Intelligent Compaction Technology for Soils Applications

DESCRIPTION

This work shall consist of the construction of the roadway fill embankment utilizing Intelligent Compaction (IC) rollers within the limits of the work as described in the plans. IC is defined as a process that uses vibratory rollers equipped with a measurement/documentation system that automatically records various critical compaction parameters correlated to agency standard testing protocols in real time during the compaction process. IC uses roller vibration measurements to assess the mechanistic soils properties and to ensure optimum compaction is achieved through continuous monitoring of the operations.

The Contractor shall supply sufficient numbers of rollers and other associated equipment necessary to complete the compaction requirements for the specific materials. The Contractor will determine the number of IC rollers to use depending on the scope of the project. The IC roller(s) may be utilized during production with other standard compaction equipment and shall be used for the evaluation of the compaction operations.

EQUIPMENT

The IC rollers shall meet the following specific requirements:

1. IC rollers shall be self-propelled single-drum vibratory rollers equipped with accelerometers mounted in or about the drum to measure the interactions between the rollers and compacted materials in order to evaluate the applied compaction effort. IC rollers may be smooth or pad footed drums.

2. The output from the roller is designated as the Intelligent Compaction Measurement Value (IC-MV) which represents the stiffness of the materials based on the vibration of the roller drums and the resulting response from the underlying materials.

3. GPS radio and receiver units shall be mounted on each IC roller to monitor the drum locations and track the number of passes of the rollers.

4. The IC rollers shall include an integrated on-board documentation system that is capable of displaying real-time color-coded maps of IC measurement values including the stiffness response values, location of the roller, number of roller passes, roller speeds, together with the vibration frequency and amplitude of roller drums.

5. The display unit shall be capable of transferring the data by means of a USB port.

6. An on-board printer capable of printing the identity of the roller, the date of measurements, construction area being mapped, percentage of the construction area

mapped, target IC-MV, and areas not meeting the IC-MV target values. *(Printer option to be selected by the xxDOT)*

High Precision Positioning System (HPPS). The Contractor shall provide a HPPS system that meets the following requirements. The goal of HPPS requirements is to achieve accurate and consistent HPPS measurements among all HPPS devices on the same project. Conversions of HPPS data need to be minimized to avoid errors introduced during the process.

GPS-Related Definitions -

- GPS: A space-based satellite navigation system that provides location and time information in all weather, anywhere on or near the Earth to determine the location in geodetic coordinates. In this specification, GPS is referred to all GPS-related signals including US GPS, and other Global Navigation Satellite Systems (GNSS).

- Hand-Held GPS rover: A portable GPS radio/receiver for in-situ point measurements.

- GPS Base Station: A single ground-based system that consists of a GPS receiver, GPS antenna, radio and radio antenna to provide L1/L2 differential GPS correction signals to other GPS receivers within a range limited by radio, typically 3 miles (4.8 Km) in radius without repeaters.

- Network RTK: Network RTK is a system that use multiple bases in real-time to provide high-accuracy GPS positioning within the coverage area that is generally larger than that covered by a ground-based GPS base station; e.g., VRS.

- GPS Correction Service Subscription: A service that can be subscribed to receive VRS signals in order to achieve higher accuracy GPS positioning normally via cellular wireless data services; i.e., without the need for a ground-based base station. Examples of GPS Correction Service subscriptions are: Trimble VRS™, Trimble VRS NOW™, OmniSTAR, etc.

- RTK-GPS: Real Time Kinematic Global Positioning Systems based on the use of carrier phase measurements of the available GPS signals where a single reference station or a reference station network provides the real-time corrections in order to achieve centimeter-level accuracy.

- UTM Coordinates: Universal Transverse Mercator (UTM) is a 2-dimentional Cartesian coordinates system that divides the surface of Earth between 80°S and 84°N latitude into 60 zones, each 6° of longitude in width and centered over a meridian of longitude. Zone 1 is bounded by longitude 180° to 174° W and is centered on the 177th West meridian. The UTM system uses projection techniques to transform an ellipsoidal surface to a flat map the can be printed on paper or displayed on a computer screen. Note that UTM is metric-based.

- Geodetic Coordinates: A non-earth-centric coordinate system to describe a position in longitude, latitude, and altitude above the imaginary ellipsoid surface based on a specific geodetic datum. WGS-84 and NAD83 datum are required for use with UTM and State Plans, respectively.

