



CONSTRUCTION SPECIFICATION FOR COMPACTING

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| 501.01 | SCOPE |
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This specification covers the requirements for compaction of earth and granular materials.

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| 501.02 | REFERENCES |
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This specification refers to the following standards, specifications, or publications:

Ontario Provincial Standard Specifications, Construction

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| OPSS 206 | Grading |
| OPSS 401 | Trenching, Backfilling, and Compacting |

Ontario Provincial Standards Specifications, Materials

| | |
|-----------|--|
| OPSS 1010 | Aggregates - Base, Subbase, Select Subgrade, and Backfill Material |
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Ontario Ministry of Transportation Publications

MTO Laboratory Testing Manual:
LS-706 Moisture - Density Relationship of Soils Using 2.5 kg Rammer and 305 mm Drop

ASTM International

D6938-10 Standard Test Method for In-Place Density and Water Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth)

501.03 DEFINITIONS

For the purpose of this specification, the following definitions apply:

Backfill Material means as defined in OPSS 401.

Bedding Material means as defined in OPSS 401.

Cover Material means as defined in OPSS 401.

Earth means as defined in OPSS 206.

Embedment Material means as defined in OPSS 401.

Rut means a sunken track or groove made at the surface by the passage of vehicles.

Utility Structures means maintenance holes, catch basins, valve chambers, ditch inlets, and other similar structures used to access services such as sewer, water, electric, and telephone to carry out maintenance and repair work.

501.05 MATERIALS

501.05.01 Granular Material

Granular material shall be according to OPSS 1010.

501.05.02 Water

Water shall be free of contaminants that could adversely affect fill material or the environment.

501.06 EQUIPMENT

501.06.01 Compaction

501.06.01.01 General

The type of compaction equipment used shall be suited to the material to be compacted, degree of compaction required, and space available.

Compaction equipment for control strips shall have a minimum static weight of 9,000 kg.

501.06.01.02 Hand Operated Vibratory Equipment

Hand operated vibratory equipment shall have a power output no greater than 9.9 kW.

501.06.02 Water

Equipment for applying water shall be capable of uniform distribution with proper flow control.

501.06.03 Nuclear Moisture and Density Gauge

Each nuclear moisture and density gauge (gauge) shall have been calibrated within the last 12 months either by the manufacturer or other qualified agent against certified density and moisture reference blocks. In addition, the Density Standard Count and the Moisture Standard Count shall be within 2.0% and 4.0%, respectively, of the most recent calibration values. The registered owner of the gauge shall maintain a valid Radioisotope License for each gauge.

501.07 CONSTRUCTION

501.07.01 General

The method of placing and lift thickness of earth or granular material shall be according to the specifications that govern the Work. When not specified, the lift thickness of earth shall not exceed 300 mm and the lift thickness for granular materials shall not exceed 150 mm.

When field testing indicate that the required degree of compaction cannot be obtained with the equipment in use or the procedure being followed, the operations shall be modified so that the equipment and procedures will produce the required results.

501.07.02 Restricted Zones

Hand operated vibratory type compaction equipment shall be used behind all retaining structures to compact fill material within restricted zones as follows:

a) Abutments and Retaining Walls

An area within a plane extending from the base of the back face of the wall where it contacts the footing upwards at a slope of 1H:1.5V to a maximum distance of 2.5 m from the wall.

b) Wingwalls

An area within 1.5 m from the back face of the wall.

501.07.03 Water for Compaction

Water shall be applied, as necessary, to achieve the degree of compaction required.

When the Contract includes a separate item for water for compaction, the water shall be applied with the approval of the Contract Administrator.

501.07.04 Quality Control

501.07.04.01 General

Quality control (QC) testing shall be carried out to ensure that earth and granular materials used in the Work are compacted according to the requirements as specified in the Contract Documents.

Field density and field moisture determinations shall be made according to ASTM D6938.

501.07.04.02 Compaction Requirements

501.07.04.02.01 General

Compaction testing shall be based on material placed and compacted in the Work on a lot-by-lot basis according to the Lot Testing clause.

Compaction acceptance shall be according to the Acceptance clause and shall be based on target densities established according to the Target Density clause, QC compaction field test results, and, where applicable, a statistical analysis of those results.

501.07.04.02.02 Submission of Test Data

Prior to construction of a control strip, a copy of all QC laboratory test results for LS-706 required by the Control Strip clause to determine optimum moisture content (OMC) of the control strip material shall be delivered to the Contract Administrator.

