac{B + D}{A + B + C + D} \times 100$$

Then calculate the weighted average value.

- 7.5 For the purpose of calculating the weighted average, consider any fraction (not tested) containing less than 5% of the as-received sample to have a value equal to the average of the next smaller and the next larger fractions. If one of these sizes is missing, assign the same value as the next larger or smaller fraction, whichever is present.

8. REPORTING OF RESULTS

- 8.1 Report the method used for sample preparation and testing (Method A or Method B).
- 8.2 Report the % crushed particles (Method A) or weighted average % crushed particles (Method B) to the nearest whole percent.

9. GENERAL NOTES

- 9.1 Material used in this test may be re-used if insufficient material is available for other required tests.

10. PRECISION

- 10.1 In a formal study of 34 well-trained observers on two samples of partly crushed gravel (proportion of crushed particles = 76%) the average standard deviation was found to be 5.2%. Therefore, the difference in results between two well-trained observers, on samples of the same material, should not exceed 14.7% of their average, nineteen times in twenty.

Note: When a mixture of well-trained and not so well-trained observers conduct this test, the average multi-operator standard deviation increases to about 7.6%.

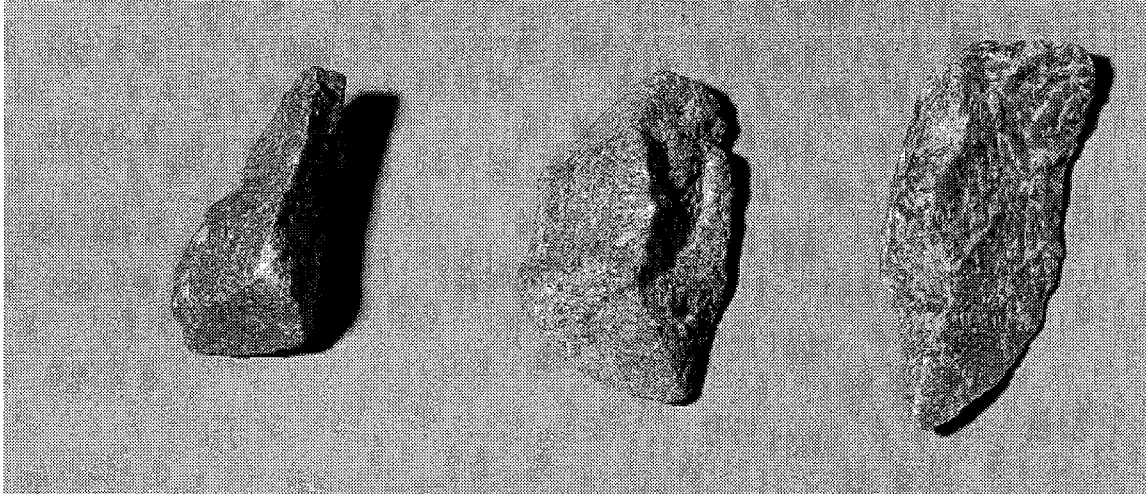


Figure 1. Crushed particle (sharp edges, rough surfaces).



Figure 2. Crushed particle (sharp edges, smooth surfaces).

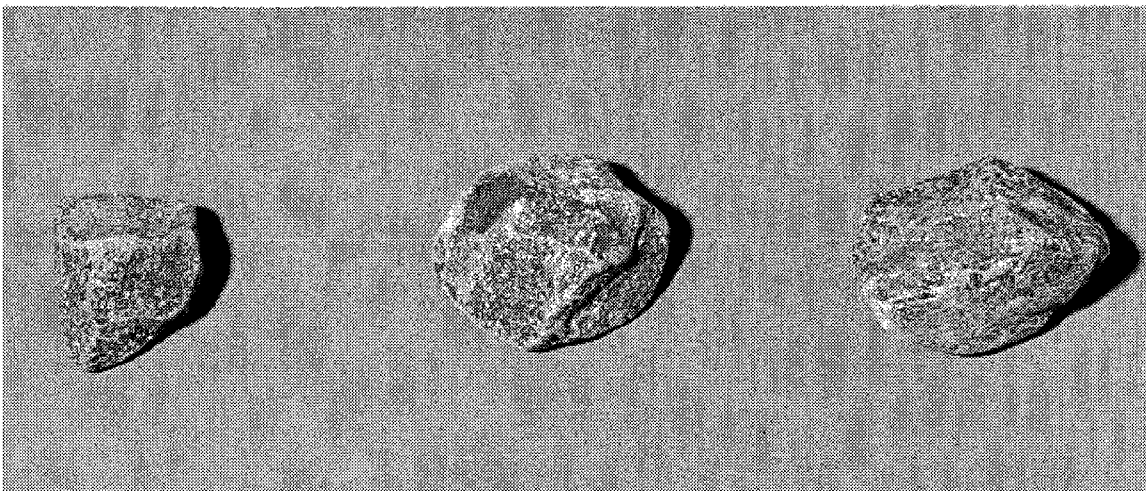


Figure 3. Crushed particle (round edges, rough surfaces).

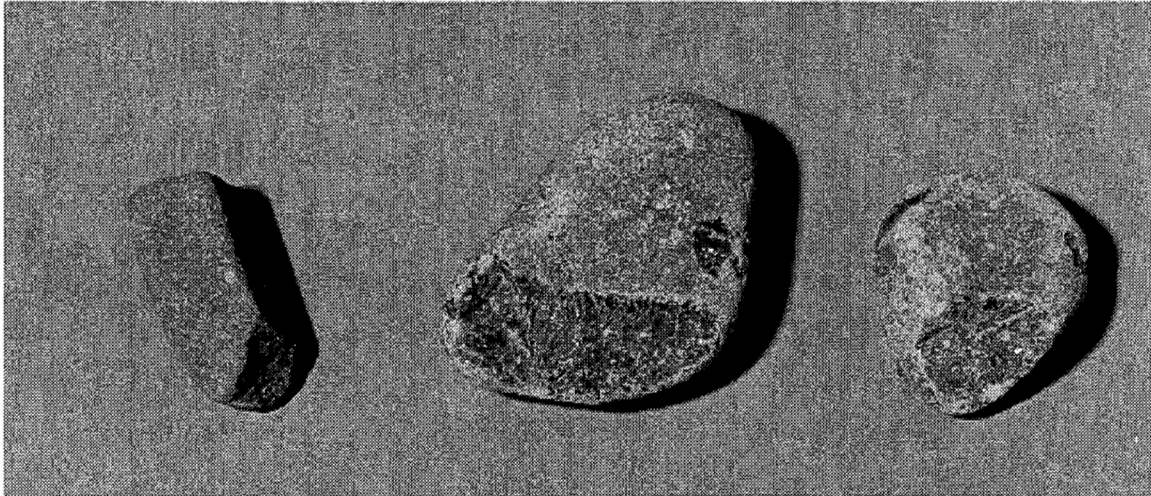


Figure 4. Uncrushed particle (chipped only).

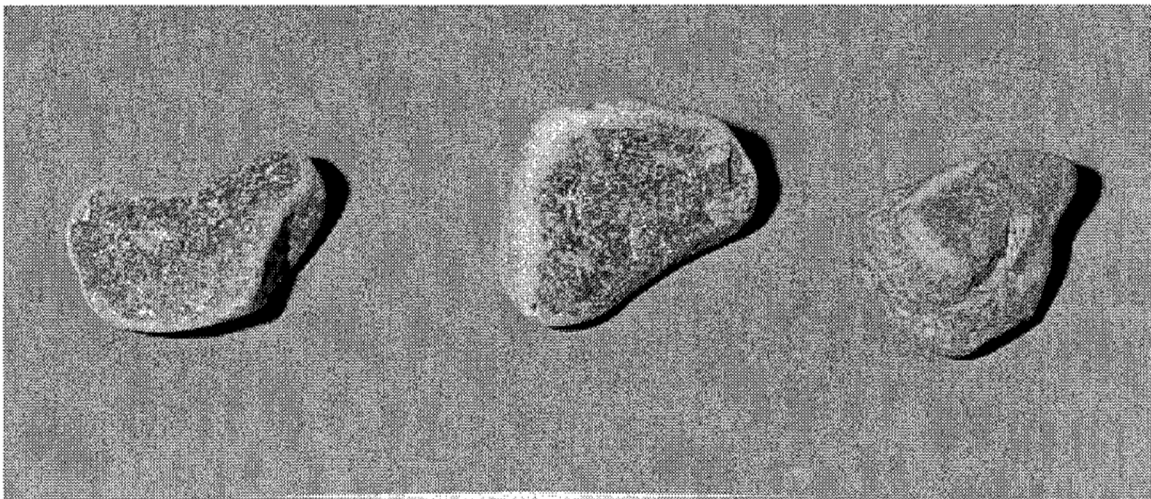


Figure 5. Uncrushed particle (round edges, smooth surfaces).

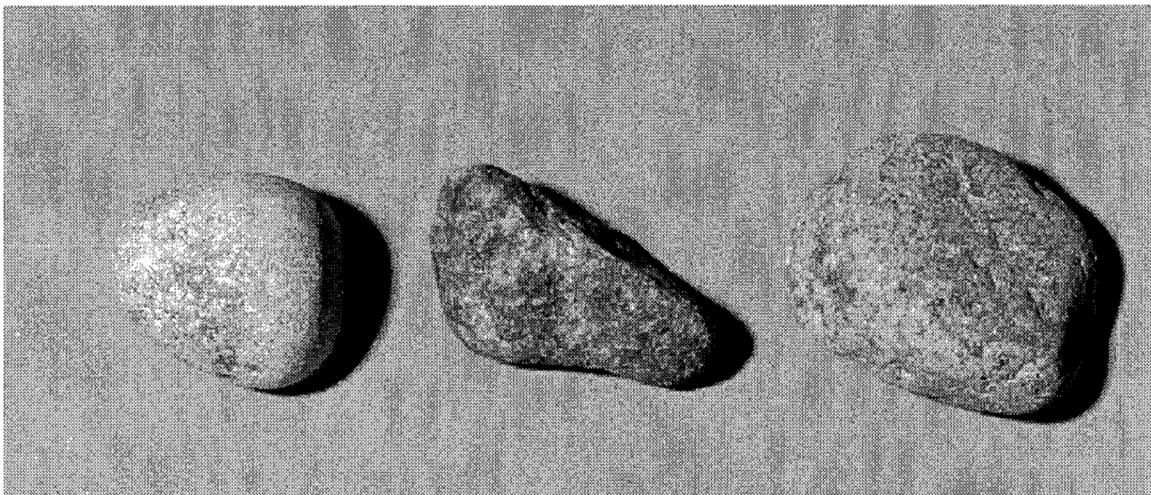


Figure 6. Uncrushed particle (rounded particles, smooth surfaces).

Table 3. Percent Crushed Particles Worksheet (all masses in grams)

Sample No.:		Date:						
Method A		Test Sample Fraction	Mass ¹	Crushed Particles, Mass (A)	Crushed Cementations, Mass (B)	Uncrushed Particles, Mass (C)	Uncrushed Cementations, Mass (D)	% Crushed Particles ³
		26.5-4.75 mm						
Method B		Test Sample Fraction	Mass ¹	% of Original Fraction ²	Crushed Particles, Mass (A)	Crushed Cementations, Mass (B)	Uncrushed Particles, Mass (C)	Uncrushed Cementations, Mass (D)
		26.5-19.0 mm						
		19.0-13.2mm						
		13.2-9.5 mm						
		9.5-6.7 mm						
		6.7-4.75 mm						
		Notes:				1. Not including reclaimed asphaltic, glass or ceramic material 2. As determined by LS-602 3. $\frac{A+B}{A+B+C+D} \times 100$ 4. % crushed particles (per fraction) x % of original fraction		
						% Crushed particles, Weighted Average (Σ Weighted per fraction) $\div$ 100		

Remarks:

Operator:

METHOD OF TEST FOR DETERMINATION OF PERCENT FLAT AND ELONGATED PARTICLES IN COARSE AGGREGATE

1. SCOPE

- 1.1 This method covers the determination of the percentage of flat and elongated particles in processed coarse aggregate, retained on the 4.75 mm sieve by measurement of individual particles.

2. RELEVANT DOCUMENTS

- 2.1 ASTM D 4791
2.2 CSA-A 23.2-13A

3. DEFINITION

- 3.1 FLAT AND ELONGATED pieces shall be those particles whose greatest dimension in the longitudinal axis, compared to the least dimension in a plane perpendicular to the longitudinal axis, exceeds a ratio of 4:1.

4. APPARATUS

- 4.1 BALANCE: A balance having a capacity of 5000 g and readable to 1.0 g or less.
4.2 CALIPERS: Figure-of-eight calipers in which the ratio of the opening at one end to the other is 4:1.

Note: The figure-of-eight calipers must be checked periodically to ensure that the 4:1 ratio is maintained throughout the range of opening.

5. PREPARATION OF TEST SAMPLE

- 5.1 Prepare the coarse aggregate according to LS-600.
5.2 Dry the sample sufficiently to obtain a clean separation of particles on the 4.75 mm sieve.
5.3 Separate the sample by sieving according to LS-602 into one or more of the individual fractions indicated in Table 1.
5.4 Prepare the test sample from each coarse aggregate fraction representing at least 5 % or more of the submitted sample according to the minimum masses shown in Table 1.

Note: the test sample only needs to be prepared from those coarse aggregate fractions representing at least five percent or more of the submitted sample. Maintain each fraction of the test sample in separate sizes.

- 5.5 When the test sample contains a mixture of natural aggregate, recovered crushed concrete, recovered asphaltic material, glass and/or ceramic material, the size of test sample shall be increased so that the amount of natural aggregate and recovered crushed concrete in the test sample meets the requirements of Table 1.

Table 1 – Sample Preparation

Coarse Aggregate Fraction		Mass (minimum), g
Passing	Retained	
37.5 mm	26.5 mm	3000
26.5 mm	19.0 mm	2000
19.0 mm	13.2 mm	1250
13.2 mm	9.5 mm	500
9.5 mm	6.7 mm	200
6.7 mm	4.75 mm	75

- 5.6 Weigh and record the mass of material of each fraction to the nearest 1 g.

6. TEST PROCEDURE

- 6.1 Spread each test fraction on a clean, flat surface large enough to permit individual particles to be easily inspected.
- 6.2 For each fraction, separate the particles of each test fraction by means of calipers into: (i) flat and elongated, and; (ii) cubical particles. Set the caliper on the maximum particle length and then check whether the least particle dimension will completely pass through the opening at the small end of the caliper.
- 6.3 Weigh and record the mass of each flat and elongated and cubical portion of the fraction to the nearest 1 g. Table 2 is a laboratory worksheet for recording test data and calculations

7. CALCULATION

- 7.1 Calculate the percent of flat and elongated particles in each test fraction (to one decimal place) as follows:

$$\% \text{ Flat \& Elongated} = \frac{A}{A+B} \times 100$$

Where A = mass of flat and elongated particles

B = mass of cubical particles

- 7.2 Calculate the percent of flat and elongated particles weighted average value for each fraction as follows: Multiply the percentage (based on the as received coarse aggregate sample mass) of each fraction and the percent flat and elongated particles for that fraction.
- 7.3 Calculate the percent of flat and elongated particles of the as-received sample as the sum of the weighted average value for each fraction divided by 100.
- 7.4 For the purpose of calculating the weighted average, consider any fraction (not tested) containing less than 5% of the as-received sample to have a value equal to the average of the next smaller and the next larger fractions. If one of these sizes is missing, assign the same value as the next larger or smaller fraction, whichever is present.

8. REPORTING OF RESULTS

- 8.1 Report the percent flat and elongated of each fraction of the test sample to the nearest whole percent.
- 8.2 Report the weighted average percent flat and elongated of the test sample to the nearest whole percent.

9. GENERAL NOTES

- 9.1 Material used in this test may be reused if insufficient material is available for all the required tests

Table 2. Percent Flat and Elongated Particles Worksheet (all masses in grams)

Sample No.: _____

Date: _____

Test Sample Fraction	Mass of Original Fraction (g)	% of Original Fraction ¹	Flat & Elongated Particles Mass (A)	Cubical Particles Mass (B)	% Flat and Elongated Particles (%FE)	
					Per fraction $\frac{A}{A+B} \times 100$	Weighted per fraction ²
37.5 – 26.5 mm						
26.5 – 19.0 mm						
19.0 – 13.2 mm						
13.2 – 9.5 mm						
9.5 – 6.7 mm						
6.7 – 4.75 mm						
Notes: 1. As determined by LS-602 2. = %FE (per fraction) x % of original fraction					% FE particles, Weighted Average ($\sum$ Weighted per fraction) ÷ 100	

Remarks: _____

Operator: _____

PROCEDURE FOR THE PETROGRAPHIC ANALYSIS OF COARSE AGGREGATE

1. SCOPE

1.1 This procedure outlines the method to be employed in the petrographic analysis of coarse aggregate. The procedure appraises the quality of coarse aggregate, and provides a numerical means (in terms of a petrographic number, or P.N.) of expressing and comparing the quality of samples from the same or different sources.

1.2 This procedure does not attempt to describe the techniques used in the geological classification of the aggregate particles, since it is assumed that the examination will be performed by persons qualified to do so by experience and training. The subsequent classification of aggregate particles into quality types employs index tests related to their strength. Sets of reference samples for the petrographic analysis can be obtained from the Petrographer, Soils and Aggregates Section, Engineering Materials Office, 1201 Wilson Ave., Downsview, Ontario, M3M 1J8.

2. RELEVANT DOCUMENTS

2.1 ASTM C 294, C 295

2.2 MTO LS-602, LS-616

2.3 EM - 91, Petrographic Examination of Aggregate and Concrete in Ontario, Engineering Materials Office, Ministry of Transportation.

3. APPARATUS

3.1 HAND LENS: 10x magnification.

3.2 ALNICO MAGNET.

3.3 POCKET KNIFE: Good quality with a blade hardness of between 5.5 and 6 on Moh's scale.

3.4 ANVIL & HAMMER: Suitable for breaking aggregate particles.

3.5 HYDROCHLORIC ACID: Technical grade, 5 % by volume, in polyethylene squeeze-type bottle with spout.

3.6 STEREOSCOPIC MICROSCOPE: 4x to 25x final magnification, with illumination source.

3.7 BALANCE: Accurate to 0.1 g and of sufficient capacity,

3.8 LIGHT SOURCE: Capable of providing excellent illumination of working area.

4. PREPARATION OF SAMPLE

4.1 A representative sample of oven dried aggregate shall be prepared to the following approximate masses:

Pass	Retained	Approx. Mass, g
75 mm	19.0 mm	10,000
53 mm	19.0 mm	5000
37.5 mm	19.0 mm	4000
26.5 mm	19.0 mm	3000
19.0mm	9.5 mm	1000
13.2 mm	9.5 mm	500
9.5 mm	6.7 mm	200
6.7 mm	4.75 mm	75

Note 1: Generally this examination is performed on the pass 19.0 mm retained 9.5 mm material (full fraction), which should consist of pass 19.0 mm retained 16.0 mm, pass 16.0 mm retained 13.2 mm and pass 13.2 mm retained 9.5 mm material proportioned according to the sieve analysis of the aggregate. The pass 13.2 mm retained 9.5 mm material should not exceed 500 g in weight. If the full fraction constitutes less than about 68.5 percent of the sample, the pass 9.5 mm retained 6.7 mm fraction shall also be examined. If these fractions together constitute less than about 68.5 percent of the sample, the pass 6.7 mm retained 4.75 mm fraction shall also be examined. Each sieve size examined should contain a minimum of 200 particles.

5. TEST PROCEDURE

5.1 The sample shall be spread on a tray or other flat working surface.

5.2 If required, the sample shall be examined visually for angularity and shape characteristics and an estimate made and noted of the percentage of crushed, as well as flat and elongated, particles.

5.3 The aggregate shall be examined for coatings (such as clay), cementations and encrustations which may affect the bond with Portland cement paste or asphalt cement. The type of coating and the degree of adhesion to the aggregate shall be noted.

5.4 If clay balls or other particles which may break down in water or with normal handling are present, these particles shall be separated out.

5.5 The sample shall be washed to remove clay and dust coatings.

Note 2: In addition, the sample shall be soaked for a period of at least 15 minutes. This will cause clay, shale, shaley, and slightly shaley particles to soften, making recognition easier.

5.6 The washed sample shall be spread on a flat surface covered with paper or cloth towel to absorb excess water.

5.7 Each particle in the sample shall be classified into a rock type listed on Form PH-CC-343 (Figure 1) or the supplementary rock type list (Table 1). A guide is provided as an appendix to this procedure.

Note 3: Index tests and microscopic examination will usually be sufficient to classify a rock particle. If not, the particle shall be referred to a petrographer for identification (possibly requiring detailed petrographic study).

5.8 In the classification of each particle, the following features may be relevant:

5.8.1 Strength; features such as fossils and clay or shale partings (including stylolites) may constitute weaknesses.

5.8.2 Relative Density.

5.8.3 Shape.

5.8.4 Texture, including porosity and cementation.

5.8.5 Colour.

5.8.6 Mineralogy.

5.8.7 Structure, including bedding and foliation.

5.8.8 Effervescence with acid.

5.8.9 State of weathering.

5.8.10 Magnetism.

5.9 On the completion of the examination, each group of classified particles shall be weighed to the nearest 0.1 g and the weights recorded on Form PH-CC-343 (Figure 1). If any rock types are present which are not found on this form, the category in which they shall be recorded will be found in the supplementary rock type list (Table 1).

6. CALCULATION

6.1 The percentage of each rock type shall be calculated to the nearest 0.1 percent. The percentages of good, fair, poor and deleterious particles shall be calculated. The sum of the sub-totals shall be 100 percent.

6.2 The petrographic number of aggregates for use in hot mix asphalt, surface treatment and concrete shall be calculated as the sum of the products of the percentage of each petrographic category (good, fair, poor or deleterious) multiplied by the appropriate factor for each category (1,3,6, and 10, respectively).

6.3 If the material is to be used for granular base or sub-base, a correction shall be applied which reflects the differing environmental conditions in which the material is used. The percentage of each rock type shall be multiplied by the appropriate correction factor (0, 2, 3, 5, 7, or 9) shown on Form PH-CC-343 and the supplementary rock type list. The sum of the values obtained shall be subtracted from the petrographic number for hot mix asphalt, surface treatment and concrete to obtain the corrected petrographic number for granular use.

Note 4: The use of a petrographic number to classify aggregate for use in granular base and sub-base has been discontinued by MTO.

6.4.1 When the test is performed on more than one size fraction, a weighted average petrographic number shall be calculated by multiplying the percentage (based on the 'as received' coarse aggregate sample grading) of each sieve fraction by the petrographic number for that fraction, adding these products, and dividing by 100.

6.4.2 For the purpose of calculating the weighted average, any fractions (not tested) that contain less than 5 percent of the 'as received' sample shall be considered to have the same value as the average of the next smaller and the next larger fraction or, if one of these fractions is missing, to have the same value as the next larger or smaller fraction, whichever is present.

7. REPORTING OF RESULTS

7.1 The report of the examination should include the following:

7.1.1 The aggregate source name, location, and Mineral Aggregate Inventory Data Bank (MAIDB) number.

7.1.2 The laboratory sample number.

7.1.3 The date, the fraction examined, and the name of the analyst.

7.1.4 The percentages (to the nearest 0.1 percent) of each rock type and of good, fair, poor, and deleterious particles.

7.1.5 The petrographic numbers (to the nearest whole number) for hot mix asphalt, surface treatment and concrete, and for granular base and sub-base.

7.1.6 The weighted average petrographic numbers (to the nearest whole number), when the test is performed on more than one size fraction.

8. GENERAL NOTES

8.1 In the event that there are a number of particularly absorptive particles, they should be dried before weighing so that water absorbed during washing will not significantly influence the mass.

8.2.1 Due to the time-consuming nature of petrographic examination on the smaller coarse aggregate sizes, a shorter procedure is usually used.

8.2.2 A full petrographic examination shall always be performed on the largest aggregate size of a sample. If smaller sizes are also to be tested, they may be separated into the petrographic categories 'good' and 'deleterious' without separation into individual rock types. The nature of the material in the 'good' and 'deleterious' categories will normally be apparent from the complete petrographic analysis on the largest size. Those particles that fall into the 'fair' and 'poor' categories must be separated into their individual rock types.

8.2.3 If the nature of the 'good' and 'deleterious' material is questionable, a full petrographic analysis of the smaller sizes must be performed.

8.3 The factors applied to each rock type are based on laboratory studies and in-service performance for the intended use and prevailing conditions in Ontario. These factors may not apply under other conditions and in other areas. The factors are subject to periodic review, and shall be changed when necessary to reflect current experience.

8.4 The petrographic factors take only physical properties into account. The possibility of the aggregate being alkali-reactive in concrete is not considered.

9. PRECISION

9.1 The petrographic number of a stockpile of coarse aggregate varies by up to 20 on either side of the mean (19 times out of 20).

COARSE AGGREGATE PETROGRAPHIC ANALYSIS - MTO LS609				
SOURCE NAME _____ MAIDB NO. _____				
LOCATION _____ LAB. NO. _____				
DATE _____ FRACTION _____ ANALYST _____				
TYPE	TYPE NO.	MASS	%	GRANULAR CORRECTION
CARBONATE (hard; silty, hard)	01			- -
CARBONATE (surf. weath.; silty, surf. weath.; med. hard; silty, med. hard)	20			- -
CARBONATE (sandy, hard or medium hard)	02			- -
CARBONATE (slightly cherty: <5% chert)	21			- -
MARBLE (hard or medium hard)	23			- -
CONGLOMERATE-SANDSTONE-ARKOSE (hard)	03			- -
CONGLOMERATE-SANDSTONE-ARKOSE (medium hard)	22			- -
GREYWACKE-ARGILLITE (hard or medium hard)	06			- -
GNEISS-AMPHIBOLITE-SCHIST (hard)	04			- -
QUARTZITE	05			- -
GRANITE-DIORITE-GABBRO (hard)	08			- -
VOLCANIC (hard or medium hard)	07			- -
TRAP (<20% sulphide)	09			- -
QUARTZ (vein or pegmatic)	10			- -
TOTAL GOOD AGGREGATE	-			- -
CARBONATE (soft; silty, soft; slightly shaley)	35			X2
CARBONATE (soft, pitted)	41			X2
CARBONATE (deeply weathered; silty, deeply weathered)	42			- -
CARBONATE (sandy, soft)	40			X2
MARBLE (brittle)	24			X2
CHERT-CHERTY CARBONATE (<20% leached chert)	26			X2
CONGLOMERATE-SANDSTONE-ARKOSE (brittle)	30			X2
GREYWACKE (brittle)	29			X2
ENCrustATION	52			X2
GNEISS-AMPHIBOLITE-SCHIST (brittle)	25			X2
ARGILLITE (medium soft)	34			X2
GRANITE-DIORITE-GABBRO (brittle)	27			X2
VOLCANIC (soft)	28			X2
TOTAL FAIR AGGREGATE	-			- -
CARBONATE (shaley; clayey; silty, clayey)	43			- -
CARBONATE (ochreous; sandy, ochreous)	44			- -
MARBLE (friable)	49			X3
CHERT-CHERTY CARBONATE (>20% leached chert)	45			X5
CONGLOMERATE-SANDSTONE-ARKOSE (friable)	46			X3
SILTSTONE	56			X3
CEMENTATION (partial)	53			X3
CEMENTATION (total)	54			- -
GNEISS-AMPHIBOLITE (friable)	50			X3
SCHIST (soft)	55			X3
GRANITE-DIORITE-GABBRO (friable)	51			X3
VOLCANIC (very soft, porous)	48			X3
TOTAL POOR AGGREGATE	-			- -
OCHRE	60			- -
SHALE	61			- -
CLAY	62			- -
VOLCANIC-GNEISS-SCHIST (decomposed)	63			- -
TOTAL DELETERIOUS AGGREGATE	-			- -
% GOOD _____ x 1 = _____ % FAIR _____ x 3 = _____ % POOR _____ x 6 = _____ % DELETERIOUS _____ x 10 = _____		TOTALS _____		
HOT MIX, SURF. TREATMENT AND CONCRETE P.N. _____		EST. PERCENT CRUSHED _____ EST. PERCENT FLAT AND ELONGATED _____		
CORRECTED GRANULAR P.N. _____				

PH-CC-343 13-08

Made from recovered materials

Figure 1 MTO Form PH-CC-343

Table 1 Supplementary Rock Type List

C A T E G O R Y	T Y P E	T Y P E N U M B E R	C O R R E C T I O N F O R G R A N U L A R
G O O D	IRON FORMATION (hard; sl. weath.)	71	-
	GYPSITE (< 10 % gypsum)	77	-
	SEDIMENT: SIBLEY GROUP (hard)	80	-
	FLINT/JASPER	81	-
F A I R	SULPHIDE	72	-
	IRON FORMATION (mod. weathered)	82	-
	VOLCANIC (glassy)	73	X2
	VOLCANIC (ochreous)	74	X2
	TRAP (21-74 % sulphide)	33	X2
	SEDIMENT: SIBLEY GROUP (med. hard)	83	-
P O O R	GYPSITE (10-49 % gypsum)	78	X3
	ARGILLITE-TUFFITE-SLATE (soft)	86	-
	IRON FORMATION (highly weathered)	84	-
	SEDIMENT: SIBLEY GROUP (soft)	85	-
	GREYWACKE (friable)	97	X3
D E L E T E R I O U S	IRON FORMATION (decomposed)	87	-
	ARGILLITE-TUFFITE-SLATE (very soft)	32	-
	GYPSITE (> 49 % gypsum)	79	-
	SEDIMENT: SIBLEY GROUP (very soft)	88	-
	SLAG-GLASS (in non-slag aggregate)	92	X9
	COAL-COKE-CINDER	31	X7
	TALC	64	-

APPENDIX TO PROCEDURE FOR THE PETROGRAPHIC ANALYSIS OF COARSE AGGREGATE (TYPE DESCRIPTIONS)

DISCUSSION

In the petrographic analysis, aggregate particles are initially subjected to a geological classification. Particles are then categorized into types, using descriptors such as 'hard', 'soft', 'brittle', 'friable', 'surface weathered', 'deeply weathered', 'decomposed', etc. For the purposes of standardization, descriptions of the various types are presented in this appendix.

Index tests related to the strength of the aggregate particles, such as scratching, scraping, peeling and plucking using a knife blade, are employed in this classification. Scratching, scraping, and peeling determine the application of hardness descriptors; and plucking determines the application of descriptors such as 'brittle' and 'friable'. Each rock group, such as carbonate, sandy carbonate, marble, volcanic, gneiss, etc., is described separately so as to highlight the decreasing quality of the group through categories 'good' to 'deleterious'. This enables an aggregate to be classified on a systematic basis.

Due to the subjective nature of this test method, descriptions of types contained in this appendix should be considered only as a guideline. The petrographic examination is largely dependent on the experience of the analyst and, where possible, should be complemented by routine tests and/or performance data. In specific cases (especially those of rocks whose performance is unfamiliar to the analyst) additional testing including the study of thin sections may be necessary. A freeze-thaw test conducted on medium hard and slightly shaley carbonate can be used to determine if the shale seams are planes of weakness, and therefore whether or not the particles are classified correctly; the material should be immersed in a 3 % sodium chloride solution in a pan and subjected to five cycles, each cycle consisting of approximately 16 hours of freezing followed by approximately 8 hours of thawing at room temperature.

CARBONATE, SILTY CARBONATE, SILTSTONE, AND CLAY

GOOD

1. Carbonate (hard): high strength; can be scratched (relatively thin scratch); typically unweathered
1. Carbonate (silty, hard): high strength; can be scratched; (relatively thin scratch); raspy sound when scratched; commonly greenish grey; typically unweathered
20. Carbonate (medium hard): high strength; can be scratched (relatively thick scratch)
20. Carbonate (silty, medium hard): high strength; can be scratched (relatively thick scratch); raspy sound when scratched; commonly greenish grey

- 20. Carbonate (surface weathered): mainly high strength; can be scratched; no more than 33 percent of particle consists of medium to low strength weathered material
- 20. Carbonate (silty, surface weathered): mainly high strength; can be scratched; raspy sound when scratched; commonly greenish grey; no more than 33 percent of particle consists of medium to low strength weathered material

FAIR

- 35. Carbonate (soft): medium strength; uniform consistency; can be scratched and scraped with ease; cannot be peeled
- 35. Carbonate (silty, soft): medium strength; can be scratched with ease and scraped with some difficulty; may contain minor low strength zones which can be scraped with ease; raspy sound when scratched; commonly greenish grey
- 41. Carbonate (soft, pitted): medium strength; can be scratched with ease and scraped with some difficulty; moderately pitted
- 42. Carbonate (deeply weathered): more than 33 percent of particle consists of medium to low strength weathered material
- 42. Carbonate (silty, deeply weathered): more than 33 percent of particle consists of medium to low strength weathered material; raspy sound when scratched; commonly greenish grey

POOR

- 43. Carbonate (clayey): contains between 33 and 75 percent very low strength material; can be scraped and peeled with ease
- 43. Carbonate (silty, clayey): contains between 33 and 75 percent very low strength material; can be scraped and peeled with ease; raspy sound when scratched
- 44. Carbonate (ochreous): contains between 33 and 75 percent ochreous material
- 56. Siltstone: fissile (tends to separate readily along thin bedding planes on which mica flakes can commonly be seen); medium to low strength; poorly cemented; friable (many pieces can be plucked easily from particle)

DELETERIOUS

- 62. Clay: greater than 75 percent of particle consists of very low strength material; can be peeled with ease and at times can be broken with the fingers or cut completely through; includes kaolin

SANDY CARBONATE

GOOD

2. Carbonate (sandy, hard or medium hard): high strength (matrix material may be slightly weaker than quartz grains); can be scratched with some difficulty; raspy sound when scratched; ranges from no weathering to thin surface weathering; contains 5 to 49 percent sand-sized quartz grains

FAIR

40. Carbonate (sandy, soft): medium strength; can be scratched with ease and scraped with some difficulty; may contain minor low strength zones which can be scraped with ease; raspy sound when scratched; contains 5 to 49 percent sand-sized quartz grains

POOR

44. Carbonate (sandy, ochreous): contains between 33 and 75 percent ochreous material; contains 5 to 49 percent sand-sized quartz grains

MARBLE

GOOD

23. Marble (hard or medium hard): high strength; can be scratched; intact (edges and corners cannot be plucked)

FAIR

24. Marble (brittle): medium strength; can be scratched with ease and scraped with some difficulty; brittle (edges and corners can be plucked); may have partial to total thin surface weathering

POOR

49. Marble (friable): low strength; friable (many pieces can be plucked easily from particle) to highly friable (particle crumbles totally when plucked); includes cleavable calcite

SHALEY CARBONATE AND SHALE (See Table 2 for petrographic classification)

GOOD

20. Carbonate (medium hard): high strength; can be scratched (relatively thick scratch)

FAIR

35. Carbonate (slightly shaley): medium strength; can be scratched with ease and scraped with some difficulty; generally shows grey or brown (sometimes greasy) streak when scratched

POOR

43. Carbonate (shaley): low strength; can be scraped with ease and peeled with some difficulty; generally shows grey, brown or black (sometimes greasy) streak when scratched

DELETERIOUS

61. Shale: low to very low strength; can be scraped and peeled with ease; sometimes greasy to touch

CHERT AND CHERTY CARBONATE

GOOD

21. Carbonate (slightly cherty: <5 % chert): high strength; hard and/or slightly weathered carbonate; particle contains less than 5 percent chert

FAIR

26. Chert-Cherty Carbonate (<20 % leached chert): high strength; hard and/or slightly weathered carbonate; particle contains 5 percent or more chert, but less than 20 percent of the particle is leached (i.e., absorptive) chert which can generally stick to the tongue

POOR

45. Chert-Cherty Carbonate (20 % leached chert): high to medium strength; particle contains 20 percent or more leached (i.e., absorptive) chert which can generally stick to the tongue

Note 5: The classification of semi-leached chert as leached chert or unleached chert should be based on the rate of absorption.

CONGLOMERATE-SANDSTONE-ARKOSE

GOOD

3. Conglomerate-Sandstone-Arkose (hard): high strength; cannot be scratched; intact (edges and corners cannot be plucked)
22. Conglomerate-Sandstone-Arkose (medium hard): high strength; generally cannot be scratched, although cementing material may be scratched with some difficulty; some edges and corners can be plucked with difficulty

FAIR

30. Conglomerate-Sandstone-Arkose (brittle): medium to high strength; generally cannot be scratched, although cementing material may be scratched with moderate ease; brittle (edges and corners can be plucked)

POOR

46. Conglomerate-Sandstone-Arkose (friable): low strength; generally poorly cemented; friable (many pieces can be plucked easily from particle) to highly friable (particle crumbles totally when plucked)

QUARTZITE

GOOD

5. Quartzite: very high strength; cannot be scratched

GNEISS-AMPHIBOLITE-SCHIST

GOOD

4. Gneiss-Amphibolite-Schist (hard): mainly very high strength; generally cannot be scratched; minor medium to high strength (e.g., micaceous and chloritic) zones which can be scratched and scraped with some difficulty; may have partial thin surface weathering

FAIR

25. Gneiss-Amphibolite (brittle): mainly medium to high strength; generally cannot be scratched; brittle (edges and corners can be plucked); minor medium to low strength zones which can be plucked with ease; may have partial to total, thin, surface weathering
25. Schist (brittle): medium strength; can be scratched with moderate ease; brittle (edges and corners can be plucked); may contain minor more friable zones which can be plucked and scraped with ease

POOR

50. Gneiss-Amphibolite (friable): low strength; friable (many pieces can be plucked easily from particle) to highly friable (particle crumbles when plucked)
55. Schist (soft): low strength; can be scraped and plucked with ease; contains chloritic and/or micaceous zones which can be peeled with ease

DELETERIOUS

63. Schist (decomposed): very low strength; can be crumbled with the fingers; high mica or chlorite content; low quartz and feldspar content
63. Gneiss (decomposed): very low strength; can be crumbled with the fingers; high mica content; low quartz and feldspar content

GREYWACKE-ARGILLITE-TUFFITE-SLATE

GOOD

6. Greywacke (hard or medium hard): high strength; can be scratched with difficulty; some edges and corners can be plucked with difficulty
6. Argillite (hard or medium hard): high to very high strength; can be scratched with difficulty

FAIR

29. Greywacke (brittle): medium to high strength; can be scratched with moderate ease and scraped with some difficulty; brittle (edges and corners can be plucked)

34. Argillite (medium soft): medium strength; can be scratched with moderate ease and scraped with some difficulty

POOR

97. Greywacke (friable): low strength; friable (many pieces can be plucked easily from particle) to highly friable (particle crumbles when plucked)
86. Argillite-Tuffite-Slate (soft): low to medium strength; can be scratched and scraped with ease; fissile (particle breaks along closely spaced fractures, and shatters when struck by a hammer); generally characterized by length to thickness ratio less than 4 to 1

DELETERIOUS

32. Argillite-Tuffite-Slate (vey soft): low to very low strength; can be scraped and peeled with ease; very fissile (particle breaks readily along very closely spaced fractures, and shatters easily when struck by a hammer); rusty weathering stains penetrate into the particle; generally characterized by length to thickness ratio greater than 4 to 1

GRANITE-DIORITE-GABBRO

GOOD

8. Granite-Diorite-Gabbro (hard): mainly very high strength; generally cannot be scratched; minor medium strength (e.g., micaceous and chloritic) zones which can be scratched and scraped with some difficulty; may have partial thin surface weathering

FAIR

27. Granite-Diorite-Gabbro (brittle): mainly medium to high strength; generally cannot be scratched; brittle (edges and corners can be plucked); minor medium to low strength zones which can be plucked with ease; may have partial to total thin surface weathering

POOR

51. Granite-Diorite-Gabbro (friable): low strength; friable (many pieces can be plucked easily from particle) to highly friable (particle crumbles when plucked)

TRAP (INCLUDES VERY HARD BASALT AND FINE GRAINED DIABASE/GABBRO)

GOOD

9. Trap (20 % sulphide): very high strength; faint scratch may be possible; fine grained; dark coloured; unweathered; may contain magnetite, hard epidote, garnet, and/or up to 20 % sulphide minerals such as pyrite

FAIR

33. Trap (21-74 % sulphide): very high strength; faint scratch may be possible; fine grained; dark coloured; generally unweathered; contains 21 to 74 percent sulphide minerals such as pyrite; may contain magnetite, hard epidote, and/or garnet

ENCrustATION

FAIR

52. Encrustation: 33 percent or more of particle is covered by a coating, usually calcium carbonate (25 percent in the case of a thick coating)

CEMENTATION

POOR

53. Cementation (partial): a group of particles cemented together, usually by calcium carbonate; one dominant host particle
54. Cementation (total): a group of particles cemented together, usually by calcium carbonate; no dominant host particle

VOLCANIC

GOOD

7. Volcanic (hard or medium hard): mainly very high strength; generally cannot be scratched; minor medium to high strength zones which can be scratched and scraped with some difficulty; may have partial, thin, surface weathering

FAIR

28. Volcanic (soft): medium strength; can be scratched with moderate ease and scraped with some difficulty; may contain minor low strength zones which can be gouged
73. Volcanic (glassy): cannot be scratched; conchoidal to semi-conchoidal fracture; includes obsidian
74. Volcanic (ochreous): contains between 25 and 50 percent ochreous material

POOR

48. Volcanic (very soft): low strength; can be scraped with ease and peeled with some difficulty; may contain up to 75 percent ochre
48. Volcanic (porous): porous; low strength; can be scratched and scraped with ease; may contain up to 75 percent ochre

DELETERIOUS

63. Volcanic (decomposed): very low strength; can be peeled with ease and crumbled with fingers

FLINT/JASPER AND IRON FORMATION

GOOD

- 71. Iron Formation (hard): high strength; cannot be scratched; unweathered
- 71. Iron Formation (slightly weathered): mainly high strength; can be scratched with difficulty; less than 5 percent of particle consists of penetrating zones of low to medium strength weathered material which can be scraped or gouged; may have partial to total thin surface weathering (rusty stains)
- 81. Flint/Jasper: high strength; cannot be scratched

FAIR

- 82. Iron Formation (moderately weathered): mainly medium to high strength; can be scratched with difficulty; outer crust can be scraped and plucked with difficulty; contains between 5 and 25 percent penetrating zones of low to medium strength weathered material which can be scraped or gouged

POOR

- 84. Iron Formation (highly weathered): contains between 25 and 75 percent low strength weathered material which can be scraped or gouged with ease; outer crust containing medium to low strength zones can be scraped and plucked with moderate ease; inner core may have appearance of ochre or pumice

DELETERIOUS

- 87. Iron Formation (decomposed): low to very low strength; greater than 75 percent of particle consists of low strength weathered material which can be scraped, peeled or gouged with ease

Note 6: Fissile iron formation should be included in the Greywacke-Argillite-Tuffite-Slate group.

OCHRE

DELETERIOUS

- 60. Ochre: greater than 75 percent of particle consists of ochre

GYPSITE

GOOD

- 77. Gypsite (< 10 % gypsum): less than 10 percent of particle consists of gypsum; host rock should be used for particle classification if it is not good aggregate

POOR

- 78. Gypsite (10-49 % gypsum): contains between 10 and 49 percent gypsum

DELETERIOUS

- 79. Gypsite (> 49 % gypsum): contains between 49 and 100 percent gypsum

SEDIMENT: SIBLEY GROUP

GOOD

80. Sediment: Sibley Group (hard): high strength; very difficult to scratch; scratching does not produce powder

FAIR

83. Sediment: Sibley Group (medium hard): high strength; can be scratched (surficial scratch only; deep scratch not possible); powder produced by scratching

POOR

85. Sediment: Sibley Group (soft): medium strength; can be scratched with ease (deep scratch possible); powders easily; ranges from scraped with difficulty to scraped with ease

DELETERIOUS

88. Sediment: Sibley Group (very soft): low to very low strength; can be scraped and peeled with ease

QUARTZ

GOOD

10. Quartz (vein or pegmatitic): does not include quartzite

TALC

DELETERIOUS

64. Talc: sectile; greasy to touch

SULPHIDE

FAIR

72. Sulphide: particle contains at least 75 percent sulphide minerals such as pyrite, marcasite, and chalcopyrite

COAL-COKE-CINDER

DELETERIOUS

31. Coal-Coke-Cinder

SLAG-GLASS

DELETERIOUS

92. Slag-Glass (in non-slag aggregate)

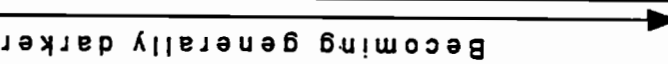
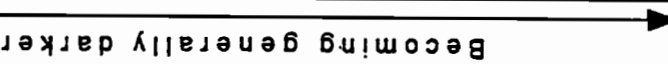
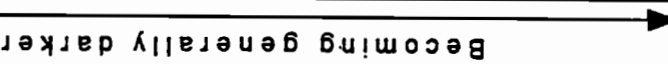
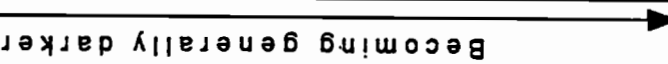
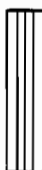
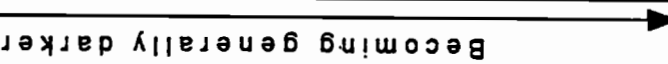
Category	Type	Color	Description
Good	Carbonate (medium hard)		High strength; can be scratched
	 Particles with a thin shale coating on one face; no more than one intraparticle shale seam		Medium strength; can be scratched with ease and scraped with some difficulty; generally shows grey or brown (sometimes greasy) streak when scratched
	 Equidimensional particles with one to three intraparticle shale seams and elongated particles with one or two intraparticle shale seams		
 Equidimensional particles with a thin shale coating on two faces; no intraparticle shale seams			
Fair	Carbonate (slightly shaley)		Low strength; can be scraped with ease and peeled with some difficulty; generally shows grey, brown or black (sometimes greasy) streak when scratched
	 Particles with a thick shale coating on one major face; no intraparticle shale seams		
	 Elongated particles with a thin shale coating on two faces; no intraparticle shale seams		
Poor	Carbonate (shaley)		
	 Equidimensional particles with a thin shale coating on two faces; one to two intraparticle shale seams		
	 Equidimensional particles with a thin shale coating on one face; two to three intraparticle shale seams		
Deleterious	 Equidimensional particles with four intraparticle shale seams		
	 Elongated particles with three intraparticle shale seams		
	 Particles extensively interbedded with shale or particles with uniform shaley (argillaceous) content throughout		
Deleterious	Shale		
	 Particles totally shale		

Table 2 Petrographic Classification of Shale-Bearing Carbonate and Shale

METHOD OF TEST FOR ORGANIC IMPURITIES IN CONCRETE SANDS

1. SCOPE

1.1 This method covers an approximate determination of the presence of possible injurious organic compounds in natural sands which are to be used in cement mortar or concrete. The principal value of the test is to furnish a warning that further tests of the sands are necessary before they are approved for use.

2. RELEVANT DOCUMENTS

- 2.1 ASTM C 40
- 2.2 ASTM D 1544
- 2.3 AASHTO T 21
- 2.4 CSA-A23.2-7A

3. PROCEDURE

3.1 Procedures of ASTM Standard C 40 shall be followed, except as noted below, for the approximate determination of the presence of possible injurious organic compounds in natural sands which are to be used in cement mortar or concrete.

