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Intelligent Compaction Implementation: Research Assessment

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16. Abstract (Limit: 200 words)

The objective of this project was to provide a qualitative assessment of the Minnesota Department of Transportation's Intelligent Compaction (IC) Specifications. IC is an attractive approach to evaluate the compaction quality because it involves continuous and instantaneous evaluation of the soil through machine-drive power or drum vibration monitoring. Four construction sites utilizing IC were visited: (1) TH 36 in North St. Paul, involving both granular and nongranular soils; (2) US 10 in Staples, with granular soil; (3) TH 60 in Bigelow, with nongranular soil; (4) US 10 in Detroit Lakes, involving both granular and nongranular soils. The report integrates comments from the four site visits and provides an interpretation on the use of IC at each site. As the technology now exists on the equipment used at these locations, IC provides only an index, which is specific to the conditions associated with a particular site. An interpretation of comments provided the basis for the following recommendations:

- Use light weight deflectometers (LWD) for quality assurance of stiffness
- Establish a procedure to determine the target LWD value
- Eliminate calibration areas (control strips)
- Simplify IC data evaluation and presentation
- Calibrate the IC roller and related transducers
- Support development of alternative IC methodologies
- Simplify or eliminate moisture corrections

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Intelligent Compaction Implementation: Research Assessment

Final Report

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EXECUTIVE SUMMARY

The objective of this project was to provide a qualitative assessment of the Minnesota Department of Transportation's Intelligent Compaction (IC) Specifications, including recommendations to improve the specifications and procedures. This was accomplished by (a) developing a strategy to interview field personnel; (b) visiting four construction sites and documenting the activity; (c) interviewing the field personnel and reviewing selected field records at the four sites; and (d) providing recommendations from the feedback obtained.

IC is an attractive approach to evaluate the compaction quality because it involves continuous and instantaneous evaluation of the soil through machine-drive power or drum vibration monitoring. In addition, there exists a possibility to optimize the compaction effort based on machine-drive power or drum vibration response. Modern IC devices also have an integrated global positioning system to provide a complete GIS-based record of the earthwork site.

Four construction sites utilizing IC were visited: (1) TH 36 in North St. Paul (S.P. 6211-81), involving both granular and nongranular soils; (2) US 10 in Staples (S.P. 7702-42), with granular soil; (3) TH 60 in Bigelow (S.P. 5305-55), with nongranular soil; (4) US 10 in Detroit Lakes (S.P. 0301-47), involving both granular and nongranular soils. The report integrates comments from the four site visits and provides an interpretation on the use of IC at each site. As the technology now exists on the equipment used at these locations, IC provides only an index, which is specific to the conditions associated with a particular site. An interpretation of comments provided the basis for the following recommendations:

- Use light weight deflectometers (LWD) for quality assurance of stiffness
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- Calibrate the IC roller and related transducers
- Support development of alternative IC methodologies
- Simplify or eliminate moisture corrections

Chapter 1

Introduction

Intelligent Compaction (IC) is an attractive approach to evaluate the compaction quality because it provides continuous and instantaneous evaluation of the soil through vibration or machine-power monitoring. In addition, there exists a possibility to control the compaction effort based on compaction-roller or vibration response. Modern IC devices may also have an integrated global positioning system to provide a complete GIS-based record of the earthwork site.

It is widely accepted that compaction is an essential part of pavement construction and transportation agencies allocate a significant portion of their highway construction budget for this operation. Subgrade and base layers should be properly compacted during construction prior to placement of the next layer in the pavement system. Ideally, the subgrade and base layers should provide a uniform support of sufficient stiffness and strength for the upper pavement layers. Achieving this simple goal is a challenge due to material heterogeneity, difficulty in maintaining prescribed lift thickness and moisture content, as well as variability in equipment and operators. Accordingly, contractor quality control (QC) and agency quality assurance (QA) are a critical part of the construction process.

A variety of devices have been proposed for the QC/QA of compaction, including the sand cone, dynamic cone penetrometer, stiffness gauge, and light weight deflectometer. These devices, however, have low productivity. As a result, only a small portion of the compacted area can be tested and the need for IC becomes apparent.

1.1 Background

Development of an IC Specification requires an understanding of the process of compaction and its effects on pavement performance. Specifically, the material parameters that are of interest to evaluate the compaction process are stiffness (e.g. Young's modulus) and strength (e.g. friction and/or cohesion). Assessing these parameters requires knowledge of specific devices and insight into pavement design. In addition, quality control and quality assurance practices (e.g. nondestructive testing and evaluation) typically use an estimate of stiffness, with a critical component of the evaluation being device calibration.

Understanding the inherent variability of the pavement foundation system and its effect on pavement performance is critical in improving pavement life. Acceptable and achievable levels of uniformity can be measured with a device that provides (virtually) continuous readings of the subgrade and base. This is where IC can have a significant impact.

It must be recognized that a typical specification for IC construction is device and system dependent. Ideally, the machine output should be directly related to a pavement design parameter such as stiffness or strength through a quantifiable procedure. However, without a method to objectively measure the input loading and the machine response for a known system, the IC value will be a function of the compactor for a given system. Thus, the IC value should be viewed as an index only, which is useful primarily for comparison purposes.

Numerous methods are used for quality assurance (QA) of soil and aggregate base compaction, ranging from visual inspection, density measurements, dynamic cone penetrometer (DCP) testing (ASTM D6951), and light weight deflectometer (LWD) testing (ASTM E2583). Visual inspection requires an inspector and typically some sort of method specification that dictates the type of roller and possibly a minimum number of passes. This method can also include specifications that control the moisture content of the material being compacted. Specified density methods generally allow the contractor to compact the material in whatever manner the contractor chooses and the agency does acceptance testing on the basis of sample density measurements.

Commonly used tests include the sand-cone test (ASTM D 1556) or the balloon test (ASTM D 2167). The field density is compared to a reference maximum density as determined from soil samples taken to the laboratory. The reference density test methods used are typically standard Proctor (AASHTO T-99) or modified Proctor (AASHTO T-180, ASTM D1557). The DCP and LWD tests are similar to the specified density method except the material is tested in a quality assurance acceptance mode with a DCP or an LWD device. Construction projects are inherently dangerous places to work. Operators of heavy equipment have limited visibility, and the noise level often limits the inspector’s ability to hear heavy equipment approaching. Many of the density test methods or other field test methods require close attention to the conduct of the test itself, leaving the inspector vulnerable.

Limitations can be identified with any of the current quality control and quality assurance methods used for compacting soils. Two of the methods, visual inspection and calibration area (control strip), hold promise of continual coverage under ideal conditions. The visual inspection, however, puts all of the responsibility on the opinion and experience of the field inspector. The calibration area method depends on site conditions to be the same as that of the calibration area and that the rolling pattern established during the calibration area is actually applied during production.

Moisture limits may be included as part of the compaction specification, as moisture has a substantial effect on soil behavior. For example, in the classic study by Seed and Chan (1959), a silty clay was compacted at various water contents (Fig. 1.1) and tested in uniaxial compression (Fig. 1.2). The effect of moisture is evident; both stiffness and strength of this soil changed by a factor of two or more.

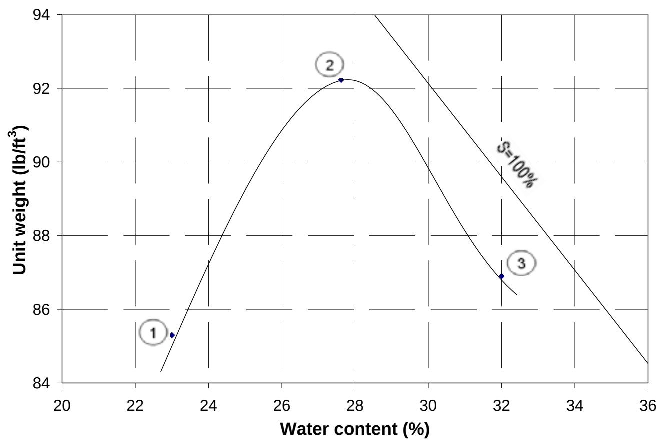

Figure 1.1. Compaction curve for a silty clay (Seed and Chan 1959).

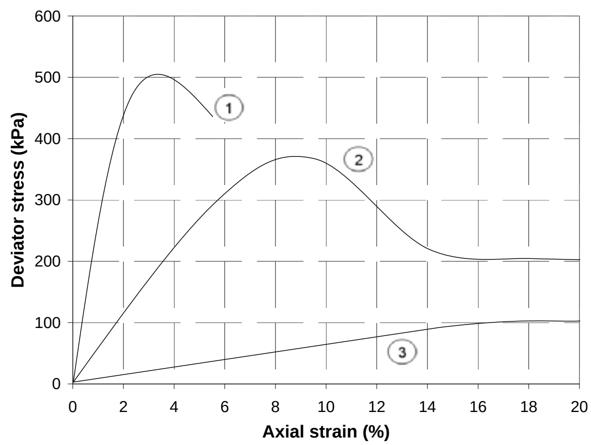

Figure 1.2. Mechanical behavior of compacted specimens tested in uniaxial compression (Seed and Chan 1959); the numbers refer to water contents (1) dry of, (2) at, and (3) wet of, optimum.

Three other methods, specified density, DCP, and LWD, are spot tests and have very little coverage; neither of these two specification methods can provide continuous coverage. In summary, the advantages of IC are nearly continuous coverage, increased productivity, specifications related to design parameters, reduction in labor for QC/QA testing, and improvement in safety.

A method that provides an indirect measure of subgrade strength is test rolling (Fig. 1.3), which has been used to determine if the soil has been adequately compacted. Test rolling involves measuring the amount of depression or rutting that occurs when a loaded cart is towed across an area under construction. If the depression depth exceeds the specified limit, problem areas that need reworking are identified.

Figure 1.3. Test rolling a compacted subgrade.

1.2 Mechanics of IC

A number of studies have attempted to quantify the operation and performance of intelligent compaction devices (Adam and Kopf 2000; Floss and Kloubert 2000; Krober et al. 2000; Thurner and Sandstrom 2000; Kloubert 2002; Briaud and Seo 2003; Sandstrom et al. 2004). In most of these investigations for vibratory rollers, the IC force and acceleration measurements are used first to resolve the soil stiffness k, with this quantity being used as an input to a static backcalculation of Young modulus's E in the context of Hertz contact theory. Two key drawbacks of this approach are the following.

- The soil stiffness k is deduced by modeling the response of a soil mass as that of a lumped spring and dashpot, a system that is by its nature frequency-independent. It is well known (e.g. Pak and Guzina 1996), however, that the dynamic soil stiffness is frequency-dependent, even for homogeneous profiles. As a result, the soil-stiffness should be modified as to include a continuum dynamic soil model (e.g. base-over-subgrade system).

- Young's modulus E is calculated from k using a static solution for the drum-soil contact problem despite the fact that intelligent compaction loading is dynamic in nature.

It is important to note that these simplifications result in modulus estimates that are dependent on the operating frequency. In practice, such differences are often attributed to the fact that lower frequencies penetrate into soil deeper than higher frequencies. Unfortunately, this explanation is only partially correct, as it neglects the dynamic effects in the soil, and may lead to appreciable errors in the backcalculation of E.

There are three types of measures for machine-based intelligent compaction: (a) compaction meter value developed by Geodynamik and used by Caterpillar and others; (b) stiffness value utilized by Case/Amman and Bomag; and (c) machine drive power method developed by Caterpillar. For the projects reported, method (a) was used for granular soils and (c) for cohesive soils. It must be recognized that the IC values furnished by the IC equipment are based on the use of proprietary manufactures' methodology and are therefore machine-dependent. Thus, IC provides only an index, which is specific to the conditions associated with a particular site.

Nevertheless, general characteristics can be described for the output from the machine. For example, one manufacturer uses the ratio between the first and second harmonics of the nonlinear soil-roller interaction (Thurner and Sandström, 1980). This in turn requires accurate measurements of the acceleration time history, and calibration of the motion sensor is critical. The ratio is sometimes called the compaction meter value (CMV), and for vibratory rollers from Caterpillar, this measure is called CCV, the Caterpillar Compaction Value. Note that the contact problem is nonlinear and the indices will depend on machine characteristics that can be varied (e.g. frequency, amplitude, speed). Furthermore, it must be recognized that the index associated with a vibratory roller is related to material stiffness and the influence of the surroundings can be pronounced, whereas machine drive power (MDP) is affected by the strength of the soil near the surface. The principles behind MDP are based on soil-machine interaction, and Hambleton and Drescher (2008) provided a thorough study of this topic with respect to test rolling.