All field test results and associated information relating to the control strip, including target density, lot location, lift thickness, probe depth, moisture content, wet density, and all QC lot compaction calculations shall be recorded at the time of testing on MTO form PH-CC-009. This form shall be available at any time for review, upon request, and shall be submitted to the Contract Administrator prior to placement of any subsequent lift and within 2 Business Days following the completion of a lot.

501.07.04.02.03 Test Equipment and Operator Training

501.07.04.02.03.01 General

Field density and field moisture measurements for QC compaction testing of earth and granular materials shall be carried out using gauges and ancillary equipment.

Only qualified operators using properly calibrated gauges shall conduct QC compaction testing.

501.07.04.02.03.02 Nuclear Moisture and Density Gauge Requirements

A copy of a valid calibration certificate, including the make, model number, and serial number for each gauge, shall be submitted to the Contract Administrator, prior to use of the gauge in compaction testing.

In addition, the Contract Administrator may request that the operator perform a standardization procedure according to ASTM D6939.

If the gauge does not meet the standardization requirements or exhibits malfunctions of any kind, the gauge shall be replaced.

501.07.04.02.03.03 Operator Requirements

Each operator shall have been trained in the safe operation, transportation, and handling of the gauge.

Prior to conducting QC compaction testing, the operator shall provide acceptable proof of proficiency in the use of a gauge and the correct procedures to determine lot and subplot sizes, field dry density, percent relative compaction, mean, standard deviation, and the Quality Index of a compacted lot of material by submitting one of the following:

- a) a gauge operator certification document or card from a training program acceptable to the Owner and conducted within the Province of Ontario within the last 2 years; or

- b) a document (e.g., instruction notice or letter) signed by the Owner showing that the operator has demonstrated proficiency on a Contract either constructed or being constructed for the same Owner within the same construction year as the compaction testing being carried out for this Contract.

If the operator cannot provide either of the two documents stated above, then at the Contract Administrator's discretion, the operator shall demonstrate their proficiency to the Owner. In this case, arrangements shall be made with the Contract Administrator regarding the schedule, location, and materials for such demonstrations. The first 2 demonstrations may include up to 5 operators and 5 gauges and shall be carried out at no charge. Additional demonstrations shall be charged at the rate of \$500. Where a demonstration is carried out, acceptability of the operator shall be valid for the current calendar year only.

501.07.04.02.04 Target Density

New target densities shall be established for each separate component of the Work (e.g., backfilling of a trench, construction of a granular base, or placement of cover) at the following times:

- a) For earth and granular materials:
 - i. At the time of initial use of each source.
 - ii. When there is a perceptible change in the appearance or gradation of the materials or both.
 - iii. At least once per calendar year on all carry-over Contracts.
- b) For earth being placed:
 - i. As backfill, after QC lots representing 2000 tonnes or 1000 m³ of material have been completed, whether accepted or rejected, based on one set of target density values, or
 - ii. For all other purposes, after each 10 QC lots of material have been completed, whether accepted or rejected, based on one set of target density values.
- c) For granular materials being placed:
 - i. As backfill, or at the discretion of the Contract Administrator, any other areas, after QC lots representing 5000 tonnes or 2500 m³ of material have been completed, whether accepted or rejected, based on one set of target density values, or
 - ii. For all other purposes, after each 25 QC lots of material have been completed, whether accepted or rejected, based on one set of target density values.

The new target density shall be established by the construction of a control strip according to the Control Strip clause, except the new target density shall be based on the maximum dry density (MDD) as determined by LS-706 not more than 14 Days prior to placing the material, when:

- a) Placing material in confined areas that do not allow equipment meeting the requirements specified in the Compaction clause to be used.
- b) With the consent of the Contract Administrator, a control strip cannot be reasonably constructed or is impractical.

The MDD used for the new target density shall be the average of the MDD calculated from a minimum of three independent samples selected from the materials to be used.

501.07.04.02.04.01 Control Strip

Prior to construction of a control strip:

- a) A minimum notice of 24 hours shall be given to the Contract Administrator, and
- b) The optimum moisture content (OMC) of the material shall be determined according to LS-706.

Each control strip shall consist of a single uniform lift not more than 0.30 m in depth and covering at least 400 m² in area. The surface of each control strip shall be graded flat.