4. REPORT

The report shall include the following:

- 4.1 The colour value of the test sample, (See Figure 1)
- 4.2 The colour value of the reference sample, tested closest to the time at which the aggregate sample was tested.
- 4.2 The colour value of the last twenty samples of reference material on a control chart.

[illegible]

OPERATOR _____

DATE _____

PH-CC-337 93-09

Figure 1 Organic Impurities – Fine Aggregate Data Card

ATTRITION TEST FOR DELETERIOUS MATERIAL IN ICE CONTROL SAND

1. SCOPE

1.1 This method covers the laboratory determination of the percentage of deleterious material in ice control sands by carrying out the Attrition test.

2. RELEVANT DOCUMENTS

2.1 MTO Method LS-602

2.2 MTO Report EM - 26, An Attrition Test for Evaluating Dirt Content of Winter Ice Control Sand, February 1979.

3. APPARATUS

3.1 DRYING OVEN: A thermostatically controlled drying oven capable of being maintained continuously at a temperature of $110 \pm 5^{\circ}\text{C}$.

3.2 BALANCE: Sensitive to 0.1 g and having a capacity of 1000 g.

3.3 SIEVE: 75 μm .

3.4 CONTAINERS: Suitable for drying test samples.

3.5 ATTRITION MACHINE: Conforming in all its essential characteristics to the design shown in Figure 1 to 6. The machine shall consist of a vertical shaft with paddles attached at one end. The other end shall be attached to an electric motor capable of rotating the shaft at a speed of 390 ± 10 rpm under load.

4. TEST SAMPLE

4.1 Samples for attrition are to be obtained from materials to be tested by use of a sample splitter or the method of quartering. The test sample shall be the end result of the sampling method and, when dry, should weigh between 490 and 520 g. Under no circumstances should an attempt be made to select samples of an exact predetermined mass.

5. PROCEDURE

5.1 Oven dry the test sample to constant mass. Weigh to the nearest 0.1 g and record the mass as the original mass.

5.2 Set the Attrition test sample tank so that there is a clearance of 5 mm between the bottom of the attrition shaft and the bottom of the tank.

5.3 Place the test sample in the tank and add 175 mL of water and cover with the lid. Run the attrition machine at 390 rpm for 10 min.

5.4 Lower the tank, wash the material on the lid and paddles into the tank with a wash bottle, and wash the sample onto a 75 µm sieve.

5.5 Wash the sample over the 75 µm sieve as described in MTO Test Method LS-602 and oven dry the material retained to constant mass.

5.6 Weigh the oven-dry sample to the nearest 0.1 g.

5.7 Record data on Attrition Test Data Card (Figure 7).

6. CALCULATION

6.1 Calculate the percentage of deleterious material (loss by attrition and washing) as follows:

$$A = \frac{\text{mass of pass 75 } \mu\text{m sieve}}{\text{mass of original sample}} \times 100 = \frac{W_1 - W_2}{W_1} \times 100$$

where: A = loss by attrition and washing, percent

W_1 = original mass of sample, g

W_2 = mass of retained 75 µm sieve after washing, g

7. REPORTING OF RESULTS

7.1 Report the percentage of deleterious material to the nearest 0.1 percent.

8. GENERAL NOTES

8.1 Care should be taken to ensure that there is no loss of material or water by splashing in the Attrition machine and that all material is washed from the attrition paddles into the sample tank.

8.2 Tap water at room temperature may be used in the test. It is important that exactly 175 mL of water is used since smaller or greater values may have a significant affect on the test result.

8.3 This test includes the pass 75 µm material in the original sample as deleterious material.

8.4 Since a 500 g sample is used, the washing procedure after test may not remove all the pass 75 µm material from very fine sands. If this is suspected, the oven dry sample, after test, should be re-sieved. Any additional pass 75 µm material should be discarded, and the oven dry sample mass (retained) used for calculation purposes. A note should be made on the data card.

9. PRECISION

9.1 Two test results on a sample of sand should not have a difference of greater than one percent. If a greater difference than one percent is obtained, the sample should be re-tested.

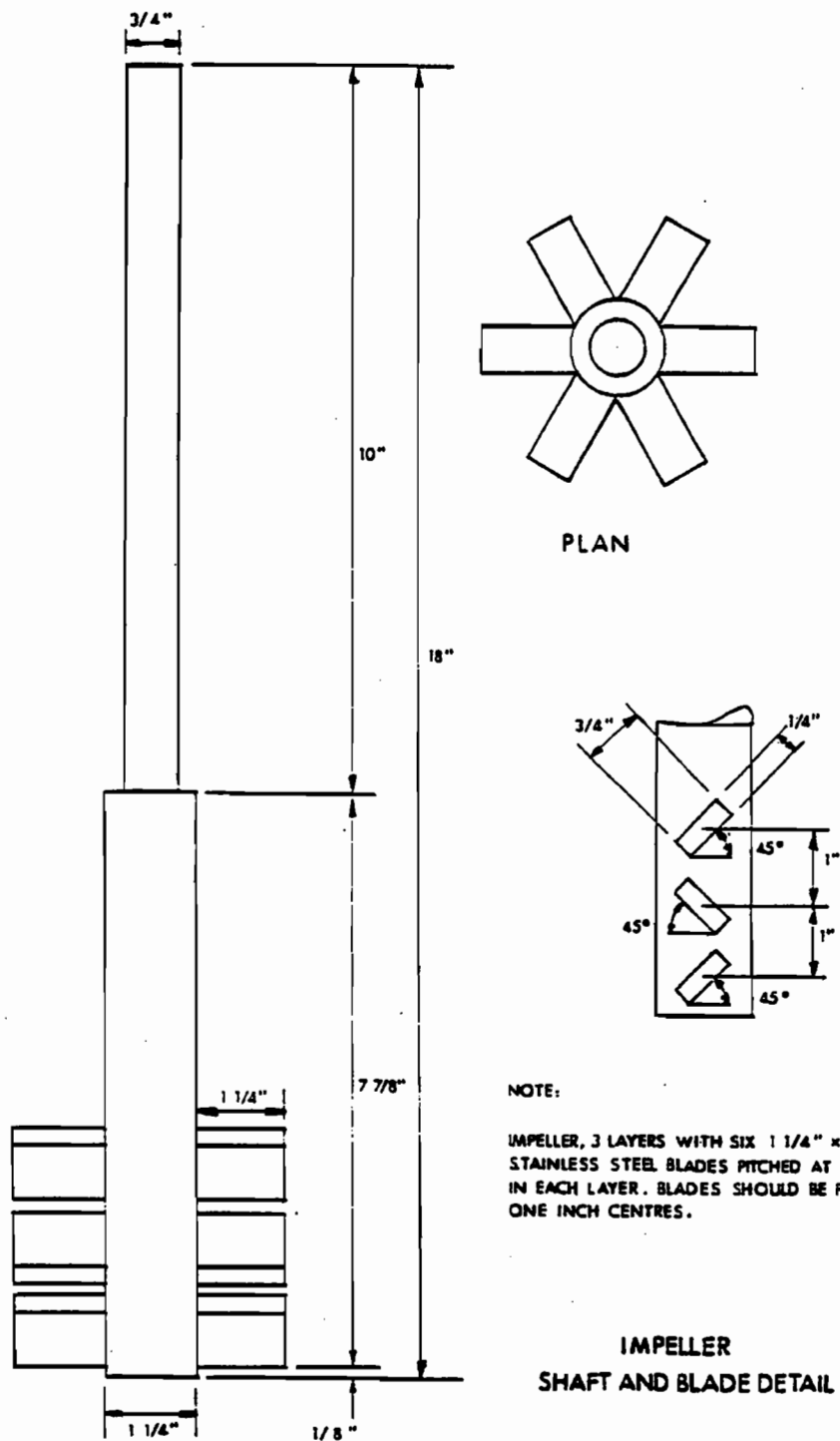
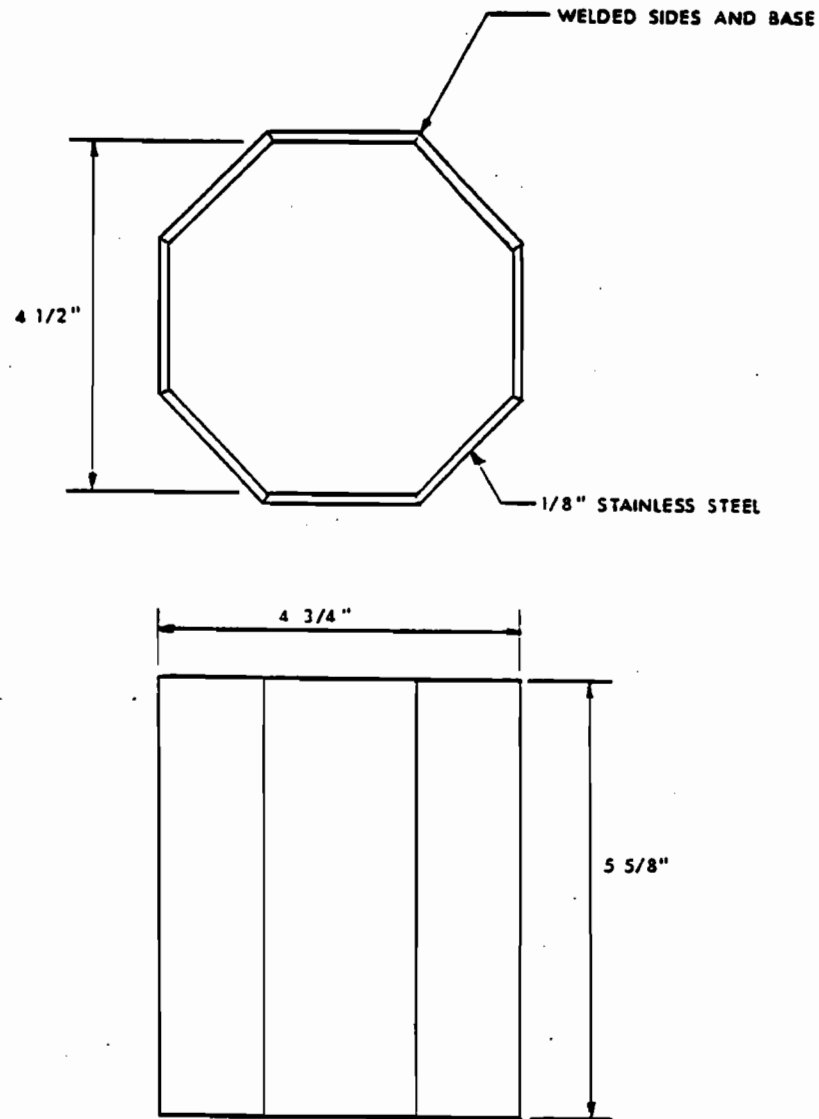


Figure 1 Shaft And Blade Detail



OCTAGONAL TANK

Figure 2 Octagonal Tank

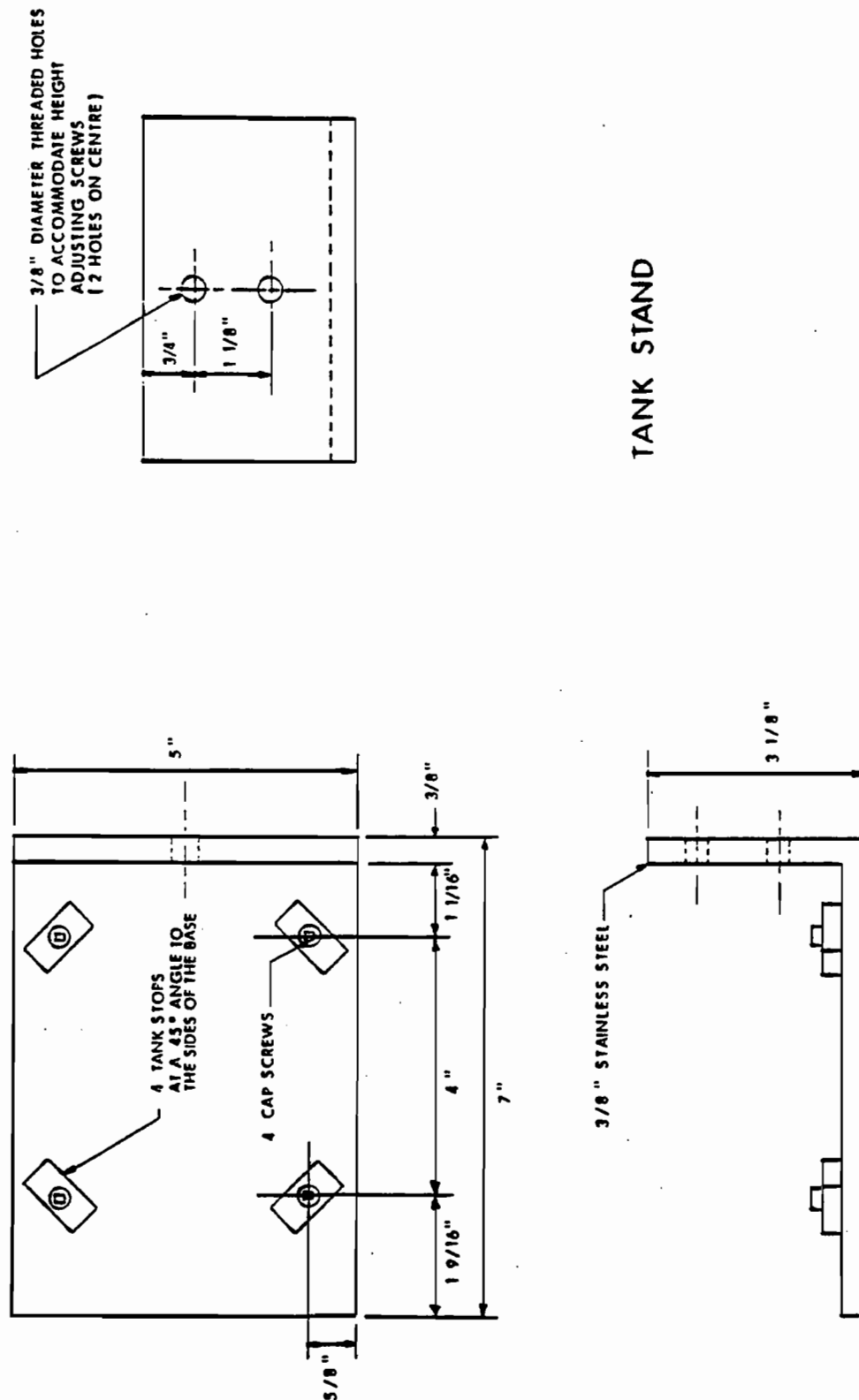
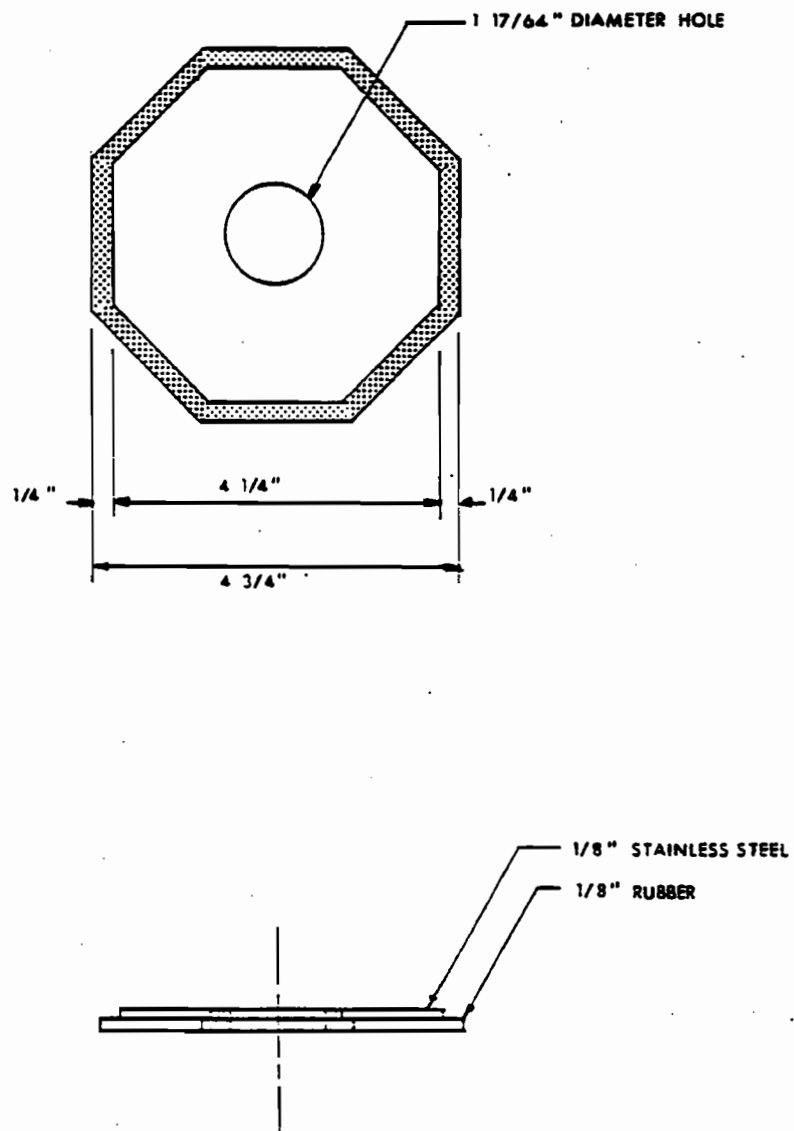


Figure 3 Tank Stand



TANK LID

Figure 4 Tank Lid

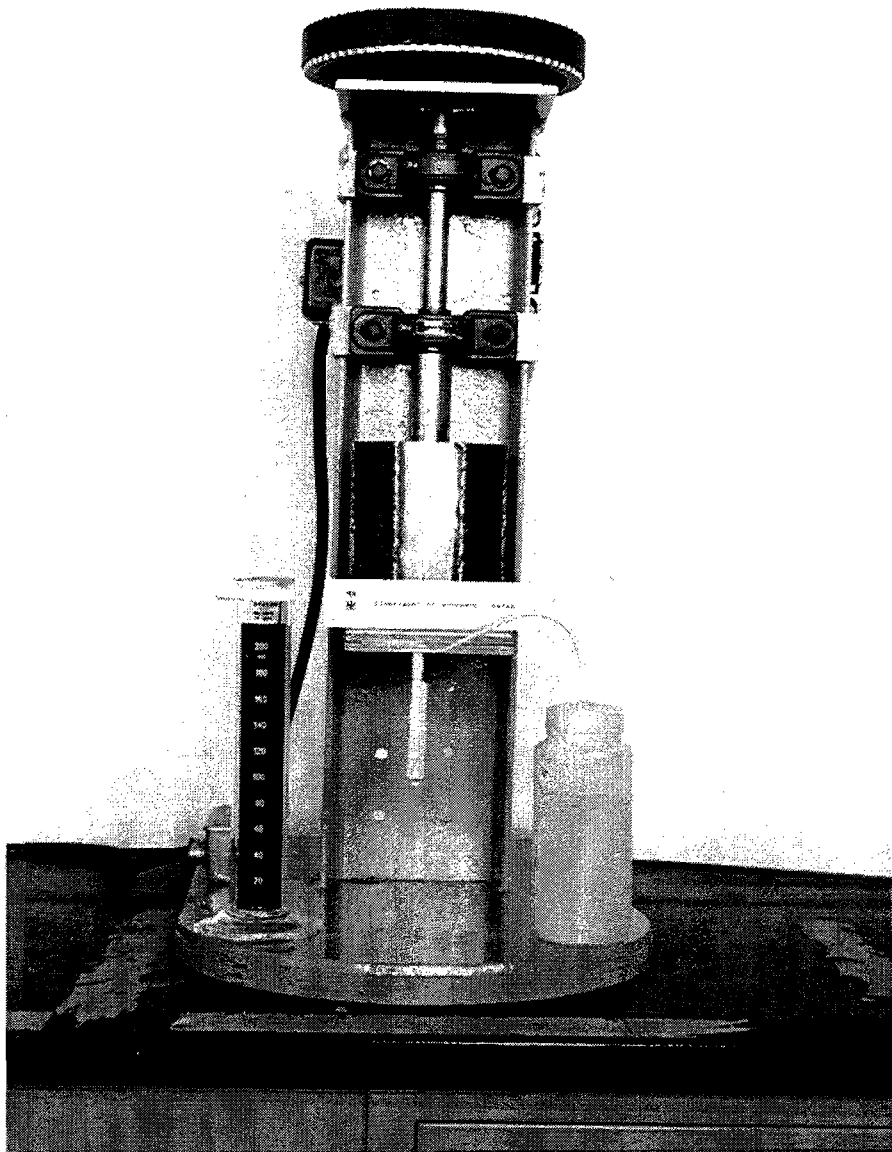


Figure 5 Attrition Apparatus

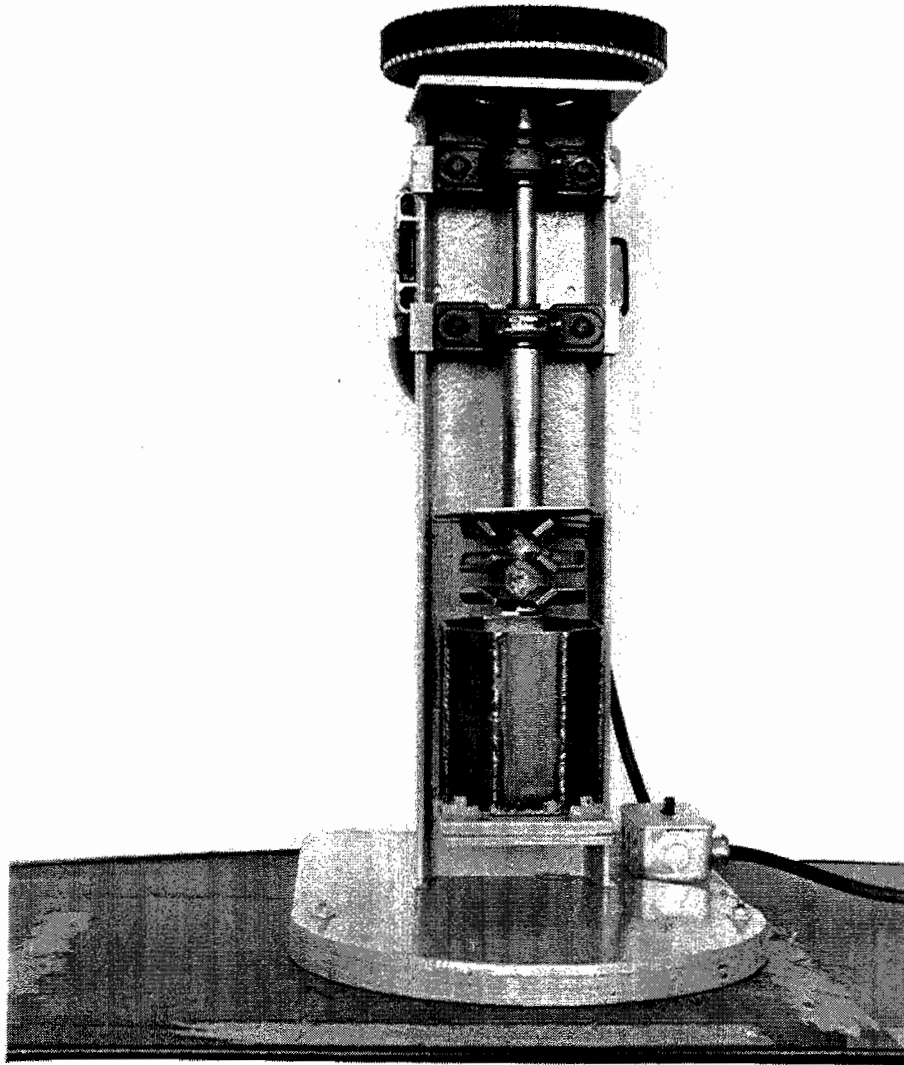


Figure 6 Attrition Apparatus

ATTRITION TEST				
LAB. NO.	ORIGINAL MASS g	MASS AFTER TEST g	LOSS g	PERCENT LOSS
DATE _____		OPERATOR _____		
REMARKS				

PH-CC-408

Figure 7 Attrition Test Data Card

**PROCEDURE FOR
FABRICATION OF BASKETS FOR
USE IN SOUNDNESS TESTING OF FINE AGGREGATES**

MTO Method LS-612 has been withdrawn.

METHOD OF TEST FOR DETERMINATION OF INSOLUBLE RESIDUE OF CARBONATE AGGREGATES

1. SCOPE

1.1 This method covers the determination of the percentage of insoluble residue in carbonate aggregates by using a hydrochloric acid solution to dissolve the carbonate minerals.

1.2 The amount and size distribution of insoluble material in carbonate aggregates is of interest when conducting investigations on pavement frictional properties.

1.3 This test helps distinguish carbonate aggregates that may polish excessively, and become slippery from those that will not.

2. RELEVANT DOCUMENTS

2.1 ASTM D 3042

2.2 MTO Test Method LS-600

2.3 MTO Test Method LS-602

3. APPARATUS

3.1 SIEVES: Sieves with square openings and of the following sizes conforming to OPSS specifications or ASTM specification E 11.

Coarse Series	Fine Series
19.0 mm	4.75 mm
16.0 mm	2.36 mm
13.2 mm	1.18 mm
9.5 mm	600 µm
6.7 mm	300 µm
4.75 mm	150 µm
	75 µm

3.2 SIEVE SHAKER: Any mechanical sieve shaker may be used which produces the thoroughness of sieving equivalent to the hand sieving described in MTO LS-602 Method of Test for Sieve Analysis of Fine and Coarse Aggregates.

3.3 SCALE OR BALANCE: A scale or balance accurate to 0.01 g.

3.4 OVEN: An oven of appropriate size capable of being maintained at $110 \pm 5^{\circ}\text{C}$.

- 3.5 BUNSEN BURNER OR HOT PLATE.
- 3.6 BOROSILICATE GLASS CONTAINER: 2 000 mL capacity.
- 3.7 CRUSHER: An aggregate crusher which may be adjusted to produce material passing the 4.75 mm sieve.
- 3.8 SPLITTER: Refer to MTO LS-600 - Method of Dry Preparation of Aggregates for Determination of Physical Constants.
- 3.9 HYDROCHLORIC ACID: This should be of technical grade, and prepared in 20 percent concentration by volume.

4. PREPARATION OF TEST SPECIMEN

- 4.1 Generally, the insoluble residue determination is performed on oven dried material passing the 19.0 mm sieve, and retained on the 4.75 mm sieve.
- 4.2 In order to obtain reliable results, at least 200 to 300 particles of each sieve fraction, representing more than 10 percent of the total sample, should be tested.
- 4.3 The 6.7 mm fraction is combined with the 4.75 mm fraction, to make a single fraction passing the 9.5 mm sieve, and retained on the 4.75 mm sieve.
- 4.4 Table 1 shows the recommended masses for each sieve fraction so that about 200 particles are tested:

Table 1		
Passing	Retained	Approx. Mass g
19.0 mm	9.5 mm	1250
13.2 mm	9.5 mm	475
9.5 mm	4.75 mm	175

5. PROCEDURE FOR DETERMINING THE TOTAL INSOLUBLE RESIDUE

- 5.1 Reduce the prepared coarse aggregate test sample to sand size particles, using a crusher.
- 5.2 Place a representative crushed aggregate sample weighing between 100 and 150 g in the pre-weighed glass container. Record the mass of the container and sample. Slowly, add a 20 percent solution of hydrochloric acid, taking care to allow for excessive effervescence or foaming to subside before further addition of acid solution. Fill the container with solution, and allow it to stand overnight.
- 5.3 When the reaction appears to have subsided (no obvious bubbling), allow the insoluble material to settle, pour off the solution, and add about 1 000 mL of 20 percent acid solution. Take care not to lose any insoluble material.

5.4 If a reaction (bubbling) is observed, agitate until the reaction subsides, and add more 20 percent acid to the solution already in the container, and allow it to stand.

5.5 When no reaction is observed, heat the container gently to bring it to the boiling point. Continue gentle boiling for approximately 30 minutes to completely digest the carbonate.

5.6 After 30 minutes, or when the reaction has stopped, cool the mixture, and allow the insoluble material to settle. Decant the acid solution, and add water to the aggregate in the container to thoroughly dilute the remaining acid. Allow the mixture to settle, decant it, and repeat the procedure, if necessary.

5.7 Oven dry the material at $110 \pm 5^{\circ}\text{C}$ to a constant mass, and weigh the dried sample to the nearest 0.01 g.

5.8 Record the data on the Insoluble Residue Test Data Sheet, Figure 2.

6. PROCEDURE FOR DETERMINING THE RETAINED 75 μm FRACTION OF INSOLUBLE RESIDUE

6.1 Perform the steps in 5.1 through 5.7.

6.2 Sieve the insoluble residue material through the fine aggregate sieve series.

6.3 The mass of material retained on each sieve is weighed, and recorded cumulatively down to the 75 μm sieve.

7. CALCULATIONS

7.1 Calculate the total percentage of insoluble residue expressed as a percentage of the total original sample mass.

7.2 Calculate the cumulative percentage of insoluble residue retained on the 75 μm sieve expressed as a percentage of the original sample mass.

8. REPORTING OF RESULTS

8.1 Report the total percentage of insoluble residue and the percentage of insoluble residue retained 75 μm sieve to the nearest 0.1 percent.

9. PRECISION AND ACCURACY

9.1 The precision and accuracy for measuring insoluble residue in carbonate aggregates has not yet been established.

9.2 Testing of a 9.5 mm stone from one source by one operator, over a period of four years, showed the following variability:

	Total insoluble residue	Insoluble residue retained 75 μ m
Average	64	54
Range	59-72	50-58
Tests	8	8

10. GENERAL NOTES

10.1 Care should be taken when reducing coarse material that an excess of passing 75 μ m is not produced. A recommended fine aggregate gradation is shown in Figure 1.

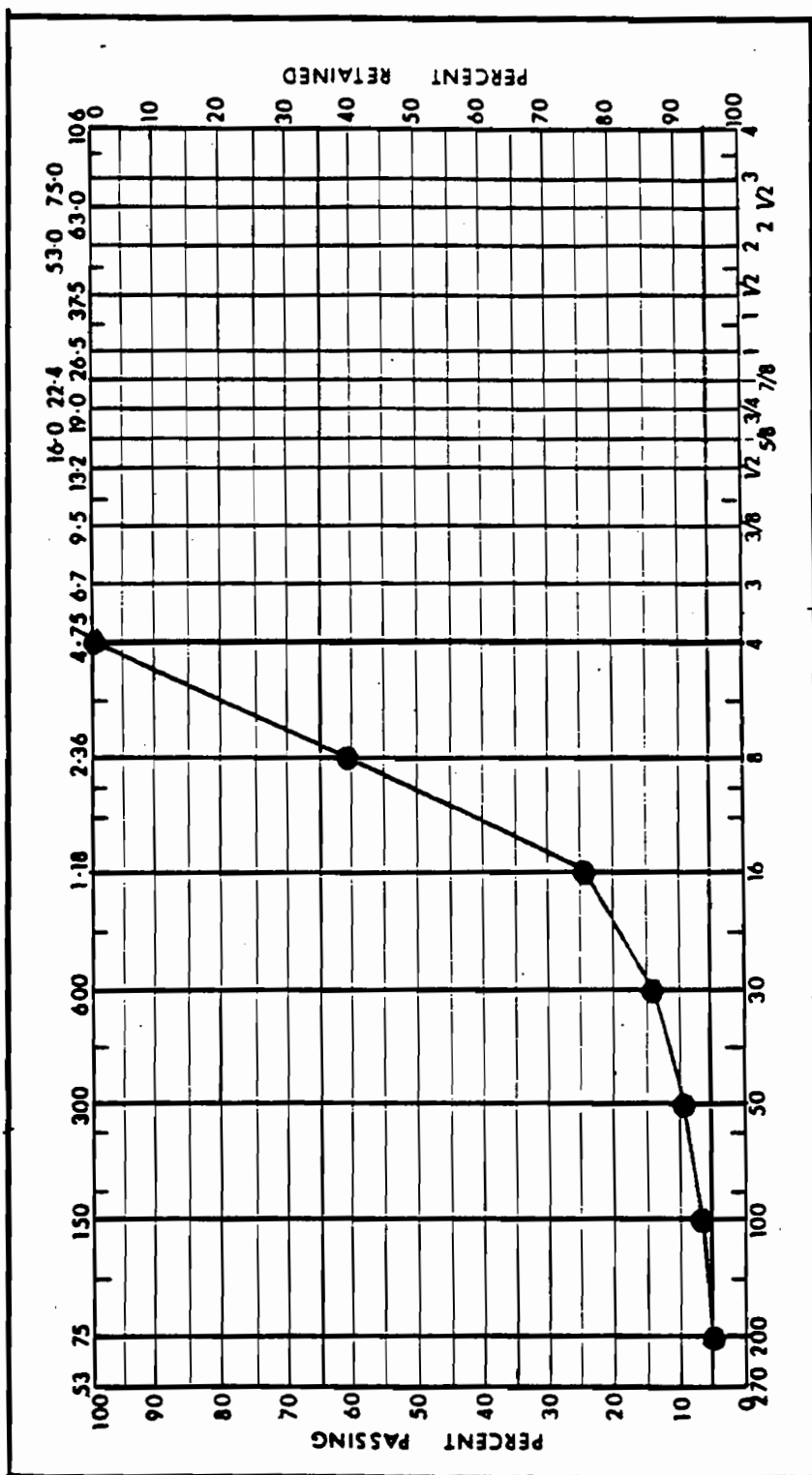
10.2 If agglomeration has occurred following the oven drying of the insoluble residue, physical reduction of the agglomerated particles should be performed by use of a mortar and rubber-tipped pestle, prior to sieve analysis. Take care to prevent the crushing of individual particle grains during this process.

10.3 Acids are diluted on a volumetric basis. To prepare a 20 percent acid solution, use 4 parts of water to 1 part of acid. ALWAYS add the acid to the water.

11. PRECAUTIONS

11.1 Exercise extreme care to prevent corrosive gas from entering the laboratory atmosphere. Hydrogen chloride gas may be destructive to laboratory equipment, and is a definite safety hazard to personnel. Under no circumstances should the test be performed without proper and adequate ventilation.

11.2 The addition of concentrated acid solutions to limestone aggregates produces violent foaming and effervescence. Proper safety apparel should be worn (i.e. goggles, gloves, apron).





Ministry of
Transportation and
Communications
Ontario

DETERMINATION OF INSOLUBLE RESIDUE
BY DIGESTION IN HYDROCHLORIC ACID

SAMPLE NUMBER _____ DATE _____	
SAMPLE LOCATION _____	
INTENDED USE _____	
BEAKER NUMBER	
MASS OF BEAKER AND SAMPLE	
MASS OF BEAKER	
MASS OF SAMPLE (A)	
MASS OF BEAKER AND INSOLUBLE RESIDUE	
MASS OF BEAKER	
MASS OF INSOLUBLE RESIDUE (B)	
PERCENT INSOLUBLE RESIDUE $\left[\frac{B}{A} \times 100 \right]$	
MASS OF INSOLUBLE RESIDUE (B)	
MASS OF INSOLUBLE RESIDUE RETAINED 75 μm (C)	
PERCENT INSOLUBLE RESIDUE RETAINED 75 μm $\left[\frac{C}{A} \times 100 \right]$	
TOTAL INSOLUBLE RESIDUE, PERCENT _____	
RETAINED 75 μm INSOLUBLE RESIDUE, PERCENT _____	
REMARKS : _____	

Figure 2 Test Data Sheet

METHOD OF TEST FOR FREEZING-AND-THAWING OF COARSE AGGREGATE

1. SCOPE

1.1 This method covers the testing of coarse aggregates to determine their resistance to disintegration by repeated freezing and thawing in a sodium chloride solution. It furnishes information helpful in judging the soundness of aggregates subject to freezing and thawing action, particularly when adequate information is not available from service records of the material exposed to actual weathering conditions.

2. REFERENCES

2.1 MTO Report, EM-87, Development of an Unconfined Freeze-Thaw Test for Coarse Aggregate.

2.2 CAN/CSA-A23.2-24A, Method of Test for Resistance of Unconfined Coarse Aggregate to Freezing-and-Thawing.

2.3 MTO Report, MERO-002, Aggregate and Soil Proficiency Sample Testing Program for 2002, February 2003.

3. APPARATUS

3.1 FREEZER: A freezer (chest, stand-up, or walk-in type) capable of maintaining a temperature of $-18.0 \pm 2.0^{\circ}\text{C}$. There shall be a fan that provides adequate air circulation so that the maximum variation within 25 cm of the top and the bottom of the space does not exceed 2.0°C . The temperature of the freezer must be continually monitored at different points within the chamber, either by thermometer or thermocouple. If thermometers are used, the bulb should be in a metal sleeve to avoid sudden temperature changes when the door or lid is opened.

3.2 SIEVES: With square openings and of suitable sizes to furnish the information required by the specification covering the material to be tested. The sieves shall conform to ASTM Specification E11 and CAN/CGSB 8.1. Half height sieves shall not be used for sieving material coarser than 9.5 mm.

Sieve Sizes

37.5 mm

26.5 mm

19.0 mm

13.2 mm

9.5 mm

4.75 mm

3.3 THERMOMETERS: Mercury or alcohol type with a range of -35°C to $+50^{\circ}\text{C}$ marked in 1° divisions readable to 0.5°C . All thermometers must be calibrated with an ASTM precision reference thermometer accurate to 0.1°C , at 0°C .

Note 1: Thermometers are available from CANLAB.

Type	Model	Temperature Range
ASTM Precision	T 2352-62	-38°C to $+2^{\circ}\text{C}$
Lab Grade	T 2025-1C	-35°C to $+50^{\circ}\text{C}$

3.4 CONTAINERS: Autoclavable plastic mason jars, with air-tight screw on caps able to withstand a continuous temperature of 110°C . One litre (1 L) jars are used for fractions retained on the 13.2 mm and 9.5 mm sieves and 500 mL jars for the fraction passing 9.5 mm retained 4.75.

Note 2: Autoclavable plastic mason jars are available from CANLAB.

To order, use:	J-3030-1	500 mL
	J-3030-2	1 L

Note 3: Containers must not come into contact with metal shelves or freezer walls because more rapid cooling will occur.

3.5 Plastic mesh baskets capable of holding four 500 mL jars or two 1 L and one 500 mL jars, and suitable wooden or plastic spacers placed between them to keep the jars from coming in contact with each other. The baskets should be stackable with sufficient clearance for the larger jars.

3.6 BALANCE: A balance or scale accurate to within 0.1% of the sample mass, or 1 g, whichever is greater, over the range required for the test.

3.7 MECHANICAL CONVECTION OVEN: Capable of maintaining a temperature of $110 \pm 5^{\circ}\text{C}$.

3.8 CONTROL AGGREGATE: A supply of standard Brechin Quarry No. 2 coarse aggregate, available from the Soils and Aggregates Section, Ministry of Transportation, 1201 Wilson Avenue, Ontario M3M 1J8, Fax (416) 235-4101.

4. PREPARATION OF SOLUTION

4.1 Prepare sufficient 3% sodium chloride solution for the aggregate to be tested. For example, dissolve 30 g of sodium chloride in 970 g of water. Domestic table salt is acceptable. (Studies have shown that a concentration of 3% caused the most severe freeze-thaw damage.) A graduated beaker or cylinder may be used for the water using $1\text{ g} = 1\text{ mL}$, but check accuracy of volume markings. Large quantities of sodium chloride solution should be prepared to minimize any error in measurement. Prior to using the solution, the container should be agitated thoroughly.

5. PREPARATION OF SAMPLE

5.1 Aggregate for the test shall consist of material retained on the 4.75 mm sieve (coarse aggregate). Separate the sample into fractions, shown in Table 1, by sieving (see Note 4). Weigh out quantities, as indicated in Table 1, of the different sizes present in the sample. If any fraction constitutes less than 5% of the original sample, it shall not be tested.

Note 4: Continuous sieving of aggregates in mechanical sieve shakers will cause continual breakdown. It is good practice to limit mechanical sieving.

Table 1: Gradings and Masses of Test Samples

Pass	Retained	Mass (g)
37.5 mm	26.5 mm	5000
26.5 mm	19.0 mm	2500
19.0 mm	13.2 mm	1250
13.2 mm	9.5 mm	1000
9.5 mm	4.75 mm	500

The retained material on each sieve is then weighed and the sample placed in the appropriate size jar. Mark a number on the jar and lid, and refer this number to the laboratory number and sieve size by recording on the laboratory test data cards. Lids of jars should be marked with an arrow to indicate the direction of rotation between cycles.

5.2 Every time a freeze-thaw test is conducted, a sample of the standard control aggregate shall also be tested. The material shall be taken from a stock supply and prepared as described in 5.1.

6. PROCEDURE

6.1 Place aggregate passing 19.0 mm retained 13.2 mm in a 1 L jar. Aggregate passing 13.2 mm and retained 9.5 mm is also placed in a 1 L jar. Aggregate passing 9.5 mm retained 4.75 mm is placed in a 500 mL jar. Aggregate larger than 19 mm shall be placed in two or more containers so that all the required sample is tested.

6.2 Saturation of samples in solution: Jars containing samples should be filled with the prepared 3% sodium chloride solution so as to completely immerse all aggregate. Seal the jars with lids to prevent evaporation and keep at room temperature for 24 ± 2 hours.

6.3 Draining samples after immersion: Rapidly drain off solution by inverting each jar over a screen smaller than 4.75 mm for about 5 seconds (do not remove aggregate from jars). For convenience, a screen of 1.18 mm mesh can be cut to fit inside a modified mason jar lid to facilitate draining and washing. Two or three mL of solution should remain in the jar. Seal the jars to maintain a 100% relative humidity condition.

Note 5 : Make sure the lids are screwed on properly to form an air-tight seal. When using a lid with a screen to drain off solution or when washing, make sure that the lid is on tight and/or hold a finger against the side of the lid to prevent loss of sample as lids may not fit all jars satisfactorily.

6.4 Freeze thaw cycles: Subject the samples to five cycles of freezing and thawing. Place the jars on their sides in baskets with spacers between to separate them. Place the baskets in the freezer at $-18.0 \pm 2.0^{\circ}\text{C}$ for 16 ± 2 hours (usually overnight), and remove them in the morning to allow approximately 8 hours to thaw out at room temperature. Rotate the jars one quarter turn each cycle to ensure that all aggregate particles receive adequate exposure to the solution.

Note 6: Damage due to freezing and thawing is more severe if the rate of cooling in the temperature range -2°C to -12°C is relatively slow. It has been found to be good practice to turn the freezer off, with the door closed, at the end of freezing cycle and then turn the freezer on when the thawed samples are put back in the freezer.

Note 7: If for any reason the sequence of freezing and thawing must be interrupted, the aggregates should be kept frozen inside the container until the cycle can be resumed.

6.5 Wash aggregate after thawing at the end of the fifth cycle. Fill the jar with water and invert over sink using a lid fitted with a screen as in 6.3 above. Repeat this washing five times, without removing the aggregate from jars.

6.6 Drying samples: Remove the lids from the jars and oven dry the samples to constant mass at $110^{\circ}\text{C} \pm 5^{\circ}\text{C}$, usually overnight.

7. QUANTITATIVE EXAMINATION

7.1 After drying the samples, place the aggregate on the same sieve used in the preparation of the sample and shake in the same sieve shaker used for sample preparation for the amount of time established by the procedure given in Appendix I (± 10 seconds). Following removal from the sieve shaker, shake gently all the aggregates on the sieve for a maximum of 5 seconds to ensure thorough sieving has taken place.

Note 8: Sieves may be inverted before the samples are sieved (i.e. 4.75 mm sieve at the top and 13.2 mm sieve at the bottom of the nest). Any material that passes through the 4.75 mm sieve will naturally fall through the larger sieves below into the pan.

Note 9: Further sieving beyond the established sieving time may lead to additional aggregate loss due to mechanical breakdown.

7.2 Weigh the individual sieve fractions and record the mass to nearest 1 g.

8. CALCULATION

8.1 Calculate the percent loss and weighted average for each fraction as follows:

$$\text{Percent Loss} = \frac{\text{Original Mass} - \text{Mass Retained After Test}}{\text{Original Mass}} \times 100$$

Calculate the percent loss to the nearest 0.1%.

8.2 Calculate the weighted average loss as follows: From the coarse aggregate grading of the material as received, take the retained percentage for each fraction and multiply this percentage by the percent loss for that fraction. The sum of these products (3 of them for the three sizes, i.e. 13.2 mm, 9.5 mm and 4.75 mm) divided by 100 is the weighted average percent freeze-thaw loss for the sample.

Table 2. Example

Fraction		Percent Loss	Percent Retained	Product
Pass	Retained			
19.0 mm	13.2 mm	15.0	20.0	300
13.2 mm	9.5 mm	18.0	30.0	540
9.5 mm	4.75 mm	16.0	50.0	800
				Total = 1640

$$\text{Weighted Average} = \frac{1640}{100} = 16.4\%$$

8.2.1 For the purpose of calculating the weighted average, consider any sizes (not tested) that contain less than 5% of the "As Received" sample to have the same value as the next larger or smaller size, whichever is present.

9. USE OF CONTROL AGGREGATE

9.1 Every time a freeze-thaw test is conducted, a sample of the control aggregate shall also be tested. The material shall be taken from a stock supply and prepared as described in 5.1.

9.2 For the purpose of calculating the weighted average loss of the control aggregate use the grading shown in Table 3.

Table 3: Grading of Control Aggregate

Sieve Fraction	Percent Retained
19 - 13.2 mm	45
13.2 - 9.5 mm	30
9.5 - 4.75 mm	25

9.3 Control Chart Use: The percent loss of the last twenty samples of control material shall be plotted on a control chart in order to monitor the variation in results.

9.4 The mean loss of the Brechin control aggregate is 15.6% (MTO MERO-002, 2003). Individual test data should not normally be greater than 20.9% or less than 10.3%.

9.5 The control aggregate is used to adjust the sieving time required for the quantitative analysis of samples for a given set of equipment (see Appendix I).

10. REPORTING OF RESULTS

10.1 Report the loss on each sieve to the nearest decimal place. Report the weighted loss to the nearest decimal place.

10.2 Report the weighted loss of the Brechin control aggregate to the nearest decimal place.

11. PRECISION

Criteria for judging the acceptability of freeze-thaw test results obtained by this method are given as follows:

Table 4a. Single-Operator Precision

19 - 4.75 mm Weighted Percent Loss	Standard Deviation	Acceptable Range of Two Results
25	1.5	4.3
19	1.6	4.5
6	0.9	2.6
5	0.8	2.3
1	0.3	0.9

Table 4b. Multi-Laboratory Precision

19 - 4.75 mm Weighted Percent Loss	Standard Deviation	Acceptable Range of Two Results
25	2.2	6.2
19	1.7	4.9
6	1.2	3.5
5	1.1	3.1
1	0.5	1.4

Note 10: The figures given in Column 2 are the standard deviations found to be appropriate for the material properties described in Column 1. The figures given in Column 3 are the limits that should only be exceeded one time in twenty, by the difference between the results of two properly conducted tests on samples of the same material.