- ECEF XYZ: Earth-Centered, Earth-Fixed Cartesian X, Y, Z coordinates.

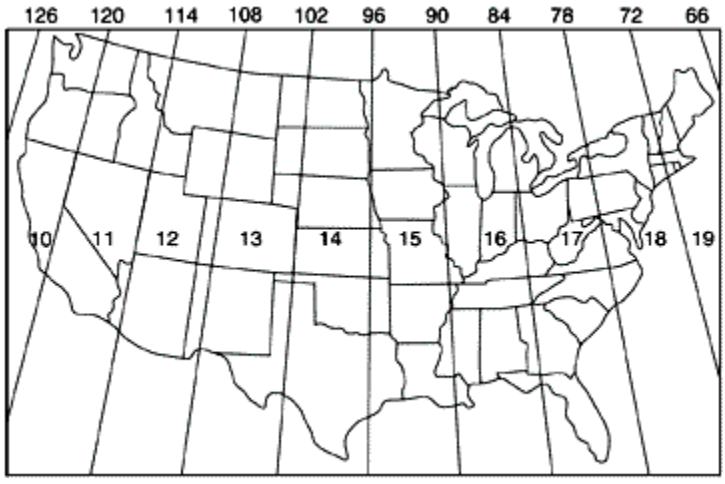
- Grid: Referred to ECEF XYZ in this specification.

- GUI Display: Graphical User Interface Display

- State Plane Coordinate: A set of 124 geographic zones or coordinate systems designed for specific regions of the United States. Each state contains one or more state plane zones, the boundaries of which usually follow county lines. The current State Plane coordinate is based on NAD83. Issues may arise when a project crosses state plane boundaries.

- UTC: Coordinated Universal Time (UTC) is commonly referred to as Greenwich Mean Time (GMT) and is based on a 24 hours' time scale from the mean solar time at the Earth's prime meridian (zero degrees longitude) located near Greenwich, England.

All GPS devices for this project shall be set to the same consistent coordinate datum/system no matter whether GPS or Grid data are originally recorded. UTM is the preference and shall be set to zone no. (xx) N for this project. (xxDOT to fill in the appropriate zone number) Zones outside of the continental United States can be acquired on the web at www.dmap.co.uk/utmworld.htm. The records shall be in meters. Use of UTM will facilitate GPS data checks onsite.



If UTM coordinates are not available, the State Plane Coordinate system can be used and set as (xx) for this project. *(xxDOT to fill in the appropriate State Plane designation)* Ad-hoc local coordinate systems should not be allowed.

Construction Requirements. Contractor shall provide the GPS system (including GPS receivers on IC rollers and hand-held GPS receivers (Rovers) that makes use of the same reference system that can be a ground-based base station or network-RTK, to achieve RTK-GPS accuracy. Examples of combinations are:

1. GPS receivers on IC rollers and hand-held GPS rovers referenced to the same on-ground base station.

2. GPS receiver on IC rollers and hand-held GPS receivers referenced to the same network RTK.

GPS Data Records and Formats. The recorded GPS data, whether from the IC rollers or hand-held GPS rovers, shall be in the following formats:

1. Time: The time stamp shall be in military format, hhmmss.ss in either UTC or local time zone. 0.01 second is required to differentiate sequence of IC data points during post process.

2. GPS: Latitudes and longitude shall in ddmm.mmmmmmmm or decimal degrees, dd.dddddddd. . Longitudes are negative values when measuring westward from the Prime Meridian.

3. Grid: Coordinates shall be in meters with at least 3 digits of significance (0.001 m or 1 mm).

When importing IC-MV data into the data analysis management program, the GPS data and associated IC measurements shall be stored with minimum data conversions and minimum loss of precisions. Users can then select unit of preference to allow real time unit conversion for the GUI display.

Post-Process GPS Check. Follow the vendor-specific instructions to export IC-MV data to Veda-compatible formats. The Contractor shall import the IC roller data in to Veda and enter GPS point measurements from the rover and visually inspect the IC map and point measurements on the Veda display screen for consistency.

Data Analysis Software. Standardized data analysis software (Veda) is available on the website www.intelligentcompaction.com or will be provided by *xxDOT*. The software program will utilize the IC-MV data from the IC roller for analysis of coverage, uniformity, and stiffness values during construction operations. As a minimum, the following Essential IC Data Information and IC Data Elements shall be available for post processing.