Chapter 2

Site Interviews

Each interview at the project sites was started with the disclaimer that all comments would remain anonymous and no individuals would be identified. General comments regarding the IC process were sought, as inspectors and contractors have extensive experience. Four construction sites utilizing Intelligent Compaction (IC) were visited:

1. TH 36 in North St. Paul (S.P. 6211-81), June 29, 2007
2. US 10 in Staples (S.P. 7702-42), August 16, 2007
3. TH 60 in Bigelow (S.P. 5305-55), September 12, 2007
4. US 10 in Detroit Lakes (S.P. 0301-47), September 25, 2007

2.1 North St. Paul project (SP 6211-81)

The construction site at the North St. Paul project was broad, as various activities were on-going in the rebuilding of Highway 36 between White Bear Avenue and Century Ave (Highway 120). Work along the two-mile span included a diamond interchange at Highway 36 and McKnight Road (County Highway 68), a bridge to carry traffic on Margaret Street over Highway 36, and a pedestrian bridge over the highway. The bid cost of the project was about $27,000,000, and the contractor was Progressive Contractors, Inc (PCI) of St. Michael, MN.

2.1.1 Soil conditions

The soils at the site varied from coarse to fine grained, and at least four soil conditions, as described by construction personnel, were encountered. The general soil description was a loamy sand or sandy loam, with 25 – 35 % fines. However, despite the soil classification, the soil typically behaved as a silt. Because of the significant variability, different compaction characteristics of the cut and fill material were encountered. The borrow material was local, and depths of cut varied from one ft to over 10 ft. Moisture was controlled by spraying. Since the soil was silty, the plasticity index had a narrow range. Thus, control of moisture was critical, and it was common for the soil to be too wet or too dry.

2.1.2 Equipment

Test rolling was the standard method for quality assurance (QA). The modified DCP target value criteria were used for spot testing and the DCP was considered to be a reliable measure of compaction quality. In addition, an LWD device was tried at the start of the project, but the modulus values were not trusted by the field personnel. Another LWD device from a different manufacturer was used later in the project and consistent results were obtained.

Two different types of Caterpillar IC rollers were used on the project, a vibratory padfoot drum and a vibratory smooth drum, depending on the soil type. Generally, a vibratory padfoot roller was used for fine-grained soils and a vibratory smooth drum roller was used for granular soils. At the time of the visit, three rollers were being used. Over the course of the project, five (two IC and three production) rollers were used. The IC rollers were used for proof rolling and production rolling. Operator training was minimal, but some was provided.

Note that IC rollers from Caterpillar provide CCV values for both the smooth drum vibratory compactor and machine drive power values from the padded drum vibratory compactor. The smooth drum vibratory rollers resulted in lower numbers, 10 – 40, while the MDP method resulted in higher values, 60 – 150. Caterpillar recommends that the production mode be in high amplitude, operated at normal speeds, with both forward and reverse modes used. For the proofing mode, Caterpillar recommends operation at a slow constant speed (2 – 3 mph) and the same direction of travel (forward), at low amplitude.

2.1.3 Field protocols

For each type of soil encountered, a new calibration area was constructed; the final number of calibration areas was 17. The first calibration area required 12 hours to construct due to initial uncertainties, but the subsequent ones were constructed in less than half that time. Modified DCP testing was performed every 75 ft (23 m) for the calibration area; in the production phase, the testing was performed every 1000 ft (300 m), following specifications.

During proof rolling, speed was kept constant at 3 mph for both the padfoot and smooth drum vibratory rollers. The compaction process used on the site consisted of air drying and compacting the soil, but over-drying was a common problem. The target IC value varied from 5 – 20, depending on soil type. IC monitoring involved an inspector looking at the screen in the cab after the proof rolling. The downloaded IC data were reviewed when time allowed; this involved using the commercial software and viewing the output on a monitor. The software was difficult to use. Moisture was not directly considered for the IC values.

2.1.4 Specifications

Test rolling and the modified DCP provided the most trusted estimates of compaction quality. In fact, several comments were made about the possibility of reducing the load and thus rendering the QA for the test roller more forgiving. Overall, the merit in IC was recognized, but the need for a clear and coherent specification is critical for implementing the technology. The specification is contained in Appendix A.

There was unanimous sentiment that IC has potential merit for providing continuous coverage and rapid identification of “weak” spots. However, there was also agreement the IC data were difficult to interpret for this site due to the high variability of soil conditions.

2.1.5 Comments

If the site conditions were uniform, the full benefits from the IC roller could be realized. Overall it was found that the visual observation of soil deflection under a 120,000 lb (54 kN) dump truck driving over the fill was a very good indicator for QA. Following the modified DCP and the test roller, the visual observation of soil deflection under a wheel load was the most highly regarded.

It was also noted that the primary objective of soil compaction is to get the soil to support the loads from the paving operation. The stresses induced in the soil during construction were recognized to be much higher than those developed from traffic over the paved system. An interesting observation was made regarding the IC reading for the base material (e.g. class VI). In particular, the CCV values were nearly identical for the exposed subgrade and the base-over-the-subgrade profiles for base layers 1 – 2 ft (0.3 – 0.6 m) thick.

A major advantage of IC is the ability to provide real-time, continuous coverage. However, the IC value is recognized to be an index parameter and not a mechanical property of the soil. Accordingly, the acceptable compaction measurement value range needed to be re-calibrated for every different soil type, posing a key obstacle for using IC on this project. It is suggested that the specification be written to allow some flexibility (e.g. target range instead of a target value) in interpreting the IC index.

2.2 Staples project (SP 7702-42)

The Staples project involved the expansion of Highway 10 in Todd County. A new four-lane road was constructed one block south of the old alignment. The project included four new lanes of highway (about 2.4 miles), turn lanes and safety improvements, utilities, and several drainage ponds. Mathiowetz Construction of Sleepy Eye, MN was the contractor for the $10,000,000 project.

2.2.1 Soil conditions

The project was quite linear; a length of approximately 3,000 ft (900 m) was observed at the time of the visit. The soil was described as uniform sand with good working conditions (Fig. 2.1). Select granular was used for the entire site. Additional soil was taken from an offsite borrow pit, close to the project site. It was difficult to keep the material at the optimum moisture content (14.5%) with the dry weather. Moisture was typically added to ensure conditions were between 65 – 95% of optimum on the dry side, which was considered a good range for construction. Standard grading practice was followed and proof testing was performed on a 2 ft (0.6 m) interval. The depth of cut varied from one to several feet. The soils report is contained in Appendix B.

Figure 2.1. Construction of Highway 10 in Staples, MN.

2.2.2 Equipment

The Caterpillar IC roller was not difficult to operate, as it is similar to other construction equipment. Data from the IC roller was downloaded once per week and it was viewed when time permitted. There were no problems with compatibility of equipment and no GPS frequency interference. The modified DCP (Fig. 2.2) and the Zorn LWD device (Fig. 2.3) were used (sand cones were not) for quality assurance. The IC vibratory smooth drum roller was utilized during both proofing and non-proofing production layers. A smooth-drum roller identical to the IC roller was also used, but infrequently. The production mode of the IC compactor was performed at a high-amplitude setting. The roller operator kept a record of activities such as where in the construction site the IC roller was proofing and the general conditions of the soil. The training involved an overview of IC. From the operators prospective, this training was adequate. Software support could be improved for data presentation and interpretation.

Figure 2.2. IC roller.

2.2.3 Field protocols

The IC CCV target value was 13, as determined from a single calibration area. Moisture effects were not directly considered, although it was acknowledged that moisture had an effect. The calibration area was constructed in two days, but future calibration areas could be constructed faster. The scale for the CCV appeared to be non-physical and it did not scale linearly (e.g., with soil density). Some of the IC CCV readings were as high as 40. The IC roller for proof testing was operated at 2.2 mph and at a low amplitude setting.

The LWD was not specified, but it was used throughout the site to spot check. The Zorn LWD catch/release assembly was moved to the top of the shaft to achieve the maximum drop height. The LWD and DCP results agreed qualitatively with IC measurement trends. Even though the specification called for one DCP test every 1000 ft (300 m), moisture content, DCP, and LWD readings were taken once every 300 ft (90 m). Additional testing was performed because the LWD device was easy to use.

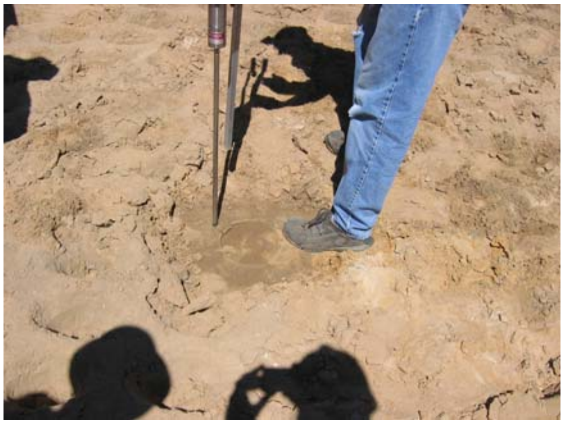

Figure 2.3. DCP testing.

2.2.4 Specifications

The IC roller did a good job identifying poor spots that should be tested with the DCP and the LWD. No quantitative analysis of IC acceptance criteria was performed due to time constraints. Visual judgment and QA testing with the DCP were used to determine acceptance. The LWD target value for the calibration area were not specified, but 25 – 30 MPa (3630 – 4350 psi) were considered good values. Standard MnDOT procedures were followed, as instructed by personnel from MnDOT Office of Material.

The QC was accomplished by monitoring real-time measurements during the operation of the IC roller. The IC roller, DCP, and LWD were in good agreement. However, moisture had some effect on the LWD and IC roller measurements. (The DCP indicated passing, where LWD and IC roller indicated failing in regions with high water content.) An LWD modulus value of 28 MPa (4060 psi) or greater implied passing quality assurance and this was confirmed by the DCP, while a LWD of 14 MPa (2030 psi) or less implied poor compaction and the DCP would typically fail.

Figure 2.4. LWD testing.

2.2.5 Comments

The DCP is considered reliable, quick, and easy to perform and appears to give consistent interpretation of compaction. The information from the IC roller is complicated and the data require filtering. Engineering judgment (i.e., observing deflections of the soil beneath construction equipment) is still commonly used to evaluate the adequacy of compaction.

The IC roller has the potential to make construction more efficient by easily identifying areas that require more compaction and areas requiring no further effort. Additionally, one can easily see soil conditions improving with increasing compaction. However, the IC compaction measurement values have no meaning during production, and the values can only be used as a proof testing tool. It should be noted that any compaction measurement device should be used in a consistent, prescribed manner in order to produce reliable results.

2.3 Bigelow project (SP 5305-55)

The Bigelow project involved the expansion of Highway 60 (Fig. 2.5), and it included about three miles of four-lane construction of a bypass around Bigelow in Minnesota and two more miles of four-lane in Iowa. The Bigelow project extends from just north of 120th street in Iowa to about one mile north of Nobles County Road 4 in Minnesota. The purpose of this project is to continue the four-lane Highway 60 expansions in both Iowa and Minnesota, bypass Bigelow, replace worn out pavement, and eliminate unsafe geometrics at intersections. MnDOT is the lead on the project, working in close cooperation with the Iowa Department of Transportation. Mathiowetz Construction of Sleepy Eye, MN was the contractor for the $11.6 million project. Minnesota's share of the cost is about $7.2 million and Iowa's share is $4.4 million.

2.3.1 Soil conditions

Uniform cohesive soil was present; 90% of the soil was the same with an occasional appearance of blue clay. The in-situ soil was quite wet. Additional soil, where needed, was taken from an on-site borrow location. A few Proctor tests were performed at the start of the project. The optimum moisture content was relatively high, although the exact number was not available. The typical fill depth was 4 – 8 ft (1.2 – 2.4 m) with some locations requiring 20 – 30 ft (6 – 9 m). The soil report in contained in Appendix C.

2.3.2 Equipment

The IC roller was manufactured by Caterpillar with machine-drive power IC measurement and 7 ft (2.1 m) wide drum. The IC roller was equipped with wireless communication, but this feature was not fully utilized as data was downloaded once per week using a memory key. The IC roller was used for proofing only. The IC personnel were trained at this project in addition to at the previous training obtained at the Staples project. No compatibility problems were encountered with the IC data. A Zorn LWD, with an 8 in. (0.2 m) diameter plate was used for acceptance. The job will shut-down over the winter and the test roller will be used for QA in Spring 2008.

Figure 2.5. The linear nature of the Bigelow project.

2.3.3 Field protocols

At the time of the survey, only one calibration area had been constructed; another calibration area was anticipated due to occasional heterogeneity (the blue clay). The first calibration area was time consuming, requiring 2 – 3 days to complete. The IC target machine drive power (MDP) was in the range of 138 – 150. The operating speed of the IC roller was about 2 mph during proofing runs. Occasionally, the sand cone test was used. The LWD modulus values were in the range of 7 – 60 MPa (1015 – 8700 psi) due to moisture variations. Values greater than 15 – 20 MPa (2180 – 2900 psi) were deemed acceptable.