Appendix I Determination of Sieving Time for Quantitative Analysis

- A1. The following procedure has been established to reduce inter-laboratory variation of the weighted percent loss of an individual sample due to differences that may arise from the use of different types of laboratory equipment, eg. mechanical shaker, diameter of sieves. The amount of time required for quantitative sieving is established through incremental timed-testing of the control aggregate. Sieving time is interpolated from the mean weighted freeze-thaw loss of the control aggregate as given in Section 9. This time is then used for testing all other samples.
- A2. Prepare and test a minimum of three control aggregate samples.
- A3. For each sample, after drying, place the aggregate on the same sieves and shake in the same sieve shaker used for the sample preparation for 1 minute. Following removal from the sieve shaker, shake gently all the aggregates on each sieve for a maximum of 5 seconds to ensure thorough sieving has taken place (see Note 8).
- A4. Weigh each individual sieve fraction separately and record the mass to the nearest 1 g. Return each fraction to the corresponding sieve and continue shaking in the sieve shaker for 1 additional minute.
- A5. Repeat step A4 for a cumulative total of 5 minutes.
- A6. Repeat steps A3 through A5 for the remaining control aggregate samples. (See example, Table A1.)
- A7. Calculate the cumulative percent loss for each individual sieve for all the control aggregate samples. (See example, Table A2.)
- A8. Calculate the cumulative weighted freeze-thaw loss for each control aggregate sample at each incremental test time. (See example, Table A3.)
- A9. Calculate the average weighted freeze-thaw loss of each sample at each incremental test time. (See example, Table A3.)
- A10. Plot the average weighted freeze-thaw loss vs. sieving time. (See example, Figure A1.)
- A11. For the freeze-thaw loss of the control aggregate given in Section 9, interpolate the required sieving time from the plot. (See example, Figure A1.)
- A12. Use the sieving time determined in these steps in the quantitative examination of samples as given in Section 7.
- A13. Repeat this procedure to establish a quantitative sieving time for each individual sieve set, shaker, or combination thereof every 12 months or whenever changes in equipment or control aggregate occur.

Example. WEIGHTED PERCENT FREEZE-THAW LOSS: LS-614 CONTROL AGGREGATE

Sieve Set: Set A, 300mm diam., 13.2mm, 9.5mm, 4.75mm, pan
Shaker: Shaker X, Gilson, 300mm

Table A1. Mass of individual sieves as a function of time

sample	Sieve	Initial	1 minute	2 minutes	3 minutes	4 minutes	5 minutes
1	13.2	1250.1	1084.0	1034.2	984.9	969.7	960.7
	9.5	1000.5	772.4	726.3	698.6	670.3	654.9
	4.75	500.4	411.6	396.6	388.6	380.5	376.8
2	13.2	1250.0	1123.0	1083.5	1054.8	1020.2	997.3
	9.5	1000.3	760.7	691.7	663.4	645.0	630.6
	4.75	500.2	397.1	384.8	377.4	370.5	367.0
3	13.2	1250.7	1121.0	1076.8	1045.1	1027.5	1008.6
	9.5	1000.9	799.7	744.2	713.0	690.4	659.0
	4.75	499.9	413.6	395.4	380.0	381.6	376.6

Table A2: Cumulative percent loss for individual sieves

sample	Sieve	1 minute	2 minutes	3 minutes	4 minutes	5 minutes
1	13.2	13.3	17.3	21.2	22.4	23.2
	9.5	22.8	27.4	30.2	33.0	34.5
	4.75	17.7	20.7	22.3	24.0	24.7
2	13.2	10.2	13.3	15.6	18.4	20.2
	9.5	24.0	30.9	33.7	35.5	37.0
	4.75	20.6	23.1	24.6	25.9	26.6
3	13.2	10.4	13.9	16.4	17.8	19.4
	9.5	20.1	25.6	28.8	31.0	34.2
	4.75	17.3	20.9	24.0	23.7	24.7

Table A3. Average weighted freeze-thaw loss

time (min)	sample			AVERAGE
	1	2	3	
1	17.9	18.1	15.8	17.3
2	21.7	22.2	20.0	21.3
3	24.5	24.4	22.9	23.9
4	26.4	26.5	24.1	25.7
5	27.4	27.8	25.9	27.0

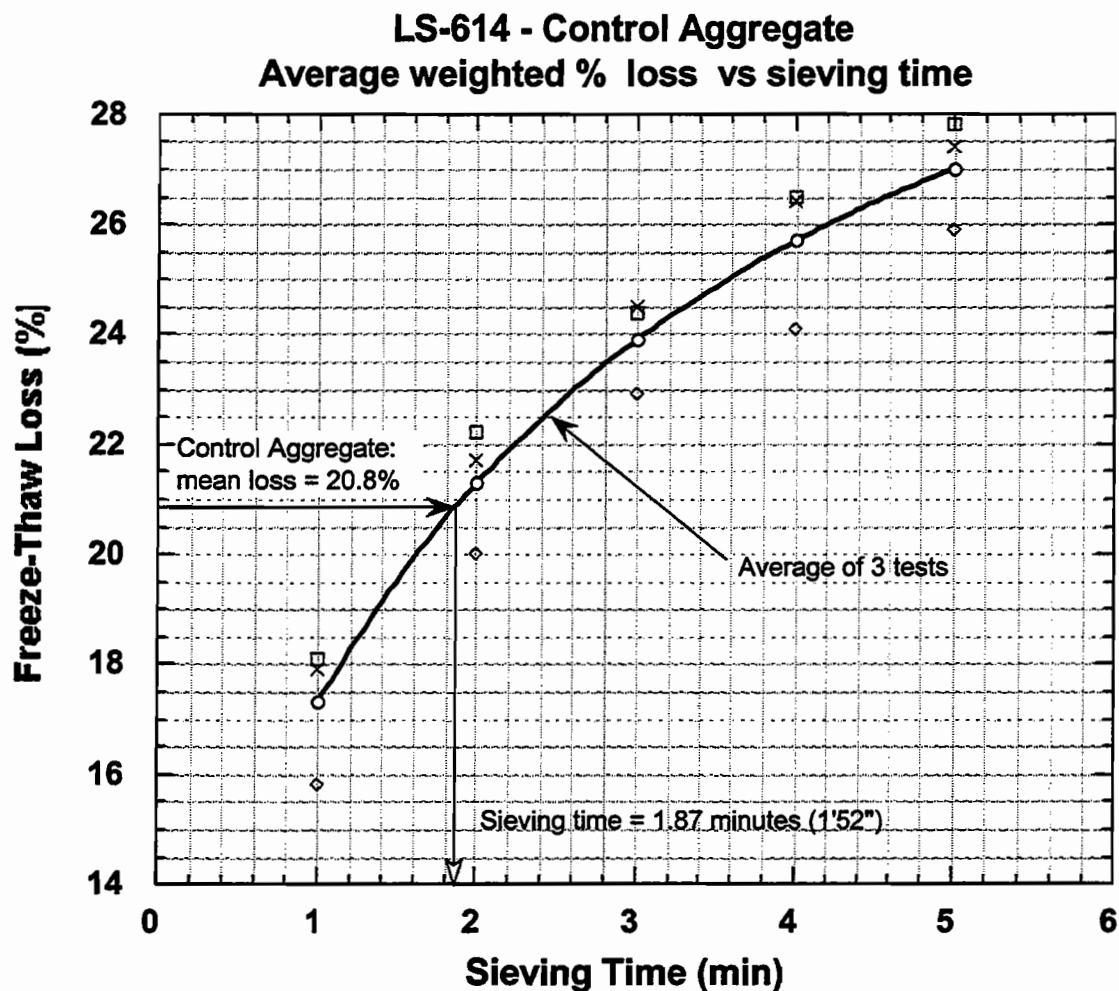


Figure A1. Plot of average weighted Freeze-Thaw loss of control aggregate vs time. (The time of 1 min 52 s is established for quantitative sieving of samples when prepared, tested, and evaluated using sieve set A and shaker X).

Note: The plot shown above is that of the Brechin Quarry No. 1 Control Aggregate used prior to 2003. The same principle applies to the use of the Brechin Quarry No. 2 Control Aggregate.

[illegible]

Figure 1. Test Data Card

METHOD OF TEST FOR THE DETERMINATION OF POTENTIAL ALKALI-CARBONATE REACTIVITY OF CARBONATE ROCKS BY CHEMICAL COMPOSITION

1. SCOPE

1.1 This method covers a procedure for testing quarried carbonate aggregates to determine whether or not they are potentially alkali-carbonate expansive.

1.2 Alkali-carbonate reactive aggregates are dolomitic limestones with a high clay content. Other carbonate rocks are not alkali-carbonate reactive. Dolomitic limestone may be recognized by determining CaO : MgO ratio. Clay content may be determined by measuring alumina (Al_2O_3) content.

1.3 Carbonate rocks which are not alkali-carbonate reactive may be alkali-silica reactive. This test procedure does not determine the potential for alkali-silica reactivity.

2. RELEVANT DOCUMENTS

2.1 ASTM C 702, Methods of Reducing Field Samples of Aggregate to Testing Size.

2.2 CSA-A23.2-1A, Sampling Aggregates for Use in Concrete.

2.3 CSA-A23.2-26A, Determination of Potential Alkali-Carbonate Reactivity of Quarried Carbonate Rocks by Chemical Composition.

3. APPARATUS

3.1 Crushing Equipment - a small jaw crusher or other suitable equipment capable of crushing approximately 2 kg of aggregate to pass a 2.00 mm sieve.

3.2 Grinding Equipment - a chatter box or other suitable equipment capable of grinding approximately 30 g of aggregate to pass a 150 μm sieve.

4. SELECTION AND PREPARATION OF TEST SAMPLES

4.1 The procedures outlined in CAN/CSA-A23.2-1A should be followed to obtain a representative sample of the aggregate to be tested. The sample, if possible, should be obtained from a stockpile of aggregate produced in a manner identical to that which will be used in subsequent production.

4.2.1 The procedures outlined in ASTM C 702 should be followed to obtain representative test specimens of the aggregate sample. The mass of the test specimens is determined by the particle size of the aggregate as shown in Table 1.

Table 1

Pass	Retain	Approx. Mass, g
19.0 mm	13.2 mm	1000
13.9 mm	9.5 mm	500
9.5 mm	6.7 mm	200
6.7 mm	4.75 mm	75

4.2.2 No attempt should be made to obtain the required test specimen mass by adding or subtracting individual pieces. When preparing test specimens of aggregates larger in size than 20 mm, the mass of the sample should be such that a minimum of 200 particles will be obtained of each sieve size.

4.3 The various test specimens shall be combined and crushed, using a small bench crusher, or other suitable means, so that the entire sample passes a 2.00 mm sieve. Care should be taken that the jaw crusher is clean, and that no material is lost.

4.4 The crushed test specimen shall be mixed thoroughly, and further separated, using a sample splitter to obtain a specimen of about 30 g. This 30 g test specimen shall be pulverized, using suitable equipment so that it passes a 150 μ m sieve. Any material retained on the 150 μ m sieve shall be further treated to pass the sieve. Care should be taken that no material is lost.

4.5 The pass 150 μ m sieve specimen shall be mixed thoroughly, and split to obtain specimens of a suitable size for chemical analysis.

5. TEST PROCEDURE

5.1 Where analytical data obtained in accordance with this method are required, any method may be used that meets the requirements of 5.2. A method is considered to consist of the specific procedures, reagents, supplies, equipment, instrument, etc., selected and used in a consistent manner by a specific laboratory.

Note 1: Examples of methods used successfully for analysis of carbonate rocks are given in references 1, 2, and 3.

5.1.1 If more than one instrument, even though substantially identical, is used in a specific laboratory for the same analyses, use of each instrument shall constitute a separate method, and each shall be qualified separately.

5.2 Qualification of a Method - Prior to use for analysis of aggregate, the method chosen must be qualified for such analysis.

5.2.1 Using the method chosen, make single determinations for each oxide on the Standard Reference Materials (see note). Complete two rounds of tests on non-consecutive days, repeating

all steps of sample preparation. Calculate the differences between values and averages of the values for the two round of tests.

Note 2: The Standard Reference Materials are National Institute of Standards and Technology, Gaithersburg, Maryland, Reference Materials Nos. 1C and 88A.

5.2.2 The differences between duplicates shall not exceed the limits shown in column 3 of Table 2.

5.2.3 The average for each component shall not differ from the certified concentrations by more than the value shown in column 4 of Table 2.

6. REPORT

6.1 The report shall include the following:

6.1.1 Source of aggregate including a description of the elevation and location of the quarry face that was sampled.

6.1.2 Any relevant information concerning the preparation of the sample.

6.1.3 Maximum size of the aggregate.

6.1.3 The weight percentage of the various oxides to the nearest 0.1 percent.

6.1.4 The type of analytical method used, together with data to show that the method used meets the precision and accuracy limits shown in Table 2.

Table 2 Maximum Permissible Variation in Results

Column 1	Column 2	Column 3	Column 4
Standard reference material (S.R.M.)	Component	Maximum difference between duplicates	Maximum difference of the average of duplicates from the S.R.M. certificate values
N.I.S.T. 1C	CaO	0.6 %	± 0.5 %
	MgO	0.1 %	± 0.1 %
	Al ₂ O ₃	0.1 %	± 0.2 %
N.I.S.T. 88A	CaO	0.5 %	± 0.5 %
	MgO	0.4 %	± 0.5 %
	Al ₂ O ₃	0.1 %	± 0.1 %

7. INTERPRETATION OF RESULTS

7.1 A correlation between data obtained by this method, expansion of concrete prisms, rock cylinders, and performance of aggregates in concrete structures has been published (4). On the basis of this data, an area on the graph in Figure 1 has been established where potentially expansive

alkali-carbonate reactive rocks are found. Aggregates that fall in this area should be considered to be potentially deleterious until the innocuous character of the aggregate is demonstrated by service records or by a supplementary test in accordance with CSA-A23.14A.

8. PRECISION

Preliminary data indicate that the multi-laboratory coefficient of variation (for experienced laboratories) is dependent upon the element being analyzed. Multi-laboratory coefficient of variation, for an alkali-carbonate reactive rock, obtained in a study with twelve participants is given in Table 3. The D2S values are the limits that should not be exceeded by the difference between the results of two properly conducted test, in different laboratories, expressed as a percent of their mean. These values are only applicable to carbonate rock with a chemical composition similar to that given in Table 3.

Table 3 Multi-Laboratory Variation

	CaO	MgO	CaO : MgO	Al ₂ O ₃
Value	43	6	7	2
C. of V.*	1.5 %	6.9 %	7.6 %	13 %
D2S**	4.3 %	20 %	22 %	37 %

* Coefficient of variation.

** D2S = acceptable maximum difference between two results (see ASTM C 670).

9. REFERENCES

- 9.1 SHAPIRO, L.; 1975, Rapid Analysis of Silicate, Carbonate and Phosphate Rocks - Revised Edition; United States, Geological Survey, Bulletin 1401, 76 p.
- 9.2 NORRISH, K., and CHAPPELL, B.W.; 1977, X-ray Fluorescence Spectrometry; in Physical Methods in Determinative Mineralogy, Ed by J. ZUSSMAN, Academic Press, London, Chapter 5, pp 201-272.
- 9.3 ASTM C25-83 Standard Methods of Chemical Analysis of Limestone, Quicklime and Hydrated Lime; Annual Book of ASTM Standards, Vol. 04.01.
- 9.4 ROGERS, C.A.; 1985 Evaluation of the Potential for Expansion and Cracking Due to the Alkali-Carbonate Reaction; Ontario, Ministry of Transportation and Communications, Engineering Materials Office, Report EM-75, 38 p., Feb. Also published in Cement, Concrete and Aggregates, CCAGDP, Vol. 8, No. 1, Summer 1986, pp 13-23.

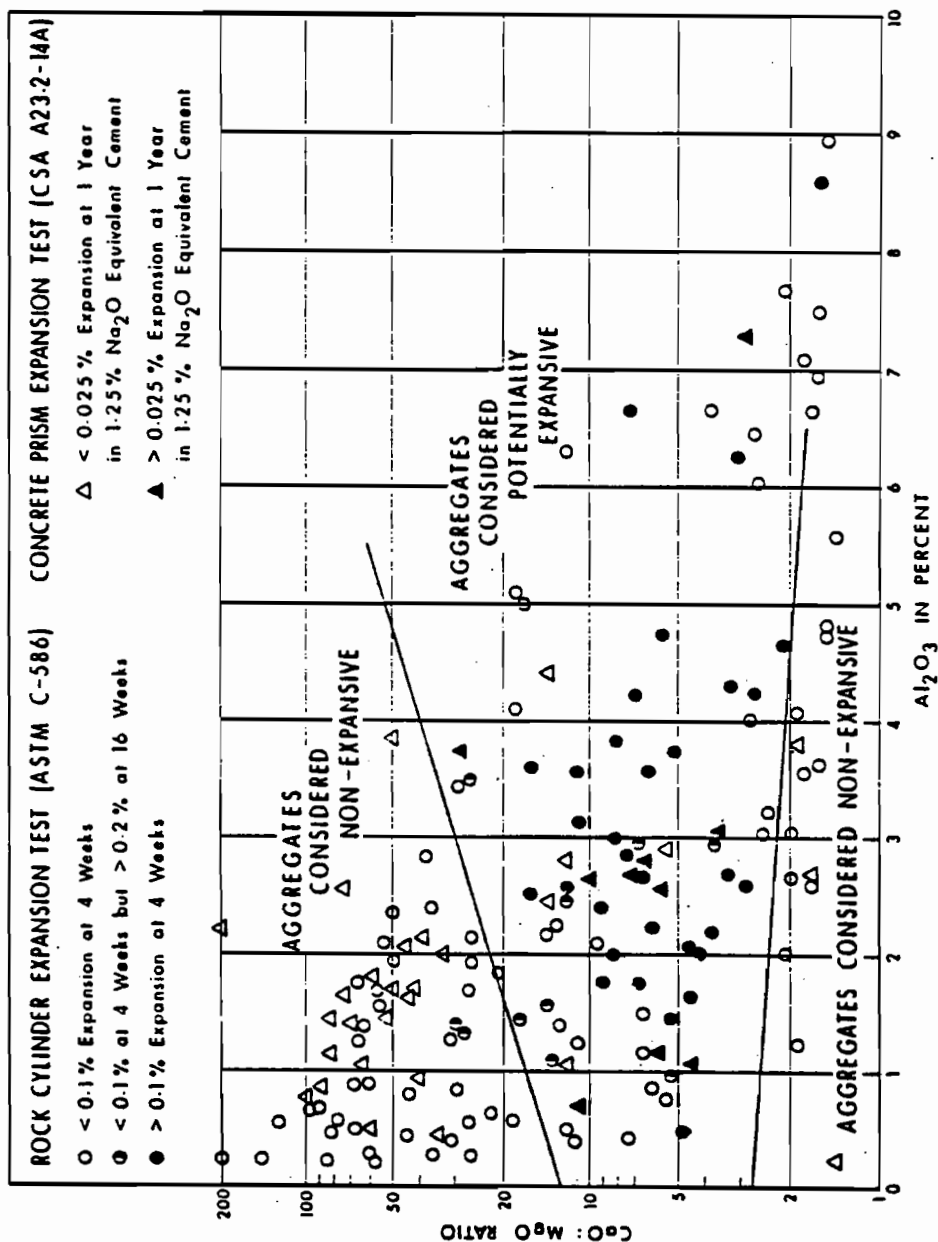


Figure 1: Illustration Of The Division Between Non-Expansive And Potentially Expansive Aggregates On Basis Of Chemical Composition.

PROCEDURE FOR THE PETROGRAPHIC ANALYSIS OF FINE AGGREGATE

1. SCOPE

1.1 This procedure outlines the method to be employed in the petrographic analysis of fine aggregate. Unlike the petrographic analysis of coarse aggregate, this method does not provide a petrographic number. The procedure appraises the quality of the fine aggregate. Firstly, the method determines amounts of silicate and carbonate rock types. Secondly, the amount of deleterious material including, for example, shale, mica and chert, is recorded. The latter is required in order to assess the potential for problems such as lack of freeze-thaw durability and alkali-aggregate reaction.

2. RELEVANT DOCUMENTS

- 2.1 ASTM C 294, C 295
- 2.2 MTO LS-602, LS-609
- 2.3 EM - 91, Petrographic Examination of Aggregate and Concrete in Ontario, Engineering Materials Office, Ministry of Transportation.

3. APPARATUS

- 3.1 Epoxy, hardener and resin (5 minute setting).
- 3.2 Mixing surface, disposable e.g. cardboard.
- 3.3 Mixing stick, disposable e.g. coffee stirrer.
- 3.4 Precleaned glass microscope slides, 50 x 75 mm (e.g. Fisher Scientific, catalogue #12-550C).
- 3.5 Stereoscopic microscope, with cross hairs in at least one eyepiece, final magnification of not less than 50x. A source of illumination.
- 3.6 Mechanical stage i.e. electrically triggered specimen carriage (Notes 1 & 2).
- 3.7 Automatic point counter with at least 10 separate channels.
- 3.8 Pointer, metal, to scratch particles.
- 3.9 Hydrochloric acid (5 percent).

Note 1: In MTO laboratories, point counting is undertaken using a Swift automatic point counter. In the event that such equipment is not available, it is permissible to use non-automatic equipment such

as a mechanical stage and a mechanical means of counting provided that particles selected for examination are done so on a random basis.

Note 2: The Swift mechanical stage, if used, should be equipped with a 1/3 mm stepping gear rather than the 1/6 mm gear usually supplied.

4. SAMPLE PREPARATION

4.1 Dry the sample to a constant mass at a temperature of $110 \pm 5^{\circ}\text{C}$, and then cool to room temperature.

4.2 The fine aggregate portion (pass 4.75 mm material) of the sample should be reduced in mass by splitting to approximately 250 to 300 gm.

4.3 Place test sample in the uppermost of a progressive series of sieves including the 2.36 mm, 1.18 mm, 600 μm , 300 μm , 150 μm and 75 μm sizes. Sieving should be undertaken according to MTO Method LS-602. Place each size in a separate bag and label.

4.4 In order to accommodate a glass slide in the point counter, it is necessary to leave a 5 mm wide sand free border around the perimeter of the slide. This can be achieved by overlapping masking tape a width of about 5 mm around the edge of the slide prior to applying resin. In preparation for sticking sand grains to glass slides, mix about 1 ml of 5 minute epoxy resin with 1 ml of epoxy hardener on a disposable surface, not on the glass slide. This is normally sufficient for the preparation of 2 slides. Apply resin evenly over 2 glass slides (Note 3). Do not attempt to do more than this number at one time. Using a teaspoon, dig deeply into the sand sample and spread the sand grains evenly over the slide.

Note 3: A 27 x 45 mm glass microscope slide, on edge, can be used to spread an even film of epoxy resin on the 50 x 75 mm slide.

4.5 In the case of the large size fractions (i.e. retained 2.36 and 1.18 mm), grains should be pressed into the resin to obtain a better bond. This can be achieved by applying pressure to another glass slide placed on top of the grains.

After 3 or 4 minutes, turn slide upside down in order to remove loose grains. Remove the masking tape. Repeat the procedure to prepare the remainder of the slides.

4.6 In the event that there are less than 200 particles in an individual sieve fraction, a specimen should nevertheless be prepared on a glass slide. All particles should be observed and classified. A note should be made on the report form of the total number of particles examined.

Note 4: In order to examine at least 200 particles of the retained 2.36 mm fraction, it is necessary to prepare 2 slides.

Note 5: The thickness of the epoxy resin on slides should decrease with grain size, so that small grains are not totally submerged in epoxy which would make identification more difficult.

5. SETTING UP APPARATUS

- 5.1 Attach the mechanical stage to the base of the microscope and plug the automatic point counter into the stage.
- 5.2 Zero the vernier gauge on the mechanical stage and insert the glass sample slide into the stage.
- 5.3 Enter a 'sampling target' of 200 particles in the point counter. Set the 'stage interval' at #6 (2 mm) for all size fractions. Where the majority of particles retained on the 2.36 mm sieve are on the large size, the 'stage interval' must be adjusted to accommodate the larger particle sizes (usually #9 or 3 mm intervals).
- 5.4 Allocate and label separate channels on the automatic point counter for each rock type category e.g. Silicate, Carbonate, Shale etc. Refer to Form PH-CC-437 for recommended categories.

6. PROCEDURE

- 6.1 Switch on automatic point counter.
- 6.2 Start examination in upper left hand corner of the glass slide. Identify the particle under the crosshairs and press button for the appropriate rock type. This reading is recorded and the slide is automatically moved a regulated distance set by 'stage interval'. Identify the next particle under the crosshairs and repeat this procedure.

Note 6: In the identification and classification of each particle the following features may be relevant: Particle shape, surface texture, scratch hardness, colour, mineralogy and porosity.

Note 7: In the identification and recognition of sand containing carbonate rock types and minerals, a light acid etch may be found useful. Place the prepared slide face down in a petri dish containing dilute (5 percent) hydrochloric acid and agitate rapidly for 5 to 10 seconds. Remove from the acid and wash gently in water to remove the acid. Allow the sample to air dry before examination. When using this technique with sizes smaller than 300 μm , there is a danger of dissolving too much carbonate.

Note 8: In the event that difficulty exists in the classification of a sand particle, the particle may be removed from the glass slide and referred to a petrographer for detailed study using such techniques as immersion mounts or x-ray diffraction.

- 6.3 If there is no particle under the crosshairs, press the 'stage only' button. The total reading will not change and the slide will be moved the regulated distance to another particle.
- 6.4 Continue the point count from left to right until the carriage stops at the right hand side. The range of movement of the stage is only about half of the length of the slide i.e. about 15 readings.
- 6.5 Return the carriage to the left hand side. Use spacing lever to move slide upwards to the start of the next row; 4 mm movement for the retained 2.36 mm fraction and 3 mm for all other

fractions. East/West and North/South spacings must be judged so that 200 particles can be examined across the slide. Repeat this examination procedure on the second line of particles and on the rest of the first half of the slide until 100 particles are counted (or 50 particles in the case of the retained 2.36 mm fraction).

6.6 Remove slide from stage, rotate it through 180 degrees and replace it in the stage. Undertake the examination of this second half as described in 6.2 to 6.5 above.

6.7 When the sampling target is reached, i.e. when 200 particles have been examined, a buzzer will sound. The petrographic examination is complete for that size fraction.

6.8 Press button for the first 'rock type'. Record number of particles for the channel. Press percentage button to determine percentage for the channel. Repeat this procedure for each channel in turn. After all readings have been recorded, press re-set button to clear memory. For the retained 2.36 mm fraction do not clear memory until 2 slides have been examined.

6.9 Repeat the procedure outlined in 6.2 - 6.8 for each size fraction.

7. CALCULATION

7.1 Determine the number of particles of each material type and record each amount on the Report Form (PH-CC-437). Calculate the percentage of each material for each fraction.

7.2 Calculate the weighted percent chert of the sample as follows:

$$\text{Weighted percent chert} = \sum_{i=1}^n \frac{A_i \times B_i}{100}$$

where A_i = % of total sample of sand (minus 4.75 mm portion) retained on an individual sieve (non cumulative).

B_i = % chert in that sieve fraction.

n = number of individual sieve fractions.

7.2.1 For the purpose of calculating the weighted percent chert, consider the minus 75 μm fraction to have the same composition as the retained 75 μm sieve fraction.

Note 9: When desired, or required, the weighted percent of other materials present in the sample may be calculated using the procedure above (7.2). Materials of interest might be shale, mica or contaminating material such as glass or coal.

8. REPORTING

- 8.1 The report of the examination should include the following:
 - 8.1.1 The aggregate source name, location and mineral aggregate inventory number.
 - 8.1.2 The sample number and date.
 - 8.1.3 The name of the analyst.
 - 8.1.4 The percentage of various rock types on each individual sieve size.
 - 8.1.5 The weighted average percent chert and other materials present in the sample.
 - 8.1.6 The percentage of any component to one decimal place.

9. SAMPLE STORAGE

- 9.1 Samples should be retained indefinitely on their glass slides. Wooden boxes for storage are available commercially.

Note 10: A wooden slide box suitable for storing 75 x 50 mm glass slides is available from Fisher Scientific (catalogue #12-550C).

10. PRECISION

10.1 Single-Observer Precision

For sands with a chert content of between 2 and 5 percent, the single-observer standard deviation has been found to be 0.62 %.* Therefore, results of two properly conducted examinations by the same observer on samples of the same sand should not differ by more than 1.8 %.*

For sands with a shale content of between 9 and 14 percent, the single-observer standard deviation has been found to be 0.62 %.* Therefore, results of two properly conducted examinations by the same observer on samples of the same sand should not differ by more than 1.8 %.*

10.2 Multi-Observer Precision

For sands with a chert content of between 2 and 5 percent, the multi-observer standard deviation has been found to be 0.82 %.* Therefore, results of two properly conducted examinations by two experienced observers on samples of the same sand should not differ by more than 2.3 %.*

For sands with a shale content of between 9 and 14 percent, the multi-observer standard deviation has been found to be 1.68 %.* Therefore, results of two properly conducted examinations by two experienced observers on samples of the same sand should not differ by more than 4.7 %.*

* These numbers represent, respectively, the (1S) and (D2S) limits as described in ASTM Practice C670, for Preparing Precision Statements for Test Methods for Construction Materials.

MTO LS - 616 FINE AGGREGATE PETROGRAPHIC ANALYSIS



SOURCE NAME: _____ DATE: _____

GRAN. I. NO.: _____

	SIEVE SIZE					
	4.75 - 2.36	2.36 - 1.18	1.18 - 600	600 - 300	300 - 150	150 - 075
	#	%	#	%	#	%
ANALYST:						
SILICATE ROCKS (AND ASSOCIATED MINERALS, QUARTZ, FELDSPAR, AMPHIBOLE), SANDSTONE, QUARTZITE						
CARBONATE ROCKS AND ASSOCIATED MINERALS, CALCITE, DOLOMITE						
SHALE, ARGILLITE (soft), CLAY, OCHRE						
MICA (Biotite, Muscovite, Chlorite)						
CHERT (Leached and Unleached), FLINT, JASPER						
CONTAMINATION, (e.g. glass, slag, coal, etc.						
CEMENTED PARTICLES						
TOTAL						
PERCENT RETAINED ON GRADATION, INDIVIDUAL SIEVE						
ESTIMATED PERCENT TOTALLY CRUSHED PARTICLES						

WEIGHTED AVERAGE
PERCENT CHERT

COMMENTS AND NOTES:

Made from recovered materials

PH 02-137 91-08

Figure 1 Fine Aggregate Petrographic Analysis Data Card

**METHOD OF TEST FOR
DETERMINATION OF PERCENT PARTICLES WITH TWO
OR MORE CRUSHED FACES AND UNCRUSHED PARTICLES
IN PROCESSED COARSE AGGREGATE**

1. SCOPE AND SIGNIFICANCE

1.1 This method covers the visual determination of the percent, by mass, of particles with two or more crushed faces and percent, by mass of uncrushed particles in a processed coarse aggregate.

1.2 The anticipated purpose of this test procedure is to assist in identifying those sources of crushed gravel that may be suitable for moderate high stability asphalt pavements. When sources have been approved the test would also be used to ensure consistent quality is achieved.

2. DEFINITION

2.1 A particle with two or more crushed faces is defined as a piece of coarse aggregate with at least two well-defined broken faces resulting from fracture. A well-defined face is one in which the area of the crushed face is at least about 20 percent of the total surface area. The face is surrounded by edges which are sharp or slightly rounded. In most cases such a particle will have fractured surfaces consisting of 50 percent or more of the total surface of the particle. The internal angle between the faces should be 150° or less. Particles with smooth faces and rounded edges, or with only small chips removed, are considered to be uncrushed particles.

3. APPARATUS

3.1 **BALANCE:** Of sufficient capacity and sensitive to 1 g or less.

4. PREPARATION OF TEST SAMPLE

4.1 Prepare the coarse aggregate in accordance with the Method for Preparation of Coarse Aggregate, MTO Method LS-600.

4.2 The test sample shall be prepared from coarse aggregate fractions representing at least 5 % or more of the submitted sample.

4.3 A sample shall be prepared to the approximate mass shown in Table 1.

Table 1

Coarse aggregate fraction		Approx. Mass, g
Pass	Retained	
37.5 mm	19 mm	200 Particles Minimum
19.0 mm	13.2 mm	1250
consisting of:		
19.0 mm	16.0 mm	750
16.0 mm	13.2 mm	500
13.2 mm	9.5 mm	750
9.5 mm	6.7 mm	200
6.7 mm	4.75 mm	75

5. TEST PROCEDURE

5.1 Weigh each fraction to the nearest 1 g. Record this mass (A).

5.2 Spread the sample on a clean, flat surface large enough to permit the particles to be visually inspected.

5.3 Separate the particles into portions containing two or more crushed faces, one crushed face and no crushed faces. (If cementations are present, they should be considered as uncrushed particles).

5.4 Weigh the portion of particles with two or more crushed faces, and the uncrushed portion of the sample, to the nearest 1 g. Do not weigh the portion of particles with one crushed face.

6. CALCULATION

6.1 Calculate the percentage of particles with two or more crushed faces in the test sample (to one decimal place), using the following formula:

$$\text{Percent particles with two or more crushed faces} = \frac{B}{A} \times 100$$

where A = mass of original sample

B = mass of particles with two or more crushed faces.

6.2 Calculate the percentage of uncrushed particles (to one decimal place), using the following formula:

$$\text{Percent uncrushed particles} = \frac{C}{A} \times 100$$

where A = mass of original sample

C = mass of uncrushed particles

6.3 When the test is performed on several test fractions or where the as-received sample contains less than 5 % on any size, a weighted average value shall be calculated as follows:

6.3.1 Multiply the percentage (based on the as-received coarse aggregate sample mass) on each fraction by the percent particles with two or more crushed faces for that fraction. The sum of those products divided by 100 is the weighted average percentage for the as-received sample. The same procedure is used for uncrushed particles.

6.3.2 For the purpose of calculating the weighted average consider any sizes (not tested) that contain less than 5 % of the as-received sample to have the same value as the average of the next smaller and the next larger size or if one of these sizes is missing, to have the same value as the next larger or smaller size, whichever is present.

7. REPORTING OF RESULTS

7.1 Report the weighted average particles with two or more crushed faces to the nearest whole percent.

7.2 Report the weighted average uncrushed particles to the nearest whole percent.

8. GENERAL NOTES

8.1 If a dirt or dust film makes it difficult to determine that the particles have well-defined fractured faces, it is permissible to wash the particles. However, the samples should be dried before weighing.

8.2 Material used in this test may be re-used if insufficient material is available for other required tests.

8.3 It is anticipated that results should be reported in the following manner:

% Particles with two or more crushed faces / % uncrushed particles = 55/5

This would mean that there were 55 % particles with two or more crushed faces and 5 % uncrushed particles.

8.4 From time to time it may be desired to measure the amount of totally crushed particles. In this case, paragraphs 4 to 6 of this procedure should be followed using the following definition:

"A totally crushed particle is defined as a piece of coarse aggregate which has no rounded surfaces and consists of well-defined broken faces resulting from fracture. Particles with smooth faces and rounded edges, or with only small chips removed, are considered to be uncrushed particles. Partly crushed particles are those which are neither totally crushed nor uncrushed particles".

8.5 When testing for the amount of totally crushed particles, it is anticipated that results should be reported in the following manner:

% totally crushed particles / % uncrushed particles = 40/10

This would mean that there were 40 % totally crushed particles and 10 % uncrushed particles

Laboratory sample No.	Sieve size	Mass of sample,g	Mass of particles with two or more crushed faces	Mass of uncrushed particles	Percent particles with two or more crushed faces	Percent uncrushed particles

Date: Operator: Remarks:

Figure 1: Data Card for MTO LS-617 Percent Particles With Two or More Crushed Faces

METHOD OF TEST FOR THE RESISTANCE OF COARSE AGGREGATE TO DEGRADATION BY ABRASION IN THE MICRO-DEVAL APPARATUS

1. SCOPE

1.1 This method covers the testing of coarse aggregates to determine their abrasion loss in the presence of water and an abrasive charge. It furnishes information helpful in judging the suitability of coarse aggregate subject to weathering action when adequate information is not available from service records.

2. RELEVANT DOCUMENTS

- 2.1 ASTM C 136, Standard Method for Sieve Analysis of Fine and Coarse Aggregates.
- 2.2 ASTM E 11, Standard Specification for Wire-Cloth Sieves for Testing Purposes.
- 2.3 LS-602, Method of Test for Sieve Analysis of Aggregates.
- 2.4 L'Haridon, R.; Essai Micro-Deval destiné à prévoir à partir de petits échantillons, les qualités routières des roches carottées; Bulletin Liaison Laboratoire Routières Ponts et Chaussées, Paris, France, No. 14, pp.1-17/1-21, 1965.
- 2.5 Chevassu, G.; Variation des résultats de l'essai Deval humide en fonction du nombre de pierres tendres; Bulletin Liaison Laboratoire Routières Ponts et Chaussées, Paris, France, No. 41, pp.43-45, 1969.
- 2.6 Tourenq, C.; L'essai micro-Deval; Bulletin Liaison Laboratoire Routières Ponts et Chaussées, Paris, France, No. 50, pp.69-76, 1971.
- 2.7 BNQ-2560-070; Détermination du coefficient d'usure par attrition à l'aide de l'appareil micro-Deval; Bureau de Normalisation du Québec (BNQ), Ministère de l'Industrie, du Commerce et du Tourisme, Québec G1R 4Z8.
- 2.8 MTO Report, MERO-002, Aggregate and Soil Proficiency Sample Testing Program for 2002, February 2003.

3. APPARATUS

- 3.1 MICRO-DEVAL ABRASION MACHINE: A jar rolling mill capable of running at 100 ± 5 rpm (Figure 1).
- 3.2 CONTAINERS: Stainless steel, micro-Deval abrasion jars having a 5-litre capacity with a rubber ring in the rotary locking cover. External diameter = 194 - 202 mm, internal height = 170 - 177 mm. The inside and outside surfaces of the jars shall be smooth and have no observable ridges or indentations.

Note 1: Occasionally, concentric grooves may be worn into the inside of the jar by the steel balls. These grooves are not objectionable provided that the distance between crest and trough is not more than 3mm and the control aggregate test data meets the requirements given below.

3.3 ABRASION CHARGE: Stainless steel balls are required. These shall have a diameter of 9.5 ± 0.5 mm. Each jar requires a charge of 5000 ± 5 g of balls.

3.4 SIEVES: Sieves with square openings, and of the following sizes conforming to ASTM E 11:

19.0 mm,	16.0 mm,
13.2 mm,	9.5 mm,
6.7 mm,	4.75 mm,
1.18 mm	

3.5 OVEN: An oven capable of maintaining a temperature of 110 ± 5°C.

3.6 BALANCE: A balance or scale accurate to 1.0 g.

3.7 LABORATORY CONTROL AGGREGATE: A supply of standard Brechin Quarry No. 2 coarse aggregate available from the Soils and Aggregates Section, Ministry of Transportation, 1201 Wilson Avenue, Downsview, Ontario M3M 1J8, Fax (416) 235 4101.

4. PREPARATION OF TEST SAMPLE

4.1 Prepare the coarse aggregate in accordance with the Method for Preparation of Coarse Aggregate, MTO Method LS-600 to meet either A, B, or C Grading.

4.2 **A Grading:** Aggregate for the test shall normally consist of material passing the 19.0 mm sieve, retained on the 9.5 mm sieve. An oven dry sample of 1500 ± 5 g shall be prepared as follows:

Passing	Retained	Mass
19.0 mm	16.0 mm	375 g
16.0 mm	13.2 mm	375 g
13.2 mm	9.5 mm	750 g
	Total	1500 g

4.3 **B Grading:** In cases where the maximum nominal size of the coarse aggregate is less than 16.0 mm, a sample of 1500 ± 5 g shall be prepared as follows:

Passing	Retained	Mass
13.2 mm	9.5 mm	750 g

9.5 mm	4.75 mm	750 g
	Total	1500 g

4.4 **C Grading:** In cases where the maximum nominal size of the coarse aggregate is less than 13.2 mm, a sample of 1500 ± 5 g shall be prepared as follows:

Passing	Retained	Mass
9.5 mm	4.75 mm	1500 g
	Total	1500 g

5. TEST PROCEDURE

5.1 Wash the sample.

5.2 Oven dry the sample to constant mass.

5.3 Prepare a representative 1500 ± 5 g sample. Record the Mass 'A' to the nearest 1.0 g.

5.4 Saturate the sample in 2.0 ± 0.05 L tap water (temperature $20 \pm 5^\circ\text{C}$) for a minimum of 1 hour.

5.5 Place the sample in the micro-Deval abrasion container with 5000 ± 5 g of steel balls and the water. Place the micro-Deval container on the machine.

Note 2: It is permissible to saturate the sample in the water within the micro-Deval abrasion container rather than in a separate container.

5.6 Run the machine at 100 ± 5 rpm for the following times based on the preparation of the test sample (refer to Para. 4.2, 4.3, or 4.4):

Time	Test Sample
120 ± 1 minute	A Grading
105 ± 1 minute	B Grading
95 ± 1 minute	C Grading

5.7 Carefully pour the sample over two superimposed sieves: 4.75 mm and 1.18 mm. Take care to remove the entire sample from the stainless steel jar. Wash the retained material with water (a hand-held spray will be found useful) until the washings are clear. Remove the stainless steel balls using a magnet or other suitable means.

5.8 Combine the material retained on the 4.75 mm and 1.18 mm sieves, being careful not to lose any material.

5.9 Oven dry the sample to constant mass at $110 \pm 5^{\circ}\text{C}$.

5.10 Weigh the sample to the nearest 1.0 g. Record the Mass 'B'.

6. CALCULATIONS

6.1 Calculate the micro-Deval abrasion loss, as follows, to the nearest 0.1 %.

$$\text{Percent Loss} = \frac{A - B}{A} \times 100$$

7. USE OF LABORATORY CONTROL AGGREGATE

7.1 Every 10 samples, but at least every week in which a sample is tested, a sample of the standard reference aggregate shall also be tested. The material shall be taken from a stock supply and prepared according to 4.2.

7.2 Trend Chart Use: The percent loss of the last twenty samples of reference material shall be plotted on a Trend chart in order to monitor the variation in results (Figures 2 and 3).

7.3 The mean loss of the Brechin Quarry No. 2 standard reference aggregate prepared to the grading shown in 4.2 is 19.1%. Individual test data should not normally be greater than 20.7%, or less than 17.5% (MERO-002 & 008, 2003 & 2004).

8. REPORT

The Report shall include the following:

8.1 The percent loss of the test sample to one decimal place;

8.2 The maximum size of the aggregate tested;

8.3 The percent loss of the reference sample, tested closest to the time at which the aggregate sample was tested, to one decimal place; and

8.4 The percent loss of the last twenty samples of reference material on a control chart.

9. PRECISION

The multi-laboratory precision has been found to vary over the range of this test. The appropriate coefficients of variation for a range of abrasion losses are given in Table 1. D2S% is the acceptable difference between two properly conducted tests in different laboratories, on samples of the same aggregate, 19 times in 20.

Table 1

Material Property		D2S
% Mean Loss	Coefficient of Variation (1s)	% of Value
5	10.0%	28
12	6.4%	18
17	5.6%	16
21	5.3%	15

For example, for a material with an abrasion loss of 12%, the acceptable range of two test results (D2S%) would be 18% of 12, or 2.2%.

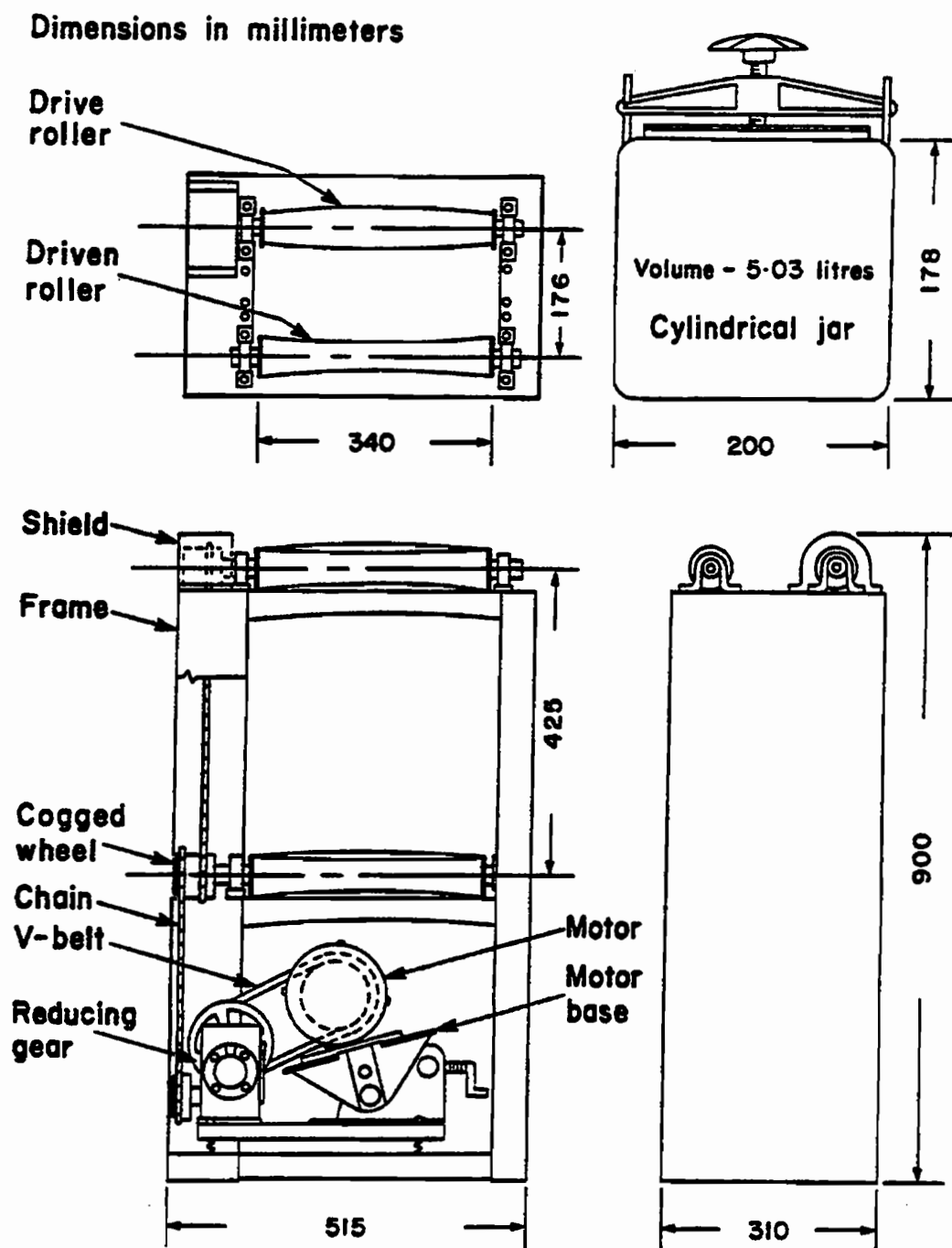


Figure 1 Micro-Deval Abrasion Machine and Container

METHOD OF TEST FOR THE RESISTANCE OF FINE AGGREGATE TO DEGRADATION BY ABRASION IN THE MICRO-DEVAL APPARATUS

1. SCOPE

1.1 This method covers the testing of fine aggregates to determine their abrasion loss in the presence of water and an abrasive charge. It furnishes information helpful in judging the suitability of fine aggregate subject to weathering action when adequate information is not available from service records.