- Essential IC Data Header Information for Each Data File or Section:

Item No.	Description

1	Section Title
2	Machine Manufacture
3	Machine Type
4	Machine Model
5	Drum Width (m)
6	Drum Diameter (m)
7	Machine Weight (metric ton)
8	Name index of intelligent compaction measurement values (IC-MV)
9	Unit index for IC-MV
10	Reporting resolution for independent IC-MVs – 90 degrees to the roller moving direction (mm)
11	Reporting resolution for independent IC-MVs – in the roller moving direction (mm)
12	UTM Zone
13	Offset to UTC (hrs)
14	Number of IC data points

- Essential IC Data Elements for Each Data Point:

Item No.	Date Field Name	Example of Data
1	Date Stamp (YYYYMMDD)	e.g. 20080701
2	Time Stamp (HHMMSS.S -military format)	e.g. 090504.0 (9 hr 5 min. 4.0 s.)
3	Longitude (decimal degrees)	e.g. 94.85920403
4	Latitude (decimal degrees)	e.g. 45.22777335
5	Easting (m)	e.g. 354048.3
6	Northing (m)	e.g. 5009934.9
7	Height (m)	e.g. 339.9450
8	Roller pass number	e.g. 2
9	Direction index	e.g., 1 forward, 2 reverse
10	Roller speed (kph)	e.g. 4.0
11	Vibration on	e.g., 1 for yes, 2 for no
12	Frequency (vpm)	e.g. 3500.0
13	Amplitude (mm)	e.g. 0.6
14	Surface temperature (^{o}C) - HMA	e.g. 120
15	Intelligent compaction measurement values	e.g. 20.0

Items 3 and 4 can be exclusive with items 5 and 6, and vice versa. Item 14 is only required for asphalt application. The size of data mesh after post-processing shall be less than 18 inches (450 mm) by 18 inches (450 mm) in the X and Y directions.

QUALITY CONTROL PLAN

The Contractor shall prepare and submit a written Quality Control Plan (QCP) for the project. As a minimum, the QCP shall contain the following information:

General Requirements.

1. QCP shall be contract specific, stating how the contractor proposes to control the materials, equipment, and construction operations including subcontractors and suppliers as well as production facilities and transportation modes to the project for the embankment operations.

2. The QCP shall include an organizational chart showing all quality control personnel and how these personnel integrate with other management/production and construction functions and personnel.

3. The QCP shall be signed and dated by the Contractor's representative at the time the QCP is submitted to the Engineer. The QCP shall be submitted no later than 15 days prior to commencing the embankment operations.

4. The *xxDOT* will review, sign, and date the QCP if the contents of the QCP are in compliance with the requirements as stated herein.

5. The QCP shall be maintained to reflect the current status of the operations, and revisions shall be provided in writing prior to initiating the change. The QCP revision shall not be implemented until the revision has been accepted.

6. The QCP shall contain the name, telephone number, duties, and employer of all quality control personnel necessary to implement the QCP. The minimum qualifications of quality control personnel shall be as follows:

    a. QCP Field Manager or Plan Administrator. The person responsible for the execution of the QCP and liaison with the Engineer. Additionally the QCP Field Manager requirements include:

        1. Full-time employee of the Contractor or an independent consultant not involved with the Quality Assurance (acceptance) activities on the project.

        2. Minimum (x) years' experience (*as determined by the DOT*) in quality control activities in construction operations

        3. Full authority to institute actions necessary for successful implementation of the QCP.

b. Quality Control Technician (QCT). The person(s) responsible for conducting quality control and inspection activities to implement the QCP. There may be more than one QCT on a project.

1. Full-time employee of the Contractor or an independent consultant with a minimum (x) years' experience (*as determined by the DOT*) in quality control activities in construction operations.

2. Completed the *xxDOT* requirements for the applicable testing.

3. Full authority to institute actions necessary for successful implementation of the QCP.

c. IC Roller Operator. The person responsible for operating the IC roller and attached IC equipment. Sufficient training for the roller operator shall be supplied by a representative of the manufacturer of the equipment.

7. IC Equipment. The Roller supplier, make, roller model, number of IC rollers to be provided, and the GPS system supplier to be utilized.