The field personnel were efficient with the LWD, conducting approximately 20 tests in one day. The LWD testing was performed at 150 – 200 ft (46 – 61 m) spacing, basically because of the efficiency of the operator. For LWD testing, the soil crust was manually scraped with a shovel and standard MnDOT testing procedures were followed. The moisture was assessed qualitatively as "high" or "low." The IC data was reviewed when time allowed.

2.3.4 Specifications

Acceptance was determined by the LWD; the DCP was not used for this project. Lifts of 8 – 12 in. (0.2 – 0.3 m) were used and the IC roller mapped every third lift (2 ft or 0.6 m). A difficulty with IC is that there are no standard forms to present the data. There is the need for the capability for data/comment input into the IC data collection system. The specifications are asking for more than the IC can deliver (e.g. it is not clear how large amounts of data should be processed).

At the site, no IC mapping was performed after reworking the soil, e.g. due to rain, pipe construction. Consequently, the IC information may not be up to date because there were not any repeated IC measurements after the soil was accepted even if it was reworked afterwards. Bridging was observed due to a dried-up top layer, thereby compromising the IC MPD value; the MPD values may not representative of the underlying material.

Some personnel expressed the concern that the IC capabilities are exaggerated. Caterpillar equipment was used and it was not clear why other manufacturers were not considered (although it may be related to the use of IC machines for cohesive soil measurements with a padded drum roller). Test rolling will be done next spring, yet there will be a freeze-thaw cycle in between. They will likely have to take off the top 2 ft (0.6 m) and re-compact. It was not known if IC testing will be performed again next season.

2.3.5 Comments

IC is somewhat difficult to apply to a linear project, one that requires long grading over protracted time in a narrow area, as opposed to a project that is more open. Visual inspection of surface deflections resulting from the passing of scrapers, trucks, etc. was an important part of QC. There was no particular preference for the use of the test roller as a QA tool.

The management and presentation of IC data was cumbersome. Significant time was required to track and understand the individual IC plots (e.g. which lift). In general, the sentiment at the site was that the IC provides too much data, which needs to be filtered and better documented for easier use. The use of IC as a QC tool was deemed to be inefficient for this (linear) type of project due to limited access. In particular, the IC required the closure of significant parts of the site to construction traffic and delayed the overall construction.

2.3.6 Notes from Contractor

Based on experience from the Staples and Bigelow projects, Mathiowetz Construction (MC) put together a presentation that summarized their perspective of IC. The following notes were taken from the presentation.

The non-granular target value was 150, and a range of 138 – 150 was used. The granular target value was 13. MC mapped the bottom of the sub-cut, which did not have to meet a target value. MC proof tested at two foot intervals and compared the results to LWD data. In the cab of the IC roller, the display shows the CCV value, location and elevation, number of passes, speed, and amplitude. The IC roller generated massive amounts of data, and it was not clear if these data were being utilized. It was difficult to organize the data into something useable, even though a large number of printouts could be produced.

The non-granular IC process involved smoothing the area with a scraper to eliminate bumps. A comment was noted that additional passes were needed with a double drum packer outside of an ordinary double drum. The area was packed with a DW 20 and an IC roller using the vibrator, and then proof rolled with the IC roller. It cost about $0.25/cy – $0.35/cy for proofing and preparation work. The costs not associated with this are technology costs (laptops, printers, computer supplies, and man-hours). MC estimated it costs an additional $0.04/cy for technology costs, bringing the total costs between $0.29/cy – $0.39/cy. The amount of time on the non-granular IC roller was 330 hours for the year. Other methods were used to compact the soil; the IC roller was mainly used to map.

When the section was ready to be proof rolled, the granular IC process involved watering the grade and fine grading with a scraper to eliminate bumps. It was noted that dry sand in the top two inches served as a shock absorber and created "failures." The area was packed by an IC roller, assisted by a second smooth drum vibratory roller, and then proof rolled with the IC roller. It cost about $0.15/cy – $0.25/cy for proofing and preparation work. The costs not associated with this are technology costs (laptops, printers, computer supplies, and man-hours). MC estimated it costs an additional $0.04/cy for technology, bringing the total between $0.19/cy – $0.29/cy. The amount of time on the non-granular IC roller was 780 hours for the year. The IC roller was used to map as well as compact the sandy soils.

The control strips were time consuming, some taking two days to complete. New control strips were required for each type of material encountered. The control strips have a difficult time directly representing the material in the fill when blending and mixing soils together. There was concern that the control strip could cut-off the haul road.

An IC roller forces the contractor to fill one section at a time. The contractor cannot fill or travel through areas that are being prepared for proof rolling. The proofing area may cut off the haul road, so fill areas may be blocked behind the IC roller. If there is no place to fill, operations may be suspended for a period of time.

When an area has passed the IC process, it is accepted and good for that moment. The next moment a disc will run through it to prepare for the next layer. A lot of time and money goes into the top crust that is needed for acceptance. There should be a way for an IC roller to work effectively in rough terrain to avoid fine grading costs.

The IC roller may be needed in multiple places at the same time. This will hold up production in all but one location. Heavy equipment reacts differently in good and poor soils. Watching and listening to equipment is a strong indicator of quality compaction. Going through the entire IC process to get to this same conclusion is timely and costly.

The use of LWD is seen as a positive development. LWD data may be more reliable than IC data. The IC roller in non-granular soils is based on horsepower and does not measure stiffness of soil below the smooth crust. The IC roller in granular soils is based on vibration and the response may be influenced by the material several (6 ft) feet below the surface. In both non-granular and granular soils, the project team felt more comfortable with the LWD rather than the IC roller.

The positive aspects of IC are the following:

- Compaction process produces a more uniform subgrade
- Entire surface is compacted and documented to a certain IC value
- Safety of the field personnel is improved (inspectors are not outside taking sand cones)
- Test results are instantaneous (with sand cones a contractor could wait a day for results)
- Forces the contractor to look ahead to see where soil was needed and how much
- Can check sub-cut with the IC roller
- Record keeping is improved (but IC generates a lot of data that takes a long time to process

IC may be more suitable for small jobs like city blocks, parking lots, building pads, and shouldering jobs. Fine grading every layer is not a practical option. The IC roller would be spread too thin on large jobs where different areas are being filled simultaneously. Additional IC rollers would be needed to keep up with the hauling equipment

2.4 Detroit Lakes project (SP 0301-47)

The Detroit Lakes project involved a $42 million reconstruction to improve safety and mobility along the Highway 10 corridor. The project, located in the City of Detroit Lakes, is a joint effort between Detroit Lakes, Becker County, MnDOT, and Burlington Northern Sante Fe Railroad. Work includes reconstruction and realignment of approximately three miles of Highway 10, realignment of the BNSF railroad tracks, construction of a Roosevelt Avenue underpass of Highway 10 and the BNSF railroad, reconstruction of approximately one-half mile of Highway 59 between Highway 10 and Highway 34, and the construction of a frontage road around Big Detroit Lake from East Shore Drive to downtown Detroit Lakes. The primary contractor is Hoffman Construction, Black River Falls, WI.

2.4.1 Soil conditions

The project site was approximately 3 miles (4.8 km) in length, and the soil was described as being non-uniform by some and uniform by others. The off-grade materials ranged from 100% clean (0% fines) down to 15% fines. Three proctor tests were performed on the borrow material and the optimum moisture content was approximately 12%. Heterogeneous sandy soil (from black sand to uniform sand) was present. Off-site, select granular borrow pits were utilized. Occasionally moisture was added to reach optimum moisture content; no problems were encountered during this process. The fill depth ranged from 1 – 16 ft (0.3 – 4.9 m).

2.4.2 Equipment

A smooth drum, vibratory IC roller, manufactured by Caterpillar, was used during construction of proofing and production. The drum was 7 ft (2.1 m) wide. Two other rollers, in addition to the IC roller, were used on the project. QC was performed using the IC roller. A Zorn LWD with 8 in. diameter plate used for QA. No wireless capabilities were present on-site.

2.4.3 Field protocols

A roller speed of 1.7 mph was used for proofing. Two calibration areas were constructed: one at 6% fines to represent "clean" select material and the other at 9% fines to represent "dark" select material. It took two days for construction of the first calibration area and one day to construct the second calibration area. There was only one proof roll that conflicted with LWD measurements, where the LWD indicated failure. The compaction values tend to measure low when the operator speed is too fast. No apparent "decompaction" was noted; if any, it was mostly due to changing moisture.

The IC roller data card was provided to MnDOT personnel on a daily basis. No sand cone tests were performed on this project. However, it should be noted that sand cone and DCP testing was utilized during QA during the previous construction year. Moisture measurements were performed by both MnDOT and a private company (for the Contractor). On average, the LWD testing was performed every 200 ft (61 m), which was more frequent than called for by the specifications due to ease of testing. Data from the IC roller were viewed when there was time.

2.4.4 Specifications

Neither DCP nor test rolling was used for this project. The IC CCV target value was 14 and 20 for 6% and 9% fines, respectively. The LWD target value was 40 and 48 MPa (5800 and 6960 psi) for 6% (clean select) and 9% (dark select) fines, respectively. LWD values greater than 40 MPa (around the pipe areas mid 30's) were considered acceptable. Occasionally, LWD values varied from 37 – 60 MPa (5370 – 8700 psi) over the span of a few feet. Lifts were constructed 1 ft thick. IC proofing was performed every 2 ft in thickness. Standard MnDOT procedures were followed for LWD testing; this included scraping 6 – 8 in. (0.15 – 0.2 m) of soil before performing LWD (apparently for consistency with smooth-drum IC measurements). The specifications are contained in Appendix D.

2.4.5 Comments

The use of IC on this linear project created a lot of bottlenecks; construction activity was slowed or halted as proofing took place. It was difficult to manage and interpret the IC data due to time constraints and the large volume of data present. The LWD was viewed as a reliable device that was easy to use. It was not clear how the IC data should be used beyond the proofing stage. Both LWD and IC numbers were found to be consistent. It was felt that the influence depth of the IC measurement penetrates deeper then the LWD. The manufacturer's technical staff must work more closely with the Contractor.

The use of IC as a QC tool was not deemed to be efficient for this linear type of project. In particular, IC required the closure of significant parts of the site to construction traffic due to limited access and delayed the overall construction. The speed of IC rollers must increase (1.7 mph is too slow). If the IC roller speed changes from 1.7 to 2 mph (for example), the CCV may change from 14 to 7 or from 25 to 20. "Decompaction" was associated with changing moisture. Lack of uniformity and moisture were the biggest problems encountered during construction. LWD and IC values significantly changed due to non-uniformity.

Chapter 3

Recommendations

Each interview at the project sites was started with the disclaimer that all comments would remain anonymous and no individuals would be identified. General comments regarding the IC process were sought, as inspectors and contractors have extensive experience. The interpretation of their comments provided the basis for the following recommendations. A critique of the specifications (Appendices A and D) was not part of the project scope.

3.1 Use LWD for quality assurance of stiffness

One of the breakthroughs in nondestructive testing of pavements is the development of the falling weight deflectometer (FWD) device. Following the principles of FWD, a light weight deflectometer (LWD) estimates the elastic modulus of the pavement foundation on the basis of the measurement of deflection (velocity or acceleration), and for some devices, the force applied to a loading plate. The inherent appeal of an LWD device is the portability and efficiency, which makes it an attractive tool for quality assurance.

It is recommended that a standard procedure be adopted and followed for using the LWD device as QA for measuring stiffness. The procedure should include details of surface preparation prior to testing (e.g. the amount of soil "crust" to be removed). Although a standard LWD device uses peak (i.e. dynamic) force and deflection values in estimating static stiffness, the consequent peak-to-peak ratio yields a reasonable estimate of foundation (e.g. combined base and subgrade) modulus in many cases. It should be recognized that strength of the soil may be important for construction of the roadway, while sufficient stiffness and uniformity may be crucial for pavement performance.

3.2 Establish a procedure to determine the target LWD value

In trying to relate laboratory and field determined Young's moduli for given moisture and density conditions, it is important to realize that the modulus estimate will depend not only on the boundary conditions (type of test), but also on the strain level. For example, in laboratory testing, the modulus determined from seismic methods has a higher value than the resilient modulus. The LWD and IC Young's moduli are expected to have intermediate values, depending on the applied load. To establish the necessary basis for the application of a QC/QA specification, it is therefore essential that the order-of-magnitude strain level associated with LWD and IC field testing be assessed.