2. RELEVANT DOCUMENTS

2.1 ASTM C 117, Standard Test Method for Materials Finer Than 75 μm Sieve in Mineral Aggregate by Washing.

2.2 ASTM C 136, Standard Method for Sieve Analysis of Fine and Coarse Aggregates.

2.3 ASTM E 11, Standard Specification for Wire-Cloth Sieves for Testing Purposes.

2.4 LS-601, Method of Test for Materials Finer than 75 μm Sieve in Mineral Aggregates by Washing.

2.5 LS-602, Method of Test for Sieve Analysis of Aggregates.

3. APPARATUS

3.1 MICRO-DEVAL ABRASION MACHINE: A jar rolling mill capable of running at 100 ± 5 rpm (Figure 1).

3.2 CONTAINERS: Stainless steel, micro-Deval abrasion jars having a 5 litre capacity with a rubber ring in the rotary locking cover. external diameter = 194 - 202 mm, internal height = 170 -177 mm. The inside and outside surfaces of the jars shall be smooth and have no observable ridges or indentations.

3.3 ABRASION CHARGE: Stainless steel balls are required. These shall have a diameter of 9.5 ± 0.5 mm. Each jar requires a charge of 1250 ± 5 g of balls.

Note 1: Prior to use, new containers and new steel balls should be conditioned. Conditioning is accomplished by running the equipment with a charge of 500 g of silica sand with 750 ml of water for a period of four hours. At the end of four hours this procedure must be repeated with a new sand sample. From time to time it may be necessary to recondition the containers and steel balls. The need for this will be indicated by significant change in loss with the control material. It has been found

that reconditioning is usually needed when the equipment has been used for testing carbonate coarse aggregate in MTO LS-618, which leads to polishing of the container and ball surfaces.

3.4 SIEVES: Sieves with square openings, and of the following sizes conforming to ASTM E 11 specifications:

2.36 mm

1.18 mm

600 μ m

300 μ m

150 μ m

75 μ m

A minimum 200 mm diameter 75 μ m sieve is to be used for washing the aggregate. A 6.7 mm sieve will be found useful for separating the steel balls from the aggregate.

3.5 OVEN: An oven capable of maintaining a temperature of $110 \pm 5^{\circ}\text{C}$.

3.6 BALANCE: A balance or scale accurate to 0.1 g.

3.7 LABORATORY CONTROL AGGREGATE: A supply of standard screenings (James Dick) is available from the Soils and Aggregates Section, Ministry of Transportation, 1201 Wilson Avenue, Downsview, Ontario, M3M 1J8. Phone (416) 235-3735 Fax (416) 235-4101.

4. SAMPLE PREPARATION

4.1 Aggregate for the test shall consist of material passing the 4.75 mm sieve (fine aggregate). Split a representative 725 ± 25 g sample for the micro-Deval test and place in a sealed container.

5. PROCEDURE

5.1 Wash the sample over a 75 μ m sieve until the wash water is clear, as described in MTO Method LS-601, Method of Test for Materials Finer Than 75 μ m Sieve in Mineral Aggregates by Washing.

5.2 Oven dry the sample to a constant mass at a temperature of $110 \pm 5^{\circ}\text{C}$.

5.3 The sample shall be sieved into separate sizes. The sample shall be made up to a fineness modulus (FM) of 2.8 using the gradation given below and then tested. Record the Mass 'A' to the nearest 0.1 g.

Pass	Retained	Mass
4.75 mm	2.36 mm	50 g
2.36 mm	1.18 mm	125 g
1.18 mm	600 µm	125 g
600 µm	300 µm	100 g
300 µm	150 µm	75 g
150 µm	75 µm	25 g
TOTAL		500 g

Note 2: Where prior testing has shown the loss of a material from a source to be less than 17 %, a representative 500 ± 5 g sample from the original 700 g sample may be tested without sieving into individual fractions. Testing of low Micro-Deval loss material without sieving into separate fractions has a small effect on the measured loss and may considerably reduce the complexity of the testing. If testing shows this loss to be greater than 17 %, then a further sample shall be tested which has been prepared to an FM of 2.8 using the gradation specified in 5.3. This loss shall be reported as the final test result.

5.4 Saturate the sample in tap water for 24 ± 4 hours.

5.5 Pour off the excess water and place the sample in the micro-Deval abrasion container with 1250 ± 5 g of steel balls and 750 ± 25 mL of tap water. Place the micro-Deval container on the machine.

5.6 Run the machine at 100 ± 5 rpm for 15 min ± 10 sec.

5.7 Remove the balls from the sample by passing the sample and water through a 6.7 mm sieve over a pan. Wash the aggregate over a 75 µm sieve, according to the procedure described in LS-601, being careful not to lose any retained 75 µm material.

5.8 Oven dry the sample to a constant mass at 110 ± 5°C.

5.9 Weigh the sample to the nearest 0.1 g. Record the Mass 'B'.

6. CALCULATION

6.1 Calculate the micro-Deval abrasion loss, as follows, to the nearest 0.1 %:

$$\text{Percent Loss} = \frac{A - B}{A} \times 100$$

7. USE OF LABORATORY CONTROL AGGREGATE

7.1 Every 10 samples, but at least every week in which a sample is tested, a sample of the standard reference aggregate shall also be tested. The material shall be taken from a stock supply and prepared according to the following procedure. The material shall be sieved into separate sizes,

and each size fraction thoroughly washed and dried to a constant mass. The reference sample shall be made up using the following gradation:

Passing	Retained	Mass
4.75 mm	2.36 mm	170 g
2.36 mm	1.18 mm	115 g
1.18 mm	600 μ m	75 g
600 μ m	300 μ m	55 g
300 μ m	150 μ m	50 g
150 μ m	75 μ m	35 g
TOTAL		500 g

7.2 Control Chart Use: The percent loss of the last twenty samples of reference material shall be plotted on a control chart in order to monitor the variation in results. The average loss of the control material should be 18.9%. Individual test data should not normally be greater than 21.0% or less than 16.8%.

8. REPORT

The Report shall include the following:

8.1 The percent loss of the test sample to one decimal place.

8.2 The percent loss of the reference sample tested closest to the time at which the aggregate sample was tested, to one decimal place.

8.3 The percent loss of the last twenty samples of reference material on a control chart.

9. PRECISION

9.1 The multi-laboratory precision has been found to vary over the range of this test. The appropriate coefficients of variation for a range of abrasion losses are given in below. The $d2s\%$ is the acceptable difference between two properly conducted tests in different laboratories, on samples of the same aggregate, 19 times in 20.

Fine Aggregate Abrasion Loss (%)	Coefficient of Variation (1s%)	Acceptable Range of Two Results ($d2s\%$)
7	8.1	23
10.5	6.0	17
19	5.6	16
20	4.1	12
38	2.6	7

For example, for a material with an abrasion loss of 7%, the acceptable range of two test results ($d2s\%$) would be 23% of 7, or 1.6%.

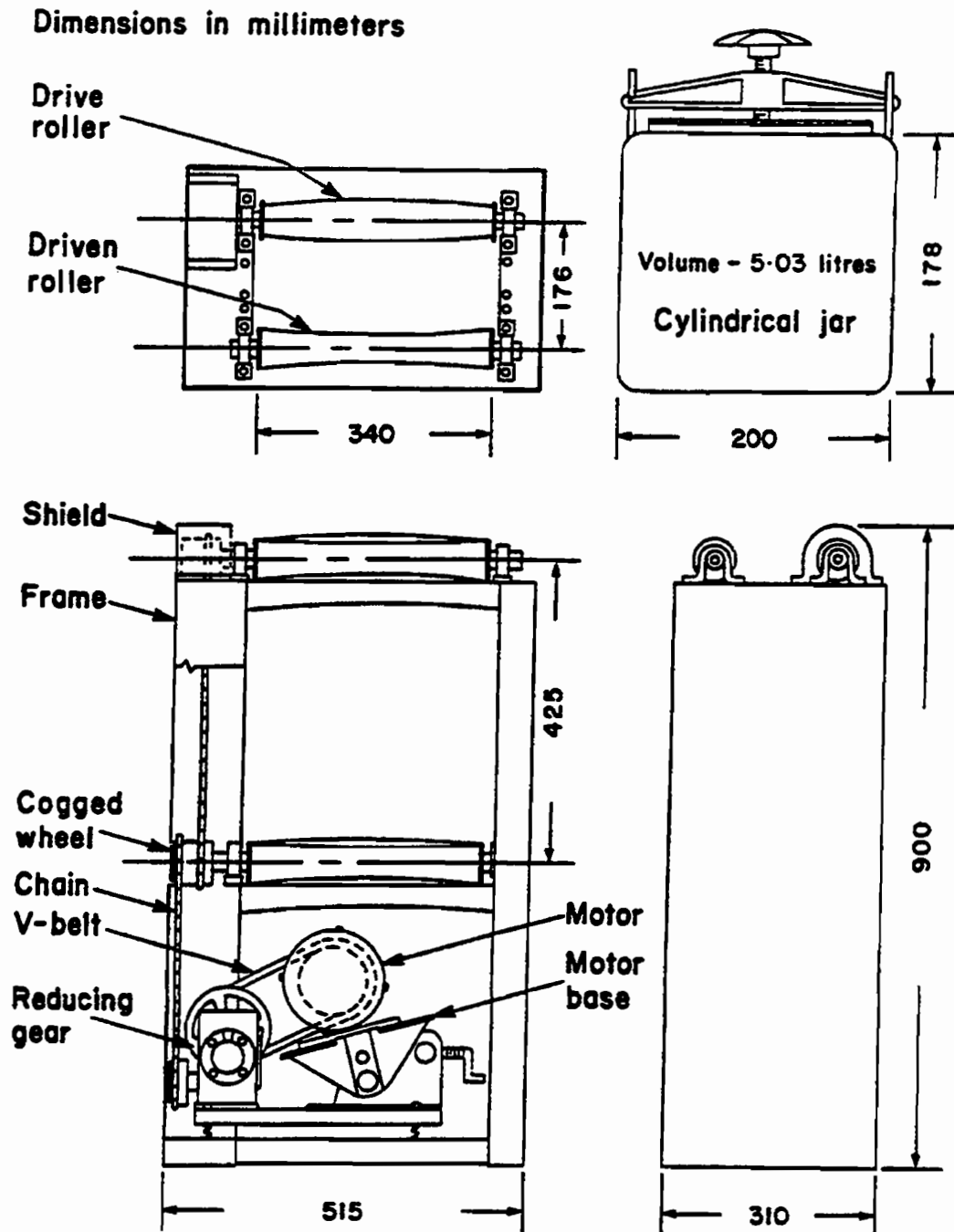


Figure 1

Micro-Deval Abrasion Machine and Container



MICRO - DEVAL ABRASION TEST

LAB. NO.	DUE DATE	ORIGINAL MASS g	MASS AFTER TEST g	LOSS g	PERCENT LOSS	PASS 4.75 F.M.

DATE _____ OPERATOR _____ CONTROL NO. _____
REMARKS _____

PH-CC-448 90-08

Figure 2

Test Data Card

METHOD OF TEST FOR ACCELERATED DETECTION OF POTENTIALLY DELETERIOUS ALKALI-SILICA REACTIVE AGGREGATE BY EXPANSION OF MORTAR BARS

1. SCOPE

1.1 This test method allows detecting within 16 days the potential for deleterious expansion of mortar bars due to the alkali-silica reaction.

1.2 This test method may involve hazardous materials, operations, and equipment. This test method does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this test method to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. A specific precautionary statement is given in Note 5.

2. RELEVANT DOCUMENTS

2.1 ASTM C 109, Test Method for Compressive Strength of Hydraulic Cement Mortars (using 2-in or 50-mm Cube Specimens)

2.2 ASTM C 295, Practice for Petrographic Examination of Aggregates for Concrete

2.3 ASTM C 305, Practice for Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency

2.4 ASTM C 490, Specification for Apparatus for Use in Measurement of Length Change of Hardened Cement Paste, Mortar, and Concrete

2.5 ASTM C 511, Specification for Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes

2.6 ASTM C 856, Practice for Petrographic Examination of Hardened Concrete

2.7 ASTM D 1193, Specification for Reagent Water

2.8 ASTM E 11, Specification for Wire-Cloth Sieves for Testing Purposes

3. SIGNIFICANCE AND USE

3.1 This test method provides a means of detecting the potential of an aggregate used in concrete for undergoing alkali-silica reaction and resulting potentially-deleterious internal expansion. It is based on the NBRI Accelerated Test Method [1, 2, 3]. It may be especially useful for aggregates that react slowly or produce expansion late in the reaction.

Note 1: This procedure is similar in all important matters to the CSA version of this test. It differs from CSA in that a standard supply of cement is specified and the use of a laboratory control aggregate is also specified.

3.2 When excessive expansions are developed, it is recommended that supplementary information be developed to confirm that the expansion is actually due to alkali reactivity. Sources of such supplementary information include: (1) petrographic examination of the aggregate (Practice C 295) to determine if known reactive constituents are present; (2) examination of the specimens after tests (Practice C 856) to identify the products of alkali reactivity.

3.3 When it has been concluded from the results of tests performed using this test method and supplementary information that a given aggregate should be considered potentially-deleteriously reactive, additional studies, possibly using alternative methods, may be appropriate to develop further information on the potential reactivity.

4. APPARATUS

4.1 The apparatus shall conform to Specification C 490, except as follows:

4.1.1 Sieves: Square hole, woven-wire cloth sieves shall conform to ASTM E 11.

4.1.2 Mixer, Paddle, and Mixing Bowl: Mixer, paddle, and mixing bowl shall conform to the requirements of Practice C 305, except that the clearance between the lower end of the paddle and the bottom of the bowl shall be 5.1 ± 0.3 mm.

4.1.3 Tamper and Trowel: The tamper and trowel shall conform to Test Method C 109.

4.1.4 Containers: The containers must be of such a nature that the bars can be totally immersed in either the water or 1N NaOH solution. The containers must be made of material that can withstand prolonged exposure to 80°C and must be inert to a 1N NaOH solution (Note 2). The containers must be so constructed that, when used for storing specimens, the loss of moisture is prevented by tight-fitting covers, by sealing, or both (Note 3). The bars in the solution must be placed and supported so that the solution has access to the whole of the bar, therefore, the specimens must not be allowed to touch the sides of the container or each other. The specimens, if placed on end in the solution, shall not be supported by the metal gauge stud.

Note 2: The NaOH solution will corrode glass or metal containers.

Note 3: A covered container that has been found to be acceptable for this purpose is sold by Rubbermaid as a microwave-proof food storage container.

4.1.5 Oven: A convection oven with temperature control maintaining $80.0 \pm 2.0^\circ\text{C}$.

5. REAGENTS AND MATERIALS

5.1 Sodium Hydroxide (NaOH): USP or technical grade may be used, provided the Na^+ and OH^- concentrations are shown by chemical analysis to lie between 0.99N and 1.01N.

5.2 Purity of Water: Unless otherwise indicated, references to water shall be understood to mean reagent water conforming to Type IV of Specification D 1193.

5.3 Sodium Hydroxide Solution: Each litre of solution shall contain 40.0 g of NaOH dissolved in 900 mL of water, and shall be diluted with additional distilled or deionized water to obtain 1.0 L of

solution. The volume proportion of sodium hydroxide solution to mortar bars in a storage container shall be 4.0 ± 0.5 volumes of solution to 1 volume of mortar bars (Note 4).

Note 4: The volume of a mortar bar may be taken as 184 mL.

*Note 5: **Precaution:** Before using NaOH, review: (1) the safety precautions for using NaOH; (2) first aid for burns; and (3) the emergency response to spills, as described in the manufacturer's Materials Safety Data Sheet or other reliable safety literature. NaOH can cause very severe burns and injury to unprotected skin and eyes. Suitable personal protective equipment should always be used. These should include full-face shields, rubber aprons, and gloves impervious to NaOH. Gloves should be checked periodically for pin holes.*

5.4 Control Aggregate: A supply of 'Spratt' alkali-silica reactive aggregate prepared as described in 7.2. This aggregate is available from: The Soils and Aggregates Section, Ministry of Transportation, 1201 Wilson Avenue, Downsview, Ontario, M3M 1J8.

6. CONDITIONING

6.1 Maintain the temperature of the molding room and dry materials at not less than 20°C and not more than 27.5°C. The temperature of the mixing water, and of the moist closet or moist room, shall not vary from 23°C by more than 1.7°C.

6.2 Maintain the relative humidity of the molding room at not less than 50 % . The moist closet or room shall conform to Specification C 511.

6.3 Maintain the storage oven in which the specimens are stored in the containers at a temperature that shall not vary from 80°C by more than 2.0°C.

7. SAMPLING AND PREPARATION OF TEST SPECIMENS

7.1 Process materials proposed for use as fine aggregate in concrete as described in 7.2 with a minimum of crushing. Process materials proposed for use as coarse aggregates in concrete by crushing to produce as nearly as practical a graded product from which a sample can be obtained. The sample shall have the grading as prescribed in 7.2, and be representative of the composition of the coarse aggregate as proposed for use.

7.1.1 When a given quarried material is proposed for use both as coarse and as fine aggregate, test it only by selection of an appropriate sample crushed to the fine aggregate sizes, unless there is reason to expect that the coarser size fractions have a different composition than the finer sizes and that these differences might significantly affect expansion due to reaction with the alkalis in cement. In this case, test the coarser size fractions in a manner similar to that employed in testing the fine aggregate sizes.

7.2 Preparation of Aggregate: Grade all aggregates to which this test method is applied in accordance with the requirements prescribed in Table 1. Crush aggregates in which sufficient

quantities of the sizes specified in Table 1 do not exist until the required material has been produced. In the case of aggregates containing insufficient amounts of one or more of the larger sizes listed in Table 1 and, if no larger material is available for crushing, the first size in which sufficient material is available shall contain the cumulative percentage of material down to that size as determined from the grading specified in Table 1. When such procedures are required, make a special note in the test report. After the aggregate has been separated into the various sieve sizes, wash each size with a water spray over the sieve to remove adhering dust and fine particles from the aggregate. Dry the portions retained on the various sieves and, unless used immediately, store each portion individually in a clean container provided with a tight-fitting cover.

Table 1 Grading Requirements

Sieve Size		Mass, %
Passing	Retained	
4.75 mm	2.36 mm	10
2.36 mm	1.18 mm	25
1.18 mm	600 µm	25
600 µm	300 µm	25
300 µm	150 µm	15

7.3 Preparation of Cement: Pass cement for use in this test through a 850 µm sieve to remove lumps before use.

7.4 Preparation of Test Specimens:

7.4.1 Number of Specimens: Make at least three test specimens for each cement-aggregate combination.

7.4.2 Preparation of Molds: Prepare the specimen molds in accordance with the requirements of Specification C 490, except that the interior surfaces of the mold shall be covered with a release agent (Note 6). A release agent will be acceptable if it serves as a parting agent without affecting the setting of the cement and without leaving any residue that will inhibit the penetration of water into the specimen.

Note 6: TFE-Fluorocarbon tape complies with the requirements for a mold release agent.

7.4.3 Proportioning of Mortar: Proportion the dry materials for the test mortar using 1 part of cement to 2.25 parts of graded aggregate by mass. The quantities of dry materials to be mixed at one time in the batch of mortar for making three specimens shall be 440 g of cement and 990 g of aggregate made up by re-combining the portions retained on the various sieves (see 7.2) in the grading prescribed in Table 1. For natural fine aggregates, use a water to cement ratio equal to 0.44

by mass. For coarse aggregates or manufactured sands, use a water to cement ratio equal to 0.50 by mass (Note 7).

Note 7: Ruggedness tests indicated that mortar bar expansions were less variable at a fixed water to cement ratio than when gauged to a constant flow [3]. The water to cement ratios selected should give acceptable workability in most cases [4].

7.4.4 Mixing of Mortar: Mix the mortar in accordance with the requirements of Practice C 305.

7.4.5 Molding of Test Specimens: Mold test specimens with a total elapsed time of not more than 2 min and 15 sec after completion of the original mixing of the mortar batch. Fill the molds with two approximately equal layers, each layer being compacted with the tamper. Work the mortar into the corners, around the gauge studs, and along the surfaces of the mold with the tamper until a homogeneous specimen is obtained. After the top layer has been compacted, cut off the mortar flush with the top of the mold and smooth the surface with a few strokes of the trowel.

8. PROCEDURE

8.1 Initial Storage and Measurement: Place each mold in the moist cabinet or room immediately after molds have been filled. The specimens shall remain in the molds for 24 ± 2 h. Remove the specimens from the molds and, while they are being protected from loss of moisture, properly identify and measure for initial length. Make and record the initial and all subsequent measurements to the nearest 0.002 mm. Place the specimens made with each aggregate sample in a storage container with sufficient tap water to totally immerse them. Seal and place the containers in an oven or room at $80 \pm 2.0^\circ\text{C}$ for a period of 24 h.

8.2 Zero Measurements: Remove the containers from the oven one at a time. Remove other containers only after the bars in the first container have been measured and returned to the oven. Remove the bars one at a time from the water and dry their surfaces with a towel paying particular attention to the two metal gauge measuring studs. Take the zero measurement (Note 8) of each bar immediately after drying, and read as soon as the bar is in position. Complete the process of drying and measuring within 15 ± 5 s of removing the specimen from the water. After measurement, leave the specimen on a towel until the remainder of the bars have been measured. Place all three specimens in a container with the 1N NaOH, at $80 \pm 2.0^\circ\text{C}$. The samples must be totally immersed. Seal the container and return it to the oven.

Note 8: The comparator bar should be measured prior to each set of specimens since the heat from the mortar bars may cause the length of the comparator to change.

8.3 Subsequent Storage and Measurement: Undertake subsequent measurement of the specimens periodically, with at least three intermediate readings for 14 days after the zero reading, at approximately the same time each day. The measuring procedure is identical to that described in 8.2, except that the specimens are returned to their own container after measurement. If the mean

expansion of the mortar bars exceeds 0.14 % at 14 days, the bars shall be returned to the container and stored for a total of 28 days. At least one reading per week shall be taken between 14 and 28 days. If the expansion after 28 days exceeds 0.30 % the bars shall again be returned to the container and stored for a total of 56 days. At least one reading per week shall be taken between 28 and 56 days.

9. CALCULATION

9.1 Calculate the difference between the zero length of the specimen and the length at each period of measurement to the nearest 0.001 % of the effective gauge length and record as the expansion of the specimen for that period. Report the average expansion of the three specimens of a given cement-aggregate combination to the nearest 0.001 % as the expansion for the combination for a given period.

10. USE OF CONTROL AGGREGATE

10.1 Every 10 samples, but at least once every six months in which a sample is tested, a sample of the control aggregate described in 5.4 shall be tested. The mean multi-laboratory expansion of this aggregate with high alkali cement has been found to be 0.42 % with a standard deviation of 0.062 % at 14 days in solution [5]. Therefore results obtained with this material should fall in the range 0.30 - 0.54 %, nineteen times in twenty.

11. REPORT

11.1 The report shall include the following:

11.1.1 Type and source of aggregate,

11.1.2 Alkali content of cement as percent potassium oxide (K_2O), sodium oxide (Na_2O), and calculated sodium oxide (Na_2O) equivalent, if the standard cement was not used,

11.1.3 Average length change in percent at each reading of the specimens,

11.1.4 Any relevant information concerning the preparation of aggregates, including the grading of the aggregate when it differs from that given in 7.2,

11.1.5 Any significant features revealed by examination of the specimens during and after test.

11.1.6 Amount of mixing water expressed as mass percent to cement,

11.1.7 Type, source, proportions, and chemical analyses, including Na_2O and K_2O , of any pozzolans employed in the tests,

11.1.8 A graph of the length change data from the time of the zero reading to the end of the period of testing,

11.1.9 A graph of the length change data from the time of the zero reading to the end of the 14-day period of the aggregate used as a control.

12. PRECISION

12.1 Within-Laboratory Test Variation: It has been found that the average within-laboratory coefficient of variation for materials with an average expansion greater than 0.1% at 14 days is 2.94%*. Therefore, the results of two properly conducted tests within the same laboratory on specimens of a sample of aggregate should not differ by more than 8.3%* of the mean expansion, 19 times out of 20.

**These numbers represent, respectively, the 1s% and d2s% limits as described in ASTM Standard C 670*

12.2 Multi-Laboratory Variation: It has been found that the average multi-laboratory coefficient of variation for materials with an average expansion greater than 0.1% at 14 days is 15.2%*. Therefore, the results of two properly conducted tests within the same laboratory on specimens of a sample of aggregate should not differ by more than 43%* of the mean expansion, 19 times out of 20.

**These numbers represent, respectively, the 1s% and d2s% limits as described in ASTM Standard C 670*

13. REFERENCES

1. Oberholster, R.E. and Davies, G., "An Accelerated Method for Testing the Potential Alkali Reactivity of Siliceous Aggregates", Cement and Concrete Research, Vol.16, 1986, pp. 181-189.
2. Davies, G. and Oberholster, R.E., "Use of the NBRI Accelerated Test to Evaluate the Effectiveness of Mineral Admixtures in Preventing the Alkali-Silica Reaction", Cement and Concrete Research, Vol.17, 1987, pp. 97-107.
3. Davies, G. and Oberholster, R.E., "An Interlaboratory Test Programme on the NBRI Accelerated Test to Determine the Alkali-Reactivity of Aggregates", National Building Research Institute, CSIRO, Special Report BOU 92-1987, Pretoria RSA, 197, 16 pp.
4. Rogers, C.A., Ontario Ministry of Transportation and Communications, Personal Communication, "Tabulation of Mean W/C for Acceptable Flow of Mortar Bars with Fine and Crushed Coarse Aggregates", Oct. 25, 1988.
5. Rogers, C.A., Boothe, D. and Jiang, J., "Multi-Laboratory Study of the Accelerated Mortar Bar Test for Alkali-Silica Reaction", Ministry of Transportation, Ontario, Engineering Materials Report 101, January, 1996, 20 pp. .

METHOD OF TEST FOR DETERMINATION OF AMOUNT OF ASPHALT COATED PARTICLES IN COARSE AGGREGATE

1. SCOPE

1.1 This method describes the procedure for the determination of the amount of asphalt coated particles blended with natural aggregates for use in granular base, sub-base, or shoulder material.

2. DEFINITIONS

2.1 A STAINED PARTICLE is defined as one in which the original aggregate particle surface is discoloured due to the absorption of asphalt cement. The surface of the particle can still be observed through the discolouration. The stain cannot be removed by a knife blade without abrasion or removal of the original particle surface.

2.2 A COATED PARTICLE is defined as one in which asphaltic material covers the original aggregate particle surface. The coating can be penetrated by a knife blade and has a measurable thickness which can be observed by cutting it with the blade. The coating can be removed without damage to the original particle surface. Coating is measured as a percentage of the total external surface area of the particle.

2.3 An ASPHALT MATRIX PARTICLE is defined as one which is predominantly asphaltic concrete. It may contain variable amounts of asphalt cement and fine and/or coarse aggregate particles.

3. TEST METHOD

3.1 Separate by splitting approximately 1000 g from the stone portion (retained on the 4.75 mm sieve) of a sample of aggregate containing blended asphaltic material.

3.2 Weigh the sample to the nearest 1.0 g and record the mass as "A".

3.3 Examine the particles and separate them into the following categories:

Category I Coated particles with more than one third (33 %) coating, and asphalt matrix particles.

Category II All other particles: Uncoated, unstained particles, stained particles, and coated particles with less than one third (33 %) coating.

3.4 Weigh the particles contained in Category I to the nearest 1.0 g and record the mass as "B".

4. CALCULATIONS

4.1 Calculate the percent asphalt coated particles (ACP) in the test sample using the following formula:

$$\% \text{ ACP} = (B/A) \times 100$$

where A = original mass of sample

B = mass of asphalt coated particles with more than one third (33%) coating and asphalt matrix particles (Category I).

Note: The percent reclaimed asphalt pavement (RAP) in the test sample may be calculated by removing the unstained, uncoated particles from Category II, the remaining mass is then added to the mass of Category I and expressed as a percentage of the original sample. The percent RAP and percent ACP may differ.

5. REPORTING RESULTS

5.1 Report the percentage of asphalt coated particles to the nearest whole percent.

6. INTERPRETATION OF RESULTS

6.1 Specifications contain permitted limits on the maximum amount of asphalt coated particles in granular materials. For example, Ontario Provincial Standard Specification 1010 allows a maximum of 30 % asphalt coated particles in granulars. In some cases, the amount of reclaimed asphalt pavement (RAP) may be required i.e. Special Provision 314S1 allows a maximum of 40 % reclaimed asphalt pavement in granulars. In these cases, see note above.

METHOD OF TEST FOR DETERMINATION OF FREE LIME CONTENT OF STEEL SLAG AGGREGATES

1. SCOPE

1.1 This method covers the procedures for the determination of free lime content of steel slag aggregates.

Note 1: The determination of free calcium oxide (free lime) is based on soluble calcium glycolate formed by ethylene glycol and free lime without influencing the combined lime in silicates, aluminates, etc. The method has been adopted from the cement industry.

2. APPARATUS

2.1 CRUSHER: Small aggregate crusher capable of reducing 19.0 mm particles to pass through a 2.36 mm sieve.

2.2 PULVERIZER: Aggregate pulverizer or shatter box capable of reducing pass 4.75 mm material to a fine powder passing a 75 μ m sieve.

2.3 SPLITTER: Any suitable means of obtaining a representative sample may be used. It is preferable, where practical, to use a mechanical splitter. Riffle type splitters shall have an even number of equal width chutes, but not less than a total of eight for coarse aggregate or twelve for fine aggregate, which discharge alternately to each side of the splitter. The minimum width of the individual chutes shall be approximately 50 percent larger than the largest particles in the sample to be split. The splitter shall be equipped with two receptacles to hold the two halves of the sample following splitting. It shall also be equipped with a hopper or straightedged pan which has a width equal to or slightly less than the over-all width of the assembly of chutes by which the sample may be fed at a controlled rate to the chutes. The splitter and accessory equipment shall be so designed that the sample will flow smoothly without restriction or loss of material.

3. PREPARATION OF TEST SAMPLE - COARSE AGGREGATE

3.1 A representative sample of oven-dried aggregate shall be prepared in accordance with LS-609, Procedure for the Petrographic Analysis of Coarse Aggregate.

3.2 The test specimen is then spread evenly over a flat, non-magnetic surface, and the magnet is moved back and forth over the surface until all magnetic particles are removed.

3.3 The test specimen free of magnetic particles is then crushed using a small crusher so that the entire sample passes a 2.36 mm sieve. Care should be taken that the crusher is clean, and that no material is lost.

3.4 Repeat step 3.2 on the crushed specimen to remove any magnetic particles that may be released in the crushing operation.

3.5 The crushed specimen free of magnetic particles shall be mixed thoroughly, and further reduced using a sample splitter to obtain a specimen of approximately 150 g. This 150 g test specimen shall be pulverized using suitable equipment such as the shatter box, so that it passes a 75 μ m sieve. Any material retained on the 75 μ m sieve shall be further treated to pass the 75 μ m sieve. Care should be taken that no material is lost.

3.6 The pass 75 μ m sieve specimen shall be mixed thoroughly and free lime content determined following clause 5.

Note 2: All equipment used in the preparation of these test specimens must be thoroughly cleaned before preparing the next specimen. All possibilities of contamination must be reduced to ensure accurate results.

4. PREPARATION OF TEST SAMPLE - FINE AGGREGATE

4.1 A representative 250-300 g sample of oven-dried aggregate that has passed the 4.75 mm sieve shall be obtained by the use of a splitter, as described in Test Method LS-600, section 3.6.

4.2 The test specimen is then prepared in an identical manner as the coarse aggregate, steps 3.1-3.6, specimen for the determination of free lime content of steel slag, with the exception of step 3.3, the crushing operation.

5. DETERMINATION OF FREE CALCIUM OXIDE

5.1 Weigh out 1 g of finely ground steel slag (minus 75 μ m), and transfer to a 200 ml flask, together with a pinch of dry standard sand (C109 Ottawa sand).

5.2 Add 30 ml ethylene glycol and 15 ml absolute methyl alcohol.

5.3 Bring the sample into suspension by shaking, and then place the flask in a water bath and boil for 30 minutes under a reflux condenser, with occasional shaking.

5.4 Filter the contents of the flask through a suction filter, using a SS-White filter paper. Wash the flask twice with 10 ml alcohol, and finally wash the filter once with 10 ml alcohol.

5.5 Add 10 drops bromo-thymol blue indicator and titrate with 0.1 N HCL until yellow-green, record the value of HCL used.

5.6 $\% \text{ free CaO} = \text{ml of HCL} \times 0.28 \%$

Note 3: To get a proper result, the sample has to be ground very finely. The ethylene glycol used must be anhydrous, neutral, and clear to suppress reaction with the combined lime. Furthermore, it must be very pure, and should not be regenerated more than twice. All equipment used for the determination has to be absolutely dry.

6. REPORT

The report shall include the following.

- 6.1 Type and source of steel slag.
- 6.2 Maximum sieve size of the aggregate.
- 6.3 The amount of free lime (CaO) present to the nearest 0.01 %.

7. PRECISION

This test method has not been submitted to a formal multi-laboratory study. Results of a limited between laboratory study are presented in Table 1.

Table 1

SAMPLE NO.	Free CaO % 8 hour extraction MTO Lab (mean of 2)	Free CaO % 0.5 hour extraction MTO Lab	Free CaO % 0.5 hour extraction Dofasco Lab	Difference between Dofasco and MTO Lab	Type of Material and Source
87-9031	3.26	1.76	1.80	+ 0.04	Lasco f.a.
9026	1.76	1.33	1.40	+ 0.07	Lasco f.a.
9051A	4.89	3.56	4.10	+ 0.54	Levy c.a.
9051B	4.88	3.62	4.10	+ 0.48	Levy c.a.
9033	13.90	7.17	6.40	- 0.77	Red-D f.a.
9046	6.02	4.09	5.20	+ 1.11	Red-D c.a.
9038	6.96	4.27	5.10	+ 0.83	Steetley c.a.
9039	9.98	3.40	2.00	- 1.40	Steetley f.a.
9047	13.80	4.98	6.00	+ 1.02	Red-D f.a.
9040	15.00	5.28	5.90	+ 0.62	Steetley f.a.
Average	8.05	4.00	4.20		

ONE POINT PROCTOR TEST (OPT)

1. SCOPE

1.1 This method establishes the maximum wet density, the maximum dry density and the optimum moisture content using the Family of Proctor Curves.

2. RELEVANT DOCUMENTS

2.1 MTO Report, Engineering Materials Office, EM-54, One Point Proctor Test Determination of Moisture-Density relationships using a Family of Proctor Curves

2.2 ASTM D 698

3. APPARATUS

3.1 MOLDS: 1 mold 152.4 mm in diameter, (or 1 mold 101.6 mm in diameter), conforming to the specifications of ASTM D698.

3.2 PROCTOR HAMMER: 2.5 kg mass, conforming to the specifications described in ASTM D698.

3.3 BALANCES: 15 kg capacity and accurate to 0.1 % of the test load at any point within the range of use.

3.4 OVEN: A drying oven, or nuclear moisture-density gauge.

3.5 STRAIGHTEDGE: A steel straightedge 300 mm in length and with one edge beveled.

3.6 MIXING TOOLS: Miscellaneous tools such as a rotatable table on which to place the mixing bowl, spoon, trowel, spatula, etc. together with a means of adding controlled amounts of water to the sample while mixing. A mechanical mixing device may be used for some soils such as sand which will not clog the blades.

4. PREPARATION OF SPECIMEN

4.1 Obtain a field sample of material with an approximate mass of 9 kg.

4.2 If the test portion of the soil contains particles larger than about 25 mm, these should be picked out and discarded. An equal mass of coarse aggregate smaller than 25 mm should be added to the sample to replace the larger particles.

4.3 If the test portion is visibly much drier or much wetter than the optimum, water should be added or the sample should be dried out so that the test is carried out on material having moisture content close to the optimum.

4.4 The OPT method is designed to use the 152.4 mm diameter mold. It is preferred that this large mold be used for the test, even if the material is fine grained.

4.5 For silts and clays having less than 5 % gravel however, the small mold (101.6 mm diameter) may be used if the larger mold is not available. The sample is compacted in the mold (with collar attached) in three equal layers using the 2.5 kg hammer, falling 30 cm. Each layer should receive 56 blows (large mold) or 25 blows (small mold), distributed uniformly over the surface. The final compacted depth should be about 13 cm. The collar is then removed, the sample trimmed flush using the straightedge and any surface irregularities are repaired with fresh material. The total mass of mold and soil are recorded. The mass of the mold previously recorded is subtracted from the total mass and then is divided by the volume of the mold to obtain the wet density. The volume of the 152.44 mm mold is approximately 2.13 dm³, (and the 101.6 mm mold is 0.944 dm³).

Note 1: These values are an approximation suitable for use in the calculations of this method, tolerances for these volumes are specified in ASTM D698.

The formula for wet density is:
$$\text{Wet density} = \frac{\text{Mass of soil}}{\text{Volume of mold}}$$

The wet density is expressed in t/m³

4.6 For the conventional drying method a representative sample of about 500 g is taken from the interior of the molded soil. This sample is taken from the interior of the soil mass after it has been demolded. The soil mass, in most cases, retains the molded shape, place this molded soil sample into a pan setting the sample on its flat base. Separate the sample into thirds by cutting horizontally through the soil sample. The 500 g oven sample is then removed from the center of the middle section. The mass of this sample is recorded, the sample is then oven-dried to a constant mass and the new mass is recorded. The moisture content of the sample can then be determined with the following formula:

$$\text{Moisture Content} = \frac{(\text{Mass of Wet Soil}) - (\text{Mass of Dry Soil})}{\text{Mass of Dry Soil}} \times 100$$

The moisture content is expressed as a percentage.

Note 2: MTO Report EM-54, previously allowed the use of a nuclear gauge in the field to determine the moisture content of the in situ soil. This method of determining moisture content for the one point proctor is no longer an option, the conventional drying method described above (4.6) shall be used.

4.7 The dry density is calculated by the formula:

$$\text{Dry Density} = \frac{\text{Wet Density} \times 100}{100 + \text{Moisture Content (\%)}}$$

The dry density is expressed in t/m³.

4.8 Plot value of dry density and moisture content on the appropriate Family of Proctor Curves. The point so obtained on the diagram may lie on or near a typical Proctor curve. To obtain the maximum dry density and optimum moisture content corresponding to the particular soil follow upward parallel to the curves to reach the locus of maximum densities. The vertical scale of this point determines the maximum dry density and the horizontal scale the optimum moisture content.

In exceptional cases, a point may fall to the left of the dotted line on the dry side of the curves. In this instance, the test should be repeated at a higher moisture content. If a point plots to the right of the dotted line on the wet side of the curves, the test should be repeated at a lower moisture content.

4.9 Form PH-CC-10 is used for the calculation of the One Point Proctor Test in the field. The process (4.1 - 4.8) is repeated three times with the field sampled material, each test is performed at slightly different moisture content. The results are averaged to determine the Proctor Data. Figure 4 shows this form, the nuclear determination section of PH-CC-10 can be ignored, (See note 2 in 4.6).

5. EXAMPLE

5.1 Following the compaction of a cohesive soil sample into the 152.4 mm diameter mold, assume the following information.

Mold Volume = 2.13 dm³

Mass of mold and wet soil = 8.75 kg

Mass of mold = 4.31 kg

Further assume that the moisture content computed by oven drying was 15 %.

CALCULATIONS:

MOISTURE	
TEST OR TIN NO.	1
Gross Wet Mass	306.0
Gross Dry Mass	274.5
Moisture Loss (N)	31.5
Mass of Tin	64.5
Dry Soil Mass (P)	210.0
% Moisture (M) = $\frac{N}{P}$	15.0

Volume of Proctor		
Mold Used - 2.13 (J)		
TEST NO.	1	
Mass of Mold & Soil	8.75	
Mass of Mold	4.31	
Mass of Wet Soil (K)	4.44	
Wet Density (L) = $\frac{K}{J}$	2.084	
Moisture % (M)	15.0	*
Dry Density = $\frac{(L)}{100 + M}$	1.812	*

* Plot dry density and moisture content on the cohesive family of proctor curves diagram (point 'T' on Figure 5). Follow this point parallel to the curves up to the locus of maximum densities and obtain point 'U'. Read the corresponding maximum dry density on the vertical scale and the optimum moisture content on the horizontal scale.

The values so obtained are: maximum dry density = 1.846 t/m³

 optimum moisture content = 15.8 %

6. GENERAL NOTES

6.1 Proctor curve diagrams were developed separately for cohesive and non-cohesive materials. Since the characteristics of non-cohesive materials in Northwestern Ontario are somewhat different from the rest of the province, non-cohesive curves were developed specifically for this region.

6.2 Typical Moisture Density Curves for Non-Cohesive Soils in Ontario (See Figure 2, Imperial Units, and Figure 3, Metric). This set of curves should be used to determine the maximum dry density and optimum moisture content for all granular base and sub-base materials, all coarse grained soils, except those having more than 12 % plastic fines (GC & SC), and for non-Plastic silts (ML).

6.3 Typical Moisture Density Curves for Cohesive Soils in Ontario (See Figure 1). This set of curves should be used for coarse grained soils having more than 12 % plastic fines (GC & SC) and for all fine grained soils except non-plastic silts (ML). For borderline soils requiring dual symbols there may be some difficulty in selecting the proper set of curves. In such cases it may be necessary to plot the points on both sets of curves. If the moisture content is close to optimum the points will plot closer to the line of optimums for the correct set of curves.