8. Embankment operations shall not begin before the QCP has been accepted.

9. The Engineer may require the replacement of ineffective or unqualified equipment or Quality Control personnel. Construction operations may be required to stop until Quality Control corrective actions are taken.

References. ***(****to be modified/expanded as applicable by the DOT****)***

1. **AASHTO Standards**.

AASHTO T 99	Moisture-Density Relations of Soils Using a 2.5-kg (5.5-lb) Rammer and a 305-mm (12-in.) Drop
AASHTO T 272	Family of Curves – One-Point Method
AASHTO PP81-14	Standard Practice for Intelligent Compaction Technology for Embankment and Asphalt Pavement Applications

2. **ASTM Standards**.

ASTM D 2583	Measuring Deflections with a Light Weight Deflectometer (LWD)

ASTM D 6951	Dynamic Cone Penetrometer in Shallow Pavement Applications (17.6-lb (8-kg) hammer)

3. ***xxDOT* Standards**.

xxx	Field Determination of Moisture Content of Soils
xxx	Field Determination of Deflection Using Light Weight Deflectometer

Quality Control Technician. The QCT shall be responsible for the following minimum functions:

1. GPS check testing for the IC roller(s) and rover(s).

2. Test section construction and establishing target values for the maximum dry density, optimum moisture content, production moisture content, strength of the materials using the dynamic cone penetrometer (DCP), light weight deflectometer (LWD), nuclear gauge, and the IC-roller(s).

3. Monitoring of the construction operations and the IC roller(s) during production and final proofing operations.

4. Quality control testing for the maximum dry density and moisture content.

5. Downloading and analysis of the IC-data from the roller(s).

6. Daily set-up, take down and secure storage of GPS and IC roller components

Testing Facility. The location of the testing facility and a list of test equipment shall be included. The testing facility shall be sufficient size to conduct the Quality Control tests, and a satisfactory base on which compaction of the soil can be achieved in accordance with AASHTO T 99 Method A (*or as otherwise defined by the DOT*) shall be provided. A statement of accessibility of the testing facility shall be included that allows *xxDOT* personnel to witness Quality Control activities and to review Quality Control tests.

A list of the testing equipment proposed for Quality Control testing and the test methods and frequency of calibration or verification of the equipment shall be included. The Contractor shall maintain a record of all equipment calibration or verification results at the testing facility. The minimum frequency and procedures shall be as follows:

Equipment	Requirement	Minimum Frequency	Procedure*
Balances	Verification	12 months	xxx
Sieves	Check Physical Condition	12 months	xxx
Etc.*	*	*	

**to be filled in by the DOT*

Materials Sampling and Testing. The procedures for sampling and testing of the soil embankment and the frequency of tests shall be identified and include as a minimum the following: *(details to be modified/expanded as applicable by the DOT)*

1. Moisture. The procedure for measuring the moisture content of the soil during production compaction. The minimum frequency of tests per lift of material shall be one test for each construction area.

2. Strength. The procedure for measuring the in-place strength of the soil. The minimum frequency of tests shall be a minimum of one test for each construction area.

3. Maximum Dry Density and Optimum Moisture Content. The procedure for measuring the maximum dry density and optimum moisture content of the soil for the test sections and when there is a change in the soil type.

4. IC Roller Data. The procedure for obtaining the IC roller data. The frequency of obtaining the data shall be a minimum of two times each day of soil compaction. The data is date/time stamped which permits for external evaluation at a later time.

GPS Check Testing. Prior to the start of production, the Contractor, GPS representative and IC roller manufacturer shall conduct the following to check the proper setup of the GPS, IC roller(s) and the rover(s) using the same datum:

1. On a location nearby or within the project limits, the GPS base station (if required by the GPS) shall be established and the IC roller and the GPS rover tied into the same base station.

2. Verification that the roller and rover are working properly and that there is a connection with the base station.

3. Production shall not begin until proper GPS verification has been obtained. IC vendors' recommended verification process can be used to augment the following procedure.

   Move the IC roller around until the GPS header computation is initialized. Move the IC roller and park at a selected location. Record the GPS measurements from the IC roller ensuring the distance offsets are applied so that the GPS coordinate is at the center or at left/right edges of the front drum. Mark two locations on the ground adjacent to the right and left edges of the front drum contact patch. Move the IC roller from the marked locations. Use a hand-held rover to measure at the marked locations. Average the rover GPS measurements if the roller GPS measurement is at the center of the front drum. The differences between the roller

GPS and rover measurements shall be within 12 inches (300 mm) for northing and easting.