3.3 Eliminate calibration areas (control strips)

A major advantage of IC is the ability to provide real-time, continuous coverage with a permanent record of the data. However, the IC value is recognized to be an index parameter and not a mechanical property of the soil. Accordingly, the acceptable compaction measurement value range must be site specific, i.e. re-calibrated for every different soil type or soil condition, which is an obstacle for using IC on any project. It is suggested that the calibration area be eliminated, and the frequency of LWD testing be increased. For example, based on performance of field personnel at the various sites, a testing frequency of 1 every 300 ft (90 m) may be reasonable, although the issue of material variability would need to be considered from a statistical framework. Further research is needed to establish the target LWD value.

Furthermore, it is recommended that the IC index be used strictly for uniformity control and not as a measure of foundation stiffness. In particular, IC has been found to be very useful in identifying local heterogeneities that may need further attention. Due to the large variation in the IC index over different sites, it was found that it is not practical to interpret the specific CCV or MDP in terms of an achieved modulus value. This is true for any equipment that does not include verification testing that would validate the force and motion measurements and the related interpretation of the IC value.

3.4 Simplify IC data evaluation and presentation

A benefit of IC is the virtually continuous monitoring of the compaction process. However, the amount of data generated in a typical compacting operation poses a significant problem in processing the data to allow a reasonable timeframe for decision making in real time. The post-processing phase of IC evaluation should be further streamlined to facilitate its use by construction personnel. For example, the data could be processed to indicate locations where the target value was not reached over a specified distance. Furthermore, a hand-held monitor may be useful for the field inspector to view, in real time, the same screen that the roller operator is seeing. This would improve safety in that the inspector would not need to ride along in the cab, and it would provide the inspector with a visual output of the IC roller.

3.5 Calibrate the IC roller and related transducers

An assessment of the dynamic force at the roller-soil interface during intelligent compaction revolves around a relatively simple formula that unfortunately requires an in-depth knowledge about the inner design and operation of a vibratory roller. Depending on the particular approach, such assessment may also require the dynamic characteristic of a soil profile (e.g. base and/or subgrade) to be approximated as a spring-and-dashpot system with an *a priori* assumption about the damping constant. In view of the critical role of IC in the quality control process, a natural question arises as to the fidelity of the vibratory force and motion (i.e. acceleration) measurements recorded by the IC rollers. Thus, it is suggested that a calibration device be developed to validate the measurements recorded by an IC roller.

In addition, the development of specifications for vibratory smooth drum rollers must be inherently different from machine drive power rollers, as one measurement is related to stiffness and the other is related to strength. In the case of rolling resistance IC, as in test rolling, the interaction between a roller and soil, manifesting itself as a rut, should be investigated with regard to strength, applied load, and rut depth, which may be related to gradation, density, and moisture.

3.6 Support development of alternative IC methodologies

A precursor to IC was the test roller, which is used to determine if the underlying subgrade of a roadway being built has been adequately compacted. In test rolling, the amount of depression or rutting that occurs when a loaded cart vehicle is towed across an area of an embankment under construction is monitored. If the rutting depth exceeds the specified limit, problem areas that need reworking are identified.

Owing to the widespread acceptance and simplicity of the test rolling as a QA device, it may be worthwhile to consider having a continuous record of the rut depth via an instrumented test roller. Such a record of the construction uniformity would be more robust than that obtained by IC, which entails data interpretation that is proprietary and cannot be verified. At the very least, the IC values should be verified or confirmed through an independent calibration device that measures the force and deflection values separately.

3.7 Simplify or eliminate moisture corrections

Moisture is critical to achieve adequate compaction in soils and aggregate base. There must be enough moisture to allow the material to be molded into a smaller space, but not so much moisture that the volume of water physically limits the compaction process due to zero air voids or results in an unstable material. However, the problem of estimating moisture conditions in the field is not resolved. New technology involving ground penetrating radar (GPR) may offer the opportunity for continuous measurements similar to IC, but the correlation between the GPR material constant (the dielectric) and water content must be established. Although it is recognized that moisture affects stiffness and strength, it may be more efficient to allow a range of moisture contents as long as a target stiffness or strength is achieved.

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Appendix A

TH 36 in North St. Paul (S.P. 6211-81) Specifications

(2106) EXCAVATION AND EMBANKMENT – (QC/QA) IC QUALITY COMPACTION (PILOT SPECIFICATION FOR GRANULAR TREATMENT

All work shall be performed in accordance with Section S-53 (EXCAVATION AND EMBANKMENT) of these Special Provisions. Compaction requirements will be in accordance with this Section S-55 (EXCAVATION AND EMBANKMENT – (QC/QA) IC QUALITY COMPACTION (PILOT SPECIFICATION) For Granular Treatment) as described below.

Description

This work shall consist of measuring the compaction parameters of the granular treatment with a smooth drum vibratory roller. The roller shall be equipped with a measurement and documentation system that allows for continuous recording of the roller location by the global positioning system and the corresponding compaction parameters.

The Contractor will develop and implement a Project specific Quality Control Procedure for embankment construction that is based on Contractor IC compaction parameters, moisture testing and other Quality Control practices; and will provide ongoing Quality Control data to the Engineer.

Compaction of all granular treatment used in embankment construction shall be obtained by the “(2106) Excavation and Embankment – (QC/QA) IC Quality Compaction (Pilot Specification) Granular Treatment" method.

Definitions

Embankment Grading Materials

Are defined as all grading materials placed in the roadbed subgrade as indicated in the Plans. The embankment shall be the zone under the base, pavement and curb structures bounded by the roadbed slopes shown in the Plan or 1:1 slopes from the shoulder PI (for fills under 30 feet) or 1.0 vertical to 1.5 horizontal slopes (for fills over 10 meters **(30 feet)** in height).

Granular Treatment

Is defined as Granular Material (3149.2B1) and Select Granular Material (3149.2B2).

Quality Compaction

Is defined in Specification 2106.3F2 Quality Compaction (Visual Inspection) Method.

Quality Control

Is defined as a procedure whereby the Contractor develops, utilizes, and documents Quality Control activities that govern how the embankment is constructed on this Project.

Quality Assurance

Is defined as a procedure where the Engineer monitors the Contractor’s Quality Control activities and performs assurance monitoring and/or testing for final acceptance of all embankment construction.

Intelligent Compaction (IC)

This process involves measuring and recording the time, location and compaction parameters of the granular treatment during the compaction process with a vibratory roller that is equipped with an accelerometer-based measuring system and a global positioning system.

Intelligent Compaction Test Pad

Is defined as a location where the Contractor will demonstrate to the Engineer that the IC roller and the intelligent compaction instrumentation meet all the requirements of this specification. The Contractor and Engineer will agree on a location(s) within the Project to construct the IC test pad.

Intelligent Compaction – Compaction Target Value (IC-CTV)

The target compaction parameter reading obtained from control strips compacted with the IC roller for each type of granular treatment used on the Project. The IC-CTV is determined for a specific drum amplitude; drum frequency, roller speed, and roller direction.

Proof layer

Is defined as a predetermined layer that requires Quality Control measurements by the Contractor and Quality Assurance measurements by the Engineer to ensure compliance with the IC & LWD Compaction Target Values prior to placing successive lifts.

Portable Light Weight Deflectometer (LWD)

Is a hand operated device that uses a sensor to measure the deflection of the 200 mm (8 inch) flat plate, impacted by a falling weight to measure the stiffness of the granular treatment. The LWD shall have one sensor directly below the falling weight. The device measures the deflection and estimates the modulus based on the force required to generate a given deflection for the type of granular material.

Compaction Parameters

Includes modulus, stiffness or other compaction related parameters

Modulus Test Value

At each LWD test location, the LWD drop shall be repeated six (6) times without moving the plate. The first, second and third drops are designated as seating drops. The LWD Modulus Test Value shall be the average modulus estimated from the fourth, fifth and sixth drops in the testing sequence.

Portable Light Weight Deflectometer – Compaction Target Value (LWD-CTV)

The target modulus measurement for each type of embankment grading material determined by LWD testing on the control strip(s) constructed on this Project.

Equipment Requirements

A) Smooth Drum Vibratory Roller

The vibratory roller shall weigh at least 11,300 kg (**24,000 pounds**) and be approved by the Engineer.

A smooth drum vibratory roller with an accelerometer-based measurement system is required for the compaction and recording of the compaction parameter measurements on the granular treatment.

Alternatively, rollers equipped with other dynamic measurement value systems may be utilized as approved by the Engineer.

B) Intelligent Compaction Instrumentation

The vibratory roller shall be equipped with an measurement and documentation system that allows continuous recording of roller location, through the global positioning system within the accuracy specified by the Engineer.

The data output from IC roller during compacting the embankment grading material must:

1) Enhance the ability of the roller operator and Project inspection personnel to make real-time corrections to the compaction process.
2) Be available for the Engineer to review when requested

3) Be exportable into a comma delimited ASCII format or other approved data submittal format.
4) Contain the drum parameters, including frequency, amplitude and acceleration, compaction parameter(s), the position data, including x, y, z coordinates for each side of the drum in UTM NAD 1983 zone 15 N format and a time stamp for each data point accurate to the frequency of the drum
5) Allow for a plan-view, color-coded plot of roller stiffness and roller pass number measurements throughout a designated section of roadway

C) Equipment Approval

Within 15 days after award of the Contract, the Contractor must provide the following information to the Engineer:

<u>Intelligent Compaction Roller</u>
Model:
Manufacturer:
Operating Weight:
Drum Width:
Drum Diameter:
Drum Mass:
Maximum Vertical Dynamic Force:
Roller Horsepower:

The Contractor shall make available an on-site equipment manufacturer's representative for construction of the initial control strip and as required or requested by the Engineer throughout the portion of the Project that which utilizes IC.

The Contractor will be required to complete a IC test pad to demonstrate that the roller and the intelligent compaction instrumentation meets all the requirements of this specification. The Contractor and Engineer will agree on a location(s) within the Project to construct the IC test pad. The IC test pad shall be on the Project site, using the granular treatment that will be used on the Project, and be in a location that demonstrates the ability of the system to fully function throughout the Project site. The IC test pad size and the lift thicknesses will be the same as the control strip requirements or as otherwise determined by the Engineer. Portions of the Project that require using the IC roller shall not proceed until the IC roller meets all the specification requirements and is approved by the Engineer.

The IC test pad can not be one of the required control strips.

D) Testing Equipment

The Engineer may order the contactor to provide a Light Weight Deflectometer and/or electronic moisture meter or other moisture testing device with payment to be made as Extra Work.

<u>Construction Requirements</u>

A) Proof Layers

For granular treatment less than or equal to750 mm (2.5 feet) in thickness, the proof layer shall be designated as the top of the granular treatment.

For a granular treatment more than 750 mm (2.5 feet) and less than 1.2 meters (4 feet) in thickness, the proof layers shall be designated as the midpoint and the top of the granular treatment thickness.

For a granular treatment equal to or greater than 1.2 meters (4 feet) in thickness the proof layers shall be successive 600 mm (2 foot) layers in thickness from the bottom and up to the top of the granular treatment.

The designation of proof layers is general in nature and may require modification by the Engineer to meet Project specific embankment heights. The proof layers do not change control strip and production maximum lift thickness requirements, but are the designated layers in the granular treatment where acceptance testing is performed.

IC compaction parameter measurements will be recorded continuously on all proof layers of granular treatment by the IC roller. The LWD Modulus Test measurements will be recorded on all proof layers of granular treatment. The Contractor shall give the Engineer timely notification of proof layer testing so that this activity may be observed and tested by the Engineer for acceptance.

B) Quality Control/Quality Assurance (QC/QA)

1. Contractor Quality Control (QC) Requirements

The Contractor shall utilize the data gathered from the control strip construction to develop a Quality Control Procedure for granular treatment. This procedure shall detail how Quality Control will be accomplished, including, but is not limited to, identifying IC equipment and procedures, collecting and reporting IC compaction parameter measurement results, ensuring uniformity of the granular treatment, confirming acceptable moisture and compaction parameter results on granular treatment lifts between proof layers, determining the anticipated number, pattern and speed of roller passes to obtain optimum compaction parameter results on all layers, not just the proof layers, and other items that may contribute to an effective Quality Control Procedure.

The Quality Control Procedure shall include any corrective construction actions that may be required as a result of Quality Control measurements, such as adding water and/or drying soils, re-compacting non-compliant granular soils or other corrective actions that have been undertaken.

The Contractor will perform all IC compaction parameter measurements required by the approved Quality Control Procedure, and will modify construction operations so that acceptable compaction results are obtained. The Contractor shall also document all Quality Control IC compaction parameter results, Quality Control activities and corrective construction actions taken as a result of the Quality Control measurements to meet the requirements of this specification with a Weekly Quality Control Report in a format acceptable to the Engineer. The documentation shall be submitted to the Engineer for acceptance on a weekly basis.