TYPICAL MOISTURE - DENSITY CURVES
COHESIVE SOILS IN ONTARIO
(DRY DENSITY CURVES)

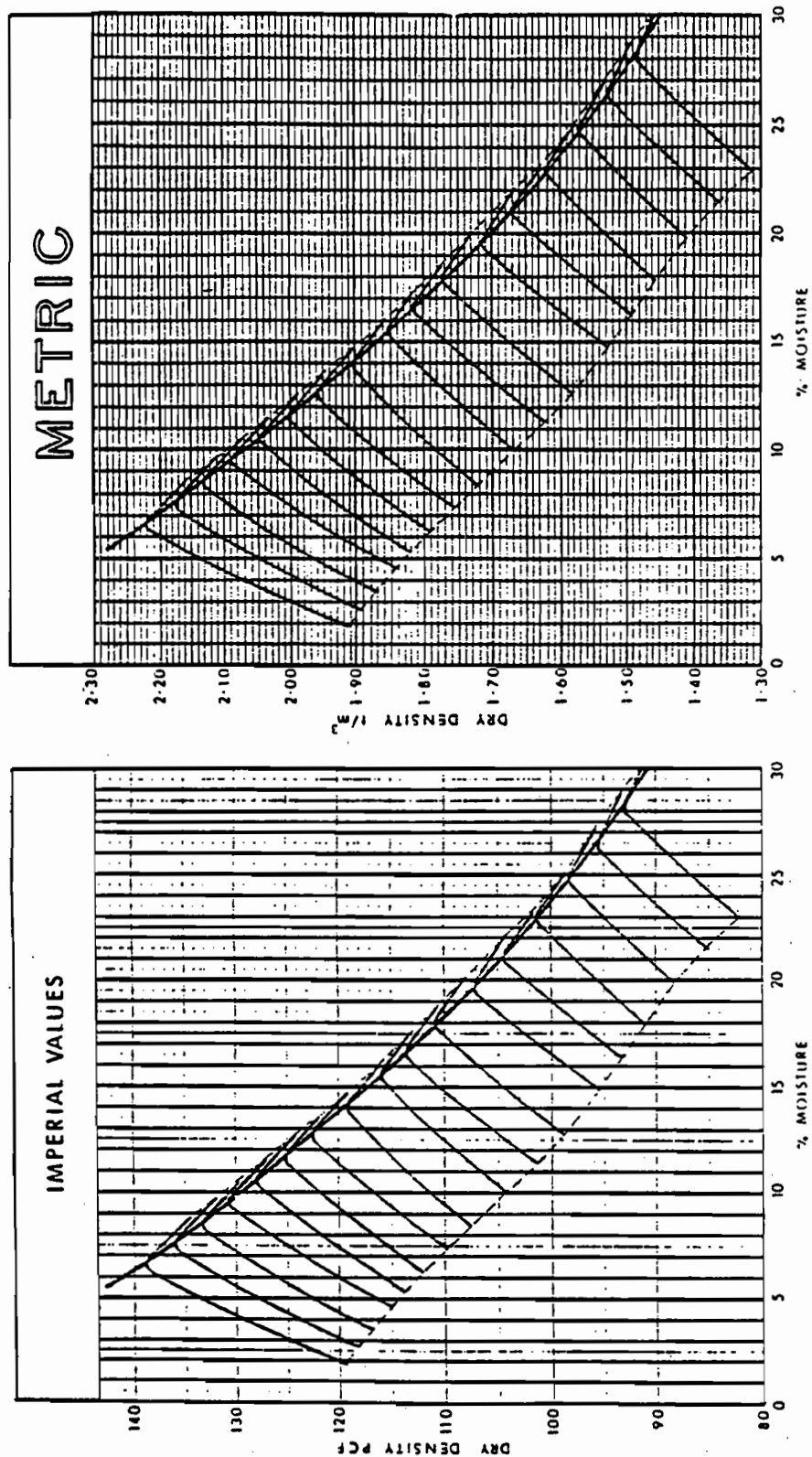


Figure 1 Cohesive Soils in Ontario

TYPICAL MOISTURE-DENSITY CURVES
NON COHESIVE SOILS IN ONTARIO
(DRY DENSITY CURVES)

METRIC

METRIC

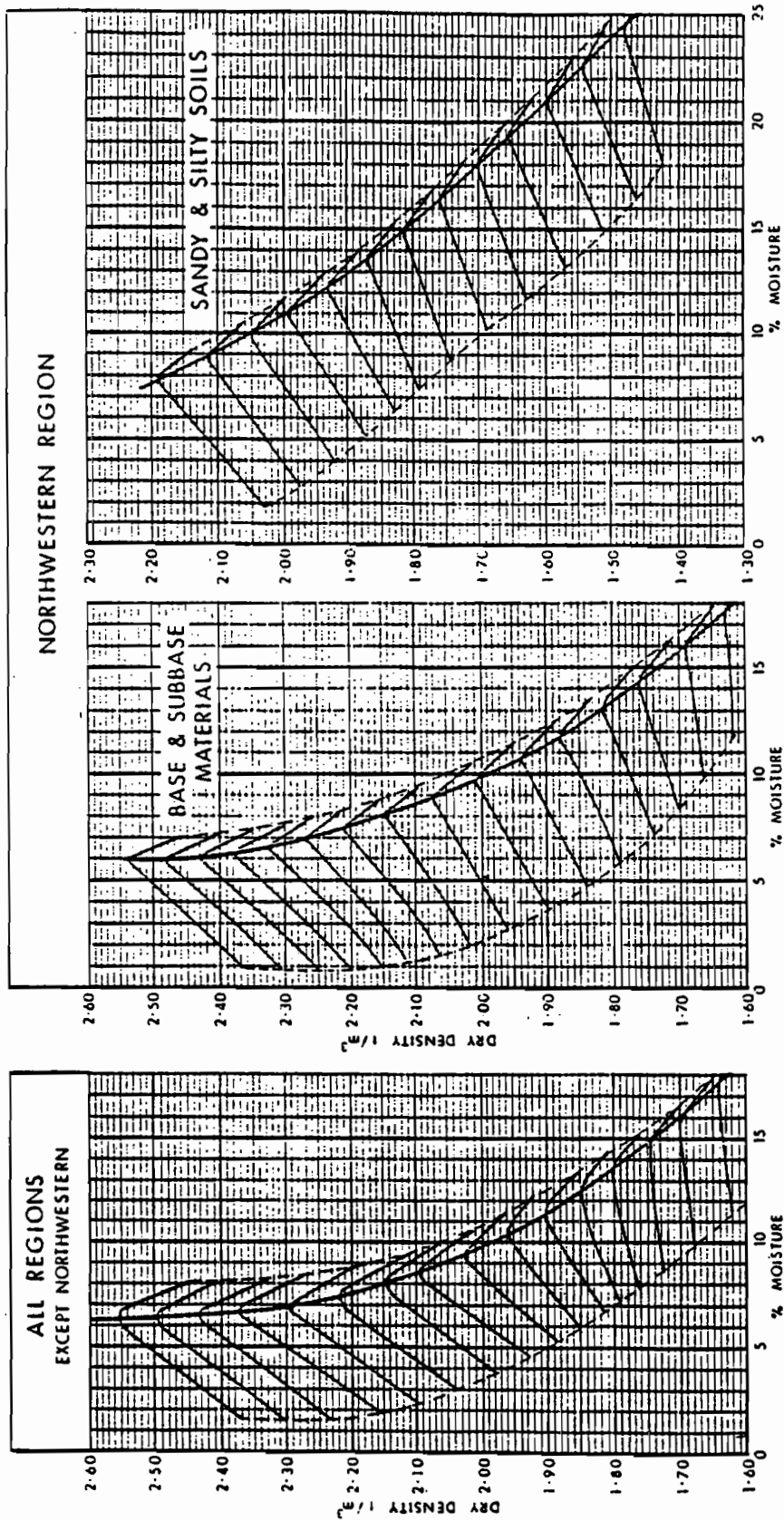


Figure 2 Non Cohesive Soils in Ontario

TYPICAL MOISTURE - DENSITY CURVES
NON COHESIVE SOILS IN ONTARIO
(DRY DENSITY CURVES)

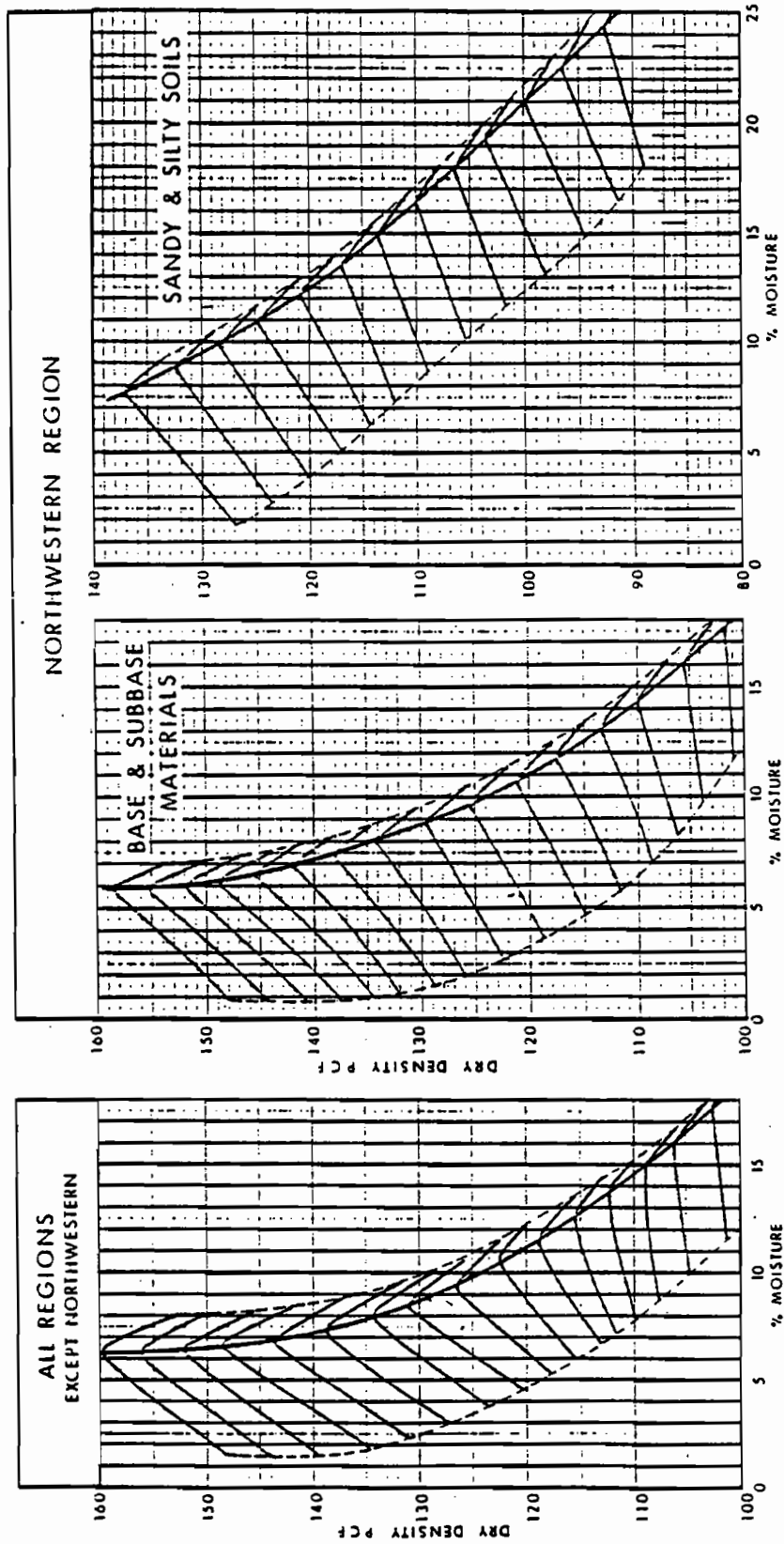
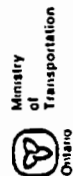


Figure 3 Non Cohesive Soils in Ontario (Imperial)



ONE POINT PROCTOR TEST

CONTRACT No. _____
HIGHWAY No. _____

REGION _____

SOURCE _____

TYPE OF MATERIAL _____

NUCLEAR MOISTURE DETERMINATION										
REFERENCE STANDARD READING		① MOISTURE -		② DENSITY -				GAUGE No		
LOCATION		MOISTURE		DENSITY				DATE:		
TEST No.	STATION	OFFSET	③ COUNT PER MINUTE	④ RATIO $\frac{C}{A}$	⑤ WATER CONTENT $\frac{E}{F-E} \times 100$	⑥ DRY DENSITY $\frac{D}{1+m^3(pcf)}$	⑦ WET DENSITY $\frac{D}{1+m^3(pcf)}$	⑧ RATIO $\frac{D}{B}$	PROBE POSITION	REMARKS

MOISTURE DETERMINATIONS (IF NUCLEAR GAUGE NOT USED)

TEST OR TIN No	GROSS WET MASS	GROSS DRY MASS	⑨ MOISTURE LOSS	MASS OF TIN	⑩ DRY SOIL MASS	⑪ % MOISTURE $\frac{N}{P} \times 100$

PROCTOR MOULD VOLUMES

LARGE - 152.4 mm (6 in) = 2.13 dm^3 ($\frac{1}{13.3} = 0.075 \text{ cu. ft.}$)
SMALL - 101.6 mm (4 in) = 0.94 dm^3 ($\frac{1}{30} = 0.033 \text{ cu. ft.}$)

TECHNICIAN: _____

COPIES TO: WHITE - REGIONAL QUALITY ASSURANCE CANARY - CONTRACTOR PINK - PROJECT SUPERVISOR GOLDENROD - CONSTRUCTION SUPERVISOR/ORIGINATOR

PH-CC-10 86-07

① VOLUME OF PROCTOR MOULD USED -

TEST No	MASS OF MOULD & SOIL kg (lb)	MASS OF MOULD kg (lb)	⑫ MASS OF WET SOIL kg (lb)	⑬ WET DENSITY $\frac{K}{J}$	⑭ MOISTURE %	DRY DENSITY $(\frac{L}{100+M}) \times 100$

OPTIMUM MOISTURE %	MAX DRY DENSITY

MAXIMUM WET DENSITY = $\frac{MDD \times (100 + OMC \%)}{100}$

* NOTE:

Apply these values to the appropriate moisture - density curves to obtain the optimum moisture and maximum dry density for each test.

PROCTOR DATA AVERAGE OF THREE OPT	
OMC %	
MDD	
MWD	

Figure 4 - One Point Proctor Test (Form PH-CC-10)

TYPICAL MOISTURE - DENSITY CURVES
COHESIVE SOILS IN ONTARIO
(DRY DENSITY CURVES)

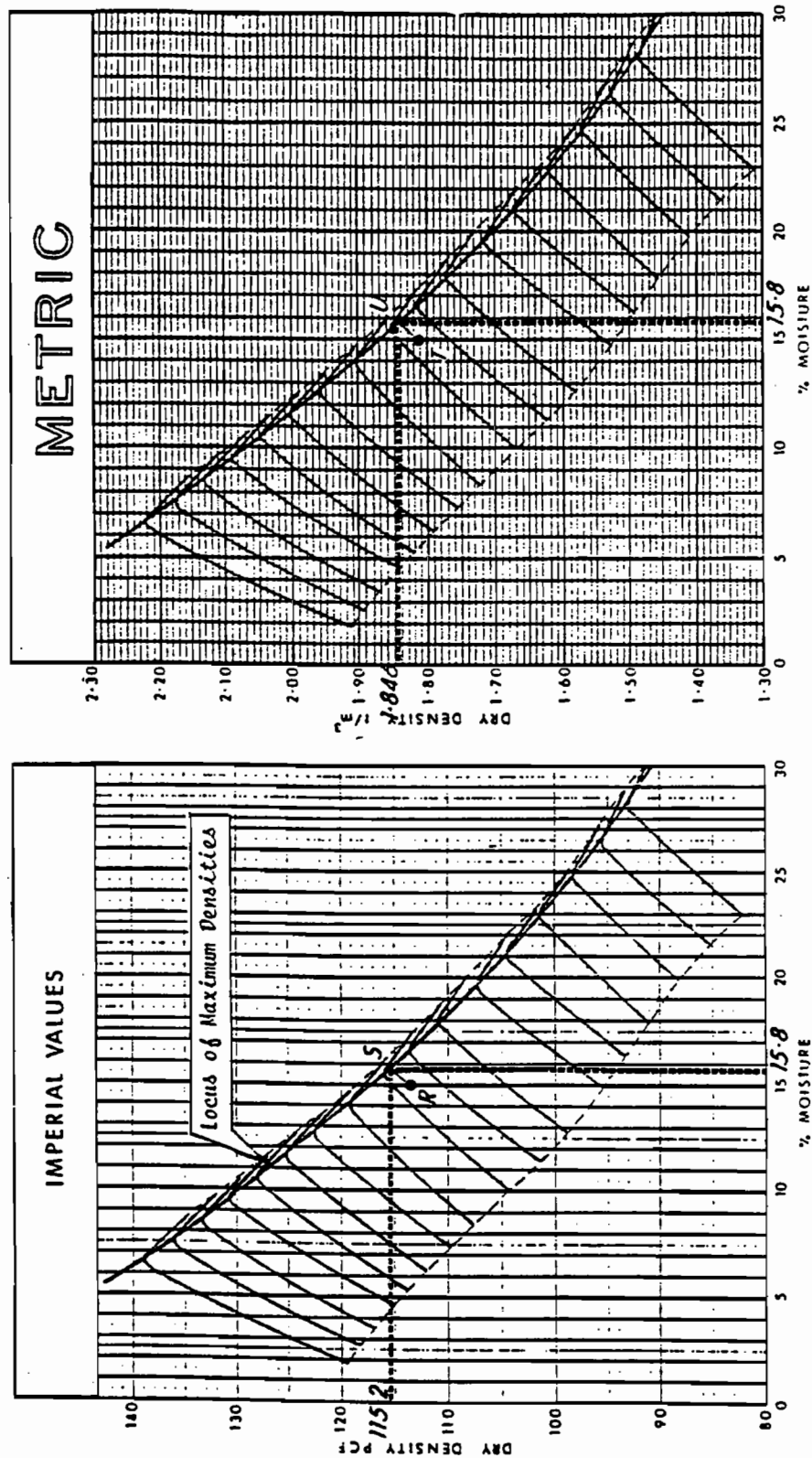


Figure 5 Example of Section 5.

GUIDELINES FOR THE USE OF CONTROL CHARTS FOR CONSTRUCTION AGGREGATES

1. SCOPE

1.1 The purpose of this guideline is to outline the procedures and requirements for creating control charts based on construction aggregate Quality Control (QC) test results.

2. RELEVANT DOCUMENTS

2.1 ASTM Manual on Presentation of Data and Control Chart Analysis, MNL7, 6th Edition. April 1990.

2.2 International Standard ISO 7870 Control Charts - General Guide and Introduction

2.3 International Standard ISO 8258 Shewhart Control Charts

3. GENERAL

2.1 A control chart is a QC technique used to graphically illustrate the variation of a measured value of a product or process. This variation may be the result of chance causes or assignable causes.

2.2 Control charts are used to determine whether the product or process is *in control* through the application of statistical principles.

2.3 Control charts described by this guideline are limited to:

- i) Control charts for individuals based on single values (X) and moving range (mR), designated as a **Type 1** chart; and
- ii) Shewhart control charts for variables $\bar{X}$ ¹ (average, or mean) and R (range), designated as a **Type 2** chart.

Note 1: Acceptance of products on contracts is based exclusively on meeting the applicable Quality Assurance requirements. Control charts are used solely for the QC purpose of determining testing frequency as allowed by the appropriate specification and are independent of acceptance or rejection of the material.

4. DEFINITIONS

assignable cause variation within a set of test data that is either random or systematic that occurs outside the stable pattern of chance causes

¹ The symbol $\bar{X}$ is read as **X bar** and the symbol $\bar{\bar{X}}$ is read as **X double bar**. The bar over any symbol always indicates an average - thus, $\bar{X}$, means an average of the X's.

central line	a value determined as the process average for the purposes constructing of a control chart.
chance cause	variation within a set of test data that is the result of attributes inherent in any stable system of production and inspection
control limit	a value based on 3-sigma (3σ) limits (root-mean-square deviation) of a normal distribution plotted on a Type 1 or Type 2 control chart. Control limits are determined by the subgroup size and average range ($\bar{R}$) of a set of data and may be either an Upper Control Limit (UCL) or a Lower Control Limit (LCL).
quality assurance	means a system or series of activities that are performed on manufactured or processed material in order to provide confidence that the product complies with applicable specification requirements.
quality control	means a system or series of activities that are carried out during the process or manufacturing of a product in order to ensure that it meets the intended specifications.
specification limit	a value for a given test method indicated by the appropriate specification or special provision that forms the basis of acceptance or rejection of the material. A specification limit may either be a maximum value (Upper Specification Limit USL) or a minimum value (Lower Specification Limit LSL)
subgroup	one of a series of groups of observations. Subgroups are selected so that each item inspected within the subgroup is as nearly representative of production as possible over a given period of time.
target value	an established process average determined from a minimum number of subgroups or test data

5. SYMBOLS

The following symbols are referred to by this guideline:

k	number of subgroups;
n	number of observed values within a data set or within a subgroup;
X	observed value of a measured characteristic. Specific values may be designated as $X_1, X_2, X_3, \dots, X_i, \dots, X_n$;
$\bar{X}$	average (arithmetic mean);
$\bar{\bar{X}}$	average of a set of values for $\bar{X}$. The value $\bar{\bar{X}}$ is also known as the grand average;
R	range of a set of observed values calculated as the difference between the largest and smallest value within a subgroup;
mR	moving range formed from successive pairs of observations. Adjacent moving ranges will have one value in common;

$\bar{R}$, $m\bar{R}$	average of a set of values for range R , and moving range mR ;
A_2	a factor of $\bar{R}$ used to determine the distance from the central line to 3σ control limits on an $\bar{X}$ chart;
D_4	a factor of $\bar{R}$ and $m\bar{R}$ to determine the 3σ upper control limit on a chart for R , or mR respectively;
E_2	a factor of $\bar{R}$ to determine the 3σ control limits on an individual X chart.

6. OBJECTIVES OF A CONTROL CHART

5.1 Control charts for construction aggregates may be used for some or all of the following objectives:

- a) to determine whether the aggregates can meet the given specifications;
- b) to determine whether a change in aggregate production is required;
- c) to determine whether a change in inspection procedures is validated;
- d) to provide a basis for action whenever assignable causes of variation are indicated.

Note 2: When creating control chart, it is important that test data for a specific product and location within a source is collected separately. For instance, different benches within a quarry may yield aggregates with widely different physical properties. Also, different aggregate products, such as HL3, or HL8 stone may have widely different production properties. In order to produce a meaningful chart, test data for different aggregate products and/or from widely different locations within a source should not be included in the same data set.

7. TYPE I CONTROL CHART (X - mR)

7.1 See Example 1 for worked example of a Type 1 control chart.

7.2 A Type 1 control chart consists of plotting individual test results for X in order to identify the average value of the process, and trends in the individual test results. A moving range (mR) chart is used to display changes in the absolute difference between successive test results.

7.3 A plot of individual values for X is reduced to a simple run-chart with n being equal to the number of test results. Data for the mR chart are obtained from each successive pair of observations.

7.4 Individual test data from the appropriate test method are recorded in chronological order in an appropriate table.

7.5 Calculate $\bar{X}$ by summing the total of the each value in the data set and dividing by the number of observations n :

$$\bar{X} = \frac{X_1 + X_2 + \dots + X_i + \dots + X_n}{n} = \frac{1}{n} \sum X$$

7.6 Calculate individual ranges R for successive pairs in the data set, starting with the first pair of data (X_1, X_2), by subtracting the lower value from the higher value:

$$R_i = X_{max} - X_{min}$$

- 7.7 Similarly, calculate the range R between the next successive pair (X_2, X_3):

$$R_2 = X_{max} - X_{min}$$

- 7.8 Calculate the range R for each remaining pair in the data set.

- 7.9 Calculate the average moving range $m\bar{R}$ by summing the ranges of each successive pair and dividing by the number of observations minus one ($n - 1$):

$$m\bar{R} = \frac{R_1 + R_2 + \dots + R_{n-1}}{n-1} = \frac{1}{n-1} \sum R$$

- 7.10 Calculate the control limits for R using the factor D_4 from Table 1.

$$UCL_R = D_4 m\bar{R}$$

$$LCL_R = 0$$

- 7.11 Calculate the control limits for the $\bar{X}$ chart by using the factor E_2 from Table 1.

$$UCL_{\bar{X}} = \bar{\bar{X}} + E_2 m\bar{R}$$

$$LCL_{\bar{X}} = \bar{\bar{X}} - E_2 m\bar{R}$$

- 7.12 Construct the $\bar{X}$ chart. Plot the central line as a solid horizontal line at $\bar{\bar{X}}$. The control limits should be drawn as horizontal lines at the calculated values. The specification limit(s) given by the appropriate specification for the test method under consideration may be plotted on the same chart.

- 7.13 Plot individual values for $\bar{X}$ for each test result. Individual points are joined by a connecting line.

- 7.14 Construct the mR chart. Plot the central line as a solid horizontal line at $m\bar{R}$. The upper control limit should be drawn as a line at the computed value of UCL_R .

- 7.15 Individual values of R are then plotted for each subgroup in sequence. Individual points are joined by a connecting line.

8. TYPE 2 CONTROL CHART ($\bar{X}$ - R)

- 8.1 See Example 2 for worked example of a Type 2 control chart.

- 8.2 A Type 2 control chart is based on the variation of mean and range within individual subgroups, or lots. For practical purposes, each subgroup k should contain 4 values such that $n = 4$.

- 8.3 Data from the appropriate test method, or in the case of gradation, LS-602, the appropriate sieve is recorded in chronological order.

- 8.4 Calculate $\bar{X}$ for each subgroup by adding each measurement of the subgroup and dividing by n :

$$\bar{X} = \frac{X_1 + X_2 + X_3 + X_4}{4} = \frac{1}{4} \sum X$$

- 8.5 Calculate the range for each subgroup by subtracting the lowest value from the highest:

$$R = X_{max} - X_{min}$$

8.6 Calculate the average range $\bar{R}$ by summing the ranges of each subgroup and dividing by the number of subgroups, k :

$$\bar{R} = \frac{R_1 + R_2 + \dots + R_i + \dots + R_k}{k} = \frac{1}{k} \sum R$$

8.7 Calculate the control limits for R using the factor D_4 from Table 1:

$$UCL_R = D_4 \bar{R}$$

$$LCL_R = 0$$

8.8 Calculate $\bar{\bar{X}}$ by summing the $\bar{X}$ values and dividing by the number of subgroups, k :

$$\bar{\bar{X}} = \frac{\bar{X}_1 + \bar{X}_2 + \dots + \bar{X}_i + \dots + \bar{X}_k}{k} = \frac{1}{k} \sum \bar{X}$$

8.9 Calculate the control limits for $\bar{X}$ using the factor A_2 from Table 1.

$$UCL_{\bar{X}} = \bar{\bar{X}} + A_2 \bar{R}$$

$$LCL_{\bar{X}} = \bar{\bar{X}} - A_2 \bar{R}$$

8.10 Construct the $\bar{X}$ chart. Plot the central line as a solid horizontal line at $\bar{\bar{X}}$. The upper and lower control limits should be drawn as horizontal lines at the calculated values. Plot individual values for $\bar{X}$ for each successive subgroup. Individual points are joined by a connecting line.

8.11 Construct the R chart. Plot the central line as a solid horizontal line at $\bar{R}$. The upper control limit should be drawn as a line at the computed value of UCL_R . Individual values of R are then plotted for each subgroup number in proper sequence. Individual points are joined by a connecting line.

Table 1. Factors for Calculating Control Chart Limits¹

Chart for Averages A_2	Chart for Ranges D_4	Chart for Individuals E_2
0.729	3.267 (Type 1 chart) 2.282 (Type 2 chart)	2.659

¹ From ASTM Manual on Presentation of Data and Control Chart Analysis, 6th Ed. Table 6, Factors for computing control chart lines - no standard given, pg. 57; and Table 50, Factors for computing control chart lines - chart for individuals, pg 92.

9. INTERPRETING THE CONTROL CHART

9.1 When a process is in statistical control, the individual points on a control chart ($\bar{X}$, mR , $\bar{\bar{X}}$, R) will fluctuate randomly within the control limits without any recognizable pattern. In other words, the variation in the data is the result of chance causes that are inherent within the process. In general, a controlled process will meet the following criteria:

- 1) none of the points exceed the control limits;
- 2) all of the points fall randomly above and below the central line; and
- 3) most of the points are near the central line with only a few points spread out close to the control limits.

9.2 Whenever the variation indicated by the control chart is the result of causes that lie apart from those inherent in the process, several types of unnatural patterns may be observed. These patterns are indications that assignable causes are present. Assignable causes may be identified and corrected if they affect the cost of the process or the acceptability of the material.

9.3 Patterns indicating that assignable causes are present include the following:

- a) Instability - points fall outside the control limits and/or the chart is characterized by erratic up and down swings between the control limits. Examples of assignable causes for this pattern include: continual adjustment; over adjustment; carelessness.
- b) Trend - a series of consecutive points without a change in direction. Example of assignable cause: tool or equipment wear; small changes in source materials.
- c) Cycles - short repeated patterns with alternate high peaks and low valleys. Example of assignable cause: seasonal effects; staff rotation.
- d) Change in process average - a lack of control is typically indicated by runs of seven or more points in succession on the same side of the central line. Example of assignable cause: broken screen; large change in source materials; change in staff.
- e) Freaks - this occurs only if sudden causes affect the process which results in a change in the sample. Example of assignable cause: incomplete operation; wrong setting or adjustment that is corrected immediately; non-representative sample; erroneous testing or calculation.
- f) Hugging the central line - all points are near the central line.

Note 3: Any action taken as a result of the pattern of variation shown in the control charts is dependent on comparing the control chart with the applicable specification. It is beyond the scope of this guideline to identify all possible scenarios. The choice among the various actions is a matter of relative economy.

10. CONTINUED USE OF THE CONTROL CHART

10.1 Type 1 charts for physical or production characteristics of aggregates require 20 individual test results in order to establish future testing frequencies. When plotting test results for physical characteristics, it is sufficient to plot the most recent data only. Thus, when new test data is obtained,

the oldest test data may be ignored and the control chart can be re-established based on the most recent set of 20 test results.

10.2 Type 1 charts for production characteristics, ie, gradation, may be dealt with differently because of the need to generate new test data for each separate contract and to avoid the tedious recalculation of the control chart after every set of test results. Initial calculation of control chart parameters based on a minimum of 20 values may be used to establish target values that can be used to monitor the variation of future production. Subsequent values may be plotted on the existing chart without recalculating a new average, $\bar{X}$. When using a Type 1 chart for gradation, the central lines and control limits should be revised periodically after every 10 or 15 samples. In this case, as for a Type 1 chart for physical characteristics, the control chart may be re-established based on the most recent set of 20 test results.

10.3 For Type 2 charts, a minimum of 20 subgroups should be examined before statistically valid target values can be determined. It should be noted that initial subgroups from the start of production may not be representative of continued production. As a result, control limits based on less than 20 subgroups are preliminary and should be regarded as trial control limits only. The analysis of trial control limits should be limited to determining whether past operations were in control i.e., control chart analysis should only be applied to the data used in their calculation. Provided that trial control limits show that the process is in control, they should be modified as more subgroups are obtained in order to apply them to future production.

10.4 If the process has been in control according to averages and ranges, trial control limits may be extended to future production. Frequent monitoring of control charts at regular intervals so that meaningful and up-to-date control lines are maintained, e.g., weekly, monthly, every 20,000 tonnes of production etc.

10.5 In any case, after a process change control charts should be revised as soon as 20 samples under the new conditions have accumulated.

EXAMPLE 1. Worked Example for Type 1 Control Chart.

Aggregate type: Granular O

Test Method Name: Freeze-Thaw

LS-Number: 614

USL: 15.0%

Sample	Test Result	Moving Range	Sample	Test Result	Moving Range
<i>n</i>	<i>X</i>	<i>mR</i>	<i>n</i>	<i>X</i>	<i>mR</i>
1	10.9	-	11	8.5	0.8
2	11.4	0.5	12	11.3	2.8
3	12.2	0.8	13	10.6	0.7
4	9.8	2.4	14	10.9	0.3
5	9.6	0.2	15	9.3	1.6
6	10.4	0.8	16	9.5	0.2
7	11.2	0.8	17	13.1	3.6
8	10.9	0.3	18	12.3	0.8
9	9.6	1.3	19	11.8	0.5
10	9.3	0.3	20	11.1	0.7
Total (<i>n</i> = 20)				213.7	19.4

Calculations:

Calculate $\bar{X}$: $n = 20$

$$\bar{X} = \frac{213.7}{20} = 10.7$$

Calculate $m\bar{R}$:

$$m\bar{R} = \frac{19.4}{19} = 1.02$$

Calculate control limits for the *mR* chart:

$$UCL_R = D_4 \bar{R} = 3.267(1.02) = 3.3$$

$$LCL_R = 0$$

Calculate the control limits for the *X* chart:

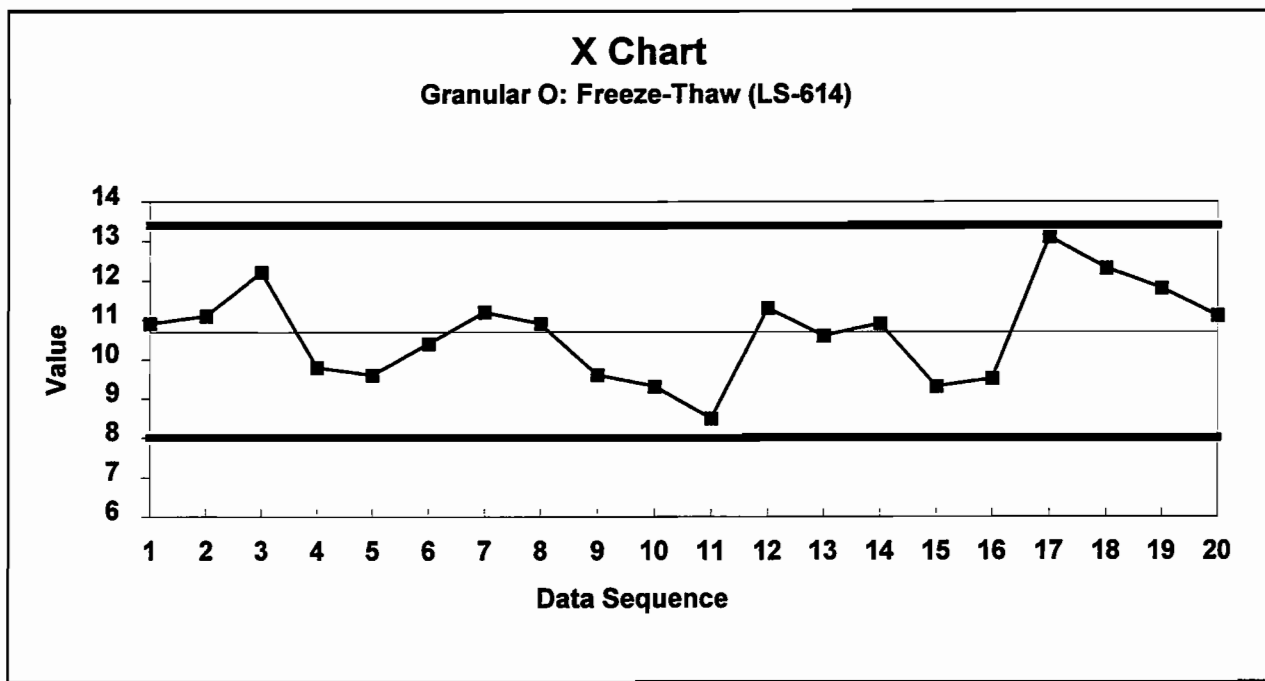
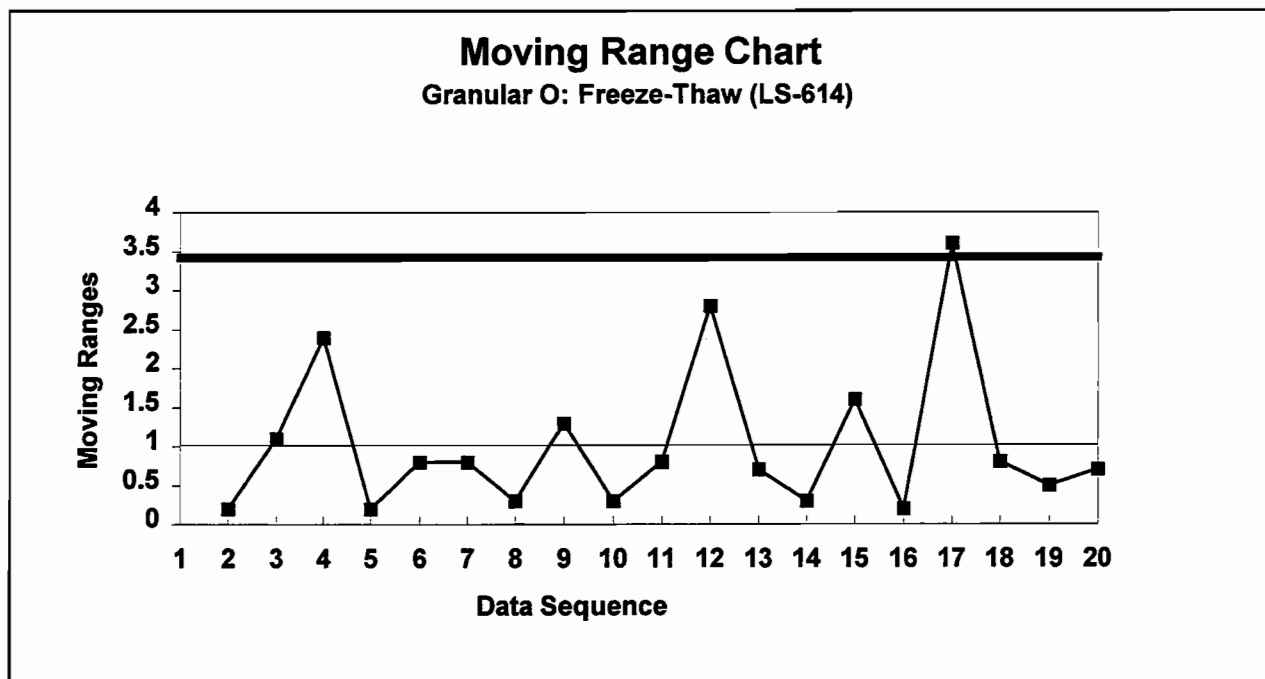
$$UCL_X = \bar{X} + E_2 m\bar{R} = 10.7 + (2.659)(1.02) = 13.4$$

$$LCL_X = \bar{X} - E_2 m\bar{R} = 10.7 - 2.7 = 8.0$$

Plot the control chart:

Each data point in the following charts is determined from individual test data.

Type 1 control chart:



The moving range chart is examined first. If this chart is not in control, then the values chart cannot be in control. In the above example, the range at data point 17 lies outside the 3σ limits for statistical control. This indicates that an assignable cause for the variability is present. For conditions such as these, the cause may be investigated and, if found, corrected. Identifiable causes that have been properly documented and eliminated, may justify the removal of the data and recalculation of the control chart. If the cause cannot be found, the data must be included in all subsequent recalculations of the control chart.

Note 4: In these examples, all products meet the appropriate material specifications for acceptance.

EXAMPLE 2. Worked Example for Type 2 Control Chart.

Record Sheet for $\bar{X}$ and R Control Chart

Aggregate type: Granular A

Test Method Name: Gradation **Number:** LS-602

Sieve: 75 μ m **USL:** 8.0% **LSL:** 2.0% **Maximum Range:** 5%

Subgroup (Lot)	Individual values ($n = 4$)				Average	Range
K	1	2	3	4	$\bar{X}$	R
1	7.3	7.8	7.0	7.9	7.5	0.9
2	7.8	7.7	7.2	6.4	7.3	1.4
3	6.7	6.6	7.2	6.4	6.7	0.8
4	5.5	7.2	7.1	6.5	6.6	1.7
5	7.1	6.2	5.4	6.6	6.3	1.7
6	6.9	7.1	7.3	7.1	7.1	0.4
7	7.0	7.0	6.9	6.9	7.0	0.1
8	6.4	5.2	4.8	4.7	5.3	1.7
9	6.2	6.8	6.8	6.1	6.5	0.7
10	7.3	4.3	7.5	4.0	5.8	3.5
11	6.0	6.1	6.4	3.7	5.6	2.7
12	4.9	3.2	4.5	4.7	4.3	1.7
13	4.4	6.7	4.1	4.6	5.0	2.6
14	4.0	4.4	6.0	4.6	4.8	2.0
15	4.1	4.1	3.4	3.3	3.7	0.8
16	3.6	5.1	3.9	6.6	4.8	3.0
17	3.2	4.3	4.4	3.3	3.8	1.2
18	4.9	4.1	4.5	4.9	4.6	0.8
19	6.0	4.6	4.4	5.1	5.0	1.6
20	3.8	4.6	4.2	6.7	4.8	2.9
TOTALS $k = 20$	-	-	-	-	112.3	32.2

Calculations:

Calculate $\bar{\bar{X}}$:

$$\bar{\bar{X}} = \frac{112.3}{20} = 5.62$$

Calculate $\bar{R}$:

$$\bar{R} = \frac{32.2}{20} = 1.61$$

Calculate control limits for the R chart:

$$UCL_R = D_4 \bar{R} = 2.282(1.61) = 3.67$$

$$LCL_R = 0$$

Calculate the control limits for the $\bar{X}$ chart:

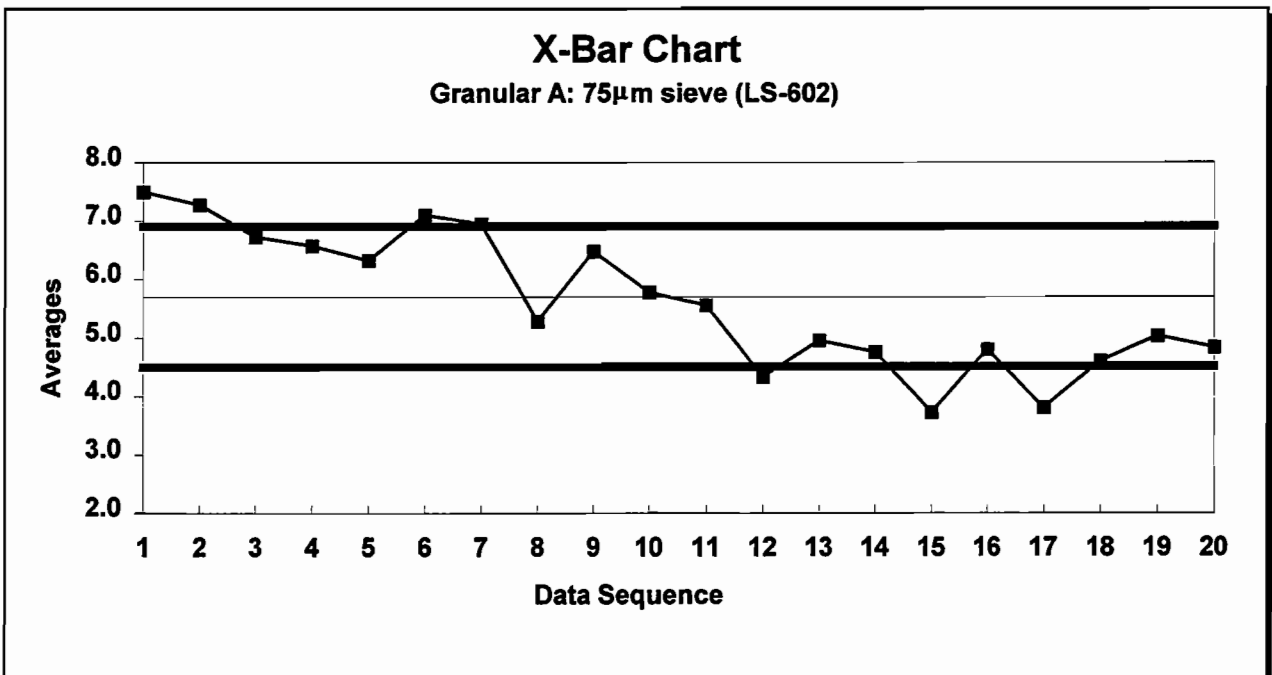
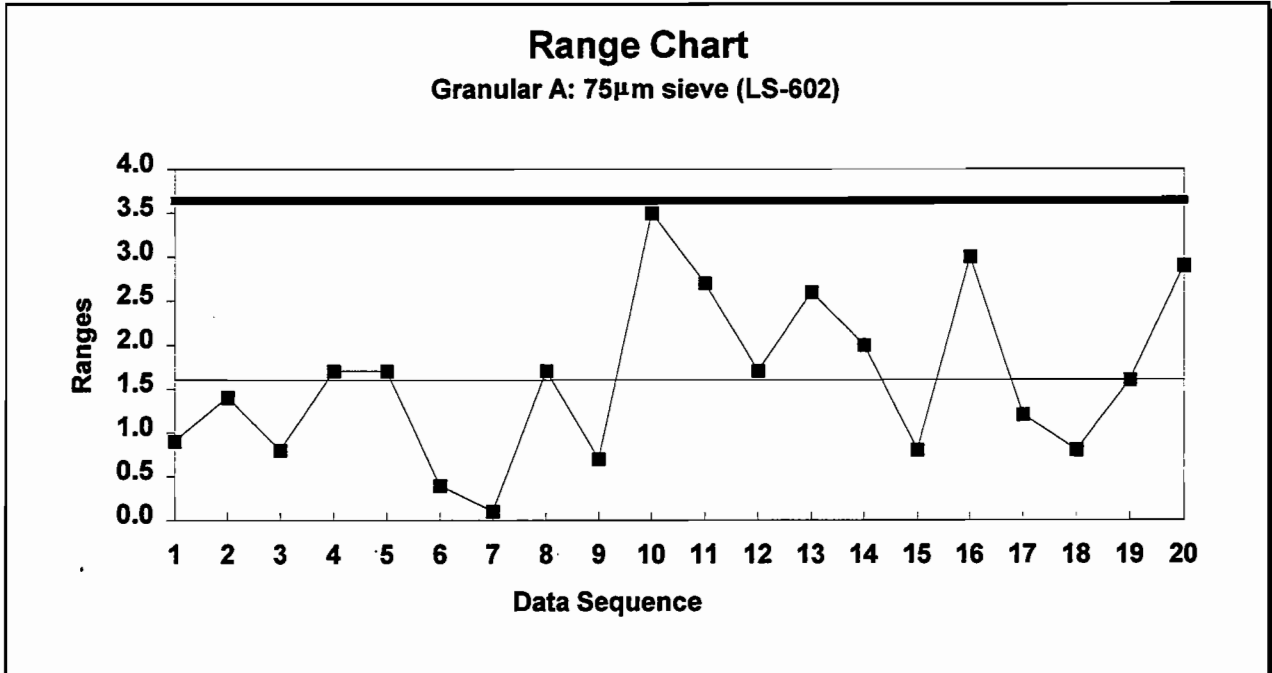
$$UCL_{\bar{X}} = \bar{\bar{X}} + A_2 \bar{R} = 5.62 + (0.729)(1.61) = 6.79$$

$$LCL_{\bar{X}} = \bar{\bar{X}} - A_2 \bar{R} = 5.62 - (1.17) = 4.45$$

Plot the control chart:

Each data point shown on the following graphs represents the individual statistics (average, range) from a subgroup of 4 test results.

Type 2 Control Chart



In this example, the range chart shows that the range variation between each subgroup is in *statistical control*. However, the X-bar chart shows that the process is significantly *out of control*. The data shown here is indicative of a process that is undergoing progressive changes and has not yet achieved any consistency in either the material, the production, or the testing of the product. Assignable causes for this case are most likely simple to identify. If they can be isolated, documented, and eliminated, the data which represents the remaining stable process may be recalculated in a new control chart.

GUIDELINES FOR SAMPLING OF GRANULAR MATERIALS

1. SCOPE

1.1 The purpose of these guidelines is to outline procedures and requirements for sampling of granular materials for Quality Assurance testing.

2. GENERAL

2.1 Whether stockpile, delivery, or road sampling has been chosen, the procedure for obtaining a sample must be strictly adhered to. All samples must be taken and submitted for testing by personnel trained in the sampling of materials.

3. SAMPLING EQUIPMENT

When sampling aggregates for gradation testing, the following equipment is required:

- 3.1 Tile spade with attached side walls, (Figure 1)
- 3.2 Sample containers
- 3.3 Random number tables
- 3.4 Sample data sheets and tags, (Figure 2)
- 3.5 Tape measure

4. SAMPLING LOCATION

Acceptable locations for sampling are:

- 4.1 From existing stockpiles.
- 4.2 From stockpiles during their construction, provided:
 - (1) The stockpile is built in layers a thickness of 1 m or less, and
 - (2) Material does not spill over the edges of the stockpile.
- 4.3 At the location and time of loading onto, or unloading from the delivery vehicles (Delivery Sampling).
- 4.4 From the work after placement but prior to compaction (Road Sampling)

Note: When taking subplot samples within a lot, it is recommended that stockpile, delivery, or road samples are not combined in the same lot.

5. SAMPLING DURING STOCKPILE CONSTRUCTION

5.1 Stockpile samples must be taken from a leveled area of the stockpile after all processing for the lot or subplot is complete. Additional material is not permitted to be placed on the stockpile until after the sample has been obtained.

5.2 It is a requirement of stockpile sampling that a front-end loader be used to obtain the sample. The front-end loader will be required to dig as close as practical to the full depth of the leveled lot or subplot at the location indicated by the random numbers. This material is then placed on the ground and leveled by blading it with the bucket to a height of between 0.3 to 0.5 m.

5.3 The random area method must be used, first, to obtain the location within the leveled lot or subplot from where the front-end loader will obtain the material to be sampled; and, second, to determine the location within the area of the material placed and leveled by the front-end loader from where the actual sample is to be taken.

5.4 Obtain the sample, from the location determined by random numbers within the leveled bucketful by excavating the material as deep as possible with a tile spade, making sure that the sample is not mixed with the underlying material.

5.5 Never shake or jiggle the spade to remove excess material when filling the sample bag as this may eliminate a portion of the sample causing segregation.

6. SAMPLING EXISTING STOCKPILES

6.1 Truly random samples cannot be obtained from a stockpile after it is built as only the outside of the stockpile can be sampled. In addition, segregation often occurs with coarser particles accumulating on the outside of the pile.

6.2 Sampling from an existing stockpile should only be done when no other alternative is available.

6.3 When required, samples should be obtained by excavating into the stockpile with a front-end loader, then dumping a load, blading it with the bucket to a height of between 0.3 to 0.5 m, and obtaining a sample from one random location of the spread load.

6.4 Never shake or jiggle the spade to remove excess material when filling the sample bag as this may eliminate a portion of the sample causing segregation.

7. DELIVERY SAMPLING

7.1 Delivery sampling is carried out at the location where the delivery vehicles are being loaded from a stockpile, at the point of discharge from a delivery vehicle, or from a uniform pit face of subbase or subgrade aggregate (Granular B Type 1, or Select Subgrade Material). Delivery samples should not be taken at locations where aggregates are loaded directly from a variable pit face. Judgment will be necessary in determining whether or not a pit face is uniform. If it is felt that the gradation of the material is similar along the open pit face, the face will be assessed as being

uniform. Examples of uniform pit faces are predominantly sand deposits or stratified materials having horizontal layers of finer and coarser strata with no obvious silt layers. If the open face of a pit exhibits irregular stratification with pockets, random seams, and lenses of dissimilar material, the face will be deemed variable and delivery sampling from the pitface will not be valid.

7.2 For delivery sampling, either the random time or the random quantity method may be used to select that portion for the aggregate to be sampled. The procedure for securing a delivery sample is as follows: as the selected delivery vehicle is being loaded (in the case of random quantity method) or at the random time (in the case of random time method), the operator of the front-end loader should place the next bucketful of material on the ground. The material is then leveled by blading it with the bucket so that the thickness of the leveled-off aggregate is between 0.3 and 0.5 m.

7.3 The leveled surface of the load may be somewhat irregular in shape. Nevertheless, the actual location of the sample within the leveled surface should be decided by the random area method. Reworking of this load of material should be minimized.

7.4 Obtain the sample from the location given by the random numbers by excavating the material as deep as possible with the tile spade, making sure that the sample is not mixed with the underlying material.

7.5 Never shake or jiggle the spade to remove excess material when filling the sample bag as this may eliminate a portion of the sample causing segregation.

8. ROAD SAMPLING

8.1 Road sampling is carried out after the aggregates have been placed and spread, but prior to compaction. Either the random time method or the random quantity method may be used to select the portion of aggregate to be sampled. In the case of random time, the sample shall be taken from the material of the first delivery vehicle arriving after the calculated time. The exact location of the sample from the spread vehicle load should be determined by the random area method, by measuring out the longitudinal position and the offset distance indicated by the random numbers.

8.2 Take the sample from the designated area outlined by using a template (e.g., sample bag). Always place the bag so that the longer side is at right angles to the direction in which the discharge vehicle was moving. If the random numbers fall too close to the edge, then sample from the edge towards the middle of the dumped area.

8.3 Obtain the sample by lifting the material with the tile spade from the full depth of the layer, being careful not to include any material from the underlying layer. For thin layers, it may be necessary to increase the size of the template. Do this by staying parallel to the original template lines.

8.4 Never shake or jiggle the spade to remove excess material when filling the sample bag as this may eliminate a portion of the sample causing segregation.

8.5 No attempt must be made to select or avoid obvious areas where segregation, dirt, or other fault in the material may be evident. The sample must be taken where the random numbers direct. If the material is being placed in a manner which does not allow road sampling, then either a change in the method of operation or another sampling location will have to be selected.