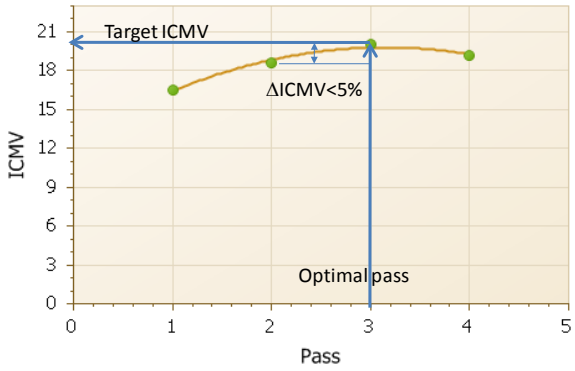
4. The project plan file provided by xxDOT shall be uploaded into the IC Data analysis software and depending on the roller manufacture, the on-board IC computer.

5. GPS check testing shall be conducted daily during production operations to ensure consistency and accuracy of GPS measurements for all GPS devices prior to the paving and compaction operations.

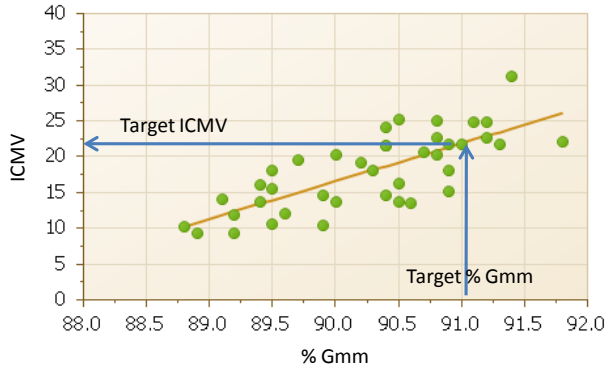
Test Sections. Test section evaluations are intended to determine the number of passes it takes to achieve compaction at the optimum moisture content for the materials. Test sections shall be approximately 225 ft (75 m) long and 24 ft (8 m) wide and may be part of the initial production operations. *(Test section details to be modified/expanded as applicable by the xxDOT)*

The evaluations shall be conducted for the various material types, on every lift where there is a change of materials. The IC rollers shall use the same settings (speed, frequency) throughout the section. After each roller pass, a nondestructive density device shall be used to estimate the density or stiffness of the material and a hand-held GPS rover to measure the positions at least 10 locations uniformly spaced throughout the test section.

The estimated target density will be the peak of the nondestructive readings within the desired moisture range. The IC roller data using software will create an IC compaction curve for the mixture. The target IC-MV is the point when the increase in the IC-MV of the material between passes is less than 5 percent on the compaction curve. The IC compaction curve is defined as the relationship between the IC-MV and the roller passes. A compaction curve example is as follows:



Linear regression relationships between the point test results and the IC-MV results will be used to establish the production target IC-MV as the target density meets the xxDOT in-place compaction requirements. The target ICMV is recommended only for QC. A linear regression curve example is as follows.



Pre-Mapping. Pre-construction mapping/proofing of the initial layer of the fill is recommended to identify weak areas that may need to be addressed in advance of the production fill operations. Subsequent mapping may be conducted at any time to recognize the changes in the fill that affects the target IC-MV or the density verification testing. Mapping operations are intended to provide the Contractor and understanding of the stiffness of the existing roadway being compacted. At a minimum, production mapping is recommended at the final surface of the fill and the elevation levels at 1.0 ft., 2.0 ft., 4.0 ft., and 8.0 ft. below the final surface as applicable. The stiffness of the underlying materials should increase with subsequent lifts of material. The Contractors procedures for mapping shall be included.

Soil Management. The procedures for management of the borrow pit and soil cut sections to assure uniform soil material shall be included in the QCP. The procedures for the necessary adjustments in compaction because of a change in soil type shall be stated.

Response to Test Results. The response to quality control tests for the test sections and during production compaction shall include as a minimum the following:

1. Moisture. The procedure for corrective action when the QC moisture tests are not within -3 and +2 percentage points of the optimum moisture content.