Prior to compaction, the field moisture content of the control strip material shall be determined using a nuclear gauge at a minimum of three randomly selected locations. The average moisture content at those three locations shall be within the range of no less than 2.0% lower than and no more than 1.0% greater than the OMC of the control strip material. If the average moisture content is not within this range, the moisture content of the material shall be uniformly adjusted (e.g., by adding water and re-mixing or scarifying and drying). The material shall then be graded flat and re-tested using a nuclear gauge. This process shall be repeated until the average moisture content of the material, at a minimum of three randomly selected locations, is within the range of no less than 2.0% lower than and no more than 1.0% greater than the OMC of the control strip material.

When the OMC is within the acceptable range, the compaction equipment shall make six passes over the entire surface of the control strip. A pass shall be deemed to be compaction of the full width of the control strip in one direction only. The field wet density and field moisture content shall be determined at a minimum of three randomly selected locations. The dry density shall be calculated for each of these locations and the average dry density used as the initial value for the dry density.

All passes of the compaction equipment for the control strip shall be carried out in vibratory mode at a speed of no more than 5 km/hour.

The compaction equipment shall then make two additional passes over the entire surface of the control strip.

A minimum of three separate random field density and moisture content determinations shall then be made, and a new average dry density shall be calculated.

If the new average dry density exceeds the previous value by more than 0.030 t/m³, then additional passes of the equipment shall be carried out as described above. If the new average dry density does not exceed the previous value by more than 0.030 t/m³, then the compaction of the control strip shall be considered satisfactory and complete.

Upon satisfactory completion of the control strip, an additional seven field wet density and moisture content tests shall be taken at random locations and the dry density values determined. The final dry density of the control strip, which shall be deemed to be the target density, shall be the average of the dry density values determined at these seven additional random locations plus the three most recent values that were determined upon completion of the control strip.

501.07.04.02.05 Lot Testing

For compaction control, a unique set of lots distinguished from each other by an appropriate letter or number designation, shall be established for each of the following:

- a) Each separate component of the Work (e.g., backfilling a structure or a trench or construction of a granular base).
- b) Materials from different sources.
- c) Materials with different compaction properties.
- d) When recompaction is carried out following restoration, scarification, or placement of additional material onto previously tested and accepted lots.
- e) When directed by the Contract Administrator.

The individual lots within each unique set of lots shall be consecutively numbered and with no duplication. Lot sizes shall not exceed the limits as shown in Table 1.

All visibly soft or loose areas shall be compacted prior to testing.

For the situations described in Table 1, Part IV, a minimum of 2 field density and moisture content tests shall be carried out at random locations within each lot.

For all other situations, each lot shall be divided into 4 equal sublots and a minimum of one field density and moisture test shall be carried out at random locations within each subplot and the results used to calculate the Quality Index according to the Quality Index clause.

In addition, regardless of the situation, when a lot of material is split between both sides of a pipe, sewer, or culvert, at least one field density and moisture content test shall be taken on each side of that pipe, sewer, or culvert.

The gauge probe shall extend to the full depth of the lift, unless otherwise allowed by the Modified Layer Compaction Method according to OPSS 206. The probe shall not extend beyond the lift being tested.

During the compaction process, the field wet density value and moisture content for each gauge test shall be recorded on MTO form PH-CC-009. The field dry density of each subplot shall then be calculated as a percentage of the target density to the nearest 0.1%. The mean and standard deviation and the Quality Index, where applicable, of the field dry density values shall be calculated to the nearest 0.1% and recorded on the form for each lot.

MTO form PH-CC-009 shall be constantly updated with new test data and the associated calculations completed as the testing is being done. This form shall be made available to the Contract Administrator at any time, upon request.

501.07.04.02.06 Quality Index

The Quality Index (Q_i) shall be calculated from the mean (\bar{x}) and standard deviation (s) of the percent target density which has been determined from all sublots within a QC compaction lot during the compaction process. The values for Quality Index, lot mean, and lot standard deviation shall be computed as follows:

- a) For materials placed in embankments within 50 m of a structure; placed as bedding, embedment, cover, or backfill material to pipes, sewers, or culverts; or placed as backfill to structures, utility structures, or small foundations (e.g., anchor blocks, sign posts, and formwork):

$$\text{For earth materials: } Q_i = \frac{\bar{x} - 95}{s} \qquad \text{For granular materials: } Q_i = \frac{\bar{x} - 98}{s}$$

- b) For materials placed in all other situations:

$$\text{For earth materials: } Q_i = \frac{\bar{x} - 90}{s} \qquad \text{For granular materials: } Q_i = \frac{\bar{x} - 95}{s}$$

Where:

Q_i = Quality Index, calculated to two decimal places.