As part of the Quality Control Procedure, the Contractor will perform moisture content tests on the granular treatment at a minimum of 1 per 3,000 cubic meter (CV) [1 per 4,000 cubic yards (CV)] for compliance. The Contractor moisture content tests may be performed by a Project calibrated electronic moisture meter, reagent method, burner method, oven dry method, or other gravimetric methods as approved by the Engineer. The Engineer may perform additional moisture content tests.

2. Agency Quality Assurance (QA) Requirements

The Engineer will observe the final compaction recording pass of the IC roller on each proof layer, review and approve the Contractor's Quality Control data documenting acceptable compaction results submitted in the form of the Weekly Quality Control Report and perform companion and verification LWD and moisture testing.

The Engineer will also perform companion a LWD Modulus Test and a moisture content test at the minimum rate of one (1) LWD Modulus Test Value measurement per proof layer, per 300 meters **(1,000 feet)** for the entire width of embankment being constructed during each operation.

The Contractor shall provide a relatively smooth uniform surface that has been shaped to approximate line and grade of each proof layer for the purpose of taking all LWD Modulus Test Value measurements at the required locations for this specification, with no direct compensation made therefore. The Contractor shall make the proof layer surface available for Quality Assurance testing in a safe condition on an ongoing basis, or within 24 hours of the completion of compaction activities.

For acceptance of compaction at each proof layer during general production operations, all segments of the granular treatment shall be compacted so that at least 90% of the IC compaction parameter measurements are at least 90% of the applicable corrected IC-CTV prior to placing the next lift. The Contractor shall re-compact (and dry or add moisture as needed) all areas that do not meet these requirements. Additional IC compaction parameter measurements shall be taken for acceptance of the re-compacted areas.

If localized areas have an IC compaction parameter measurement of less then 80% of the corrected IC-CTV, the Contractor shall re-compact (and dry or add moisture as needed) these areas to at least 90% of the IC-CTV prior to placing the next lift.

If a significant portion of the grade is more than 20% in excess of the selected corrected IC-CTV, the Engineer shall re-evaluate the selection of the applicable control strip corrected IC-CTV. If an applicable corrected IC-CTV is not available, the Contractor shall construct an additional control strip to reflect the potential changes in compaction characteristics.

If the Engineer determines that the Contractor appears to be performing acceptable compaction efforts, but the IC compaction parameter measurements consistently do not meet the applicable corrected IC-CTV, the Engineer shall re-evaluate the selection of the applicable control strip corrected IC-CTV. If an applicable corrected IC-CTV is not available, the Contractor shall construct an additional control strip to reflect the potential changes in compaction characteristics.

The Engineer may perform additional LWD Modulus Tests and moisture content tests in areas that visually appear to be non-compliant, or as determine by the Engineer.

Each LWD Modulus Test Value taken shall be at least 90% but not more than 120% of the corrected LWD-CTV obtained on the proof layer of the applicable control strip prior to placing the next lift. The Contractor shall re-compact (and dry or add moisture as needed) all areas that do not meet these requirements. Additional LWD Modulus Test measurements shall be taken for acceptance of the re-compacted areas.

Final Acceptance shall be determined when the following criteria are met:

a) The final compaction parameter measurement pass observed by the Engineer meets the requirements of this specification.
b) The Contractor has submitted Weekly Quality Control Reports documenting that acceptable compaction results were obtained for all embankment construction.
c) All Quality Assurance tests taken by Mn/DOT meet specification requirements.
d) The Engineer has reviewed the IC compaction related parameter measurements taken on all proof layers and approved the Weekly Quality Control Reports.

C) Control Strip

The Contractor shall construct compaction control strips to determine the Intelligent Compaction Target Value (IC-CTV) for each type and/or source of granular soil. Additional control strips shall be constructed for materials with observable and/or quantifiable variations in material properties that affect the IC-CTV, as determined by the Engineer.

The compaction of the control strip shall be limited to the compaction produced by the IC roller approved for use on the Project by the Engineer. No other compactive equipment shall be utilized to achieve compaction during the construction of the control strip.

It is anticipated that the IC-CTV and LWD-CTV for the granular treatment may be moisture sensitive to some degree. Therefore, to determine the moisture sensitivity correction for the IC-CTV and LWD-CTV, a control strip shall be constructed at or near each extreme of 65% and 95% of optimum moisture. This data will be utilized to produce a Correction Trendline showing a linear relationship of the IC-CTV and LWD-CTV at different moisture contents.

The control strip shall be at least 100 meters **(300 feet)** long and at least 10 meters **(32 feet)** wide at the base, or as determined by the Engineer. The lift thicknesses for the control strip and the constructed embankment shall be limited to the maximum lift thickness allowed in Mn/DOT Specification 2106.3E. The total thickness of each control strip shall equal the planned granular treatment thickness being constructed. The total thickness of each control strip shall be a maximum of 1.2 m (4.0 feet).

Both the Contractor and the Engineer shall save a material sample from each control strip for comparison to the embankment material being compacted during QC/QA procedures in order to determine the applicable control strip IC-CTV.

The costs of constructing the control strips for each identifiable different type and/or source of grading material, for each material with observable and/or quantifiable variations in material properties, including but not limited to, moisture content, gradation, texture, and silt & clay content, that affect the IC-CTV, or for each compaction method, shall be part of the work required for this specification with no direct compensation made therefore.

D) Control Strip Construction

1) The Contractor and Engineer will agree on a location(s) within the Project to construct the control strip(s).

2) After the layer below the granular treatment has been compacted, the Intelligent Compaction roller shall be used to record the compaction parameters of the layer prior to placing the granular treatment. The data shall be utilized as an Intelligent Compaction Base Map to determine uniformity of the embankment grading materials and to identify any inherent soft spots.

3) Place the granular treatment in lifts. The lift thicknesses for the control strip shall be limited to the maximum lift thickness allowed in Mn/DOT Specification 2106.3E.

4) The Contractor will make repeated compaction passes on each lift, using a roller pattern approved by the Engineer, with continuous compaction parameter measurements being recorded by the IC roller. The optimum value is reached when additional roller passes do not result in a significant increase in the compaction parameter values on that lift, as determined by the Engineer.

5) The Engineer will perform LWD Modulus Test Value measurements on each layer at three (3) separate LWD test locations spaced at least 25 meters (75 feet) apart, or as modified by the Engineer.

6) Repeat 3 to 5 until it has reached the proof layer.

7) The Engineer will perform Light Weight Deflectometer (LWD) Modulus Test measurements tests at each proof layer at three (3) separate LWD test locations spaced at least 25 meters **(75 feet)** apart, or as modified by the Engineer.

8) The proof layer LWD-CTV will be the average of the LWD Modulus Test Values at the three (3) LWD test locations measured on the designated proof layer(s) during construction of the control strip. LWD Modulus Test Value measurements at additional locations may be taken on the proof layer(s) and included in the calculation of the average LWD-CTV as determined by the Engineer. The proof layer LWD-CTV's obtained from the control strips that were constructed at each moisture content extreme, will be used to determine the LWD-CTV Correction Trendline.

9) The proof layer Intelligent Compaction-Compaction Test Value (IC-CTV) will be the optimum value obtained from the Intelligent Compaction stiffness measurements on the designated test layer during construction of the control strip. The optimum value is reached when additional passes do not result in a significant increase in stiffness values, as determined by the Engineer.

10) Repeat 3 to 6 until the next proof layer is reached and repeat 7 to 9.

The proof layers in the control strip construction are general in nature and may require modification by the Engineer to meet specific Project conditions.

E) Moisture

At the time of compaction, both for the construction of the test pad and during production, the moisture content of the granular materials shall be not less than 65% or more than 95% of Optimum Moisture. The Engineer will determine the Optimum Moisture by the Standard Proctor Density Method.

The Contractor shall add water and blend as needed to meet the moisture requirements. The Engineer may order the application of additional water for compaction if necessary. If any embankments are constructed with materials that contain excessive moisture, the Contractor shall dry or replace it with material having the required moisture content.

Additional water ordered by the Engineer, or efforts to dry materials or replace soils that are excessively wet which are taken by the Contractor to meet Quality Control procedures or otherwise ordered by the Engineer, will not be considered extra work, but shall be considered part of the work required for this specification with no direct compensation made therefore.

F) Production Requirements

The Contractor shall provide at least one IC instrumented roller during embankment construction. Additional rollers that are utilized may be non-instrumented, but the IC roller must be the final roller used to obtain compaction on the proof layers. When using non-instrumented rollers, the actual compaction efforts, such as number of passes, type of drum, moisture content, and speed of the roller during compaction shall be shown in the Quality Control Procedure as determined by the information gathered during control strip construction. The Weekly Quality Control Report shall indicate how these requirements are met on embankments compacted with non-instrumented compactors.

The bottom of the subcut or fill shall be compacted by Quality Compaction prior to the start of placing the granular treatment.

After the layer below the granular treatment has been compacted, the Intelligent Compaction roller shall be used to record the compaction parameters of the layer prior to placing the granular treatment. This data shall be utilized as an Intelligent Compaction Base Map to determine uniformity of the embankment grading materials and to identify any inherent soft spots.

In the event embankment construction is suspended prior to completion to a proof layer elevation, the area shall be re-compacted prior to resuming embankment construction in the partially completed embankment area.

Compaction and mixing efforts shall be complete and uniform, to the greatest extent practical, from bottom to top of all roadbed embankments, and for the entire length and width of the roadbed embankment.

(2106) EXCAVATION AND EMBANKMENT – (QC/QA) IC QUALITY COMPACTION (PILOT SPECIFICATION) FOR NON-GRANULAR SOILS

All work shall be performed in accordance with Section S-53 (EXCAVATION AND EMBANKMENT) of these Special Provisions. Compaction requirements will be in accordance with this Section S-55 (EXCAVATION AND EMBANKMENT – (QC/QA) IC QUALITY COMPACTION (PILOT SPECIFICATION) For Non-Granular soils) as described below.

Description

This work shall consist of measuring the compaction parameters of the non-granular soils using at least one (1) pad foot vibratory roller Intelligent Compaction (IC) Roller when compacting embankment grading materials **on TH 36 mainline west of McKnight**. The Contractor may use other rollers (either intelligent compaction or non-intelligent compaction rollers) necessary to obtain the density and production requirements of the project in other areas.

The Contractor will develop and implement a Project specific Quality Control Procedure for embankment construction that is based on Contractor IC compaction parameters, moisture testing and other Quality Control practices; and will provide ongoing Quality Control data to the Engineer.

Compaction of all non- granular soils used in embankment construction shall be obtained by the “(2106) Excavation and Embankment – (QC/QA) IC Quality Compaction (Pilot Specification) For Non-Granular Soils" method.

Definitions

Embankment Grading Materials

Are defined as all grading materials placed in the roadbed subgrade as indicated in the Plans. The embankment shall be the zone under the base, pavement and curb structures bounded by the roadbed slopes shown in the Plan or 1:1 slopes from the shoulder PI (for fills under 30 feet) or 1.0 vertical to 1.5 horizontal slopes (for fills over 10 meters **(30 feet)** in height).

Non-Granular Soils

Is defined as All Soils except, Granular Material (3149.2B1) and Select Granular Material (3149.2B2).

Quality Compaction

Is defined in Specification 2106.3F2 Quality Compaction (Visual Inspection) Method.

Quality Control

Is defined as a procedure whereby the Contractor develops, utilizes, and documents Quality Control activities that govern how the embankment is constructed on this Project.

Quality Assurance

Is defined as a procedure where the Engineer monitors the Contractor’s Quality Control activities and performs assurance monitoring and/or testing for final acceptance of all embankment construction.

Intelligent Compaction (IC)

This process involves measuring and recording the time, location and compaction parameters of the granular treatment during the compaction process with a vibratory roller that is equipped with an accelerometer-based measuring system and a global positioning system.

Intelligent Compaction Test Pad

Is defined as a location where the Contractor will demonstrate to the Engineer that the IC roller and the intelligent compaction instrumentation meet all the requirements of this specification. The Contractor and Engineer will agree on a location(s) within the Project to construct the IC test pad.

Equipment Requirements

A) Pad Foot Vibratory Roller

Rollers shall be Pad Foot vibratory rollers with an accelerometer or a rolling resistance (energy) based measurement system and capable of recording the compaction parameter measurements. Rollers shall weigh at least 11,300 (24,000 lbs) and be approved by the Engineer.

The Contractor shall use at least one (1) Pad Foot vibratory (IC) Roller when compacting the non-granular embankment on TH 36 mainline west of McKnight. The Contractor may use other rollers (either IC or Non-IC rollers) necessary to obtain the density and production requirements of the project.