8.6 The area has to be undisturbed by any compaction equipment until the sample has been taken.

9. RANDOM SAMPLING PROCEDURES

Random sampling means choosing samples in such a manner that each portion in the lot has an equal probability of being selected.

Random number tables must be used to carry out random sampling. Random number tables may be selected from published tables or generated by computation, i.e., computer software, and displayed in three digit decimal form. An example of a random number table is given in Figure 3 (the random numbers are grouped in sets of four to facilitate their use in testing of four sub-lots within a lot). In selecting numbers, a pencil or pen should be arbitrarily stabbed onto a sheet of random numbers with the eyes closed. The group of numbers closest to the location should be chosen for the first lot. Successive random numbers should be picked by following a systematic pattern until all the numbers are used. If more random numbers are required, the procedure above should be repeated, using another table. The random numbers used for each lot should be recorded in a sampling diary.

9.1 RANDOM SAMPLING ON TIME BASIS

9.1.1 This method applies to road or delivery sampling when it is more practical to estimate the time it will take to load, or to deliver to the work, the quantity of aggregate representing a lot.

9.1.2 For example, if it is estimated that 3,000 t of a particular material will be loaded and delivered during the next two days, this time may be used as a lot. One subplot, thus, will contain 750 t. If the total working time in two days is, say, 16 hours, one subplot will take about four hours or $4 \times 60 = 240$ minutes. The two days will then be divided into the four subplot times as follows: FIRST DAY 8 a.m. to 12 noon = first subplot; 1 p.m. to 5 p.m. = second subplot; SECOND DAY 8 a.m. to 12 noon = third subplot; 1 p.m. to 5 p.m. = fourth subplot. In this example, a one hour down time (lunch) between 12 noon and 1 p.m. has been assumed.

9.1.3 A group of four random numbers is selected and each of these numbers is multiplied by the time in minutes required for one subplot, in this case, 240 minutes. Since all random numbers are decimal digits, the products of the multiplication will always be less than the total time of one subplot. The four products are added to the starting times of each subplot, giving the random times for the samples. In this example, if the random numbers selected were 0.584, 0.216, 0.233, and 0.805, the products and the actual sampling times would be as shown in Table 1.

Table 1 Example of Random Sampling on Time Basis

Sublot	Calculations	Starting Time	Sampling Time
1st	$0.584 \times 240 = 140 \text{ min.}$	8 a.m.	10:20 a.m.
2nd	$0.216 \times 240 = 52 \text{ min.}$	1 p.m.	1:52 p.m.
3rd	$0.233 \times 240 = 56 \text{ min.}$	8 a.m.	8:56 a.m.
4th	$0.805 \times 240 = 193 \text{ min.}$	1 p.m.	4:13 p.m.

9.1.4 The samples should be taken as close as possible to the times calculated.

9.1.5 Random sampling on a time basis will be fairly easy in the case of continuous, uninterrupted haulage. When the delivery is intermittent or irregular, which is often the case, it will be difficult to predetermine the time necessary to load or to deliver the material for one lot. In this situation, the time of a lot should be estimated by assuming a frequency of loading that would not likely be exceeded.

9.1.6 Assuming that, with irregular delivery, there will not likely be more than 2,000 t delivered in one day and a 4,000 t lot size can be established as two days delivery. By the method explained earlier in this section, the random times for sampling should be calculated, preferably for more than one day (for the whole week, if practical). Now at the time of sampling, the sampler arrives at the appropriate place and, if there is no truck at the determined time or within a reasonable waiting period, one sample may be skipped and the time extended for the lot accordingly. If this practice is employed, it is important that the actual size of the lot will never be larger than the allowable maximum size. After the sampling and testing is completed, the actual lot size must be determined by computing, from the weight tickets, the quantity of material delivered for the applicable time period.

9.2 RANDOM SAMPLING ON QUANTITY (TONNAGE) BASIS

9.2.1 This method is applicable to road or delivery sampling only. In situations when it is simpler to determine the lot size by the number of truck loads, random samples may be selected according to the truck load. This method will require close communication between the sampler and the weigher and checker, especially if delivery is intermittent.

9.2.2 The procedure for this sampling plan is:

Determine how many truck loads are required to haul the aggregate representing one lot. If the maximum size of the lot of 4,000 t is used, and the average load of a truck is 30 t, then one lot will consist of approximately 132 truck loads. The sublots will also be determined by the number of truck loads so that the first sublot is represented by the first 33 truck loads, the second by truck loads 34-66, the third by 67-99, and the fourth by 100-132. Random numbers are multiplied by the number of truck loads in a sublot to establish the particular truck load from where the random sample should be

obtained. In this example, if the random numbers selected were 0.217, 0.181, 0.721, and 0.347, the actual sampling would be as shown in Table 2.

Table 2 Example of Random Sampling on Quantity (Tonnage) Basis

Sublot	Calculations	Last Truck in Previous Sublot	Truck Load to be Sampled
1st	$0.217 \times 33 = 8\text{th load}$	+0	8th
2nd	$0.181 \times 33 = 6\text{th load}$	+33	39th
3rd	$0.721 \times 33 = 24\text{th load}$	+66	90th
4th	$0.347 \times 33 = 12\text{th load}$	+99	111th

9.2.3 Always round the decimal up to the next truck load.

9.2.3 In the case of road sampling, the sample will be collected from the truck load after it is placed in the work, but prior to compaction. For delivery sampling, the sample will be obtained as the randomly selected truck is loaded. As in the case of Random Sampling on Time Basis, the actual lot size should be determined from weigh records.

9.3 RANDOM SAMPLING ON AREA BASIS

9.3.1 This method must be used for sampling during stockpiling to establish the sampling location within the leveled sublot. This method may also be used for road sampling to determine the location of the sample within the area of the spread truck load. For delivery sampling and sampling during the construction of a stockpile, the random area method will be used to define the location within the bucketful, leveled by the front-end loader, where the sample will be obtained.

9.3.2 The exact location of a sample within a given area should be determined by two random numbers picked from a Random Number Table.

9.3.3 For example, during road sampling of Granular A placed in a road widening where the selected truck load was placed 2 m wide, 45 m long, with an uncompacted thickness of 150 mm. The two random numbers chosen are 0.406 and 0.035. The first number is used to determine the longitudinal distance from the beginning of the spread material, and the second number is used to determine the offset from the edge of the layer.

9.3.4 The sampling location calculation is:

$$\begin{array}{rclcl}
 0.406 & \times & 45 \text{ m} & = & 18.3 \text{ m from the start of spread; and} \\
 0.035 & \times & 2 \text{ m} & = & 0.07 \text{ m from edge.}
 \end{array}$$

10. FREQUENCY OF SAMPLING

10.1 The frequency of sampling is governed by the size of the lot or subplot as determined in the contract documents. One sample is obtained from each lot or from each subplot where the lot is divided into sublots.

10.2 If each lot is decisioned separately for acceptance, rejection, or adjusted payment, it is necessary to record the quantities in each lot. The weigh tickets should be used for this purpose where possible. Otherwise, the production rate could be used as a basis for estimating the quantities.

11. SAMPLE SIZE

11.1 Field samples obtained from stockpile, delivery or road samples should provide sufficient mass of material to conduct the necessary gradation and/or physical quality tests. Table 3 contains minimum field sample masses that are expected to furnish reasonable quantities for most routine testing. A standard MTO canvas sample bag will hold approximately 25-30 kg of material.

Table 3 Sample Size

Material	Minimum mass of field samples (kg)
Granular A, Granular M	25
Granular B, SSM	50
Granular B, SSM (100% passing 26.5 mm sieve)	25

12. SHIPPING SAMPLES

Samples should be placed in clean bags or containers free of particles from previous samples that are constructed to prevent the loss of any part of the material or contamination or damage to the contents during shipment. The containers should be sufficiently strong and must be securely fastened. Metal or cardboard containers are unacceptable. To ensure ease of handling, a container should not contain more than 30 kg of material. Proper identification should be included both inside and outside of the sample container. An example of an identification tag which requires suitable information is shown in Figure 2.

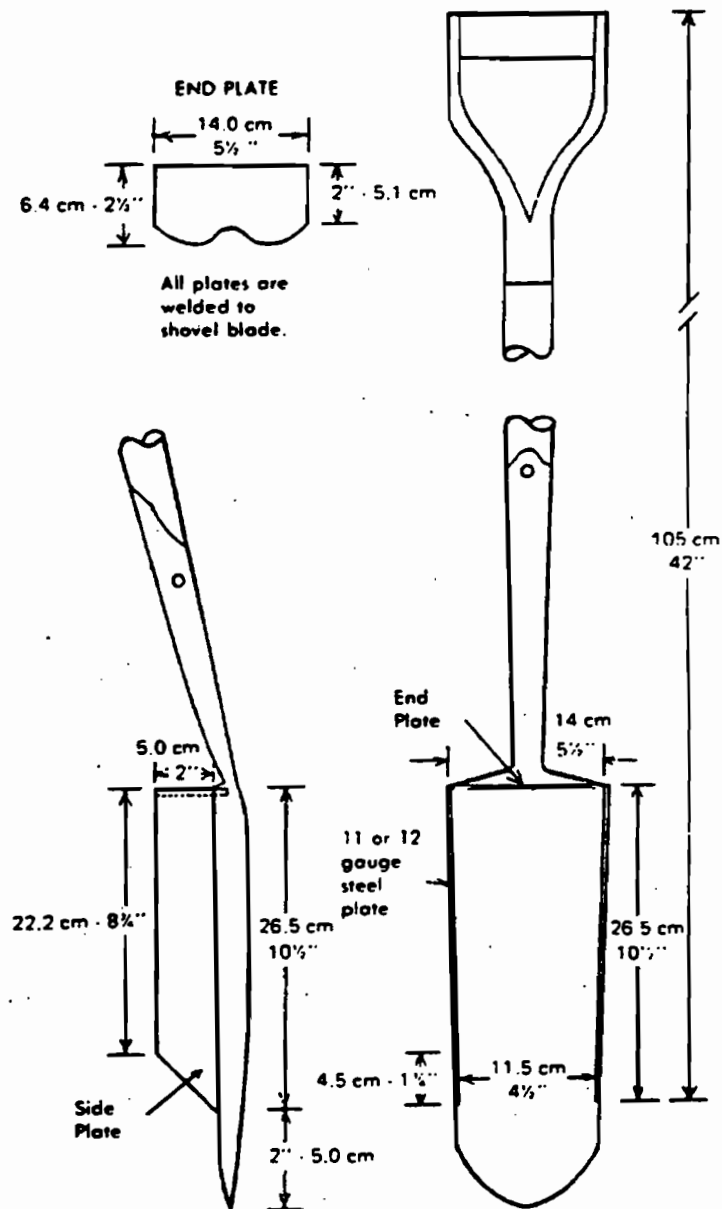


Figure 1

Tile Spade with Attached Walls

	SAMPLE DATA SHEET
Contract or W. P. _____ Dist. _____ Hwy. _____	
Work and location _____	
Milita Sheet _____ Source No. _____	
Inv. Code No. _____ Co-Ord. _____ E-- _____ N	
Source Name or Owner _____	
County _____ Twp. _____ Lot _____ Con. _____	
Source location _____	

SAMPLE FROM : Channelled face ☐ , Test pit ☐ , Into Stockpile ☐ , Out of Stockpile ☐ , Stopped belt ☐ , End of belt ☐ , Power Auger ☐ , Bin ☐ , Road ☐ , Hand auger ☐ , Diamond drill core ☐ , Other _____ ☐ , Date of prod. of s'pile _____ Quantity in s'pile _____ tonnes AT: Hole, face, station _____ Dist. to _____ Is mat'l. washed ? _____ DEPTH: From _____ m to _____ m Total depth _____ m Formation _____ STRIPPING REQUIRED: A B & M _____ m H.L. & Conc. _____ m Est. cum. % st. ret. _____ > 150 _____ > 100 _____ > 65 _____ > 25 _____ > 5 (mm) Intended use _____ History of use _____ M.T.O. Soil Classification _____ TYPE OF SAMPLE: Precont. eng. ☐ , Prelim. cont. ☐ , Early prod. ☐ , Prod. cont. ☐ , Mix design ☐ , Commercial ☐ , Other _____ ☐ , Type of mix design req'd. _____ FIELD OPTION: Suitable for _____ Borderline for _____ Unsuitable for _____ No. of bags in sample _____ Remarks _____ _____	
DATA FORWARDED: Sketch ☐ , Field notes ☐ .	
Sampled by _____ Date _____	
Field sample no. _____ Date rec'd. _____	
Lab. sample no. _____ Date req'd. _____	
Result to _____ Fax No. _____	
TEST REQUIRED P. N. ☐ , Soundness ☐ , L.A. Abr. ☐ , Abs. & Dr. ☐ , % Crush ☐ , % Flats ☐ , W. P. 75 μ m ☐ , Organic ☐ , Micro - Deval C. A. ☐ , Gradation ☐ , Moisture ☐ , Proctor ☐ , P. I. ☐ , Hydrometer ☐ , Attrition ☐ , A. A. V. ☐ , P. S. V. ☐ , Micro - Deval F. A. ☐ , Chem. Anal. ☐ , A. M. Bar ☐ , Freeze - Thaw ☐ , Insoluble Residue ☐ . Special tests : _____	

0.067	0.296	0.041	0.623	0.126	0.883	0.766	0.412	0.591	0.868	0.841	0.889	0.232	0.807
0.026	0.939	0.353	0.268	0.279	0.525	0.677	0.115	0.149	0.899	0.163	0.731	0.635	0.382
0.626	0.942	0.945	0.304	0.422	0.347	0.826	0.984	0.879	0.522	0.055	0.793	0.664	0.575
0.109	0.785	0.355	0.474	0.887	0.192	0.518	0.181	0.669	0.780	0.094	0.345	0.575	0.587
0.815	0.588	0.911	0.438	0.170	0.174	0.470	0.011	0.465	0.896	0.118	0.223	0.660	0.612
0.559	0.530	0.441	0.779	0.966	0.730	0.503	0.478	0.285	0.659	0.126	0.075	0.876	0.908
0.306	0.542	0.986	0.095	0.733	0.283	0.722	0.756	0.319	0.005	0.952	0.448	0.197	0.042
0.213	0.033	0.525	0.414	0.250	0.269	0.758	0.978	0.808	0.098	0.789	0.169	0.885	0.556
0.893	0.008	0.014	0.505	0.242	0.106	0.513	0.396	0.897	0.062	0.160	0.701	0.237	0.891
0.342	0.410	0.652	0.034	0.507	0.610	0.015	0.072	0.315	0.980	0.025	0.588	0.185	0.137
0.768	0.696	0.692	0.928	0.969	0.705	0.423	0.539	0.263	0.487	0.168	0.546	0.136	0.062
0.644	0.023	0.249	0.364	0.922	0.882	0.973	0.642	0.820	0.517	0.604	0.727	0.324	0.714
0.322	0.431	0.499	0.370	0.010	0.758	0.627	0.749	0.831	0.298	0.845	0.934	0.487	0.875
0.136	0.300	0.314	0.919	0.774	0.321	0.483	0.918	0.841	0.704	0.519	0.589	0.387	0.025
0.544	0.579	0.218	0.281	0.141	0.068	0.156	0.088	0.676	0.678	0.066	0.310	0.041	0.933
0.120	0.113	0.724	0.434	0.091	0.071	0.712	0.773	0.059	0.688	0.962	0.649	0.929	0.722
0.661	0.461	0.513	0.343	0.744	0.408	0.811	0.102	0.450	0.356	0.705	0.032	0.667	0.512
0.390	0.468	0.134	0.927	0.809	0.316	0.098	0.290	0.448	0.464	0.872	0.628	0.358	0.029
0.407	0.217	0.342	0.624	0.343	0.138	0.506	0.285	0.027	0.360	0.675	0.678	0.153	0.187
0.006	0.692	0.471	0.147	0.969	0.823	0.611	0.227	0.594	0.102	0.965	0.848	0.822	0.705
0.166	0.432	0.001	0.964	0.950	0.168	0.451	0.373	0.917	0.135	0.974	0.945	0.665	0.059
0.565	0.306	0.006	0.303	0.049	0.888	0.493	0.672	0.616	0.207	0.719	0.466	0.997	0.268
0.517	0.657	0.625	0.313	0.871	0.918	0.533	0.279	0.972	0.621	0.905	0.879	0.249	0.105
0.841	0.978	0.697	0.294	0.772	0.368	0.726	0.559	0.961	0.849	0.238	0.374	0.528	0.243
0.283	0.001	0.405	0.229	0.283	0.730	0.767	0.075	0.613	0.083	0.014	0.912	0.876	0.742
0.117	0.740	0.412	0.670	0.203	0.100	0.652	0.177	0.649	0.856	0.392	0.787	0.946	0.255
0.944	0.864	0.898	0.071	0.259	0.072	0.121	0.954	0.958	0.897	0.979	0.578	0.061	0.772
0.189	0.852	0.265	0.903	0.739	0.991	0.724	0.485	0.217	0.809	0.458	0.197	0.928	0.862
0.164	0.564	0.401	0.105	0.915	0.659	0.510	0.643	0.102	0.405	0.082	0.901	0.417	0.841
0.441	0.702	0.681	0.062	0.756	0.474	0.241	0.881	0.471	0.314	0.078	0.382	0.114	0.626
0.790	0.482	0.643	0.072	0.786	0.750	0.919	0.420	0.281	0.825	0.601	0.033	0.563	0.592
0.302	0.856	0.889	0.637	0.208	0.601	0.315	0.323	0.155	0.059	0.391	0.759	0.479	0.304
0.228	0.013	0.739	0.346	0.474	0.895	0.050	0.339	0.707	0.199	0.442	0.336	0.132	0.520
0.033	0.841	0.416	0.710	0.786	0.652	0.599	0.787	0.907	0.292	0.891	0.584	0.370	0.285
0.184	0.125	0.234	0.084	0.753	0.962	0.627	0.102	0.004	0.989	0.557	0.972	0.850	0.545
0.369	0.700	0.738	0.001	0.609	0.361	0.307	0.343	0.277	0.030	0.145	0.623	0.100	0.647
0.992	0.399	0.574	0.625	0.273	0.328	0.545	0.593	0.055	0.382	0.059	0.561	0.030	0.776
0.425	0.571	0.675	0.299	0.989	0.005	0.774	0.376	0.201	0.354	0.877	0.892	0.200	0.814
0.525	0.712	0.021	0.911	0.303	0.369	0.751	0.412	0.315	0.133	0.699	0.977	0.621	0.601
0.797	0.225	0.360	0.977	0.923	0.570	0.761	0.604	0.546	0.924	0.968	0.440	0.148	0.455
0.226	0.721	0.819	0.211	0.593	0.382	0.580	0.511	0.410	0.749	0.358	0.359	0.760	0.946
0.162	0.280	0.182	0.850	0.357	0.673	0.764	0.323	0.120	0.435	0.327	0.306	0.856	0.373
0.133	0.489	0.710	0.779	0.374	0.248	0.172	0.286	0.471	0.386	0.262	0.167	0.642	0.252
0.081	0.314	0.532	0.640	0.896	0.492	0.876	0.700	0.225	0.310	0.785	0.470	0.322	0.728
0.302	0.795	0.993	0.447	0.120	0.344	0.452	0.433	0.056	0.282	0.946	0.942	0.863	0.829
0.447	0.702	0.813	0.831	0.863	0.399	0.346	0.509	0.989	0.126	0.179	0.950	0.513	0.924
0.717	0.657	0.018	0.110	0.753	0.239	0.362	0.029	0.733	0.905	0.248	0.341	0.201	0.262
0.070	0.513	0.043	0.546	0.342	0.780	0.792	0.548	0.981	0.995	0.517	0.700	0.890	0.937
0.524	0.281	0.692	0.643	0.084	0.103	0.468	0.438	0.350	0.790	0.622	0.151	0.326	0.778
0.576	0.447	0.519	0.625	0.913	0.676	0.099	0.105	0.455	0.057	0.883	0.491	0.636	0.892
0.945	0.951	0.202	0.923	0.597	0.020	0.566	0.959	0.868	0.243	0.946	0.019	0.800	0.648
0.481	0.280	0.171	0.299	0.297	0.501	0.869	0.600	0.943	0.243	0.034	0.616	0.981	0.970
0.103	0.145	0.045	0.342	0.016	0.416	0.070	0.246	0.154	0.317	0.370	0.332	0.549	0.408
0.992	0.032	0.140	0.156	0.178	0.387	0.830	0.153	0.558	0.417	0.401	0.362	0.689	0.088
0.834	0.113	0.552	0.376	0.013	0.591	0.874	0.001	0.895	0.093	0.427	0.301	0.589	0.439
0.297	0.961	0.640	0.517	0.099	0.989	0.039	0.704	0.580	0.248	0.973	0.912	0.987	0.703
0.106	0.575	0.300	0.114	0.444	0.592	0.159	0.521	0.439	0.746	0.210	0.282	0.581	0.037
0.287	0.058	0.221	0.700	0.627	0.030	0.267	0.085	0.992	0.704	0.733	0.142	0.847	0.856
0.541	0.077	0.412	0.123	0.212	0.406	0.904	0.901	0.125	0.843	0.327	0.577	0.049	0.528
0.374	0.369	0.501	0.744	0.149	0.579	0.724	0.967	0.170	0.944	0.156	0.881	0.428	0.845
0.293	0.874	0.948	0.814	0.857	0.799	0.822	0.284	0.856	0.567	0.817	0.569	0.885	0.205
0.469	0.129	0.180	0.068	0.173	0.644	0.059	0.548	0.162	0.859	0.586	0.171	0.123	0.832
0.224	0.512	0.806	0.657	0.172	0.587	0.706	0.616	0.802	0.824	0.647	0.574	0.689	0.455
0.700	0.773	0.553	0.115	0.788	0.722	0.001	0.796	0.165	0.329	0.256	0.873	0.066	0.116

*The numbers in this table were generated using the @RAND function random number generator from the spreadsheet application Lotus 1-2-3 Release 4 for Windows

Figure 3
Random Number Table*

METHOD OF TEST FOR THE DETECTION OF ALKALI-REACTIVE COARSE AGGREGATE BY ACCELERATED EXPANSION OF CONCRETE PRISMS (TANG TEST)

1. SCOPE

- 1.1 This test allows the detection within four to eight weeks of the potential for deleterious expansion of concrete due to alkali-carbonate and alkali-silica reaction of coarse aggregate. At present, this test is under development, and there is no specification or guideline as to its application.

2. RELEVANT DOCUMENTS

- 2.1 CSA A23.1-1A Sampling Aggregates for Use in Concrete
- 2.2 ASTM C 305 Practice for Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency.
- 2.3 ASTM C 490 Practice for Use of Apparatus for the Determination of Length Change of Hardened Cement Paste, Mortar, and Concrete.
- 2.4 Xu, Z., Lan, X., Deng, M., and Tang, M.S., A New Accelerated Method for Determining the Potential Alkali-Carbonate Reactivity, Proceedings of the 11th International Conference on Alkali-Aggregate Reaction, Quebec, pp. 129-138, 2000.

3. SIGNIFICANCE AND USE

- 3.1 This test method provides a means of screening aggregates for their potential alkali-reactivity. It is based on an Accelerated Test Method developed by Professor Tang and others (Xu et al, 2000).
- 3.2 Criteria to determine the potential deleteriousness of expansions measured in this test are not known at present. When excessive expansions are developed, it is recommended that supplementary information be developed to confirm that the expansion is actually due to alkali reactivity. Sources of such supplementary information include:
 - (a) Petrographic examination of the aggregate (see ASTM Standard C 295) to determine whether known reactive constituents are present; and
 - (b) Examination of the specimens after tests (see ASTM Standard C 856) to identify the products of alkali reactivity.

- 3.3 When it has been concluded from the results of tests performed, using this test method and supplementary information, that a given aggregate should be considered potentially deleteriously reactive, additional studies using alternative methods (see CSA Test Method A23.2-14A) may be appropriate to develop further information on the potential reactivity.

4. APPARATUS

- 4.1 The apparatus shall conform to ASTM Standard C 490 except as follows:
- (a) Square hole, woven-wire sieves shall conform to CGSB Standard CAN/CGSB-8.2;
 - (b) The mixer, paddle, and mixing bowl shall conform to the requirements of ASTM Standard C 305;
 - (c) Moulds for casting prisms shall have either one or two compartments and shall be constructed so as to result in prisms with a cross section of 40 ± 1.0 by 40 ± 1.0 mm and have a length of 285 ± 1.0 mm. They may be made of either cold rolled steel or hard plastic.
- 4.2 The containers for concrete prism storage shall be of such a nature that the prisms can be totally immersed in either the water or 1 M NaOH solution. The containers shall be made of material that can withstand prolonged exposure to 80°C and shall be inert to a 1 M NaOH solution*. The containers shall be so constructed that, when used for storing specimens, the loss of moisture is prevented by tight-fitting covers, by sealing, or both. The prisms in the solution shall be placed and supported so that the solution has access to the whole of the bars; therefore, it shall be ensured that the specimens do not touch the sides of the container or each other. The specimens, if stood upright in the solution, shall not be supported by the metal gauge stud.
- 4.3 The convection oven shall have temperature control maintaining $80^{\circ} \pm 2.0^{\circ}\text{C}$.

**The NaOH solution will corrode glass or metal containers.*

†A covered container that has been found to be acceptable for this purpose is sold by Rubbermaid® as a microwave-proof storage container.

5. REAGENTS AND MATERIALS

- 5.1 USP or technical grade sodium hydroxide may be used provided that the Na^+ and OH^+ concentrations are shown by chemical analysis to lie between 0.99 M and 1.01 M.

- 5.2 Unless otherwise indicated, references to water shall be understood to mean reagent water conforming to Type IV of ASTM Standard D 1193, i.e. distilled water.
- 5.3 Each litre of sodium hydroxide solution shall contain 40.0 g of NaOH* dissolved in 900 mL of water and shall be diluted with additional distilled or deionized water to obtain 1.0 L of solution. The volume proportion of sodium hydroxide solution to mortar bars in a storage container shall be 4 ± 0.5 volumes of solution to 1 volume of mortar bars†.

*Precaution: Before using NaOH, review:

- (a) The safety precautions for using NaOH;
- (b) First aid for burns; and
- (c) The emergency response to spills as described in the manufacturer's Materials Safety Data Sheet or other reliable safety literature. NaOH can cause very severe burns and injury to unprotected skin and eyes. Suitable personal protective equipment should always be used. These should include full-face shields, rubber aprons, and gloves impervious to NaOH. Gloves should be checked periodically for pin holes.

†The volume of a prism may be taken as 456 mL.

- 5.4 A supply of cement meeting the requirement of normal Portland cement (Type 10) as specified in CSA Standard A5 shall be used. The total alkali content of the cement shall be $0.9 \pm 0.1\%$, calculated as $\text{Na}_2\text{O} + 0.658 \text{ K}_2\text{O}$, i.e. the Na_2O equivalent.

5.5 Control Aggregate

A supply of Spratt alkali-silica reactive control aggregate.

Note: This aggregate is available from the Soils and Aggregates Section, Materials Research and Engineering Office, Ontario Ministry of Transportation, 1201 Wilson Avenue, Downsview, Ontario M3M 1J8, Fax 416-235-4101.

6. CONDITIONING

- 6.1 Maintain the temperature of the moulding room, apparatus, and dry materials at not less than 20°C and not more than 26°C. Ensure that the temperature of the mixing water and of the moist closet or moist room does not vary from 23°C by more than 2.0°C.
- 6.2 The humidity of the moulding room shall be maintained at not less than 50%. The moist closet or room shall conform to ASTM Standard C 511.

- 6.3 Maintain the storage oven in which the specimens are stored in the containers at a temperature that shall not vary from 80°C by more than 2.0°C, and so that the temperature of the solution shall maintain a temperature of $80 \pm 2.0^\circ\text{C}$.

7. SAMPLING AND PREPARATION OF TEST SPECIMENS

7.1 Sample Selection

The procedures outlined in CSA Test Method A23.2-1A shall be followed to obtain a representative sample of the aggregate to be tested. The sample, if possible, shall be obtained from a stockpile of aggregate produced in a manner identical to that which will be used in subsequent production. Aggregate proposed for use as coarse aggregates in concrete shall be processed by crushing to produce, as nearly as practicable, a graded product from which a sample can be obtained. The sample shall be representative of the composition of the coarse aggregate proposed for use.

- 7.2 All aggregates to which this test method is applied shall be graded on a 13.2, 9.5, and 4.75 mm sieves, and stored individually in clean containers provided with tight-fitting covers. The coarse aggregate under test shall be composed of two equal parts consisting of material between the 13.2 – 9.5 mm, and 9.5 – 4.75 mm sieves. Oversize and undersize material shall be discarded. Test samples shall be made using equal amounts by mass of material retained on the 9.5 mm and 4.75 mm sieves. After the aggregate has been separated into the various sieve sizes, each size shall be washed with water to remove adhering dust and fine particles from the aggregate. Each fraction shall be immersed in water for a minimum of 12 hours. Prior to mixing with cement paste, the coarse aggregate shall be drained and surface dried in a large absorbent cloth or towel until all visible films of water are removed.

- 7.3 Use a Portland Type 10 cements with a total alkali content of $0.9 \pm 0.1\%$.

7.4 Preparation of Test Specimens

- 7.4.1 Make at least two test specimens for each aggregate.

- 7.4.2 Prepare the specimen moulds in accordance with the requirements of ASTM Standard C 490, except that the interior surfaces of the mould shall be covered with a release agent*. Consider a release agent acceptable if it serves as a parting agent without affecting the setting of the cement and without leaving any residue that will inhibit the penetration of water into the specimen.

**TFE-Fluorocarbon (Teflon) tape complies with the requirements for a mould release agent, or hydraulic oil. Alternatively, the use of plastic moulds may not require the use of a release agent.*

- 7.4.3 The surface dry materials for the test concrete shall be proportioned using 1 part cement to 1 part graded aggregate by mass. To make two prisms, the quantities of dry materials to be mixed at one time in the batch of concrete shall be 1000 g of cement and 1000 g of aggregate in the grading prescribed in Table 1. A water/cement ratio equal to 0.30 by mass shall be used.
- 7.4.4 Mix the paste in accordance with the requirements of ASTM Practice C 305.
- 7.4.5 Following mixing of the paste, add the saturated surface dry coarse aggregate to the mixture and stir and mix the aggregate using a scraper or large spoon until all the aggregate is well coated with paste. Cover the mixing bowl with a damp towel and let stand for 30 seconds and remix for 10 seconds.
- 7.4.6 Specimens with a total elapsed time of not more than 3 minutes after completion of the original mixing of the concrete batch. Fill the moulds with two approximately equal layers, each layer being compacted with gloved fingers. Work the concrete into the corners, around the gauge studs, and along the surfaces of the mould with gloved fingers until a homogeneous specimen is obtained. After the top layer has been compacted, cut off the concrete flush with the top of the mould and smooth the surface with a few light pats of gloved fingers. Cover the filled moulds with a plastic cover immediately following finishing.

8. PROCEDURE

- 8.1 Place each mould in the moist cabinet or room immediately after moulds have been filled. Leave the specimens in the moulds for 24 ± 2 h. Remove the specimens from the moulds and, while they are being protected from loss of moisture, properly identify them. Place the specimens made with each aggregate sample in a storage container with sufficient tap water heated to $80 \pm 2.0^{\circ}\text{C}$, to totally immerse them. Seal and place the containers in a convection oven at $80 \pm 2.0^{\circ}\text{C}$ for a period of 24 h.
- 8.2 Remove the containers from the oven one at a time. Remove other containers only after the bars in the first container have been measured and returned to the oven. Remove the bars one at a time from the water and dry their surfaces with a towel, paying particular attention to the two metal gauge-measuring studs. Make and record the initial and all subsequent measurements to the nearest 0.002 mm

(0.0001 inch). Take the initial length measurement* of each bar immediately after drying, and read as soon as the bar is in position. Complete the process of drying and measuring within 15 ± 5 s of removing the specimen from the water. Ensure that the elapsed time between removal of the container from the oven and completion of the measurements is no more than 5 minutes. After measurement, leave the specimen on a towel until the other bar has been measured. Place both specimens in a container with the 1 M NaOH, preheated at $80 \pm 2.0^{\circ}\text{C}$. Totally immerse the samples. Seal the container and return it to the oven.

**The comparator bar should be measured prior to each set of specimens since the heat from the concrete prisms may cause the length of the comparator to change. The lower measuring stud of the comparator should be wiped dry after each measurement to prevent corrosion.*

- 8.3 Undertake subsequent measurements of the specimens at 7, 14, 21, 28, 56 days and at 4-week intervals thereafter.

9. CALCULATION

- 9.1 Calculate the length change following ASTM C 490. Calculate the difference between the initial length of the specimen and the length at each period of measurement to the nearest 0.0001% of the effective length and record as the expansion of the specimen for that period. Calculate the average expansion of the two specimens to the nearest 0.001% as the expansion for a given period.

10. USE OF A CONTROL MATERIAL

- 10.1 When testing is conducted, the laboratory shall demonstrate its ability to conduct the test. At the time of testing, testing with a known reactive aggregate shall be conducted.

Note: *Spratt coarse aggregates is available in 25-kg bags from Soils and Aggregates Section, Materials Engineering and Research Office, Ontario Ministry of Transportation, 1201 Wilson Avenue, Downsview, Ontario M3M 1J8, Fax 416-235-4101.*

11. REPORT

The report shall include the following:

- (a) Type and source of coarse aggregate;
- (b) Type and source of Portland cement;

- (c) The alkali content (Na_2O and K_2O) of the cement;
- (d) The average length change, in per cent, at each reading of the prisms, with the individual values for each prism;
- (e) Any significant features revealed by examination of the concrete prisms, either during the test or at the end of the test (e.g. cracks, gel, formations, or reaction rims surrounding aggregate particles); and
- (f) The expansion of concrete made with the Spratt aggregate.

METHOD OF TEST FOR OPEN GRADED DRAINAGE LAYER (OGDL) CORE POROSITY TEST

1. SCOPE

- 1.1 This method covers the determination of porosity of a 150 mm core or 140-145 mm square saw cut sample of Open Graded Drainage Layer.

2. RELEVANT DOCUMENTS

- 2.1 Interim Report, Iowa Pore Index Test, Myers, J. D., Dubberke, W., Iowa Department of Transportation Highway Division, January 1980.

3. DEFINITION

- 3.1 Porosity is defined as the ratio of the volume of voids, to the total volume of the sample.

4. APPARATUS

- 4.1 PRESS-UR-METER: A modified Press-ur-meter is used to perform the porosity laboratory test. The pump, valve and gauge are removed from the lid and replaced by a 320 millilitre Plexiglas tube, graduated in two millilitre increments. The addition of a standard 60 psi pressure gauge complete the lid modifications. A hole is drilled through the side of the air meter bowl at the bottom, fitted with a valve, and is used for loading and unloading the air meter bowl with cold tap water. Two valves are located at the top of the Plexiglas tube. One valve is connected to a line supplying air at a constant 241 kPa (35 psi). The other valve is a vent and is opened while charging the unit with water.

5. PREPARATION OF TEST SAMPLE

- 5.1 Care shall be taken to ensure no damage to the sample occurs.
- 5.2 The sample shall be an intact 150 mm diameter core or an intact minimum dimension 140 by 140 mm, maximum dimension 145 by 145 mm square saw cut sample.
- 5.3 Air dry the sample on a clean laboratory bench for a minimum of 24 hours.

6. TEST PROCEDURE

- 6.1 Place the air-dried sample in the air meter bowl.
- 6.2 Fill air meter bowl with measured quantity, V_1 , of cold tap water to 2 cm from the top of the air meter bowl.

- 6.3 Attach the lid, open the vent valve, and fill the air meter bowl and Plexiglas tube with a measured quantity, V_2 , of cold tap water to the "0" millilitre mark. The pressure gauge on the lid must remain at the zero psi mark during this filling stage.
- 6.4 Close the water supply and vent valves and then open the 241 kPa (35 psi) air supply valve as soon as possible. The air supply valve remains open maintaining air pressure on the air meter bowl for 15 minutes.
- 6.5 Take a water level reading at one minute. The amount of water loss during this first minute fills the aggregate's macro-pores and is referred to as the primary load, p_{1L} .
- 6.6 Take a water level reading at fifteen minutes. The volume of water loss between one minute and fifteen minutes is the secondary load, p_{2L} , and represents the amount of water injected into the aggregate's micro-pore system. The secondary load in millilitres is not used in the pore index test result calculations.
- 6.7 After taking the water level reading after 15 minutes of loading close the air supply valve and open the vent valve to release the air pressure from the air meter bowl. Take a water level reading at one minute after unloading. This is referred to as the primary unload, p_{1u} .
- 6.8 Take a water level reading at 15 minutes after unloading. This is referred to as the secondary unload, p_{2u} . The secondary load in millilitres is used in the modified pore index test result calculations.

7. CALCULATIONS

- 7.1 Calculate porosity n , of sample as follows:

$$n = \frac{V_C + V_A - V_T}{V_C}$$

Where:

V_C = Volume of sample as determined by measuring dimensions in cm^3

$$V_A = V_1 + V_2 + p_{2u}$$

Where: V_1 = Volume of water added to air meter bowl in 6.2 in ml

V_2 = Volume of water added to fill Plexiglas tube to the "0" millilitre mark in 6.3 in ml

p_{2u} = Secondary unload reading determined in 6.8 in ml

V_T = Volume of water to fill the air meter bowl containing no sample and the Plexiglas tube to the "0" millilitre mark

8. REPORTING

- 8.1 Report the porosity of the sample to three decimal places.

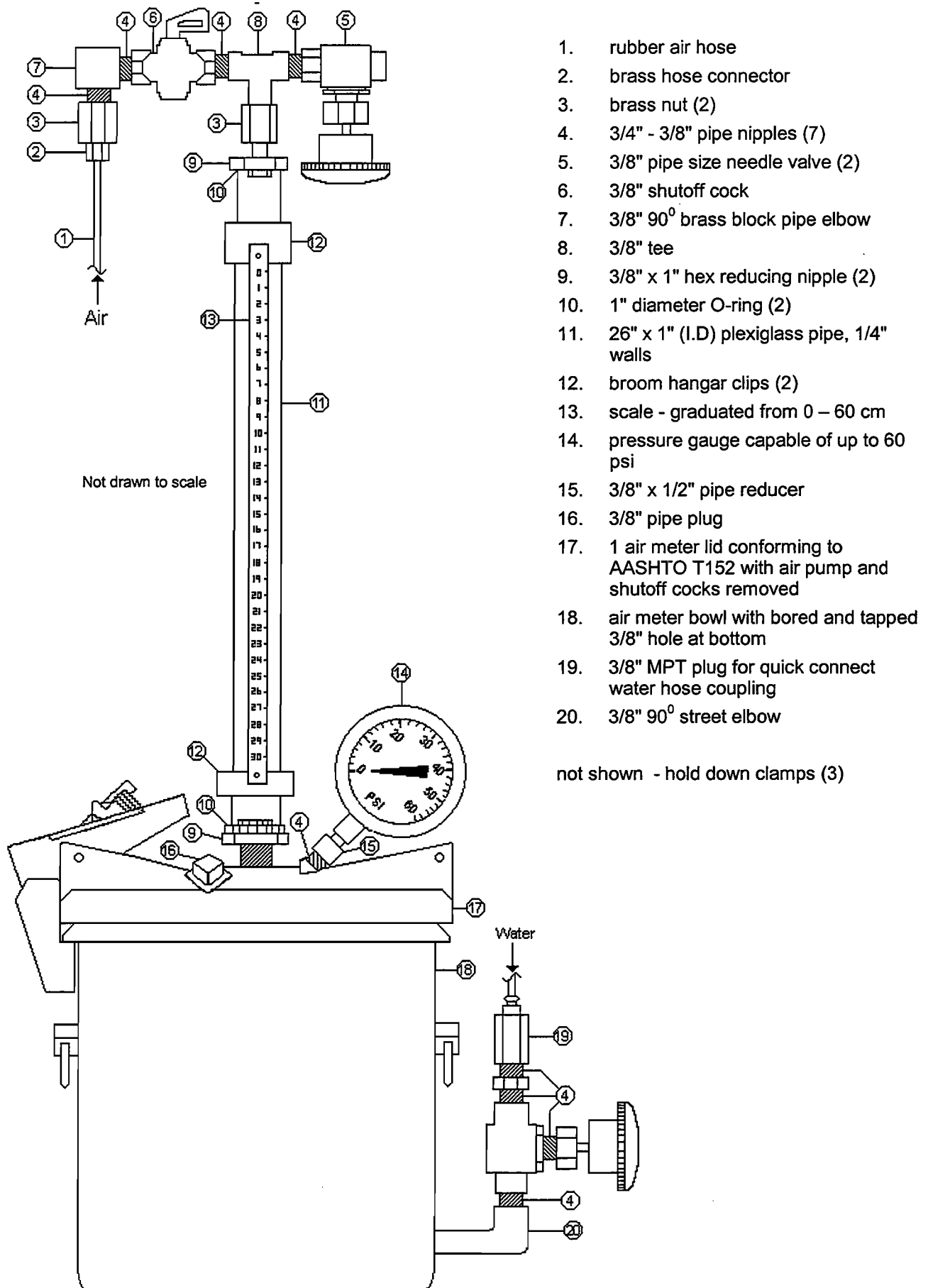


Figure 1. Modified PRESS-UR-METER Apparatus

METHOD OF DRY PREPARATION OF SOIL SAMPLES FOR DETERMINATION OF PHYSICAL CHARACTERISTICS

1. SCOPE

1.1 This method describes the dry preparation of soil samples as received from the field for particle-size analysis and the determination of soil constants.

2. RELEVANT DOCUMENTS

2.1 ASTM D 421

2.2 AASHTO T87

3. PROCEDURE

3.1 Procedures of ASTM Standard D 421 shall be followed, except as noted below, for the dry preparation of soil samples as received from the field for particle-size analysis and the determination of soil constants.

4. EXCEPTIONS

4.1 The soil sample as received from the field shall be thoroughly dried in air or a drying oven not exceeding a temperature of 60°C.

4.2 PULVERIZING APPARATUS: Conforming to ASTM Standard D 421, Clause 4.2 shall be followed, and in addition a mechanical device consisting of power-driven rubber-covered pestle (or soil mill) suitable for breaking up the aggregation of soil particles without reducing the size of the individual grains is permitted.

METHOD OF TEST FOR DETERMINATION OF MOISTURE CONTENT OF SOILS

1. SCOPE

1.1 This method covers the laboratory determination of the moisture content of soils by mass.

2. RELEVANT DOCUMENTS

2.1 ASTM D 2216

3. PROCEDURE

3.1 Procedure of ASTM Standard D 2216 shall be followed.

4. REPORT

4.1 The report shall include the moisture content, in percent, of the soil test sample.

METHOD OF TEST FOR DETERMINATION OF PARTICLE SIZE ANALYSIS OF SOILS

1. SCOPE

- 1.1 This method covers the quantitative determination of particle size distribution in soils. The distribution of particles larger than 75 μm is determined by dry sieving, and the distribution of particles smaller than 75 μm is determined by means of a sedimentation process using a hydrometer to secure the necessary data.

1.2 REQUIREMENTS

- 1.2.1 The soil sample shall be classified in accordance with MTO or Unified Soil Classification System prior to the preparation of test specimen. Atterberg Limits, for this purpose, shall be determined in accordance with MTO LS-703/704.
- 1.2.2 The specific gravity of soil particles for the computation of percentage of soil remaining in suspension be determined in accordance with MTO LS-705.

2. REFERENCE

- 2.1 ASTM D 421
2.2 ASTM D 422
2.3 ASTM D 4318
2.4 AASHTO T-88
2.5 T.W. Lambe, Soil Testing for Engineers, John Wiley & Sons, 1951

3. APPARATUS

- 3.1 Balances - A balance readable to 0.01g for weighing the material passing a 2.0 mm sieve, and a balance with the basic tolerance of $\pm 0.1\%$ of the mass of the sample for weighing the material retained on a 2.0 mm sieve.
- 3.2 Oven - A thermostatically-controlled, forced-draft type drying oven, capable of maintaining a uniform temperature of $110 \pm 5^\circ\text{C}$ throughout.
- 3.3 Stirring Apparatus - Apparatus consists of a mechanically-operated stirring device mounted with an electric motor capable of rotating a vertical shaft at a speed not less than 10 000 rpm when there is no load. The shaft shall be equipped with a replaceable stirring paddle made of metal, plastic, or hard rubber as shown in Figure 1a. The length of the shaft shall be such that the stirring paddle will operate not less than 19 mm or nor more than 38 mm above the bottom of the dispersion cup. A special dispersion cup conforming to the designs shown in Figure 1b shall be provided to hold the sample while it is being dispersed.

- 3.4 Hydrometer - Graduated to read in grams per litre of suspension, and conforming to the requirements of 152 H in ASTM Specifications E 100.
- 3.5 Sedimentation Cylinder - A graduated glass cylinder 457 mm in height and 60 ± 1.2 mm inside diameter, and marked for a volume of 1 000 ml. The diameter shall be such that the 1 000 ml mark is 360 ± 20 mm from the bottom of the cylinder measured inside.
- 3.6 Control Cylinder - A graduated glass cylinder 457 mm in height and 60 ± 1.2 mm inside diameter, and marked for a volume of 1 000 ml. The diameter shall be such that the 1 000 ml mark is 360 ± 20 mm from the bottom of the cylinder measured inside.
- 3.7 Thermometer - A thermometer readable to 0.5°C . These thermometers shall be calibrated to a thermometer accurate to 0.1°C .
- 3.8 Sieve - Set of sieves of square-mesh woven-wire cloth conforming to the requirements of ASTM Specification E 11. The set of sieves selected should give a uniform spacing of points on the grain size distribution curve.
- 3.9 Mechanical Sieve Shaker - Mechanical sieve shaker used for the sieving operation of the portions retained on 2.0 mm and $75\ \mu\text{m}$ sieves shall be capable of imparting a motion to the sieves that causes the particles to bounce and turn in various orientation to reach the sieve openings.
- 3.10 Constant-Temperature Bath - Water bath capable of maintaining the soil suspension at a constant temperature during the hydrometer test. The constant-temperature bath may not be necessary, if the test is carried out in a room or laboratory where the temperature is maintained at $20 \pm 2^{\circ}\text{C}$ throughout a period of 24 hrs.
- 3.11 Beaker - A 250-ml to 400-ml capacity glass beaker.
- 3.12 Timer - A clock, stopwatch, or digital timer readable to one second.
- 3.13 Splitter - Sample splitter shall have an even number of equal width chutes but not less than a total of twelve. Chutes shall be 12.5 to 20 mm wide. The splitter and accessory shall be so designed that the sample will flow smoothly without restriction or loss of material.

4. DISPERSING AGENT

- 4.1 Soil Identification - Prior to preparing the sodium hexametaphosphate solution (dispersing agent), the Atterberg Limits (LL & PL) and Plasticity Index (PI) of the soil sample shall be determined in accordance with MTO LS-703/704. The soil sample shall be classified according to the MTO or Unified Soil Classification System.
- 4.2 Dispersing Agent - A solution of sodium hexametaphosphate shall be prepared using distilled water only. The amount of dispersing agent used in 1 000 ml of distilled water shall depend on the type of soil to be tested. The amount of sodium hexametaphosphate per litre of solution used shall be according to the schedule in Table 1:

Table 1

Soil Type	Mass of Dispersing Agent (g/Litre)
SM, SC, ML, OL, or MI	24
CL-ML, CL, OL, OH, or MH	40
CI or CH	48

- 4.3 Water - Distilled water shall be used for the preparation of the solution and test specimen. The water for the hydrometer test shall be brought to the temperature that is expected to prevail during the test. If the sedimentation and control cylinders are to be placed in a constant temperature bath, the distilled water to be used shall be brought to the temperature of the water bath. In cases where the test is performed in a room with automatically-controlled temperature, the water for the test shall be at the temperature of the room.