\bar{x} = Lot mean, the statistical value that describes the arithmetic average of subplot test results (dry density expressed as a percentage of the target density). Lot mean is the sum of individual subplot test results divided by the number of test results, calculated to 0.1% as follows:

$$\bar{x} = \frac{x_1 + x_2 + x_3 + x_4}{4} = \frac{1}{4} \sum_{i=1}^4 x_i$$

S = Lot standard deviation (σ_{n-1}), the statistical value that describes the distribution of subplot test results (dry density expressed as a percentage of the target density) about the lot mean. Standard deviation is the square root of the sum of the squares of the difference between each subplot test result and the lot mean divided by the number of test results minus one. It is calculated to 0.1% using the following expression:

$$s = \sqrt{\frac{\sum_{i=1}^4 (x_i - \bar{x})^2}{3}}$$

501.07.04.02.07 Acceptance

For the situations described in Table 1, Part IV, acceptance or rejection of a QC lot for compaction shall be based on 2 or more random field density and moisture content tests taken within the lot. For a lot to be acceptable, all tests shall be at least 100% and 98% of the target density established for granular and earth materials, respectively. Otherwise, the QC lot shall be rejected for compaction.

For all other situations, acceptance or rejection of a QC lot for compaction shall be established by calculation of the Quality Index, according to the Quality Index clause. When Q_i has a value equal to or greater than 1.47, the QC lot shall be accepted; otherwise, the lot shall be rejected for compaction.

Accepted QC lots damaged by vehicular traffic shall be restored prior to placement of any overlying material. Surfaces of accepted QC lots with ruts greater than 50 mm in depth in earth or 25 mm in depth in granular materials shall be regraded and the upper lift recompacted to meet the specified compaction requirements. Materials that cannot be successfully recompacted shall be removed and replaced with new material.

501.07.04.02.07.01 Rejected Lots

If a QC lot is rejected for compaction, the lot shall be recompacted with adjustment to the moisture content, as required, until satisfactory compaction is achieved. The recompacted lot shall be retested and a decision made, as described in the Acceptance clause.

When compaction of a QC lot does not meet the acceptance criteria and when the Contract Administrator has been satisfied that this is not a result of the Contractor's operation or equipment, a new target density shall be established for that operation.

501.07.05 Management of Excess Material

Management of excess material shall be according to the Contract Documents.

501.08 QUALITY ASSURANCE

501.08.01 General

Field density and field moisture determinations shall be made in accordance with ASTM D6938.

501.08.02 Compaction

501.08.02.01 General

The Contract Administrator shall conduct random testing or inspection of QC records or both to establish the acceptability of the QC compaction testing and verification of the field moisture content, field dry density, OMC, MDD, target density, and the Quality Index, where applicable.

The Contract Administrator may verify that the target density established for a control strip is based on the use of suitable compaction equipment. Provided that the MDD and OMC values determined by LS-706, as applicable, indicate an adequate target density is being achieved, the compaction equipment shall be considered suitable. If the compaction equipment is not capable of obtaining an adequate target density at the required moisture content, the equipment shall be considered unsuitable and shall be replaced with equipment that is able to obtain an appropriate target density.

Reasonable access to a control strip or to compacted QC lots shall be provided prior to placement of subsequent lifts of material. Subsequent lifts, including HMA, may not be placed until QA testing has been conducted or waived by the Contract Administrator.

501.08.02.02 Gauge Verification

Gauge verification QA shall consist of taking four random field density and moisture content measurements of a compacted lot or control strip and the subsequent calculation of the average dry density. The maximum dry density (MDD) of the material within the compacted lot or control strip as determined by LS-706 shall be used for gauge verification.

The QC gauge test results shall be considered valid provided that the difference between the average percentage of the MDD determined by QC gauge test results and the average percentage of the MDD determined by QA gauge test results for the same material is no more than 4%. If the discrepancy between the QA and QC gauge test results is more than the 4%, an investigation shall take place to resolve the discrepancy. The investigation may include but is not limited to verification of appropriate probe depth, as well as parts d) and e) according to the Compaction clause.