Alternatively, rollers equipped with other dynamic measurement value systems may be utilized as approved by the Engineer.

B) Intelligent Compaction Instrumentation

The vibratory roller shall be equipped with an measurement and documentation system that allows continuous recording of roller location, through the global positioning system within the accuracy specified by the Engineer.

The data output from IC roller during compacting the embankment grading material must:

1) Enhance the ability of the roller operator and Project inspection personnel to make real-time corrections to the compaction process.
2) Be available for the Engineer to review when requested
3) Be exportable into a comma delimited ASCII format or other approved data submittal format.
4) Contain the drum parameters, including frequency, amplitude and acceleration, compaction parameter(s), the position data, including x, y, z coordinates for each side of the drum in UTM NAD 1983 zone 15 N format and a time stamp for each data point accurate to the frequency of the drum
5) Allow for a plan-view, color-coded plot of roller stiffness and roller pass number measurements throughout a designated section of roadway

C) Equipment Approval

Within 15 days after award of the Contract, the Contractor must provide the following information to the Engineer:

Intelligent Compaction Roller
Model:
Manufacturer:
Operating Weight:
Drum Width:
Drum Diameter:
Drum Mass:

Maximum Vertical Dynamic Force:
Roller Horsepower:

The Contractor shall make available an on-site equipment manufacturer's representative for construction of the Test Pad and as required or requested by the Engineer throughout the portion of the Project that which utilizes IC.

The Contractor will be required to complete a IC test pad to demonstrate that the roller and the intelligent compaction instrumentation meets all the requirements of this specification. The Contractor and Engineer will agree on a location(s) within the Project to construct the IC test pad. The IC test pad shall be on the Project site, using the non -granular soils that will be used on the Project, and be in a location that demonstrates the ability of the system to fully function throughout the Project site.

D) Testing Equipment

Construction Requirements

B) Quality Control/Quality Assurance (QC/QA)

The Contractor shall develop a Quality Control plan that utilizes the technology of the intelligent compaction rollers. This procedure shall detail how Quality Control will be accomplished, including, but is not limited to, identifying IC equipment and procedures, collecting and reporting IC compaction parameter measurement results, ensuring uniformity, confirming acceptable moisture and compaction parameter results, determining the anticipated number, pattern and speed of roller passes to obtain optimum compaction parameter results on all layers, and other items that may contribute to an effective Quality Control Procedure.

The Quality Control Procedure shall include any corrective construction actions that may be required as a result of Quality Control measurements, such as adding water and/or drying soils, re-compacting soils or other corrective actions that have been undertaken.

The Contractor will provide in electronic format the IC compaction parameter measurements measured to the Engineer upon request.

E2b. Agency Quality Assurance (QA) Requirements

The Departments Quality Assurance (QA) acceptance of the grade shall be in accordance with Test Rolling as defined in Section (2111) Test Rolling and QC/QA For Non-Granular Soils, under this contract.

(2111) TEST ROLLING AND QC/QA TESTING FOR NON-GRANULAR SOILS

All work shall be performed in accordance with Section S-53 (EXCAVATION AND EMBANKMENT) of these Special Provisions. Compaction requirements will be in accordance with this Section S-55 (2111) Test Rolling and QC/QA Testing for Non-Granular Soils as described below.

Description

This work shall consist of measuring the compaction parameters of non-granular soils on the project in all areas **except non-granular soils located on TH 36 mainline west of McKnight.**

The Contractor shall perform test rolling in accordance with Standard Specification 2111 and the following:

- Quality control testing (QCT) for relative moisture and relative density shall be performed by the Contractor using procedures proposed by the Contractor and Approved by Mn/DOT at a rate of 1/4,000 cubic yards of embankment soil.
- The optimum moisture content and maximum density shall be determined from Moisture-Density Tests performed by the Contractor.
- The cost of these tests shall be incidental to the Project.
- Quality assurance testing shall be conducted by Test Rolling performed by the Contractor and observed by Mn/DOT, using the following criteria and the table shown below:
  -- Allowable yielding and rutting specification in the 95% maximum density zone shall be 3 inches.
- Quality Assurance testing for relative moisture shall be performed by the Engineer, using the Contractor's optimum moisture content, at a rate of 1/20,000 cubic yards of embankment soil.

Verification Testing Table

<table>
<tr><th>Case</th><th>Test Rolling Location[1]</th><th>Number of passes per strip</th><th>Allowable yielding or rutting</th></tr>
<tr><td>Fills less than 4 feet measured from the bottom of the granular treatment</td><td>Bottom of Granular Treatment</td><td>Two</td><td>2 inches</td></tr>
<tr><td rowspan="2">Fills greater than or equal to 4 feet but less than 8 feet measured from the bottom of the granular treatment</td><td>Bottom of Granular Treatment</td><td>Two</td><td>2 inches</td></tr>
<tr><td>4 feet below bottom of granular treatment</td><td>Two</td><td>3 inches</td></tr>
<tr><td rowspan="3">Fills greater than 8 feet measured from the bottom of the granular treatment</td><td>Bottom of Granular Treatment</td><td>Two</td><td>2 inches</td></tr>
<tr><td>4 feet below bottom of granular treatment</td><td>Two</td><td>3 inches</td></tr>
<tr><td>8 feet below bottom of granular treatment</td><td>Two</td><td>3 inches</td></tr>
</table>

Mn/DOT reserves the right to perform sand cone density testing at all locations.

Appendix B

TH 10 in Staples (S.P. 7702-42) Soils Information

December 4, 2006

To: Bob Busch
Transportation District Engineer

From: Tony Hughes
District Soils Engineer

Subject: S.P. 7702-42 (TH 10)
Reconstruction Through the City of Staples
R.P. 105+00.840 to 108+00.461
Todd County

DESIGN RECOMMENDATION REPORT
Project Manager: Terry Humbert
Programmed Letting Date: December 15, 2006
Current Cost Estimate: $5,600,000.00

I. GENERAL PROJECT INFORMATION

A. Project Scope

This project includes the expansion of TH 10 to a four-lane expressway through the city of Staples with the new highway following an alignment approximately one block south of the existing highway. It is anticipated that the posted speeds will be 65 mph in the rural area west of town and between 30 and 40 mph in the urban area through town. The existing two-lane highway segment through downtown Staples will be turned back to the city of Staples or Todd County following the completion of the expansion project.

The primary goals of this project are to improve the safety and capacity of the highway and provide system continuity by eliminating one of the last remaining two-lane highway segments on the TH 10 corridor and the only segment that still has on street parking.

Any changes made to the scope of this project that could affect this design recommendation shall be brought to the attention of the District Soils Engineer. This will ensure that any changes made after the submittal of this recommendation will be incorporated into the as-built version of this document.

B. Project Background Information

1. Existing Conditions – Rural 4-Lane West of Staples
Functional Class –Rural Principal Arterial
Lane Width – Two 12’ Bituminous Lanes
Shoulder Widths – 10’ Paved Rt. & 3’ Paved Lt.
Posted Speed – 65 MPH

Existing Conditions – Rural 2-Lane West of Staples
Functional Class –Rural Principal Arterial
Lane Width – Two 11’ Bituminous over Concrete Lanes
Shoulder Width – 8’ Paved
Posted Speed – 55 MPH

Existing Conditions – Urban Area Through Staples
Functional Class –Rural Principal Arterial

50’ Curb to Curb Section
Through Lanes are Bituminous over Concrete
Shoulders/Parking Lanes are predominantly Concrete
Posted Speed – 30 MPH

Existing Conditions – Rural 4-Lane East of Staples
Functional Class –Rural Principal Arterial
Lane Width – Two 12’ Bituminous over Concrete Lanes
Shoulder Width – 10’ Paved Rt. (EB), 8’ Paved Rt. (WB), & 3’ Paved Lt.
Posted Speed – 55 MPH

2. Pavement Conditions

Eastbound:

R.P. 105+00.085 to 106+00.062:				R.P. 108+00.009 to 108+00.410:			
PSR	SR	PQI	YEAR	PSR	SR	PQI	YEAR
2.9	3.2	3.0	2004	3.4	3.6	3.5	2004
3.3	3.4	3.3	2002	2.6	2.6	2.6	2002
3.6	3.9	3.7	2000	2.9	2.6	2.7	2000

Westbound:

R.P. 105+00.000 to 106+00.062:				R.P. 108+00.009 to 108+00.410:			
PSR	SR	PQI	YEAR	PSR	SR	PQI	YEAR
2.9	2.2	2.5	2004	3.4	4.0	3.7	2004
3.6	2.0	2.7	2002	2.7	2.3	2.5	2002
3.7	3.8	3.7	2000	2.8	2.4	2.6	2000

Undivided Section:

R.P. 106+00.062 to 107+00.114:				R.P. 107+00.114 to 108+00.009:			
PSR	SR	PQI	YEAR	PSR	SR	PQI	YEAR
2.9	1.6	2.2	2004	3.1	3.3	3.2	2004
3.5	2.1	2.7	2002	3.3	3.8	3.5	2002
3.2	3.4	3.3	2000	3.5	3.9	3.7	2000

3. Construction History

R.P. 105+00.840 to 106+00.183 Eastbound Lanes:

Year	Work	Width	Depth
1990/1991	Grading	46’- 49’	NA
1990/1991	Aggregate Base (CL-5)	28’	2.0”
1991	Bit. Surfacing	25’- 28’	9.0”- 9.5”

R.P. 105+00.840 to 107+00.114 Westbound Lanes & Undivided Section:

Year	Work	Width	Depth
1942/1948	Grading & Gravel Surfacing	40’- 42’	NA
1948	Doweled Concrete (9-7-9)	22’	9.0”
1991	Bit. Surfacing over Concrete	26’	3.0”- 5.0”

R.P. 107+00.114 to 107+00.267 Undivided Section:

Year	Work	Width	Depth

1942	Grading	48’	NA
1942	Gravel Surfacing	48’	1.75”
1942	Bituminous Surfacing	48’	1.0”
1948	Doweled Concrete (9-7-9)	50’	9.0”
1982	Concrete Milling & Bituminous Inlay	22’	1.5”
1988	Bituminous Milling	22’	1.5”
1988	Bituminous Overlay	22’	3.0”
1997	Bituminous Milling & Overlay	22’	3.0”

R.P. 107+00.267 to 108+00.060 Undivided Section:

Year	Work	Width	Depth
1925	Grading	50’	NA
1925	Gravel Surfacing	24’	3.0”
1948	Doweled Concrete (9-7-9)	50’	9.0”
1982	Concrete Milling & Bituminous Inlay	22’	1.5”
1988	Bituminous Milling	22’	1.5”
1988	Bituminous Overlay	22’	3.0”
1997	Bituminous Milling	22’	3.0”
1997	Bituminous Overlay	22’	3.0”- 3.5”

R.P. 108+00.060 to 108+00.461 Eastbound Lanes:

Year	Work	Width	Depth
1942	Grading	42’	NA
1942	Gravel Surfacing	42’	1.75”
1942	Bituminous Surfacing	26’	1.0”
1949	Bituminous Overlay	24’	1.5”
1965/1966	Aggregate Base	28’	3.0”- 3.5”
1965/1966	8” Uniform Reinforced Concrete	24’	8.0”
2003	Variable Depth Bituminous Overlay	24’	2.0” Min.

R.P. 108+00.060 to 108+00.461 Westbound Lanes:

Year	Work	Width	Depth
1965	Grading	45’	NA
1965	Aggregate Base	28’	3.5”
1965	8” Uniform Reinforced Concrete	24’	8.0”
2003	Variable Depth Bituminous Overlay	24’	2.0” Min.

4. Traffic Data & Analysis

Nancy Davison, from the District 3 Materials Office, developed a detailed traffic forecast for the project that indicted a 20-year Equivalent Single Axle Load (ESAL) forecast of 4,739,000 ESALs for the area between Todd CSAH 9 and the west city limits of Staples and a forecast of 6,346,000 ESALs for the area from the west city limits to the east end of the project.

The report (Forecast No. F-3-0501) was completed on May 9, 2005 and was approved by the Traffic Forecasting and Analysis Unit on May 17, 2005. The report is available for review at the District 3 Materials Office in Baxter.

C. Soils Information

General
Mn/DOT auger crews from the Baxter office completed soil borings and made field classifications of the soils encountered within the project limits. Although peat and other unsuitable materials where found in several areas,

with the exception of the area between Sta. 1135+50 and 1141+50, the depth of the unsuitable materials was relatively shallow. Much of the unsuitable material encountered along the proposed eastbound alignment west of town consists of the muck disposed of during the original grading of the existing highway.