Note 1: A dispersing agent can either act as a protective colloid on the soil particle or alter the electric charge on the particle to prevent flocculation. The dispersing action of the sodium hexametaphosphate will decrease, if the solution becomes acidic. Solutions should be frequently prepared and adjusted to a pH value between 8 and 9 by means of sodium carbonate.

5. TEST SAMPLE

- 5.1 The test sample for the sieve analysis shall be prepared as outlined in MTO LS-700. Select with care a test sample which is representative of the soil to be tested. The test sample is divided into two portions during the preparation procedure by separating on a 2.0 mm sieve. The mass of the dried soil sample selected for the purpose of the test shall be sufficient to yield quantities for sieve analysis as follows:

- 5.1.1 The mass of the portion retained on 2.0 mm sieve shall depend on the maximum size of the particle, according to the schedule below:

Table 2

Nominal Diameter of Largest Particle (mm)	Minimum Mass of Portion (Kg)
9.5	0.5
19.0	1.0
26.5	2.0
37.5	3.0
53.0	4.0
75.0	5.0

- 5.1.2 The mass of the portion passing 2.0 mm sieve for hygroscopic moisture determination, and hydrometer analysis shall be approximately 120 g for sandy soils and approximately 70 g for silts and clayey soils.

- 5.2 Prepare a representative sample of the amount required for performing the Particle Size Analysis. Weigh and record the mass of the dried sample. Record this weight as the mass of the total test sample uncorrected for hygroscopic moisture. Separate the test sample into two portions by sieving through a 2.0 mm sieve. Process the fraction of the soil retained on 2.0 mm sieve into its individual particles with a rubber-covered pestle or other suitable device. Again, sieve the soil that was broken down to individual particles through a 2.0 mm sieve, and separate it into coarse and fine fractions.
- 5.3 After the second sieving operation, wash the fraction of the sample retained on the 2.0 mm sieve until the wash water is clear. Dry and weigh the material retained on the 2.0 mm sieve. This weight is recorded as the mass (M_c) of coarse material retained on 2.0 mm sieve. The percent-age passing and retained on the 2.0 mm sieve can be calculated from these two masses (i.e. the original mass, M_t of the sample selected, and the mass, M_c after washing).
- 5.4 Thoroughly mix together the portion of the soil sample passing the 2.0 mm sieve from both sieving operations. Select appropriate quantity of soil specimen as indicated in Section 5.1.2 by quartering or the use of a sample splitter.

SIEVE ANALYSIS OF PORTION RETAINED ON 2.0 MM SIEVE

6. PROCEDURE

- 6.1 Sieve the portion of the sample retained on 2.0 mm sieve through a nest of sieves consisting of 75.0, 63.0, 53.0, 37.5, 26.5, 19.0, 13.2, 9.5, and 4.75 mm. The number of sieves needed shall depend on the type of soil sample or the requirements of the specifications for the material to be tested.
- 6.2 Sieving operation shall be conducted by means of a lateral and vertical motion of the sieve, accompanied by a jarring motion. This can be achieved by manual operation, i.e. hand shaking or by using a mechanical sieve shaker. The fragments in the sample shall not be manipulated through the sieve openings by hand. The sieving operation shall be continued until not more than one percent (1%) of the retained material on the sieve passes that sieve during 1 minute of sieving. The thoroughness of the sieving should be checked manually when a mechanical sieve shaker is used.
- 6.3 Determine the mass of soil retained on each sieve using a balance conforming to the requirements of Section 3.1. The sum of these retained masses should be checked against the original sample mass. The total mass of the material after sieving should check closely with the original mass of the sample placed on the sieves. The result should not be used for acceptance if the amount differs by more than 0.3% based on the original dry sample mass.

HYDROMETER AND SIEVE ANALYSIS OF PORTION PASSING 2.0 MM SIEVE

7. CORRECTION FOR HYDROMETER READING

7.1 **Meniscus Correction** - Equations for percentage of soil remaining in suspension are based on the use of sodium hexametaphosphate solution having strength equal to that of the soil suspension. Hydrometers are generally graduated to read at the bottom of the meniscus. The soil suspension in the sedimentation cylinder is opaque and is not possible to secure readings at the bottom of the meniscus. Therefore, readings are taken at the top of the meniscus and a correction is applied.

7.1.1 Prepare a control cylinder with 1 000 ml of liquid composed of distilled water and sodium hexametaphosphate in the same proportion as used in the test. This can be prepared by adding distilled water to 125 ml of dispersing agent prepared in accordance with Section 4.2 until the total volume is 1 000 ml. Place the thermometer and the hydrometer in the control cylinder.

7.1.2 Meniscus correction H_m is determined by inserting the hydrometer into the solution with the appropriate amount of dispersing agent, and recording the absolute reading at the top of the meniscus and where the plane of the liquid surface intersects the hydrometer scale. The latter reading shall be obtained by observing a point slightly below the plane of the liquid surface. Then raising the line of vision until this surface seen as an ellipse becomes a straight line. The point where this line cuts the stem is the hydrometer reading. Holding a white sheet of paper behind the cylinder just below the liquid level will improve the visibility of the surface. These readings shall be recorded to the nearest $\frac{1}{2}$ a division. The positive difference between these two readings in divisions of g/L is the meniscus correction H_m . This correction should be applied in determining the effective depth of the hydrometer. Refer to Figure 2a for further details.

7.2 **Immersion Correction** - The surface of the suspension in the sedimentation cylinder rises when the hydrometer is inserted in it. A correction known as "immersion correction" should be applied in determining the effective floating depth of the hydrometer bulb. This correction is made by subtracting half the volume of hydrometer bulb (V_B) divided by the cross-sectional area (A) of the sedimentation cylinder from the distance (L_1), from the surface of the suspension to the centre of the bulb.

7.2.1 The volume of the hydrometer bulb is often assumed constant, but this can be quite variable. Specification E 100 does not specify a requirement for the volume of the bulb. The volume of the hydrometer bulb can be determined by inserting the hydrometer into a graduated glass cylinder filled with water adequate to immerse the bulb. The volume of the bulb is equal to the volume of water displaced by the bulb, i.e. difference in volume readings before and after the immersion of the hydrometer. The volume of the bulb shall be recorded to the nearest 1 cm^3 . Refer to Figure 2b for further details.

7.2.2 Alternatively, the volume of the hydrometer bulb can be determined from its weight and unit weight. The unit weight can be taken as equal to the lowest reading in the hydrometer scale multiplied by the unit weight of distilled water at the standard temperature of the hydrometer. The mass of the hydrometer for this purpose shall be recorded to the nearest 0.1 grams.

7.2.3 Cross-sectional area of the sedimentation cylinder can be obtained by dividing the volume between two calibration marks by the measured distance between the same two marks. Measure and record the distance between the marks to the nearest millimetre. Upon recording these measurements, calculate and record the cross-sectional area to the nearest 0.1 cm^2 . Refer to Figure 2c for further details.

7.3 **Temperature Correction** - Soil hydrometers are calibrated at 20°C , and any variations from this standard temperature produce inaccuracies in the actual hydrometer readings. The viscosity of the suspension will also be affected by the variation in temperature. The equation given under Section 11.1 Calculation and Report shall be used to compute the viscosity of the suspension within the temperature range of $20 \pm 5^\circ\text{C}$. The temperature corresponding to each hydrometer reading shall be recorded to the nearest 0.5°C .

7.4 **Hygroscopic Moisture Correction** - Hygroscopic Moisture Correction Factor is the ratio between the mass of the oven-dried sample (W_o) and the air-dried mass (W_a). To determine this factor, weigh about 10 to 15 grams of soil sample from the material passing the 2.0 mm sieve in a small metal or glass container meeting the requirements of ASTM D 2216, Section 6.3. Dry this to a constant mass in an oven at $110 \pm 5^\circ\text{C}$. Weigh and record the masses to the nearest 0.01g.

8. DISPERSION OF SOIL SAMPLE

8.1 The mass of the test sample for hydrometer analysis shall depend on the type of soil to be tested. Weigh approximately 50 g of the air-dried sample, if the soil is classified as clay, organic silt, or high plastic silt, i.e. CL-ML, CL, CI, OI, OH, CH, or MH under Section 4.1. If the soil is classified as sand or low to medium plastic silt, i.e. SM, SC, OL, ML, or MI, weigh approximately 100 g of the air-dried sample prepared in accordance with the requirements of Section 5.

8.2 Place the test specimen in a 250-ml capacity beaker and add 125 ml of sodium hexametaphosphate solution prepared according to the requirements of Section 4.2. Stir the mix (soil specimen and dispersing agent) until the soil is thoroughly wetted. Allow the mix to soak for at least 16 hours.

8.3 After at least 16 hours of soaking, transfer the soil slurry from the beaker into the special dispersion cup shown in Figure 1b. Wash any residue from the beaker into the cup with distilled water only. If necessary, add distilled water until the cup is more than half full. Disperse the soil using the stirring apparatus until the soil is broken down to its individual particles. Depending on the type of soil, the time required to disperse may range from 1 minute to as high as 10 minutes (e.g. 1 minute for non plastic soils and 10 minutes for plastic soils).

9. HYDROMETER TEST

9.1 Immediately after the dispersion of the soil, transfer the slurry to the sedimentation cylinder and add distilled water until the volume is 1 000 ml.

9.2 Mix the slurry for a period of one minute by placing a rubber stopper over the open end of the cylinder, and turning upside down and back. The number of turns during this one-minute should be about 30, counting the turn upside down and back as one. Make sure that there is no soil stuck to the base of the cylinder when it is upside down. Vigorous

- shaking of the cylinder while it is in the inverted position should loosen any soil remaining at the base. Set the sedimentation cylinder in a convenient location on the table and start the timer, after agitating the suspension for one minute.
- 9.3 Take the hydrometer readings at total elapsed time of 1, 2, 5, 15, 30, 60, 250, and 1440 minutes. The sedimentation cylinder shall be placed in the constant-temperature bath between the 2 and 5 minute readings if a bath is used.
- 9.4 After the 2-minute reading, remove the hydrometer from the suspension. For this and all subsequent readings, insert the hydrometer 20 to 25 seconds before the reading is due. Dry the hydrometer stem before each insertion into the suspension. As soon as the reading is taken, the hydrometer shall be carefully removed from the suspension and placed with a spinning motion in the control cylinder. Record the hydrometer and temperature readings in the control cylinder.
- 9.5 After each hydrometer reading, take the temperature of the suspension by inserting the thermometer.
- 9.6 After each hydrometer reading in the soil suspension, take and record the hydrometer and temperature readings in the control cylinder.

10. SIEVE ANALYSIS

- 10.1 After the final reading, transfer the suspension to a 75 μm sieve and wash it with tap water at room temperature until the wash water is clear.
- 10.2 Carefully transfer the material retained on the 75 μm sieve to a suitable container and dry it in an oven at $110 \pm 5^\circ\text{C}$.
- 10.3 Sieve the material retained on the 75 μm sieve through a set of sieves consisting of 2.0 mm, 850 μm , 425 μm , 250 μm , 106 μm , and 75 μm . The number of sieves needed shall depend on the type of soil sample or the requirements of the specifications for the material under test.

CALCULATIONS AND REPORT

11.1 Sieve Analysis Values for Portion Retained on 2.0 mm Sieve

- 11.1.1 Calculate the percentage passing the 2.0 mm sieve (P_{10}) by dividing the mass passing the 2.0 mm sieve (M_{10}) from the Section 5.3 by the original mass M_t of the soil separated on the 2.0 mm sieve, and multiplying the result by 100.

$$M_{10} = M_t - M_c$$

$$P_{10} = (M_{10}/M_t) \times 100$$

Where

M_{10}	- mass of soil passing 2.0 mm sieve
M_t	- total mass of soil originally split on 2.0 mm sieve
M_c	- mass of coarse material retained on 2.0 mm sieve
P_{10}	- percentage of soil passing 2.0 mm sieve

11.1.2 Calculate the percentage retained on each sieve by dividing the mass of soil retained on that particular sieve under consideration by the original mass of soil used in the analysis, and multiplying the result by 100.

11.1.3 The cumulative percentage retained on each sieve is equal to the sum of percentages retained on all coarser sieves. To calculate the percentage finer than on each sieve, subtract the cumulative percentage retained on that particular sieve in question from 100.

11.2 Hygroscopic Moisture Correction Factor

11.2.1 Calculate the moisture correction factor F , by dividing the oven-dried mass W_o from Section 7.4 by the air-dried mass W_a . This factor is a number less than one, except when there is no hygroscopic moisture.

$$F = (W_o/W_a)$$

11.3 Percentage of Soil in Suspension

11.3.1 Calculate the oven-dried mass of soil (M_o) used in the hydrometer analysis by multiplying the air-dried mass (M_a) by the hygroscopic moisture correction factor (F).

$$M_o = F \times M_a$$

11.3.2 Calculate the mass of total sample (W) represented by the mass of soil used in the hydrometer test from the following. Divide the oven-dried mass (M_o) used by the percentage passing the 2.0 mm sieve, and multiply the result by 100. Use this value in the equation for percentage remaining in the soil suspension.

$$W = (M_o/P_{10}) \times 100$$

11.3.3 The percentage of soil remaining in suspension or the total percent finer at the depth at which the hydrometer is measuring the density of the soil suspension shall be calculated as follows:

$$P = (\alpha R/W) \times 100$$

Where P - percentage of soil remaining in suspension or the total percent finer at the depth at which the hydrometer measures the density of the suspension

α - specific gravity correction factor to be applied to the reading of the hydrometer

$$\alpha = 0.6226 \times (G_s/(G_s-1))$$

G_s - specific gravity of the soil particles

specific gravity of the soil particles shall be determined in accordance with MTO LS-705, and the results shall be reported to the nearest second decimal, i.e. 0.01.

R - hydrometer reading with meniscus correction

$$R = H_s - H_c$$

H_s - hydrometer reading in sedimentation cylinder at elapsed time T

H_c - hydrometer reading in control cylinder at elapsed time T

W - oven-dried mass of soil in a total test sample represented by mass of soil dispersed in grams

11.4 Diameter of Soil Particle

The diameter of soil particle corresponding to the percentage of soil remaining in suspension shall be calculated according to Stokes' law. This law considers the terminal velocity of a falling sphere in an infinity of liquid. Calculate and record the constant (K), coefficient of viscosity (η) and particle diameter (D) to four significant digits (i.e. to the nearest 0.0001).

$$D = k \times (L/T)^{1/2}$$

Where D - diameter of soil particles in mm

K - a constant depends on the coefficient of viscosity of the suspending medium, temperature of the suspension and the specific gravity of the soil particles. The constant k shall be calculated using the equation given below or obtained from Table 3.

$$K = 5.533 \times 10^{-3} (\eta / (G_s - 1))^{1/2}$$

η - coefficient of viscosity of the suspending medium in millipoises

$$\eta = (2.7183)^C \times 14.77$$

$$C = ((\ln T_c - 1.4443)^2) / (-6.3182)$$

T_c - average temperature of the suspension in °C at elapsed time T

L - effective floating depth of the hydrometer bulb in cm (refer to Figure 2d)

$$L = L_1 + \frac{1}{2}(L_2 - V_B/A) - h_s (H_s + H_m)$$

L_1 - distance from the top of the bulb to reference point ('O'-reading) in cm at elapsed time T

L_2 - overall length of the hydrometer bulb in cm

V_B - volume of hydrometer bulb in cm³ from Section 7.2.1 or 7.2.2

A - cross-sectional area of sedimentation cylinder in cm² from Section 7.2.3

h_s - distance between the scale dimensions in cm/div. (refer to Figure 2e)

H_m - meniscus correction in divisions (g/L) from Section 7.1.2

Table 3

Temperature in °C	Viscosity of Water in Millipoises	Temperature in °C	Viscosity of Water in Millipoises
18.0	10.6082	23.0	9.3925
18.5	10.4747	23.5	9.2843
19.0	10.3441	24.0	9.1783
19.5	10.2162	24.5	9.0744
20.0	10.0909	25.0	8.9726
20.5	9.9684	25.5	8.8728
21.0	9.8483	26.0	8.7749
21.5	9.7308	26.5	8.6790
22.0	9.6157	27.0	8.5849
22.5	9.5029	27.5	8.4926

Sieve Analysis Values for Portion Passing 2.0 mm Sieve

- 11.4.1 Calculate the cumulative percentage of soil sample retained on the 2.0 mm sieve as described in Section 11.1.3 or by subtracting the percent passing 2.0 mm sieve (Section 11.1.1) from 100. To calculate the mass of the portion retained on 2.0 mm sieve, multiply the percentage retained on 2.0 mm sieve by the mass of the total sample represented by the mass of the soil used (M_t). This mass should be equivalent to the mass of coarse material, M_c , retained on 2.0 mm sieve.
- 11.4.2 Calculate the mass of soil passing 75 μ m sieve by adding the fractional masses retained on all the sieves, including 2.0 mm sieve, and subtract this cumulative mass from the total mass M_t .
- 11.4.3 Calculate the total masses passing or retained on each of the sieves finer than 2.0 mm sieve using the method described in 11.1.2 or 11.1.3.

11.5 Report

The results of the grain size analysis are usually presented in the form of a distribution curve. This curve is obtained by plotting the soil particle diameter against percent finer. The report shall include the following:

- 11.5.1 Details of Soil Sample:
 - 11.6.1.1 Maximum size of soil particle
 - 11.6.1.2 Soil classification
 - 11.6.1.3 Atterberg Limits (LL and PL)
 - 11.6.1.4 Specific gravity of soil particles
 - 11.6.1.5 Mass of dispersing agent (sodium hexametaphosphate) used in 1 000 ml
- 11.5.2 Details of hydrometer and sedimentation cylinder:
 - 11.5.2.1 Volume of hydrometer bulb
 - 11.5.2.2 Length of hydrometer bulb
 - 11.5.2.3 Length from '0'-reading to the top of bulb
 - 11.5.2.4 Distance between the scale dimensions
 - 11.5.2.5 Cross-sectional area of the sedimentation cylinder
- 11.5.3 Percentage passing and retained on each sieve should be tabulated and presented by plotting on a semi-log graph.
- 11.5.4 In the case of materials tested for compliance with any specification, the fraction called for in that specification shall be reported.

12.0 Use of Laboratory Control Sample:

- 12.1 Every 10 samples, but at least every week in which a sample is tested, a sample of the reference soil shall also be tested. The material shall be taken from a stock supply maintained by the Soils and Aggregates Section.

- 12.2 Control Chart Use: The percentage of silt and clay sized particles of the last twenty samples of reference material shall be plotted on a control chart in order to demonstrate the performance of the laboratory.

HYDROMETER ANALYSIS

Hydrometer and Soil Sample Details

Project:	Sample No.:	Date:
Borehole No.:	Lab No.:	Tested By:
Sample Depth:	Sample Description:	Checked By:
SOIL INFORMATION	HYDROMETER DETAILS	CALCULATION OF DRY SOIL MASS
Liquid Limit (LL):	Volume of Bulb (V_B): cm³	Oven Dried Mass (W_o): g
Plasticity Index (PI):	Length of Bulb (L_2): cm	Air Dried Mass (W_a): g
Soil Classification:	Length from '0' Reading to Top of Bulb (L_1): cm	Hygroscopic Corr. Factor ($F=W_o/W_a$):
Specific Gravity (G_s):	Scale Dimension (h_s): cm /Div.	Air Dried Mass in Analysis (M_a): g
Sg. Correction Factor (α):	Cross-Sectional Area of Cylinder (A): cm²	Oven Dried Mass in Analysis (M_o): g
Mass of Dispersing Agent /Litre: g	Meniscus Correction (H_m):	% Passing 2.0 mm Sieve (P_{10}):
		Sample Represented (W):

$$M_o = F \times M_a$$

$$W = (M_o/P_{10}) \times 100$$

$$P = (\alpha RW) \times 100$$

$$D = K (L/T)^{1/2}$$

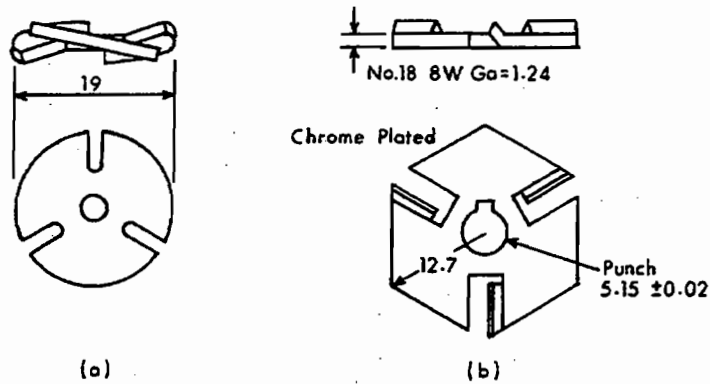
$$K = 5.533 \times 10^{-3} (\eta / (G_s - 1))^{1/2}$$

$$\eta = (2.7183)^C \times 14.77$$

$$C = ((\ln T_c - 1.4443)^2) / (-6.3182)$$

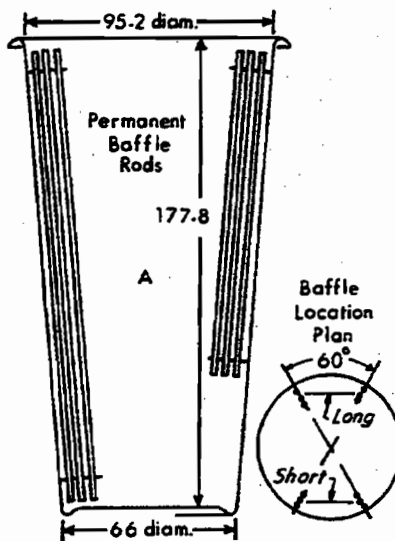
$$L = L_1 + \frac{1}{2} (L_2 - V_B/A) - h_s (H_s + H_m)$$

[illegible]



Dimensions are in millimetres

Figure 1a - Details of Stirring Paddles



Dimensions are in millimetres

Figure 1b - Details of Special Dispersion Cup

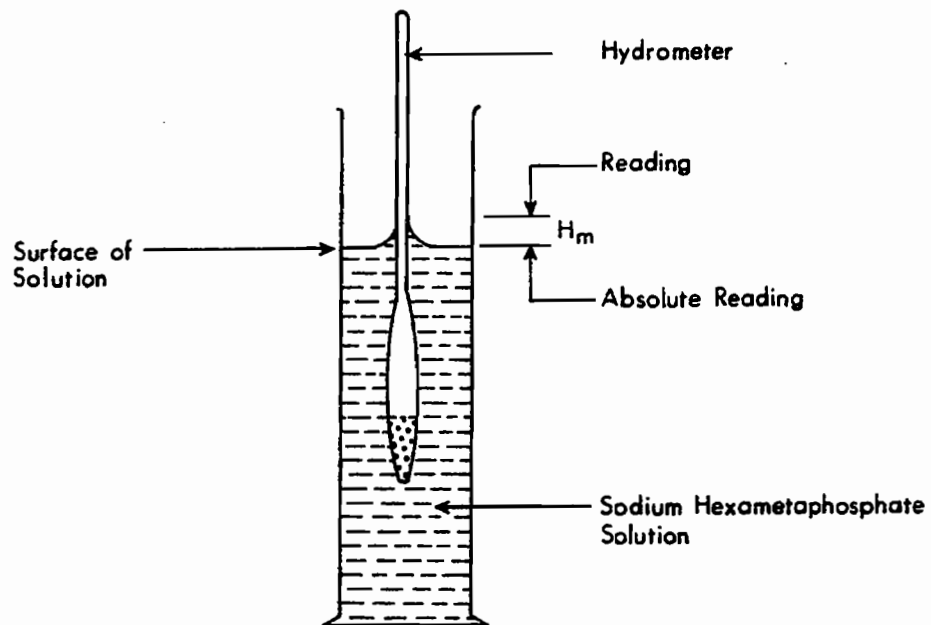


Figure 2a - Determination of Meniscus Correction

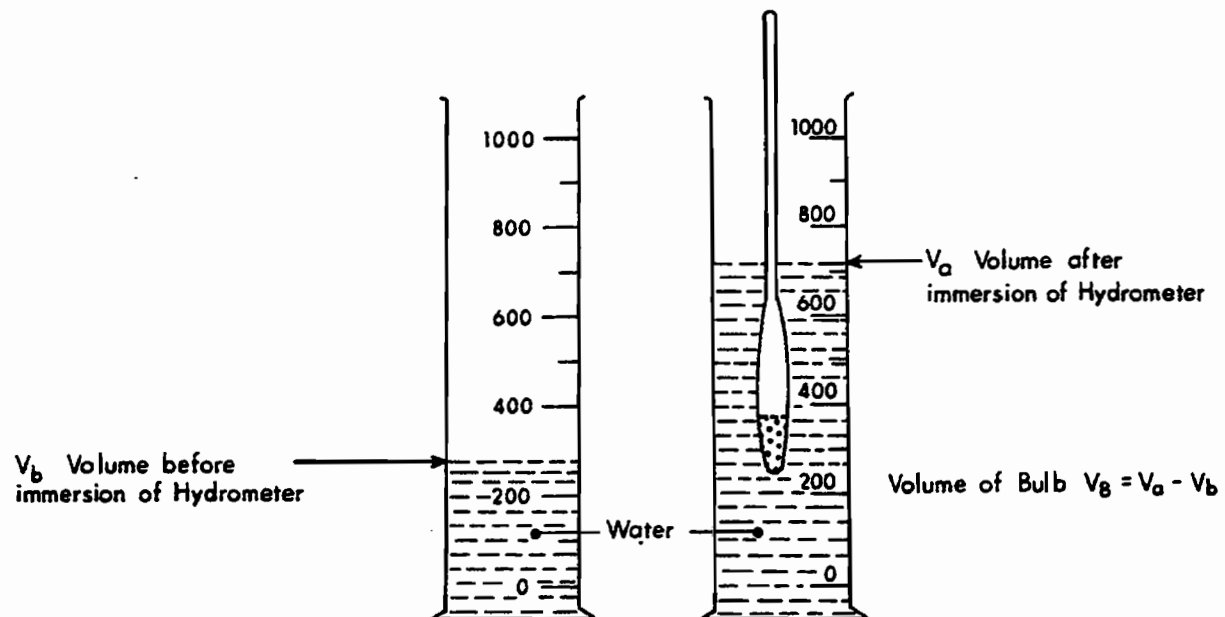


Figure 2b - Volume of Hydrometer Bulb

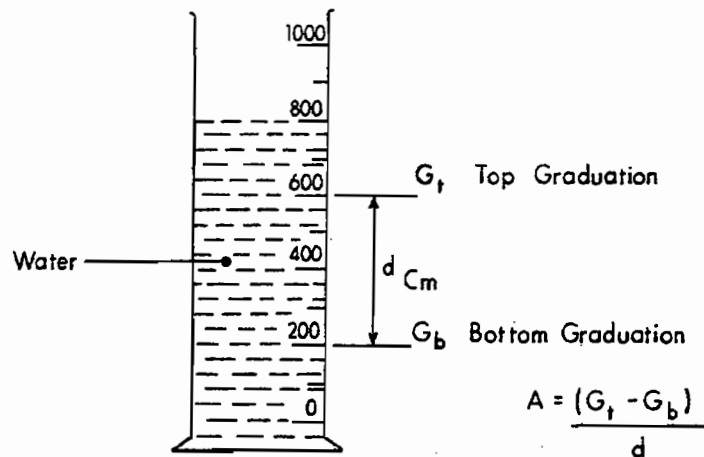


Figure 2C - Cross-Sectional Area of Sedimentation Cylinder

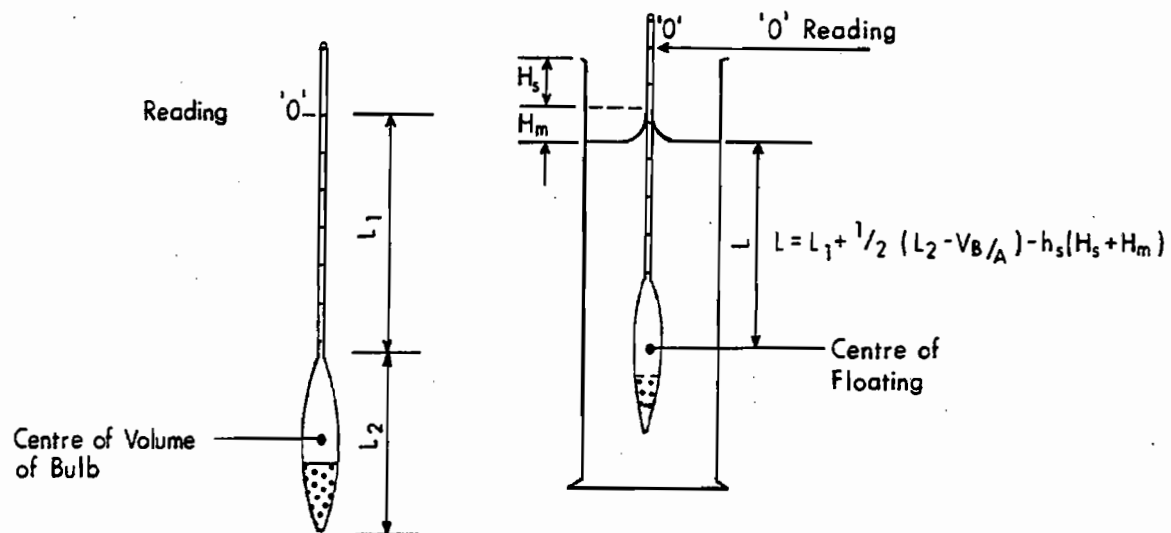


Figure 2d - Effective Floating Depth of Hydrometer Bulb

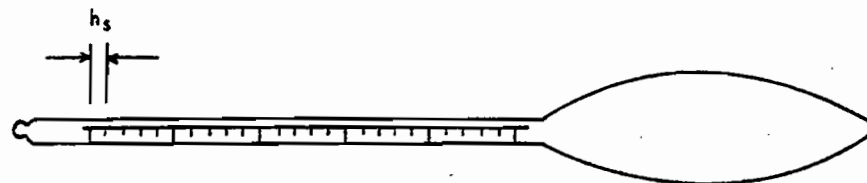


Figure 2e - Distance Between Scale Dimensions

METHOD OF TEST FOR LIQUID LIMIT, PLASTIC LIMIT AND PLASTICITY INDEX OF SOILS

1. SCOPE

1.1 This method covers the determination of the liquid limit, plastic limit and plasticity index of a soil.

2. RELEVANT DOCUMENTS

2.1 ASTM D 4318

2.2 AASHTO T 89

3. PROCEDURE

3.1 Procedures of ASTM Standard D 4318 shall be followed.

4. USE OF LABORATORY CONTROL SAMPLE

4.1 Every 10 samples, but at least every week in which a sample is tested, a sample of the standard reference soil shall also be tested. The material shall be taken from a stock supply maintained by the Soils and Aggregates Section.

4.2 Control Chart Use: The liquid limit, plastic limit and plasticity index of the last twenty samples of reference material shall be plotted on control charts in order to monitor the performance of the laboratory.

5. REPORT

The report shall include the following:

5.1 The liquid limit, plastic limit shall be plotted on a graph from which the plasticity index can be determined and reported, (see Figure 1, Atterberg Limits Soils Data Card).

5.2 With each test report, include the results of the most recently tested reference material and the control charts for the last twenty samples of reference material.



ATTERBERG LIMITS
LABORATORY SERVICES

W.O. OR W.P. NO. _____				BOREHOLE NO. _____			
OPERATOR _____				DATE _____			
(A) LIQUID LIMIT							
SAMPLE NO.							
NO. OF BLOWS							
DISH NO.							
DISH + WET SOIL							
DISH + DRY SOIL							
MOISTURE							
DISH							
DRY SOIL							
% MOISTURE							
(B) PLASTIC LIMIT							
DISH NO.							
DISH + WET SOIL							
DISH + DRY SOIL							
MOISTURE							
DISH							
DRY SOIL							
% MOISTURE							
PLASTIC LIMIT %							
LIQUID LIMIT %							
PLASTICITY INDEX							

PH-CC-325 9-73

Figure 1 Atterberg Limits of Soils Data Card

METHOD OF TEST FOR DETERMINATION OF SPECIFIC GRAVITY OF SOILS

1. SCOPE

- 1.1 This method covers the determination of the specific gravity of soils that pass 4.75 mm sieve.
- 1.2 When the soil is composed of particles larger than 4.75 mm, procedures outlined in Test Method MTO LS-604 shall be used for the material retained on 4.75 mm sieve, and this test method shall be used for material passing the 4.75 mm sieve. The weighted average of the two values shall be the specific gravity value for the soil.
- 1.3 Procedures for performing test on oven-dried as well as moist specimens are provided. The test procedure to be used shall be specified by the authority requesting the test.
- 1.4 The specific gravity test shall be made on the material passing 2.0 mm sieve, when the specific gravity value is to be used for the hydrometer portion of the Test Method MTO LS-702 and for the calculation of volume of solids in the One-Dimensional Consolidation Test Method ASTM D 2435.

2. RELEVANT DOCUMENTS

- 2.1 ASTM D 854 -98
- 2.2 AASHTO T 100
- 2.3 MTO LS-604
- 2.4 MTO LS-702

3. DEFINITION

- 3.1 The Specific Gravity of a soil is the ratio of the mass of a given volume of the material at a stated temperature to the mass of an equal volume of de-aired or gas-free distilled water at a stated temperature.

4. SIGNIFICANCE AND USE

- 4.1 The specific gravity of a soil is used in relating a weight of soil to its volume and in calculation of phase relationship, i.e., the relative volume of solids to water and air in a given volume soil.
- 4.2 The specific gravity is used in the computations of most of the laboratory tests, and is needed in nearly all pressure, settlement and stability problems in soil engineering.

5. APPARATUS

- 4.1 PYCNOMETER: The volume of the pycnometer shall be at least two times the volume of the soil to be tested, and shall consist of one of the following depending on the maximum size of the largest particle:
- 4.1.1 Stoppered Bottle, having a capacity of at least 50 ml. The stopper shall be of the same material as the bottle, and shall have a small hole through its centre to permit the emission of air and surplus water when the stopper is put in place.
- 4.1.2 Volumetric Flask, having a capacity of at least 100 ml.
- 4.2 DESICCATOR: A desiccator cabinet or large desiccator jar of suitable size containing silica gel or anhydrous calcium sulphate
- 4.3 BALANCE: A balance meeting the requirements of ASTM D 4753, Class GP1, and readable, without estimation to at least 0.1% of the specimen mass.
- 4.4 THERMOMETER: A thermometer readable to 0.5° C, and shall be calibrated to a thermometer accurate to 0.1° C.
- 4.5 OVEN: A thermostatically controlled, forced-draft type oven, capable of maintaining a uniform temperature throughout the drying chamber.
- 4.6 VACUUM SYSTEM: A vacuum pump capable of producing a partial vacuum of 100 mm Hg absolute pressure.

5. CALIBRATION OF PYCNOMETER

- 5.1 Determine and record the mass of a clean and dry pycnometer. Fill the pycnometer with distilled water to the calibration mark. After a visual inspection of the pycnometer and its content to ensure that there are no air bubbles, weigh and record the mass of pycnometer and water, m_a . Insert a thermometer in the water and record the temperature of the water, T_i , to the nearest 0.5° C.
- 5.2 From the mass m_a determined at the observed temperature T_i , prepare a table of values of masses m_a for a series of temperatures that are likely to be encountered during performance of the test. The values of m_a can be determined experimentally or calculated as follows:

$$m_a \text{ (at } T_x) = \frac{\text{density of water at } T_x}{\text{density of water at } T_i} \times [m_a(\text{at } T_i) - m_f] + m_f$$

where m_a = mass of pycnometer and water, g

m_f = mass of pycnometer, g

T_i = observed temperature of water, °C

T_x = any other desired temperature, °C

6. TEST SPECIMEN

- 6.1 The test specimen shall be representative of the total sample, and shall be oven-dried or moist for specimens of organic soils and high plastic clays. The minimum mass of specimen in its oven-dried state shall as follows:

Maximum Particle Size (100% Passing)	Sieve Size	Minimum Mass g
2.00 mm	No. 10	20
4.75 mm	No. 4	100

- 6.2 Oven-dried specimens shall be prepared by drying to a constant mass in an oven maintained at $110 \pm 5^{\circ}\text{C}$ and cooled it in a desiccator.
- 6.3 Moist specimens of high plastic clays shall be dispersed in distilled water by using the equipment specified in Section 3.3 of MTO LS-702, before the soil is placed in the pycnometer. A pycnometer with capacity not less than 500 ml shall be used when the test is performed on moist specimens.

7. TEST PROCEDURE

7.1 PROCEDURE FOR OVEN-DRIED SPECIMEN:

- 7.1.1 Prepare the specimen in accordance with Section 6.2 and keep it in a desiccator until ready for placing it in the pycnometer.
- 7.1.2 Select three clean, dry and calibrated pycnometers with capacity to accommodate twice the volume of the test specimens to be tested. Weigh and record the mass of the pycnometers selected. Place the soil specimen in the pycnometer. Weigh and record the mass of the specimen and pycnometer.
- 7.1.3 Fill the pycnometers with distilled water to a level slightly above the mark of soil (20 to 30 ml) to cover the test specimen completely. The test specimens shall be soaked for at least 12 hours.

Note 1: Kerosene may be used in place of distilled water, when soils that contain significant fraction of organic matter or that expands when water is added to oven-dried samples. If kerosene is used, a vacuum system must be used to remove the entrapped air.

- 7.1.4 Entrapped air from the test specimen shall be removed by one of the following methods:

- 7.1.4.1 Place all three pycnometers with their contents in a desiccator connected to a vacuum pressure not exceeding 100 mm Hg, and subject the contents to the vacuum for at least 30

minutes. Alternatively, the pycnometer shall be connected to the vacuum pump directly. Gently agitate the pycnometer periodically to assist in the removal of air, while the vacuum pressure is being applied. During this operation, care shall be taken to avoid violent boiling of soil specimen by reducing the air pressure at a slower rate. Upon removal of the entrapped air completely, gently release the vacuum and remove the pycnometers from the desiccator

Note 2: Oven dried specimens may require 2 to 4 hours to remove the entrapped air. However, low to high plastic clay specimens tested at its natural moisture content may require 4 to 8 hours to remove entrapped air. A larger pycnometer may be required, if violent boiling cannot be stopped by reducing the vacuum pressure.

7.1.4.2 Alternatively, the entrapped air shall be removed by boiling the specimen gently for 10 minutes. Pycnometer shall be gently agitated periodically to assist in the removal of air. Upon removal of the entrapped air, cool the heated pycnometer to the room temperature.

7.1.5 Carefully fill the pycnometer with distilled water at room temperature to slightly below the calibration mark. Add distilled water slowly and carefully to avoid entrapment of air bubbles in the specimen. Allow the pycnometer to reach a uniform water temperature.

7.1.6 Fill the pycnometer with distilled water at the same temperature to its calibration mark. Carefully remove the excess water from the outside of the pycnometers using an absorbent cloth or paper towel. Weigh and record the pycnometer filled with soil and water.

7.1.7 Insert the thermometer into the water, and record its temperature to the nearest 0.5° C.

7.2 PROCEDURE FOR MOIST SPECIMENS:

7.2.1 Place the test specimens prepared in accordance with Section 6.3 in three calibrated pycnometers, and proceed as described in Sections 7.1.4 to 7.1.7.

7.2.2 Carefully remove the specimens from the pycnometers and dry the specimens to a constant mass in suitable containers in an oven maintained at $110 \pm 5^{\circ}\text{C}$. Cool the specimens in a desiccator to the room temperature.

7.2.3 Weigh and record the mass of oven-dried specimen.

8. CALCULATIONS

8.1 Calculate the specific gravity of the soil, based on water at a temperature T_x , as follows:

$$\text{Specific Gravity, } G \text{ at } T_x = \frac{m_o}{[m_o + (m_a - m_b)]}$$

Where, m_o = mass of oven-dried specimen, g.

m_a = mass of pycnometer filled with water at temperature T_x , g, this value can be obtained from the table prepared under Section 5.2

m_b = mass of pycnometer filled with water and soil at temperature T_x , g

T_x = temperature of the contents of the pycnometer when mass m_b was determined, °C

- 8.2 Unless stated otherwise, relative density values shall be reported based on water at 20°C. This value shall be calculated from the value obtained at temperature T_x , as follows:

Specific Gravity G at 20°C = $K (G \text{ at } T_x)$

Where, K is a number found by dividing the density of water at temperature T_x , by the density of water at 20°C. Values for a range of temperatures are given in Table 1.

- 8.3 Calculate the weighted average specific gravity, G_{ws} , for soil samples that contain both material passing and retained on 4.75 mm (No. 4) sieve using the equation given below.

$$G_{ws} = 1/[(R/100G_R) + (P/100G_S)]$$

Where,

P – Percent of soil particles passing the 4.75 mm sieve

R – Percent of material retained on the 4.75 mm sieve

G_R – Specific gravity (Apparent Density) of particles retained on 4.75 mm sieve as determined by MTO LS-604

G_S – Specific gravity of soil particles passing 4.75 mm sieve as determined by this test procedure

Table 1: Density of Water and Conversion Factor K for Various Temperatures

Temperature, °C	Density of Water (g/cc)	Correction Factor K	Temperature, °C	Density of Water (g/cc)	Correction Factor K
16.0	0.99887	1.0007	23.5	0.99745	0.9992
16.5	0.99889	1.0007	24.0	0.99732	0.9991
17.0	0.99880	1.0006	24.5	0.99720	0.9990
17.5	0.99871	1.0005	25.0	0.99707	0.9988
18.0	0.99862	1.0004	25.5	0.99694	0.9987
18.5	0.99853	1.0003	26.0	0.99681	0.9986
19.0	0.99843	1.0002	26.5	0.99668	0.9984
19.5	0.99833	1.0001	27.0	0.99654	0.9983
20.0	0.99823	1.0000	27.5	0.99640	0.9982
20.5	0.99812	0.9999	28.0	0.99626	0.9980
21.0	0.99802	0.9998	28.5	0.99612	0.9979
21.5	0.99791	0.9997	29.0	0.99597	0.9977
22.0	0.99780	0.9996	29.5	0.99582	0.9976
22.5	0.99768	0.9995	30.0	0.99567	0.9974
23.0	0.99757	0.9993			

- 8.3 The calculated test results from three samples should be within 0.02 of each other, or the test must be repeated.

9. REPORTING OF RESULTS

- 9.1 The data card shown in Figure 1 may be used for recording the data and reporting the results. The mean value of the relative density shall be reported to three decimal places.
- 9.2 The report shall include the following:
- 9.2.1 Identification of the sample such as bore hole number, sample number
 - 9.2.2 Specific Gravity value of the soil at 20° C to the nearest three decimal
 - 9.2.3 Maximum particle size of the test specimen
 - 9.2.4 Type of fluid used, if distilled water not used
 - 9.2.5 The portion on which the test was performed, if any portion of the original sample was eliminated



SPECIFIC GRAVITY

Sample No: _____

Date: _____

Project: _____

Specimen No.	G1	G2	G3
Pycnometer Reference No.			
Mass of Pycnometer (m_f)			
Mass of Dry Specimen + Pycnometer (m_s)			
Mass of Dry Soil ($m_s - m_f = m_o$)			
Mass of Pycnometer + Water (m_a)			
Mass of Pycnometer + Specimen + Water (m_b)			
Mass of Water Displaced = $[(m_a + m_o) - m_b]$			
Temperature, T_x , of the Content			
Specific Gravity, $G = \frac{m_o}{[m_o + (m_a - m_b)]}$			
Mean Specific Gravity at Temperature T_x , $G_{avg} = (G_1 + G_2 + G_3)/3$			
Specific Gravity at 20° C, $G_s = K (G_{avg})$			

Removal of entrapped air by

a)	Vacuum	☐
b)	Boiling	☐

Name of Operator: _____

Remarks: _____

Figure 1 Specific Gravity Data Card

METHOD OF TEST FOR MOISTURE-DENSITY RELATIONSHIP OF SOILS USING 2.5 kg RAMMER AND 305 mm DROP

1. SCOPE

1.1 This method covers the determination of the relationship between the moisture content and density of soils using a mold of given size with a 2.5 kg rammer dropped from a height of 304.8 mm.

Three alternate procedures are provided as follows:

Procedure 1 - 101.6 mm mold with material passing a 4.75 mm sieve

Procedure 2 - 101.6 mm mold with material passing a 26.5 mm sieve

Procedure 3 - 152.4 mm mold with material passing a 26.5 mm sieve.

1.2 The method to be used should be indicated in the specifications for the material being tested. If no method is specified, the provisions of Procedure 1 shall govern.

2. RELEVANT DOCUMENTS

2.1 ASTM D 698

2.2 AASHTO T 99

3. APPARATUS

3.1 **MOLDS:** The molds shall be cylindrical in shape, made of metal, with a detachable collar assembly. The mold and collar assembly shall be so constructed that it can be fastened firmly to a detachable base. The dimensions are as follows:

3.1.1 **Mold:** 101.6 mm internal diameter and meeting the specifications described in ASTM D698.

3.1.2 **Mold:** 152.4 mm internal diameter and meeting the specifications described in ASTM D698.

3.2 **RAMMER**

3.2.1 **Manually Operated Rammer:** Meeting the specifications described in ASTM D698.

3.2.2 **Mechanical Rammer:** A metal rammer that is mechanically operated by a device equipped to control the height of drop as described in 3.2.1, (Reference to manual rammer, ASTM D698) and to uniformly distribute such drops on the surface of the soil. The operating mass shall be determined from calibration according to MTO Method LS-708, Calibration of Mechanical Laboratory Soil Compactors. There shall be 2.54 ± 0.76 mm clearance between the rammer and the smallest internal diameter of the mold.

3.3 **SAMPLE EXTRUDER (Optional):** A jack, frame or other hydraulically or mechanically operated device adapted for the purpose of extruding compacted specimens from the mold.

3.4 **BALANCES:** A balance or scale of at least 15 kg capacity sensitive to 5 g and a balance of at least 1000 g capacity sensitive to 0.1 g.

3.5 **DRYING OVEN:** A thermostatically controlled oven capable of maintaining a temperature of $110 \pm 5^{\circ}\text{C}$.

3.6 **STRAIGHTEDGE:** A steel straightedge 300 mm in length and with one edge beveled.

3.7 **MIXING TOOLS:** Miscellaneous tools such as a rotatable table on which to place the mixing bowl, spoon, trowel, spatula, etc. together with a means of adding controlled amounts of water to the sample while mixing. A mechanical mixing device may be used for some soils such as sand which will not clog the blades.

4. **PREPARATION OF SPECIMEN**

4.1 Take a sample weighing approximately 3.5 kg, 4.5 kg or 9 kg for Procedure 1, 2 and 3 respectively, obtained in accordance with the Method of Dry Preparation of Soil Samples (MTO Method LS-700) or the Method for Preparation of Coarse Aggregate (MTO Method LS-600).

5. **TEST PROCEDURE**

5.1 **PROCEDURE 1**

5.1.1 Thoroughly mix the representative sample (approximately 3.5 kg) with sufficient water to bring it to approximately four to six percentage points below optimum moisture content.