501.08.02.03 Compaction

For the situations described in Table 1, Part IV, compaction QA shall consist of taking 2 or more random field density and moisture content measurements of each compacted lot and the subsequent determination of percent target density.

For all other situations, compaction QA shall consist of taking 4 random field density and moisture measurements of a compacted lot or control strip and the subsequent calculation of the Quality Index for the lot.

Provided that the lot is acceptable, according to the requirements specified in the Acceptance clause, no further action shall be taken.

However, if the lot is rejected based on compaction testing or demonstrates errors in QC reporting, an investigation shall take place to determine and resolve the discrepancies. The investigation may include, but is not limited to, any of the following:

- a) Recompaction of the lot.
- b) Retesting of the lot by the Contractor.
- c) Establishment of a new target density by control strip.
- d) Re-inspection of the gauge or operator or both by the Owner.
- e) Recalibration of the gauges.
- f) Removal of unsuitable materials.

501.08.02.04 Quality Control Records Inspections

QC records of the lot or control strip selected by the Contract Administrator shall be inspected for calculation errors, missing test data, or improper lot quantities. If errors or omissions are found that identify insufficiently compacted or improperly or untested lots, the Contractor shall make all such lots available and recompact or retest these lots or both so that they comply with the specified compaction requirements.

501.08.02.05 Charges

The Contract Administrator shall charge the Contractor \$450.00 for each lot that requires retesting which has been identified through QA compaction testing or a review of QC records. In addition, immediately following the discovery of a discrepancy or inadequate compaction, all new lots shall be subjected to QA compaction testing prior to acceptance. If any of the new lots do not meet the specified compaction requirements, the Contractor shall be charged a fee of \$450.00 for each lot. These conditions shall continue until 3 consecutive new lots have met the specified compaction requirements.

501.09 MEASUREMENT FOR PAYMENT

501.09.01 Actual Measurement

501.09.01.01 Water for Compaction

Measurement of water for compaction shall be in cubic metres using one of the following methods:

- a) The mass of the water shall be determined by weighing as specified in the Contract Documents. The mass of the water shall be converted to cubic metres using a factor of 1,000 kg to 1 m³.
- b) The water tank shall be measured and its volume computed in cubic metres.
- c) The water shall be measured through a water meter of approved design.

501.10 BASIS OF PAYMENT

501.10.01 Compaction

Payment at the Contract price of the appropriate tender item requiring compaction of earth and granular materials shall be full compensation for all labour, Equipment, and Material to do the work of compacting, including the water used for compaction, unless the Contract contains a separate tender item for Water for Compaction.

Any work required to repair or remove and replace damaged QC lots accepted shall be at no additional cost to the Owner.

Replacement of unsuitable equipment to obtain an appropriate target density shall be at no additional cost to the Owner.

Replacement of a gauge shall be at no additional cost to the Owner.

Any work required to recompact or retest material as a result of QA compaction testing or QC records inspection shall be at no additional cost to the Owner.

501.10.02 Water for Compaction - Item

Payment at the Contract price for the above tender item shall be full compensation for all labour, Equipment, and Material to do the work.

When the Contract does not contain a separate tender item for water for compaction, the Contract price for the tender item in which the water for compaction is used shall include full compensation for all labour, Equipment, and Material to do the work.

TABLE 1
Compaction Lot Size

| Part | Construction | Lot Size |
|---|---|---|
| I | Earth embankments, granular base, granular subbase, and granular shoulders. | Every lift, 500 m maximum length. (Note 1) |
| II | Structure approach fill for earth. | Every lift, 50 m maximum length |
| III | Bedding, embedment, cover, or backfill material for pipe and sewer sections > 20.0 m in length that are being placed in one operation, earth or granular. | Every lift, 200 m maximum length. |
| IV | Bedding, embedment, cover, or backfill material for pipes and sewer sections ≤ 20.0 m in length that are being placed in one operation or backfill to utility structures or small foundations (e.g., anchor blocks, sign posts, and formwork), earth or granular. | Every lift, 20 m maximum length. |
| V | Structure backfill and culvert bedding, embedment, cover, or backfill material, granular. | Every lift for every stage of construction. |
| <p>Note:</p> <p>1) The width of the lot shall be the limits established for the placement of current material only and shall not include adjacent material to be placed at a future date.</p> | | |