2. Strength. The procedure for corrective action when tests do not meet the *xxDOT* requirements for each soil type.

3. Maximum Dry Density and Optimum Moisture Content. The procedure for corrective action when the maximum dry density and optimum moisture content test results indicate that there is a change in the soil type.

4. IC Coverage Area and Uniformity Criteria. The procedures for re-working the construction area when IC criteria for coverage area or the minimum IC-MV are not met.

Documentation. The documentation shall include the following:

1. Quality Control Tests. The results from the moisture, strength, and maximum dry density and optimum moisture content tests. All quality control test results shall be signed by the QCT and submitted to the Engineer within 24 hours of testing.

2. Equipment. Documentation of the manufacture, model, and type of rollers used each day of soil compaction and the IC roller used for mapping the compaction of the soil. The positioning of the IC roller(s) in the paving operations shall be noted.

3. IC Roller Data. At a minimum, the electronic data from IC roller(s) and the data analysis software shall be provided to the Engineer upon the completion of the Test Section, Mapping and individual IC Construction Area operations.

4. IC-MV Analysis. The Contractors will analyze the IC-MV data for conformance to the requirements for coverage area and uniformity and will submit the results to the Engineer at the completion of the individual IC Construction Area operations.

   IC data shall be exported from the vendor's software in both all passes and final coverage data files. All passes data includes the data from all of the passes and final coverage data is the data from just the last pass within a given area.

5. Construction Area. The limits of the construction areas of each lift of embankment.

IC CONSTRUCTION

Technical Assistance. The Contractor shall coordinate for on-site technical assistance from the IC roller representative during the initial seven (7) days of production and then as needed during the remaining operations. As a minimum, the roller representative shall be present during the initial setup and verification testing of the IC roller(s). The roller representative shall also assist the Contractor with data management using the data analysis software including IC data input and processing.

On-Site Training. The Contractor shall coordinate and provide for on-site training for Contractors and Agency project personnel related to operation of the IC technology. Contractor's personnel shall include the contractor's superintendent, QC technician(s), and roller operator(s). Agency's personnel shall include the project engineer and field inspector(s). (*Appropriate personnel to attend the training to be modified/expanded as applicable by the xxDOT*) Arrangements shall be provided that includes an enclosed facility with electrical availability and a projector for presentations and should be 4-8 hours in duration.

Minimum training topics shall include:

1. Background information for the specific IC system(s) to be used

2. Setup and checks for IC system(s), GPS receiver, base-station and hand held rovers

3. Operation of the IC system(s) on the roller; i.e., setup data collection, start/stop of data recording, and on-board display options

4. Transferring raw IC data from the rollers(s); i.e., via USB connections

5. Operation of vendor's software to open and view raw IC data files and exporting all-passes and final coverage data files in Veda-compatible format

6. Operation of Veda software to import the above exported all-passes and final coverage data files, inspection of IC maps, input point test data, perform statistics analysis, and produce reports for project requirements

7. Coverage and uniformity requirements

Construction Areas. IC Construction areas are defined as subsections of the project being worked continuously by the Contractor. The magnitude of the evaluation areas may vary with production but they need to be at least 25,000 ft^2 for evaluation and not greater than 100,000 ft^2. Partial construction areas of 5000 ft^2 or less will be included in the previous area evaluation. Partial construction areas of greater than 5000 ft^2 will constitute a full area to close out the mixture. Construction areas may extend over multiple days depending on the operations.

IC Construction Operations Criteria. A minimum coverage of 90% of the individual construction area shall meet the optimal number of roller passes and 70% of the target IC-MV determined from the test sections. Construction areas not meeting the IC criteria shall be reworked and re-evaluated prior to continuing with the operations in that area. The IC Construction Operations Criteria does not affect the standard *xxDOT* acceptance processes for the materials or construction operations.

METHOD OF MEASUREMENT

This item will not be measured as it will be paid as a lump sum for providing for the Intelligent Compaction for Soils on the project.

BASIS OF PAYMENT

The incorporating of the Intelligent Compaction process will be paid at the contract lump sum price for Intelligent Compaction for Soils**.**

Payment will be made under:

Pay Item	**Unit**
Intelligent Compaction for Soils.....	LS

This item includes all costs related to providing the IC roller including the fuel, roller operator, GPS system, or any other equipment required for the IC process. All quality control

procedures including IC rollers and GPS systems representatives support, on-site training and testing facility shall be included in the contract lump sum price.