The borings also revealed that, with the exception of the area between the existing and proposed mainline alignments on the east end of the project, the majority of the subsoil falls into the textural classification category of Fine Sand (FS). Gradation tests completed by the Baxter Materials Lab indicate that the material has less than 7% passing the No. 200 sieve.

In the area between the proposed westbound alignment and the existing eastbound alignment, where the proposed WB Leg and EB Leg connection roads are to be constructed, a pocket of material falling into the textural classification category of Silt (Si) was discovered. The proposed profiles of the connection roads are 5.5' to 6.5' above the existing ground line. Since the Silt is not located under the proposed mainline and fill will be placed above the silt to a depth greater than the anticipated frost penetration, it was determined that following the removal of the topsoil the silt could be left in place undisturbed.

Groundwater Concerns

Borings indicate that portions of the project site have or may have high groundwater conditions and groundwater infiltration may be a concern during and after construction. The possibility of groundwater flow into utility and pavement related excavations may require the installation of site dewatering systems.

Contamination Concerns

Several areas of potential contamination have been identified within the project limits. A consultant has been hired by the Office of Environmental Services to complete a Phase II Environmental Site Assessment. One site, the Farmers Oil Site, has already been identified as a petroleum release site and is listed with the Minnesota Pollution Control Agency. The majority of the site along the proposed alignment has already been excavated and thermally treated.

D. Pavement Field Data

The existing mainline pavement structure ranges from full-depth bituminous to 9-7-9 reinforced concrete with varying thicknesses of bituminous covering it. The city streets and township roads affected by the proposed project have surfaces ranging from 2.5" of aggregate surfacing to bituminous pavements varying from 3.0" to 11.5" in thickness. See the attached typical sections for more details.

II. DESIGN RECOMMENDATIONS

A. Removal, Salvage & Disposal

Pavements

Existing bituminous and concrete pavements encountered within the construction grading limits shall be removed as needed. The pavement removed shall become the property of the Contractor and shall be disposed of outside the right-of-way in accordance with Specification 2104.3C, or recycled in accordance with applicable Mn/DOT Specifications.

Topsoil

In accordance with Specification 2105.3D, the existing topsoil shall be salvaged and subsequently placed on any disturbed areas following the completion of the grading operations.

B. Excavation & Embankment Construction

Grading Soil Definitions
Unsuitable materials for embankment construction are defined as any non-granular materials such as loam, peat, muck, marl, silt, topsoil or other organic material and debris. Unsuitable materials may not be placed within a 1:1.5 slope, drawn down and outward, from the grading shoulder P.I., nor shall they be placed outside that line in the upper 1.0 foot of the embankment except for topsoil as called for in the plan.

Suitable Grading Material for embankment construction shall be defined as any granular material encountered within the project excavations or borrow material that meets the requirements of Mn/DOT Specification 3149.2B1, Granular Borrow.

Select Grading Material for embankment construction shall be defined as any granular material encountered within the project excavations or borrow material that meets the requirements of Mn/DOT Specification 3149.2B2, Select Granular Borrow.

Grading Grade
The grading grade is hereby defined as the bottom of the Class 6 Aggregate Base.

Mainline Subgrade Correction/Compaction Subcut Recommendations
The proposed eastbound alignment is used as the basis for the locations of the following subcut recommendations.

Sta. 1009+00 to 1047+00
A 2.0’ subcut shall be provided below the proposed grading grade along both the eastbound and westbound proposed alignments. The subcut shall be backfilled with material meeting the requirements of Mn/DOT Specification 3149.2B2, Select Granular Borrow. In addition to the 2.0’ subcut, a variable depth wedge subcut to remove unsuitable materials shall be completed between Sta. 1009+00 and 1037+00 along the right shoulder of the proposed westbound alignment as shown in the attached detail.

Sta. 1047+00 to 1052+00
The proposed eastbound and westbound alignments shall have a 4.0’ subcut below the proposed grading grade. The bottom 2.0’ of the subcut shall be backfilled with material meeting the requirements of Mn/DOT Specification 3149.2B1, Granular Borrow, and the upper 2.0’ shall be backfilled with material meeting the requirements of Mn/DOT Specification 3149.2B2, Select Granular Borrow. The transition between the 4.0’ subcut and the adjacent 2.0’ subcut shall be designed with a 1(V): 20(H) taper such that the full 4.0’ subcut is provided from Sta. 1047+00 to 1052+00.

Sta. 1052+00 to 1076+00
A 2.0’ subcut shall be provided below the proposed grading grade along both the eastbound and westbound proposed alignments. The subcut shall be backfilled with material meeting the requirements of Mn/DOT Specification 3149.2B2, Select Granular Borrow.

Sta. 1076+00 to 1080+00
The proposed eastbound and westbound alignments shall have a 4.0’ subcut below the proposed grading grade. The bottom 2.0’ of the subcut shall be backfilled with material meeting the requirements of Mn/DOT Specification 3149.2B1, Granular Borrow, and the upper 2.0’ shall be backfilled with material meeting the requirements of Mn/DOT Specification 3149.2B2, Select Granular Borrow. The transition between the 4.0’ subcut and the adjacent subcuts shall be designed with a 1(V): 20(H) taper such that the full 4.0’ subcut is provided from Sta. 1076+00 to 1080+00.

Sta. 1080+00 to 1095+00
The proposed eastbound and westbound alignments shall have a 5.0’ subcut below the proposed grading grade to remove unsuitable materials and provide a good foundation for subsequent backfill material. The bottom 3.0’ of the subcut shall be backfilled with material meeting the requirements of Mn/DOT Specification 3149.2B2, Select Granular Borrow. The upper 2.0’ shall include a drainage blanket system covered by 1.0’ of material meeting the

requirements of Mn/DOT Specification 3149.2B2, Select Granular Borrow. The transitions between the 5.0' subcut and the adjacent 2.0' and 4.0' subcuts shall be designed with 1(V): 20(H) tapers such that the full 5.0' subcut is provided from Sta. 1080+00 to 1095+00.

Sta. 1095+00 to 1134+00
A 2.0' subcut shall be provided below the proposed grading grade along both the eastbound and westbound proposed alignments. The subcut shall be backfilled with material meeting the requirements of Mn/DOT Specification 3149.2B2, Select Granular Borrow.

Sta. 1134+00 to 1143+00
The proposed eastbound and westbound alignments shall have a 4.0' subcut below the proposed grading grade. The bottom 2.0' of the subcut shall be backfilled with material meeting the requirements of Mn/DOT Specification 3149.2B1, Granular Borrow, and the upper 2.0' shall be backfilled with material meeting the requirements of Mn/DOT Specification 3149.2B2, Select Granular Borrow. The transition between the 4.0' subcut and the adjacent 2.0' subcuts shall be designed with a 1(V): 20(H) taper such that the full 4.0' subcut is provided at from Sta. 1134+00 to 1143+00.

Sta. 1143+00 to 1147+00
A 2.0' subcut shall be provided below the proposed grading grade along both the eastbound and westbound proposed alignments. The subcut shall be backfilled with material meeting the requirements of Mn/DOT Specification 3149.2B2, Select Granular Borrow. The subcut shall terminate at Sta. 1147+00 as shown in the attached East Connection Detail.

A 2.0' subcut shall also be provided along the proposed legs and ramps connecting the proposed alignment to the existing highway on the east end of the project and a 1.5' subcut shall be provided along the proposed frontage road and at any other miscellaneous entrances, connection roads, city streets, townships roads or parking areas. A 1.0' subcut shall be provided at the temporary crossovers to be constructed between the existing

eastbound and westbound alignments. All the subcuts shall be backfilled with material meeting the requirements of Mn/DOT Specification 3149.2B2, Select Granular Borrow.

Where connecting to the in-place roadways at the termini of the proposed construction, cut vertically to the bottom of the in-place surfacing or to the bottom of the new surfacing design, whichever is deeper; then at a 1(V): 20(H) taper to the bottom of the recommended subcut. This includes the east and west connections of the proposed alignment to the existing highway as well as the connection of the new frontage road to the existing highway on the west end of town.

Where matching into in-place crossroads, cut vertically to the bottom of the in-place surfacing or to the bottom of the new surfacing design, whichever is deeper; then at a 1(V): 4(H) taper to the bottom of the recommended subcut.

Muck Excavations
There are several areas along the proposed eastbound and frontage road alignments containing deposits of organic materials. In some areas these deposits extend below the existing highway alignment. These areas shall be excavated and backfilled with material meeting the requirements of Mn/DOT Specification 3149.2B1, Granular Borrow. The excavations shall be completed in accordance with the attached figure, Poor Foundation Soil Typical Subcut Section. The slope coming up and out from the bottom of the excavations shall be 2:1.

The following muck areas are relatively shallow and do not require any special considerations:

Proposed WB	Sta. 1027+00 to 1032+00
Proposed EB & WB	Sta. 1052+00 to 1067+00
Proposed EB & WB	Sta. 1071+00 to 1077+50
Proposed Frontage Rd	Sta. 1056+00 to 1078+50

An additional muck excavation area is located between Sta. 1136+00 and 1140+50 along the proposed eastbound alignment. This organic material deposit is relatively deep and borings indicate that the organic material extends below the existing eastbound alignment. A surcharge shall be placed in this area to a height of at least 5.0' above the proposed grading grade and left in place for a minimum of 60 days or as approved by the Engineer. In addition to the surcharge, the contract shall provide for three settlement plates to be installed as directed by the Engineer. The settlement plates should be located in the areas of deepest excavation and shall be placed at the existing ground elevation or just above the water table encountered during excavation if applicable.

Shrinkage Factors
The shrinkage factors of 110% and 125% shall be used for materials taken from the existing highway embankment and imported granular borrow respectively. A shrinkage factor of 135% shall be used for the granular material to be placed in the swamp excavations west of town and a shrinkage factor of 150% shall be used for the granular material to be placed in the deeper swamp excavation near the east end of the project..

Compaction Requirements
All embankment material shall be compacted as required by the Modified Penetration Index Method except for specific portions of the embankment as described in Mn/DOT Specification 2105.3F. If the Modified Penetration Index Method has not been added to the Standard Specifications by the time of letting it shall be added via the Special Provisions.

Groundwater Treatment
A drainage blanket system shall be installed from Sta. 1080+00 to 1095+00 to intercept groundwater during the spring thaw period. See the attached details for more information on the design of the drainage blanket system.

Geotextile Fabric Placement
Geotextile Fabric, Type V, shall be placed at the bottom of the excavation between Sta. 1133+00 and Sta. 1135+00 on the proposed EB Leg and between Sta. 17+75 and Sta. 19+75 on the proposed WB Leg near the east end of the project. The geotextile fabric will provide separation between the Silt and the granular backfill material. The geotextile fabric shall also extend continuously beneath the proposed concrete median separating the two Legs.

Geotextile Fabric, Type V, shall also be placed at the bottom of the proposed subcut in the contamination area between Sta. 1077+50 to 1080+00. The fabric will provide separation between the previously treated soils and the granular backfill material.

Surcharge Recommendations
In addition to the surcharge to be placed over the swamp excavation from Sta. 1136+00 and 1140+50, a surcharge shall be placed over the area where geotextile fabric is placed on the proposed EB Leg and WB Leg connection roads near the east end of town. The surcharge shall be placed to a height of at least 4.0' above the proposed grading grade and left in place for a minimum of 60 days or as approved by the Engineer.

Culvert Treatment
A granular culvert treatment shall be provided for the new centerline culvert at approximately Sta. 1004+00 on eastbound. Since the culvert is located within the mill and overlay portion of the project, a treatment using 1(V): 3(H) tapers will be required. The treatments shall be backfilled with material meeting the requirements of Mn/DOT Specification 3149.2B2, Select Granular Borrow. See the attached detail sheet for more information.

Location	Geotextile	Bedding Type	General Notes
1004+00 EB	N/A	Aggregate	

C. Pavement Structure

Bituminous Milling and Patching

The existing eastbound mainline, turn lanes and shoulders from approximately Sta. 1002+00 to 1009+00 shall be milled to a depth of 4.0”.

After milling and prior to the bituminous overlay, all cracks and deteriorated pavement shall be air blasted with equipment that is able to deliver 100 PSI of nominal pressure, as directed by the Engineer. The milled surface shall then be swept to remove all loose material dislodged from the milling and air blasting operations.