5.1.2 Form the specimen by compacting the material in the 101.6 mm mold (with collar and base plate attached) in three equal layers to give a final compacted depth not exceeding 127 mm. Each layer shall be compacted by 25 blows of the rammer, uniformly distributed over the surface of the soil. During compaction, the mold shall rest on a rigid base such as provided by a concrete cube weighing not less than 90 kg. When compaction is completed, carefully remove the collar and trim the surface of the soil even with the top of the mold using the straightedge. Remove the base plate and weigh the soil-filled mold. Record the amount of water added and the mass of the soil-filled mold.

5.1.3 Remove the material from the mold and cut vertically through the centre, taking a representative portion to determine and record the moisture content according to the Method of Determination of Moisture Content of Soils (MTO Method of LS-701).

5.1.4 Thoroughly break up the remainder of the material until it will pass a 4.75 mm sieve as judged by eye. Add a sufficient amount of water to increase the moisture content of the sample by one or two percentage points, and repeat the procedure in 5.1.2 for each increment of water added. Continue this procedure until there is either a decrease or no change in the wet density, ρ_m , in g/cm^3 of the compacted soil.

Note 1: This procedure is performed on samples containing less than 15 percent retained on a 4.75 mm sieve material, which is discarded. The maximum wet and dry densities and optimum moisture

content must be corrected to account for the effect of the stone content. The correction for amounts less than 5 percent can be ignored as the effect will be negligible.

5.2 PROCEDURE 2

Note 2: This procedure is identical to Procedure 1 with the exception that a 4.5 kg sample of pass 26.5 mm sieve material is used. Any oversize shall be replaced by an equal amount of pass 26.5 mm retained 4.75 mm material which shall have an equivalent grading to that portion of the original sample.

Note 3: This procedure is normally used only when there is insufficient material for preparation of a 9 kg compaction sample.

5.3 PROCEDURE 3

Note 4: This procedure is similar to Procedure 1 with the exception that a 9 kg sample of pass 26.5 mm sieve material is used. The specimens are compacted in three equal layers to give a total depth not to exceed 127 mm in the 152.3 mm mold, each layer being compacted by 56 uniformly distributed blows from the rammer.

Note 5: Any oversize material shall be replaced by an equal amount of pass 26.5 mm retained 4.75 mm material which shall have an equivalent grading to the original sample.

Note 6: In the case of granular 'A' materials, the oversize (pass 37.5 mm, retained 26.5 mm) should be reviewed and the final results corrected for the percent oversize using the graphical construction (Note 7).

5.4 In all these procedures, it is desirable to prepare at least five trials to produce an acceptable compaction curve. The idealized curve would consist of two points increasing in density, then one point at or near the optimum moisture content and maximum density, and two points of decreasing density, all with increasing moisture content.

6. CALCULATION (FIGURE 1)

6.1 Calculate the wet density, in g/cm³, for each trial by dividing the mass of wet soil by the mold volume in cm³.

6.2 Calculate the moisture content for each trial according to MTO Method LS-701.

6.3 Calculate the dry density, in g/cm³ as follows:

$$pd = \frac{pm}{w + 100} \times 100$$

where: w = percentage moisture in the specimen

pd = dry density, g/cm³

pm = wet density, g/cm³

6.4 Plot the wet and dry densities in g/cm³ as ordinates and the corresponding moisture contents as abscissas. Draw two smooth curves, one joining the plotted points for wet densities, and one for dry densities. The moisture content corresponding to the peak of the dry density curve shall be termed the OPTIMUM MOISTURE CONTENT of the soil.

6.5 Corrections to calculated values

6.5.1 The calculations already made for maximum densities and optimum moisture content are on the portion of the soil passing a 4.75 mm sieve and must be corrected in Procedure 1 to compensate for oversize material, which would be included in the material undergoing compaction in the field.

6.5.2 The dry density may be corrected by applying the following formula:

$$W_t = \frac{W_o W_c}{O W_c + C W_o}$$

where: W_t = calculated maximum dry density, g/cm³

W_o = bulk density of the oversize

W_c = measured maximum dry density of the portion of soil passing a 4.75 mm sieve

O = fraction by mass of oversize particles in the soil expressed as a decimal

C = fraction by mass of the portion of the soil passing a 4.75 mm sieve expressed as a decimal

Note 7: It is more convenient to utilize a graphical construction for the above calculation using a constant figure for the bulk relative density (Figure 2).

6.5.3 The optimum moisture content of the total soil is calculated as follows:

$$M_t = O A_o + C M_c$$

where: M_t = calculated optimum moisture content of the total soil expressed to 0.1 %

O = fraction by mass of the oversize particles expressed as a decimal

A_o = percentage of water absorbed by the oversize

C = fraction by mass of the portion of the soil passing a 4.75 mm sieve, expressed as a decimal

M_c = measured optimum moisture content of the portion of the soil passing a 4.75 mm sieve

Note 8: A figure of 3 % is normally used for A_o but if greater accuracy is required an absorption test shall be performed.

7. REPORTING OF RESULTS

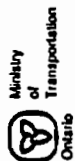
7.1 The report shall indicate the method used and also include the following:

- 7.1.1 Maximum wet density,
- 7.1.2 Maximum dry density,
- 7.1.3 Optimum moisture content

Note 9: Both uncorrected and corrected values for items 7.1.1 and 7.1.2 shall be given and reported to the nearest 0.001 and 7.1.3 to the nearest 0.1 %.

8. GENERAL NOTES AND PRECAUTIONS

- 8.1 The rammer should always be held in a vertical position during compaction.
- 8.2 Rebound of the rammer from the top of the sleeve must be avoided, otherwise the compactive effort will change.
- 8.3 Samples of heavy clays (CI - CH) should be cured at the initial water content for a minimum of 12 h in a plastic bag to ensure even moisture distribution.
- 8.4 To avoid injury keep fingers away from the ram of the hydraulic extruder or the rammer of the mechanical compactor.
- 8.5 Obtaining an even surface on a compacted granular material with the straightedge is very difficult. An attempt should be made to balance voids in the surface with an approximately equal number of pieces of aggregate projecting from the surface of the sample, using a round steel rod as a gauge.
- 8.6 Observe and note if the material under test is being degraded by repeated test runs. If major aggregate breakdown occurs it may be necessary to use fresh material for each run.
- 8.7 Observe and note the presence and degree of free water.
- 8.8 Ensure that the rammer is maintained in a clean condition and that no build-up of soil occurs on the rammer which would affect the compactive effort.
- 8.9 For granular 'A' samples containing material passing 37.5 mm - retained 26.5 mm (Procedures 2 and 3), remove the retained 26.5 mm material, calculate the percentage and use the correction chart (Figure 2) to correct the maximum wet density obtained in the test.



LABORATORY TEST FOR SOIL COMPACTION PROCTOR METHOD										LAB. No.
DATE		OPERATOR		SAMPLE MASS						
FIELD No.		CONTRACT No.		HIGHWAY No.						
DESCRIPTION										
TEST No.										
WATER ADDED mL										
MOLD + WET SOIL										
TARE										
WET SOIL MASS										
WET DENSITY g/cm ³										
MOISTURE CONTENT DETERMINATIONS										
TIN No.										
TIN + WET SOIL										
TIN + DRY SOIL										
MOISTURE LOSS										
TARE										
DRY SOIL MASS										
% MOIST										
DRY DENSITY g/cm ³										
MOLD NO.										
MAX. WET DENSITY g/cm ³										
MAX. DRY DENSITY g/cm ³										
OPTIMUM MOISTURE %										
FIELD MOISTURE										
FIELD DENSITY g/cm ³										
COMPACTION										
REPORT BY										
PH-CC-330 89-03										

WET DENSITY (g/cm³)

= $\frac{\text{WET SOIL MASS}}{\text{VOL. MOLD}}$

MOISTURE CONTENT

= $\frac{\text{MOISTURE LOSS}}{\text{DRY SOIL MASS}} \times 100 \%$

DRY DENSITY (g/cm³)

= $\left(\frac{\text{WET DENSITY}}{100 + \% \text{ MOISTURE}} \right) \times 100$

REMARKS

Figure 1 Compaction Data Sheet

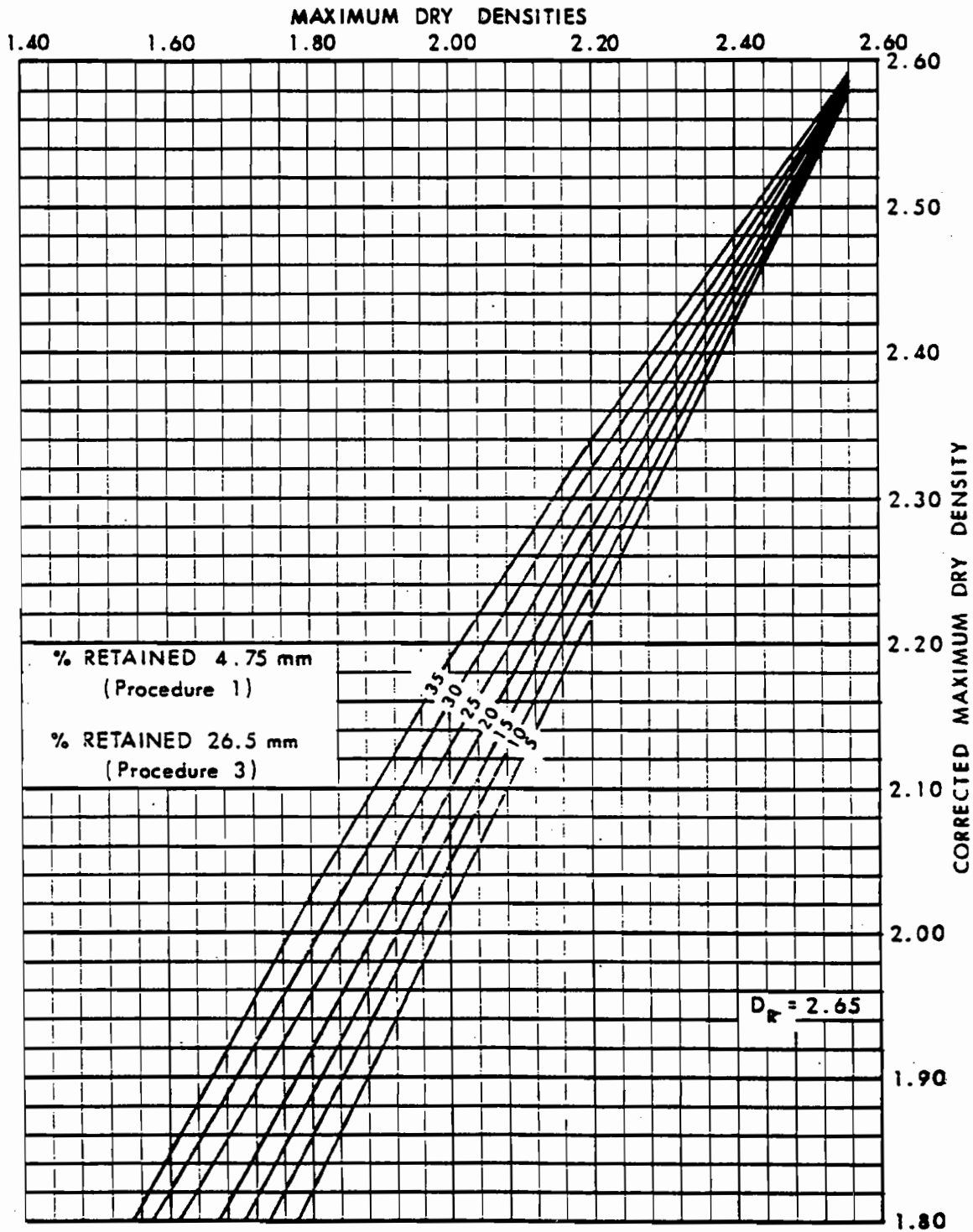


Figure 2 Plus 4.75 mm Correction Table for Dry Densities

**METHOD OF TEST FOR
MOISTURE-DENSITY RELATIONSHIP OF SOILS USING
4.5 kg RAMMER AND 457 mm DROP**

1. SCOPE

1.1 This method covers the determination of the relationship between the moisture content and density of soils using a mold of given size with a 4.5 kg rammer dropped from a height of 457 mm.

Three alternate procedures are provided as follows:

Procedure 1 - 101.6 mm mold with material passing a 4.75 mm sieve

Procedure 2 - 101.6 mm mold with material passing a 26.5 mm sieve

Procedure 3 - 152.4 mm mold with material passing a 26.5 mm sieve.

1.2 The method to be used should be indicated in the specifications for the material being tested. If no method is specified, the provisions of Procedure 1 shall govern.

2. RELEVANT DOCUMENTS

2.1 ASTM D 1557

2.2 AASHTO T 180

3. APPARATUS

3.1 MOLDS: The molds shall be cylindrical in shape, made of metal, with a detachable collar assembly. The mold and collar assembly shall be so constructed that it can be fastened firmly to a detachable base. The dimensions are as follows:

3.1.1 Mold: 101.6 mm internal diameter and meeting the specifications described in ASTM D 1557.

3.1.2 Mold: 152.4 mm internal diameter and meeting the specifications described in ASTM D 1557.

3.2 RAMMER

3.2.1 Manually Operated Rammer: Meeting the specifications described in ASTM D 1557.

3.2.2 Mechanical Rammer: A metal rammer that is mechanically operated by a device equipped to control the height of drop as described in 3.2.1, (Reference to manual rammer, ASTM D 1557) and to uniformly distribute such drops on the surface of the soil. The operating mass shall be determined from calibration according to MTO Method LS-708, Calibration of Mechanical Laboratory Soil Compactors. There shall be 2.54 ± 0.76 mm clearance between the rammer and the smallest internal diameter of the mold.

3.3 **SAMPLE EXTRUDER (Optional):** A jack, frame or other hydraulically or mechanically operated device adapted for the purpose of extruding compacted specimens from the mold.

3.4 **BALANCES:** A balance or scale of at least 15 kg capacity sensitive to 5 g and a balance of at least 1000 g capacity sensitive to 0.1 g.

3.5 **DRYING OVEN:** A thermostatically controlled oven capable of maintaining a temperature of $110 \pm 5^{\circ}\text{C}$.

3.6 **STRAIGHTEDGE:** A steel straightedge 300 mm in length and with one edge beveled.

3.7 **MIXING TOOLS:** Miscellaneous tools such as a rotatable table on which to place the mixing bowl, spoon, trowel, spatula, etc. together with a means of adding controlled amounts of water to the sample while mixing. A mechanical mixing device may be used for some soils such as sand which will not clog the blades.

4. **PREPARATION OF SPECIMEN**

4.1 Take a sample weighing approximately 3.5 kg, 4.5 kg or 9 kg for Procedure 1, 2 and 3 respectively, obtained in accordance with the Method of Dry Preparation of Soil Samples (MTO Method LS-700) or the Method for Preparation of Coarse Aggregate (MTO Method LS-600).

5. **TEST PROCEDURE**

5.1 **PROCEDURE 1**

5.1.1 Thoroughly mix the representative sample (approximately 3.5 kg) with sufficient water to bring it to approximately four to six percentage points below optimum moisture content.

5.1.2 Form the specimen by compacting the material in the 101.6 mm mold (with collar and base plate attached) in five equal layers to give a final compacted depth not exceeding 130 mm. Each layer shall be compacted by 25 blows of the rammer, uniformly distributed over the surface of the soil. During compaction, the mold shall rest on a rigid base such as provided by a concrete cube weighing not less than 90 kg. When compaction is completed, carefully remove the collar and trim the surface of the soil even with the top of the mold using the straightedge. Remove the base plate and weigh the soil-filled mold. Record the amount of water added and the mass of the soil-filled mold.

5.1.3 Remove the material from the mold and cut vertically through the centre, taking a representative portion to determine and record the moisture content according to the Method of Determination of Moisture Content of Soils (MTO Method of LS-701).

5.1.4 Thoroughly break up the remainder of the material until it will pass a 4.75 mm sieve as judged by eye. Add a sufficient amount of water to increase the moisture content of the sample by one or two percentage points, and repeat the procedure in 5.1.2 for each increment of water added. Continue this procedure until there is either a decrease or no change in the wet density, ρ_m , in g/cm^3 of the compacted soil.

Note 1: This procedure is performed on samples containing less than 15 percent retained on a 4.75 mm sieve material, which is discarded. The maximum wet and dry densities and optimum moisture content must be corrected to account for the effect of the stone content. The correction for amounts less than 5 percent can be ignored as the effect will be negligible.

5.2 PROCEDURE 2

Note 2: This procedure is identical to Procedure 1 with the exception that a 4.5 kg sample of pass 26.5 mm sieve material is used. Any oversize shall be replaced by an equal amount of pass 26.5 mm retained 4.75 mm material which shall have an equivalent grading to that portion of the original sample.

Note 3: This procedure is normally used only when there is insufficient material for preparation of a 9 kg compaction sample.

5.3 PROCEDURE 3

Note 4: This procedure is similar to Procedure 1 with the exception that a 9 kg sample of pass 26.5 mm sieve material is used. The specimens are compacted in five equal layers to give a total depth not to exceed 127 mm in the 152.3 mm mold, each layer being compacted by 56 uniformly distributed blows from the rammer.

Note 5: Any oversize material shall be replaced by an equal amount of pass 26.5 mm retained 4.75 mm material which shall have an equivalent grading to the original sample.

Note 6: In the case of granular 'A' materials, the oversize (pass 37.5 mm, retained 26.5 mm) should be reviewed and the final results corrected for the percent oversize using the graphical construction (Note 7).

5.4 In all these procedures, it is desirable to prepare at least five trials to produce an acceptable compaction curve. The idealized curve would consist of two points increasing in density, then one point at or near the optimum moisture content and maximum density, and two points of decreasing density, all with increasing moisture content.

6. CALCULATION (FIGURE 1)

6.1 Calculate the wet density, in g/cm³, for each trial by dividing the mass of wet soil by the mold volume in cm³.

6.2 Calculate the moisture content for each trial according to MTO Method LS-701.

6.3 Calculate the dry density, in g/cm³ as follows:

$$pd = \frac{pm}{w + 100} \times 100$$

where: w = percentage moisture in the specimen

pd = dry density, g/cm³

pm = wet density, g/cm³

6.4 Plot the wet and dry densities in g/cm³ as ordinates and the corresponding moisture contents as abscissas. Draw two smooth curves, one joining the plotted points for wet densities, and one for dry densities. The moisture content corresponding to the peak of the dry density curve shall be termed the OPTIMUM MOISTURE CONTENT of the soil.

6.5 Corrections to calculated values

6.5.1 The calculations already made for maximum densities and optimum moisture content are on the portion of the soil passing a 4.75 mm sieve and must be corrected in Procedure 1 to compensate for oversize material, which would be included in the material undergoing compaction in the field.

6.5.2 The dry density may be corrected by applying the following formula:

$$W_t = \frac{W_o W_c}{OW_c + CW_o}$$

where: W_t = calculated maximum dry density, g/cm³

W_o = bulk density of the oversize

W_c = measured maximum dry density of the portion of soil passing a 4.75 mm sieve

O = fraction by mass of oversize particles in the soil expressed as a decimal

C = fraction by mass of the portion of the soil passing a 4.75 mm sieve expressed as a decimal

Note 7: It is more convenient to utilize a graphical construction for the above calculation using a constant figure for the bulk relative density (Figure 2).

6.5.3 The optimum moisture content of the total soil is calculated as follows:

$$M_t = OA_o + CM_c$$

where: M_t = calculated optimum moisture content of the total soil expressed to 0.1 %

O = fraction by mass of the oversize particles expressed as a decimal

A_o = percentage of water absorbed by the oversize

C = fraction by mass of the portion of the soil passing a 4.75 mm sieve, expressed as a decimal

M_c = measured optimum moisture content of the portion of the soil passing a 4.75 mm sieve

Note 8: A figure of 3 % is normally used for A_o but if greater accuracy is required an absorption test shall be performed.

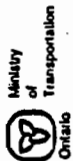
7. REPORTING OF RESULTS

- 7.1 The report shall indicate the method used and also include the following:
 - 7.1.1 Maximum wet density,
 - 7.1.2 Maximum dry density,
 - 7.1.3 Optimum moisture content

Note 9: Both uncorrected and corrected values for items 7.1.1 and 7.1.2 shall be given and reported to the nearest 0.001 and 7.1.3 to the nearest 0.1 % .

8. GENERAL NOTES AND PRECAUTIONS

- 8.1 The rammer should always be held in a vertical position during compaction.
- 8.2 Rebound of the rammer from the top of the sleeve must be avoided, otherwise the compactive effort will change.
- 8.3 Samples of heavy clays (CI - CH) should be cured at the initial water content for a minimum of 12 h in a plastic bag to ensure even moisture distribution.
- 8.4 To avoid injury keep fingers away from the ram of the hydraulic extruder or the rammer of the mechanical compactor.
- 8.5 Obtaining an even surface on a compacted granular material with the straightedge is very difficult. An attempt should be made to balance voids in the surface with an approximately equal number of pieces of aggregate projecting from the surface of the sample, using a round steel rod as a gauge.
- 8.6 Observe and note if the material under test is being degraded by repeated test runs. If major aggregate breakdown occurs it may be necessary to use fresh material for each run.
- 8.7 Observe and note the presence and degree of free water.
- 8.8 Ensure that the rammer is maintained in a clean condition and that no build-up of soil occurs on the rammer which would affect the compactive effort.
- 8.9 For granular 'A' samples containing material passing 37.5 mm - retained 26.5 mm (Procedures 2 and 3), remove the retained 26.5 mm material, calculate the percentage and use the correction chart (Figure 2) to correct the maximum wet density obtained in the test.



LABORATORY TEST FOR SOIL COMPACTION PROCTOR METHOD										LAB. No.
DATE		OPERATOR		SAMPLE MASS						
FIELD No.		CONTRACT No.		HIGHWAY No.						
DESCRIPTION										
TEST No.										
WATER ADDED mL										
MOLD + WET SOIL										
TARE										
WET SOIL MASS										
WET DENSITY g/cm ³										
MOISTURE CONTENT DETERMINATIONS										
TIN No.										
TIN + WET SOIL										
TIN + DRY SOIL										
MOISTURE LOSS										
TARE										
DRY SOIL MASS										
% MOIST										
DRY DENSITY g/cm ³										
VOLUME OF MOLD										
MOLD NO.										
MAX. WET DENSITY										
MAX. DRY DENSITY										
OPTIMUM MOISTURE										
FIELD MOISTURE										
FIELD DENSITY										
COMPACTION										
REPORT BY										

WET DENSITY (g/cm³)

$$= \frac{\text{WET SOIL MASS}}{\text{VOL. MOLD}}$$

MOISTURE CONTENT

$$= \frac{\text{MOISTURE LOSS}}{\text{DRY SOIL MASS}} \times 100 \%$$

DRY DENSITY (g/cm³)

$$= \left(\frac{\text{WET DENSITY}}{100 + \% \text{ MOISTURE}} \right) \times 100$$

REMARKS

Figure 1 Compaction Data Sheet

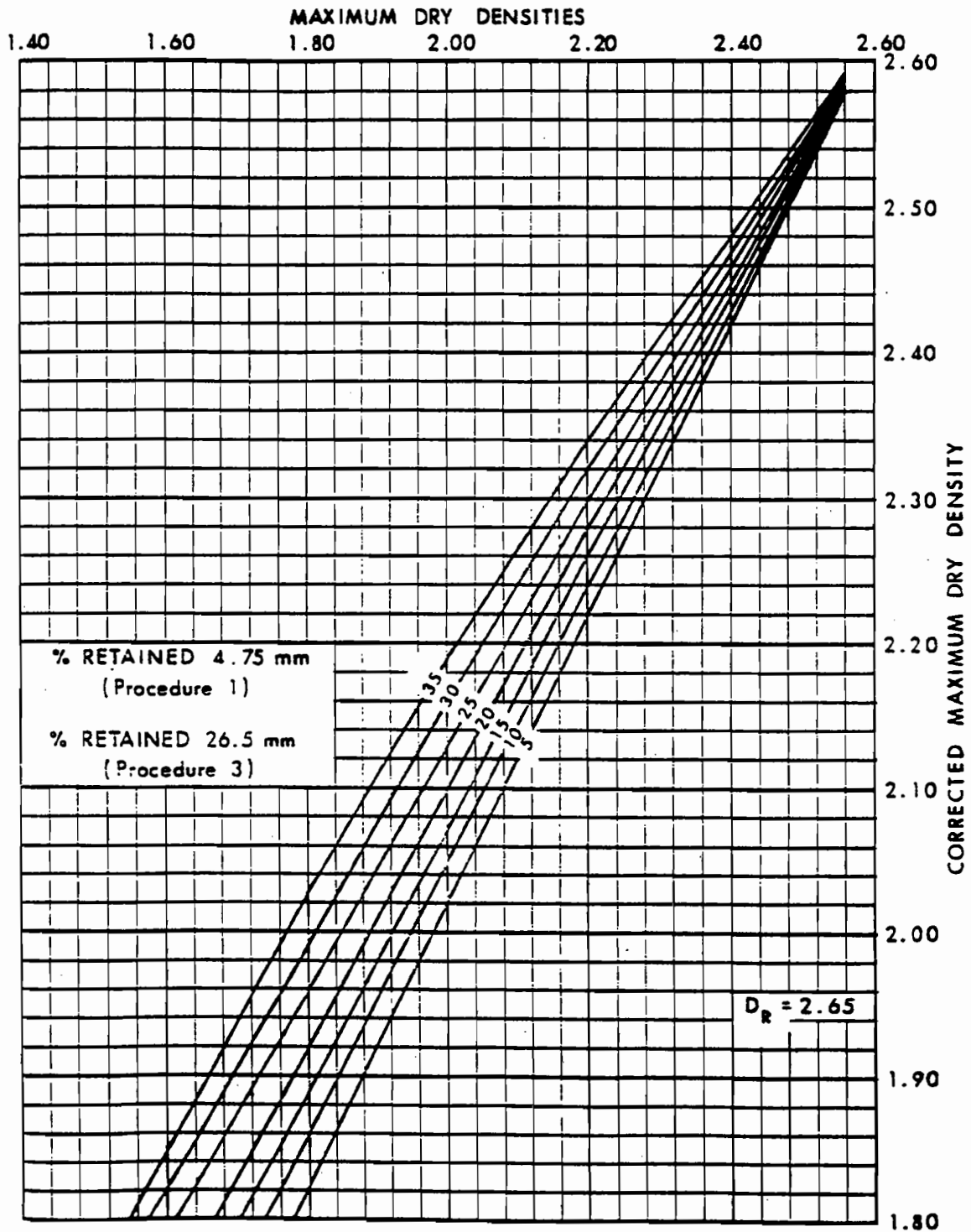


Figure 2 Plus 4.75 mm Correction Table for Dry Densities

METHOD OF CALIBRATION OF MECHANICAL LABORATORY SOIL COMPACTOR

1. SCOPE

1.1 This method for the calibration of mechanical laboratory soil compactors is for use in checking and adjusting mechanical devices to be used in compacting soil specimens for MTO Method LS-706, Test of Moisture-Density Relationship of Soils Using 2.5 kg Rammer and 305 mm Drop, and MTO Method LS-707, Test for Moisture-Density Relationship of Soils Using 4.5 kg Rammer and 460 mm Drop. Calibration is based on the deformation of a standard lead cylinder.

2. RELEVANT DOCUMENTS

2.1 ASTM D 2168

Note 1: Figures 1 through 4 refer to illustrations detailed in ASTM D 2168.

3. APPARATUS

3.1 LEAD DEFORMATION APPARATUS: Consisting of an anvil, guide collar and striking pin, as shown in Figure 1.

3.2 DIAL COMPARATOR: For measuring the deformation of the lead cylinders, as shown in Figure 2. An outside micrometer caliper reading to 0.025 mm may be used to measure the initial and final lengths of the lead cylinders to secure the deformation values.

3.3 GUIDE SLEEVE PEDESTAL: For use with guide sleeves used to control the height of drop of the rammers required in MTO Methods LS-706 and LS-707. A satisfactory pedestal design is shown in Figure 3.

3.4 CONCRETE BASE: A cylinder or cube of Portland cement concrete weighing not less than 90 kg. In the case of the cylinder, its height shall be at least equal to its diameter. The surface on which the mold is placed and its opposite face shall be plane surfaces and shall be parallel to each other.

3.5 LEAD CYLINDERS: A supply of 38-caliber lead alloy cores, each weighing 8.70 to 8.76 g (145 to 146 grains), and having a length of 17.27 ± 0.13 mm, manufactured for swaging into 9.48 g (158 grains) bullets. A minimum of 10 is required for the calibration of one mechanical compactor.

4. TEST PROCEDURE

4.1 DEFORMATION BY THE MANUAL METHOD: Secure the deformation value for the manual method as follows:

4.1.1 Check the mass of the manual rammer. The mass is required to be within 1 % of the specified mass. Check the sleeve control device for controlling the height of drop of the manual

rammer. The height of drop of the manual rammer is required to be within 1 % of the specified height.

4.1.2 Select a set of lead cylinders from the same lot or shipment. Minimum of ten is needed for the calibration of a mechanical compactor. Remove any burrs from the ends of the leads cylinders using a fine grade of emery cloth.

Note 2: Deformation of the lead cylinders is affected by changes in temperature. Precautions must be taken to maintain the cylinders at a constant temperature during the calibration of a mechanical compactor, including the securing of the values for the manual method.

4.1.3 Assemble the lead deformation apparatus with a lead cylinder in place as shown in Figure 4.

4.1.4 Place the assembled deformation apparatus on the base of the dial comparator with the top centre of the striking pin directly under the tip of the dial stem. This places the dial stem on top of the 6.4 mm steel ball. Rotate the striking pin rapidly several turns in one direction while rotating the guide sleeve rapidly several turns in the opposite direction. Read and record the dial reading.

4.1.5 Place the base plate of the compaction mold on the 90 kg cylinder or cube of concrete; place the deformation apparatus on the base plate; place the guide sleeve pedestal in position on the base plate, mount the rammer and guide sleeve on the guide sleeve pedestal, and apply one drop of the manual rammer.

4.1.6 Return the deformation apparatus to the dial comparator and secure and record the dial reading. The difference between the dial readings secured in 4.1.4 and in this step is the deformation value.

4.1.7 Repeat steps 4.1.3 to 4.1.6 using a fresh lead cylinder for each determination, until five deformation values are secured that do not vary more than 2 % from the average. The deformation value for the manual method shall be taken as this average value.

4.2 DEFORMATION BY THE MECHANICAL COMPACTOR: Clean and adjust the mechanical compactor in accordance with the manufacturer's instructions. Operate the compactor for a period of time to cause friction in the parts to become constant, allowing the rammer to fall on soil or other soft material. Check the height of drop of the rammer. This should be within 1 % of the specified height. Place the assembled lead deformation apparatus on the base of the mechanical compactor at such location that the striking pin will be centered on the face of the rammer at the moment of contact of the two. Secure the deformation value of the mechanical compactor using the procedure specified in 4.1.

4.3 ADJUSTMENT OF THE MECHANICAL COMPACTOR: If the deformation produced by the manual rammer is greater than that produced by the mechanical compactor, add mass to the rammer on the mechanical compactor in an amount necessary to produce the same deformation value as produced by the manual method. The deformation values shall be considered to be the same if the average value for the mechanical compactor does not vary more than 2 % from the average value by the manual method. If the deformation produced by the manual rammer is smaller

than that produced by the mechanical compactor, remove mass from the rammer on the mechanical compactor in an amount necessary to produce the same value as produced by the manual method. If the mass required to be added or removed from the rammer of the mechanical compactor is greater than 0.5 kg, the mechanical compactor shall not be used.

Note 3: As a final means for checking the adjusted mechanical compactor with the manual method, it is recommended that a compaction test be carried out on each using a moderately lean clay soil. If a moderately lean clay soil is not available, a silt soil may be used but the results will not be positive. Sands should not be used. The maximum dry density value should not vary from the value for the manual method value; optimum moisture content for the mechanical compactor should not vary from the value from the manual method by more than 0.5 %. For example, if the value of the manual method is 16.0 %, the value for the mechanical compactor should not be less than 15.5 % nor more than 16.5 %.

5. GENERAL NOTES

5.1 When the deformation of the lead-calibrating cylinder produced by a mechanical compactor is not the same as that produced by the manual method of compaction, the mass of the rammer on the mechanical compactor is adjusted to produce the same deformation as produced by the manual method. This method is for use only in the calibration of mechanical compactors equipped with rammers striking the surface of the soil directly. Mechanical compactors to be used in both MTO Method LS-706 and LS-707 must be calibrated using rammers with masses and heights of drop as specified in both methods. Calibration for use in one method does not qualify the equipment for use with the other.

METHOD OF TEST FOR DETERMINATION OF PERMEABILITY OF GRANULAR SOILS

1. SCOPE

- 1.1 This method covers the determination of the coefficient of permeability of soils (granular materials) by means of the constant head test apparatus.

2. REFERENCE

- 2.1 ASTM D 2434
2.2 AASHTO T 215

3. FUNDAMENTAL TEST CONDITIONS

- 3.1 Ideally, the flow of water through a test specimen should be laminar, that is to say there is no turbulence. Conditions to obtain laminar flow are a function of the void structure of the test specimen and the hydraulic gradient.
- 3.2 There should be no volume change in the test specimen during the test.
- 3.3 The voids in the test specimen must be saturated with water.

4. APPARATUS

- 4.1 The apparatus is selected on the basis of the material under test. It consists of a permeameter to contain the specimen with porous disks or screens at the top and bottom and filter paper covering the disks or screens to restrict migration of fines from the sample.
- 4.2 CONSTANT HEAD PERMEAMETER: The constant head test is carried out in a modified CBR mold, which is adapted by the addition of special top and bottom plates with rubber sealing rings to prevent water from leaking out during the test. The top and bottom plates are provided with inlets for water lines and are generally provided with valves to control the flow (Figure 1).
- 4.3 CONSTANT HEAD TANK: The supply of water to the permeameter must be maintained under a constant head. This is accomplished by means of a cylinder with a water inlet from the tap or storage tank and an overflow such that a constant stream of water is supplied. An outlet from the base of the cylinder is attached to the inlet on the bottom plate of the mold (Figure 1).
- Note 1: Water flow through the specimen should be from the bottom to the top. This will aid in preventing build up of air, as bubbles will be carried with the water flow to the outlet.*
- 4.4 SPECIMEN COMPACTION EQUIPMENT: For compacting samples, a Proctor or CBR mold may be used along with RAMMER EQUIPMENT as detailed in Test Method LS 706.

- 4.5 **VACUUM PUMP:** It may be necessary to apply a vacuum to the specimen prior to the test in order to evacuate any air present. This may be done with a vacuum pump, but the vacuum applied must be carefully monitored in order to avoid the creation of drainage channels by piping in the specimen, which may lead to erroneous results. Alternatively, a water-faucet aspirator may be most appropriate for this purpose.
- 4.6 **MISCELLANEOUS APPARATUS:** Appropriate balances, ovens, containers and tools required for sample preparation as may be necessary.

5. TEST SAMPLES

- 5.1 Samples of material for permeability must be representative of the original material. In some cases the material may be oven dried and pre-screened in order to produce a specimen of the appropriate gradation. More often, samples are tested as submitted and compacted into the mold at an acceptable water content.

6. PREPARATION OF SPECIMENS

- 6.1 The sample must be prepared to the required water content (optimum moisture) and compacted in the permeameter. The water content and density are required as data for reporting purposes.
- 6.2 Initial measurements are made of the inside diameter (D) of the permeameter, the distance (L) between the outlets, and the height (H) of the test specimen.
- 6.3 **ASSEMBLY OF PERMEAMETER:** Before placing the specimen on the base plate of the permeameter, a porous disk or screen covered by filter paper is inserted in the base plate. The apparatus is assembled with a porous disk or screen on top of the specimen separated by filter paper, and any required surcharge such as required for CBR data. The specimen is then very slowly irrigated with de-aired water by opening the valves in the top and bottom plates of the apparatus until free flow is observed. This observation depends to some extent on the grain size of the test specimen.
- 6.4 **SATURATION OF SPECIMEN:** In the majority of cases, it is desirable to apply a vacuum to the specimen to ensure removal of entrapped air. Connect the outlet on the top plate of the apparatus to a vacuum line and apply a vacuum of less than 50 cm Hg for 15 minutes to remove entrapped air. The vacuum may be varied according to the material under test. Coarse materials will in general de-air at a lower vacuum than those of finer grain size. Also, the construction of the apparatus may not withstand high vacuum levels without leaking air, which defeats the operation.

Note 2: If using tap water (non-de-aired) air bubbles may cause varying degrees of obstruction of pipe elbows, etc. Tapping very lightly with a small wood dowel may dislodge these bubbles.

7. TEST PROCEDURE

- 7.1 CONSTANT HEAD TEST: Ensure that water is flowing into the constant head cylinder and open valves on the apparatus, the bottom valve first. Monitor the water levels in the cylinder until a stable head condition is reached, i.e. no fluctuations in the water level. The quantity of water (Q) flowing through a sample of a certain area (A) is measured for any required time (t). The temperature (T) of the water discharged should also be measured. Modify the head to establish the required hydraulic gradient. This is calculated as:

$$i = \frac{h}{L}$$

where: i = hydraulic gradient

h = height of head

L = length of sample

If necessary, tests may be run at different hydraulic gradients to ensure that the testing is being performed in the range of laminar flow. This may be checked by plotting velocity of flow v (where $v = \frac{Q}{At}$) against the gradient (i). A linear relation should occur between some points on the graph, indicating the region of laminar flow.

Note 3: In general, much lower values of hydraulic gradient are required than generally recognised in order to ensure laminar flow.

- 7.2 Upon completion of the test, drain the water from the apparatus, remove the mold containing the specimen and perform a CBR test, if required. The water content of the sample should be measured before it is discarded.
- 7.3 When the test has been completed, drain the specimen and inspect for streaks or layers (evidence of segregation of fines). The calculation procedures outlined in 8.1 should then be followed.

8. CALCULATIONS

- 8.1 Coefficient of Permeability is calculated as follows: $k = \frac{Q}{iA}$

where: k = coefficient of permeability

$$Q = \frac{\text{quantity of water discharged (cc)}}{\text{time (s)}}$$

$$i = \text{hydraulic gradient} \quad \frac{h = \text{head (cm)}}{L = \text{length of specimen (cm)}}$$

A = cross-sectional area of specimen (cm²)

Correct the value of permeability to that of 20°C by multiplying k by the ratio of the viscosity of water at the test temperature to the viscosity of water at 20°C (Figure 2).

9. REPORTING OF RESULTS

9.1 The report of the test shall include the following information:

9.1.1 Value of permeability (k) at 20°C

9.1.2 Initial and final water content

9.1.3 Compacted wet and dry density

9.1.4 Void ratio (if required)

9.2 WORKED EXAMPLE:

Head (h) (cm)	1.0	1.0	1.0	2.0	2.0	3.0	3.0
Water Flow (cc)	98.1	198.0	328.4	207.6	411.1	352.0	707.6
Time t (s)	180	360	600	180	360	180	360
$Q = \frac{cc}{t(s)}$	0.545	0.550	0.547	1.153	1.142	1.956	1.966
Length of Specimen L (cm)	11.4	11.4	11.4	11.4	11.4	11.4	11.4
Hydraulic Gradient $i = \frac{h}{L}$	0.088	0.088	0.088	0.175	0.175	0.263	0.263
Area of Specimen A (cm ²)	182.65	182.65	182.65	182.65	182.65	182.65	182.65
$k = \frac{Q}{iA}$ (cm/s)	3.4×10^{-2}	3.4×10^{-2}	3.4×10^{-2}	3.5×10^{-2}	3.5×10^{-2}	4.1×10^{-2}	4.1×10^{-2}
Temp. of Water °C	15°	15°	15°	20°	20°	25°	25°
Viscosity of Water at Test Temp. (X)	1.140	1.140	1.140	Not Required	Not Required	0.894	0.894
Viscosity of Water at 20°C (Y)	1.005	1.005	1.005	Not Required	Not Required	1.005	1.005
Ratio = $\frac{X}{Y}$	1.134	1.134	1.134	Not Required	Not Required	0.889	0.889
Temp. Corrected k = (k x Ratio)	3.9×10^{-2}	3.9×10^{-2}	3.9×10^{-2}	3.5×10^{-2}	3.5×10^{-2}	3.6×10^{-2}	3.6×10^{-2}

Comments:

- Constant Head Method on open graded drainage layer (OGDL) material
- Fast penetration of water through sample
- Average of tests using various heads is 3.7×10^{-2}

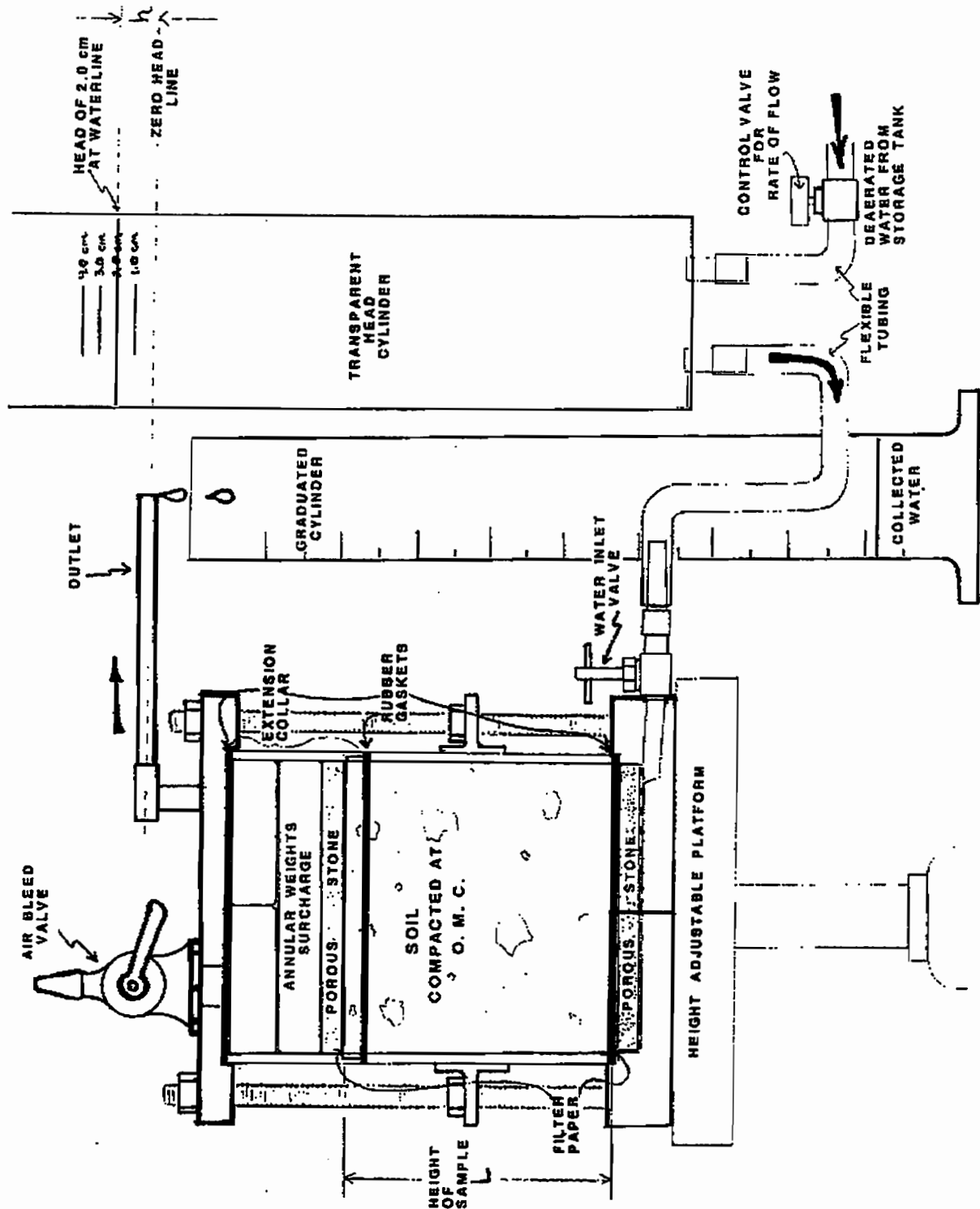


Figure 1 – CONSTANT HEAD PERMEAMETER

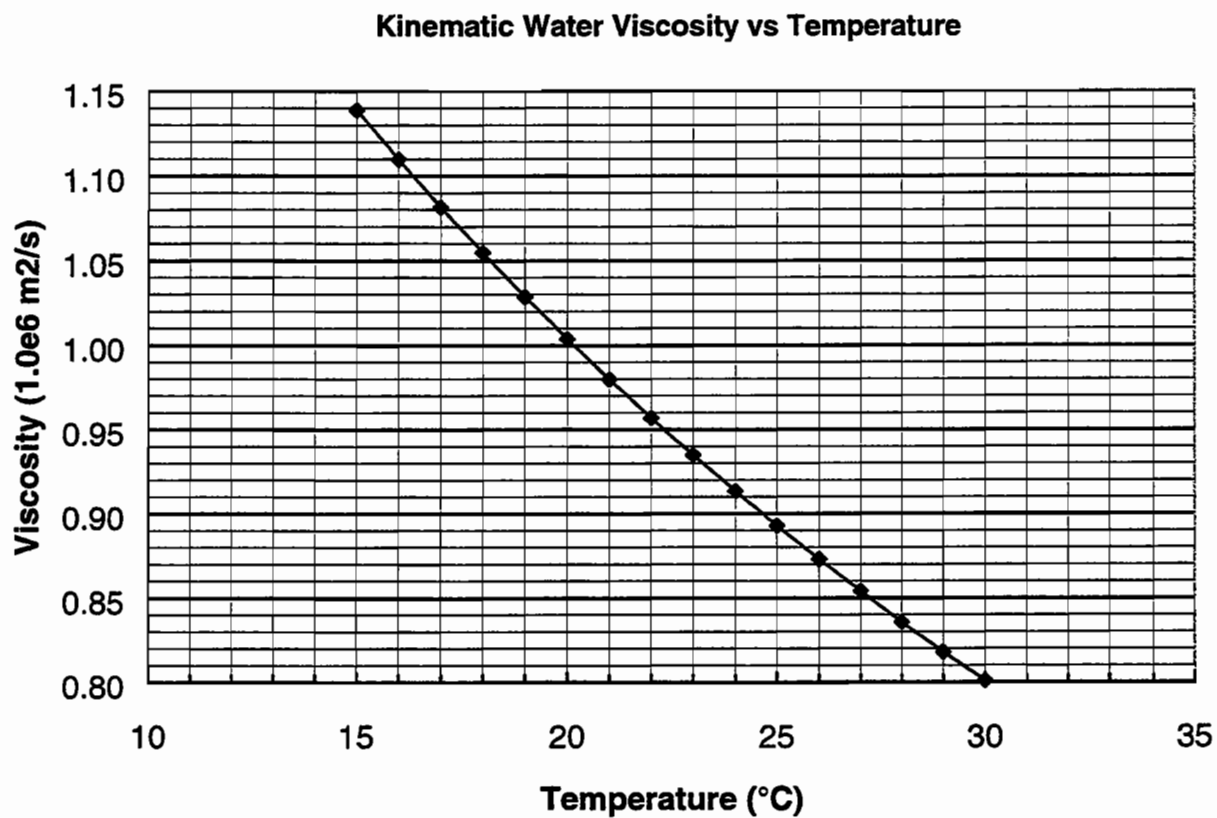


Figure 2