The contractor shall be required to patch all cracks or other pavement defects that are a minimum of 1.0” in width or depth in accordance with Mn/DOT Specification 2231.
The provisions of Mn/DOT Specification 2231.2A “Bituminous Patching Mixture” shall be modified such that the material used for patching meets the following requirements:

Aggregate Gradation	Percent by Mass
Passing 12.5 mm (1/2”) sieve	100
Passing 2.00 mm (#8) sieve	45-80
Passing 0.075 mm (#200) sieve	2.0-7.0

Bituminous Material	Percent by Mass
Asphalt Cement (PG 58-28, 52-34, or 58-34)	6.5

All bituminous patching mixture placed shall receive a minimum of two passes with an approved rubber tired roller and be compacted to the satisfaction of the Engineer. Prior to placing the bituminous patching mixture, all cracks shall be treated with a bituminous tack coat at a rate of 0.07-0.10 gal/yd2. The need for bituminous patching material has been estimated to be 5 ton/mile.

Structural Analysis

Using the current pavement design method, the Granular Equivalent (GE) required for the mainline pavement structure from Sta. 1009+00 to 1147+00 is 23.3 inches. This figure is based on a 20-year design lane ESAL forecast of 6,346,000 and an assumed R-value of 70. This assumed R-value is based on the fact that the material encountered during field investigations fell primarily into the textural classification of Fine Sand (FS). Additional factors contributing to the assumed R-value include the gradation tests on representative samples of the material indicating a granular material with less than 7% passing the No. 200 sieve and the fact that a 2.0’ minimum subcut to be backfilled with Select Granular Borrow is being completed along mainline for uniformity and compaction.

Bituminous Surfacing

All bituminous mixtures shall meet the requirements of Mn/DOT Specification 2360 and shall be as indicated in the pavement design sections given below.

Mainline, Turn Lanes & Shoulders in Mill & Overlay Area:

Material	Thickness	Mix Design	GE(inches)
Superpave Wear	4.00 inches	SPWEB540F	N/A

Mainline, Turn Lanes & Shoulders in Urban Reconstruction Area:

Material	Thickness	Mix Design	GE(inches)
Superpave Wear	4.00 inches	SPWEB540F	9.00

Superpave Non Wear 3.00 inches SPNWB430B 6.75 Aggregate Base Course 9.00 inches Class 6 9.00
Total GE 24.75

Mainline & 4’ Shoulders in Rural Reconstruction Area:

Material	Thickness	Mix Design	GE(inches)
Superpave Wear	4.00 inches	SPWEB540F	9.00
Superpave Non Wear	3.00 inches	SPNWB430B	6.75
Aggregate Base Course	9.00 inches	Class 6	9.00
Total GE			24.75

10’ Shoulders in Rural Reconstruction Area:

Material	Thickness	Mix Design	GE(inches)
Superpave Wear	4.00 inches	SPWEB230A	9.00
Aggregate Base Course	12.00 inches	Class 6	12.00
Total GE			21.00

Turn Lanes in Rural Reconstruction Area:

Material	Thickness	Mix Design	GE(inches)
Superpave Wear	4.00 inches	SPWEB540F	9.00
Aggregate Base Course	12.00 inches	Class 6	12.00
Total GE			21.00

Frontage Road:

Material	Thickness	Mix Design	GE(inches)
Superpave Wear	5.00 inches	SPWEB440B	11.25
Aggregate Base Course	6.00 inches	Class 6	6.00
Total GE			17.25

Township Roads, City Streets & Parking Lots:

Material	Thickness	Mix Design	GE(inches)
Superpave Wear	4.00 inches	SPWEB440B	9.00
Aggregate Base Course	6.00 inches	Class 6	6.00
Total GE			15.00

Temporary Crossovers:

Material	Thickness	Mix Design	GE(inches)
Superpave Non Wear	4.50 inches	SPNWB430B	10.12
Aggregate Base Course	4.00 inches	Class 6	4.00
Total GE			14.12

Culvert Replacement at Approx. Sta. 1004+00 EB:

Material	Thickness	Mix Design	GE(inches)
Superpave Wear	4.00 inches	SPWEB540F	9.00
Superpave Non Wear	5.50 inches	SPNWB430B	12.38
Aggregate Base Course	4.00 inches	Class 6	4.00
Total GE			25.38

Notes: All bituminous wearing courses and the non-wearing courses to be placed at the temporary crossovers and culvert replacement area shall be placed in two lifts. Also, given the fact that a minimum 1.5’ layer of Select Granular Borrow will be placed below the proposed pavement sections, the thickness of the aggregate base courses could have been reduced, however, 3.00 inches of the Class 6 is intended to act as a stabilizing layer and shall be placed and compacted prior to the placement of the remaining Class 6.

Miscellaneous Bituminous Items
All bituminous mixtures will meet the requirements of Mn/DOT Specification 2360 modified to include the latest Asphalt Film Thickness (AFT) and Longitudinal Joint Density provisions. Pavement smoothness will be evaluated using the IRI Equation A contained in the latest version of the Combined 2360/2350 Specification.

Prior to any bituminous surfacing, a bituminous tack coat shall be applied to any milled surfaces at a rate of 0.07-0.10 gal/yd2 and between all bituminous lifts at a rate of 0.03-0.05 gal/yd2.

Aggregate Base Compaction Requirements
Compaction of the Class 6 Aggregate Base shall be obtained by the Modified Penetration Index Method in accordance with Mn/DOT Specification 2211.3C. If the Modified Penetration Index Method has not been added to the Standard Specifications by the time of letting it shall be added via the Special Provisions.

Aggregate Surfacing
The gravel access road to be constructed in the borrow pit located on the east end of the project (Vet Rd.) shall be surfaced with 3.0" of Class 6 Aggregate Surfacing.

Compaction of the Class 6 Aggregate Surfacing shall be obtained by the Modified Penetration Index Method in accordance with Mn/DOT Specification 2211.3C. If the Modified Penetration Index Method has not been added to the Standard Specifications by the time of letting it shall be added via the Special Provisions.

Aggregate Shouldering
The Class 1 Aggregate Shouldering material shall be modified such that 12-20% passes the No. 200 sieve.

Compaction of the Class 1 Aggregate Shouldering Modified shall be obtained using the Quality Compaction Method in accordance with Mn/DOT Specification 2211.3C2.

D. Aggregate and Borrow Source

The following State owned pit shall be listed as a possible source of material.

Pit #	Owner	County	Legal Description	Material Available
77052	Mn/DOT	Todd	NE¼ NE¼ SEC 5 TWN 132N RNG 33W	Aggregate & Granular Borrow

cc:
C. Turgeon/G. Engstrom MS 645
B .Chadbourn/J. Gieb MS 645
J. Garrity MS 645
N. Sannes MS 692
E. Buckley MS 692
T. Swanson MS 692
Gary Niemi Baxter
Tony Kempenich Baxter
Gary Dirlam Baxter
Kevin Kosobud Baxter
Terry Humbert St. Cloud

Appendix C

TH 60 in Bigelow (S.P. 5305-55) Soils Information

January 27, 2006

To: Mary Dieken
Project Manager

From: John Hager, P.E.
D-7 Materials Engineer

Phone: (507) 389-6003

Subject: S.P. 5305-55, (T.H. 60)
Recommendation for Grading and Surfacing on T.H. 60 from 120th Street in Osceola County, Iowa to about 0.86 miles north of C.S.A.H. 4 in Nobles County Minnesota.

Length: Approximately 5.06 miles.

Proposed Letting Date: December 2006

General Project Information

This project is a continuation of the four-lane expansion of T.H. 60 through Iowa and ultimately to I-90 in Worthington, Minnesota. The design of the road will be a rural, four-lane expressway with a depressed median. The project includes a bypass to the east of Bigelow.

The in-place structure of T.H. 60 in Iowa consists of 10-8-10 x 22' concrete with a 10" thick 2' bituminous widening. An 8" bituminous overlay was placed 24' wide. The subgrade was constructed of Select Grading Material. Shoulders are 4'-6' wide consisting of 3"-6" of granular material.

The in-place structure of T.H. 60 in Minnesota consists of 9-7-9 x 22' concrete with a 6" bituminous overlay that is 26' in width. Shoulders are variable depth Class 1.

This project went through a Formal Pavement Selection process (F05-01). The process reviewed two rigid (concrete) and two flexible (bituminous) pavement designs. The low cost option is a rigid pavement with an Open Graded Aggregate Base.

Soils

Fourteen R-value samples were obtained along the proposed project. A composite R-value of 13.2 will be used for design. An electronic version of the soils profile will be provided to District-7 Design. If others would like a copy, contact District-7's Material Engineer.

A Microsoft Access database will be provided to Design which will provide depths of topsoil and any muck sites.

A report dated March 16, 2005 from the Office of Environmental Services titled "Phase II Environmental Site Assessment, Trunk Highway 60 New Alignment/Russel Drainage Contracting Property, CSAH 24 and County Road 52, Bigelow, Minnesota" was published to discuss contamination sites on the project. This report should be reviewed by the Designer. The contract should provide Special Provisions for dealing with contaminated soil. Contact Nancy Radle from the Office of Environmental Services for assistance in writing a provision for taking care of contaminated soil.

Soil classified as slightly organic were discovered at station 95+53 in the proposed SBL. This is just south of the cross-over. It is assumed that this site will have been addressed prior to this project.

Piezometers

Piezometers have been installed in the Iowa segment and the readings will be shown below as the information becomes available.

Locations:

Piezo #1. In ditch west of C.R. L-44 south of 100th Street/State Line.

Piezo #2. In east ditch of existing Highway 60, north of Polk Avenue.

Piezo #3. In east ditch of existing highway 60, north of Polk Avenue.

Date	Piezo #1	Piezo #2	Piezo #3
10-27-05	2.40	3.30	NA
11-3-05	2.50	2.90	3.40
12-13-05	1.50	1.55	2.50
1-26-06	1.79	2.55	2.91

Traffic Data Collection and Analysis

Traffic Forecast F7-0401 was completed in July 2004. The 20-year BESAL's are 2,869,000 and the 35 year CESAL's are 8,568,000. The 2007 base year has a two way AADT of 3800 and a 2027 design year AADT of 5100.

Construction Notes

1. Add the following sentences to the plan: 2105 (EXCAVATION AND EMBANKMENT):
    a. Ditches must be excavated before any subcuts are excavated.
    b. The grade shall be shaped and compacted to seal the surface and provide drainage at the end of each working day.
    c. Automated grade control equipment shall be used on this project for the final grading tolerance. The automatic equipment shall be capable of maintaining the proper elevation on both sides of the equipment by controlling the crown or by controlling the elevation of each side independently. The grade reference shall be achieved by the means of an erected string line or other method approved by the Engineer.
2. The following statement should be included in the Construction Notes:

Contractor's personnel or any other personnel <u>may not</u> use the new road surface for the purpose of stockpiling aggregate material or any other material as determine by the Engineer for <u>any length of time</u> during the duration of this contract.

<u>Design Recommendations</u>

1. **<u>A Soils Profile (in MicroStation Format) is being provided to Design personnel for this project. There is information in that profile that may or may not be referenced in this letter. It is critical for Design personnel to become familiar with this MicroStation Drawing and to ask the District Materials Engineer if there are any questions.</u>**

2. Prior to any embankment construction, the inplace topsoil shall be removed and stockpiled. All of the topsoil shall be removed in fill sections. At the completion of the project, the salvaged topsoil should be replaced to a 6-inch minimum. Estimated topsoil depths range from 0.3 feet to +3 feet. Provide for removal of the inplace topsoil according to the <u>soil profile</u> and the <u>Road Design Manual Fig. 4-2.02A and 4-2.02B dated February 2000</u>. Depths are measured from top of existing ground.

3. The grading grade is hereby defined as the bottom of the Class 5 Aggregate.

4. All salvaged roadway materials, such as concrete, bituminous, and aggregates, can be utilized according to the Specifications & Special Provisions or as noted in this letter. Salvaged concrete is <u>*not*</u> allowed for reuse into the new concrete mix. Materials not utilized on this project will become the property of the contractor and disposed of off of the R/W as agreed upon by the Engineer.

5. Selected grading materials will be all materials encountered except topsoil, silt, debris and other organic materials. Soil shall be uniform or be sufficiently mixed and blended to produce a uniform soil texture. Materials with an organic content exceeding 5.0% shall not be used for selected grading material, unless they are sufficiently blended with other soils to lower the resultant percentage of organic below 5.0%.

6. On the T.H. 60 mainline subcuts provide for 1:20 transition tapers after making a vertical cut in the existing pavement structure at the beginning of the project to eliminate the possibility of an abrupt soils differential. Also provide for 1:20 transition tapers when there is a change in the material type (granular vs. plastic soils). The 1:20 tapers shall be constructed so that the granular material overlies the adjacent plastic soils. Also provide 1:20 tapers for change in subcut depth. **Unless otherwise noted, provide for a uniform <u>3.5’</u> subcut below grading grade (bottom of the Class 5) for the T.H. 60 mainline on the entire project and backfill with Select Grading Materials. Compaction to be by the <u>Specified Density Method</u>**.

7. County and Township Roads - Where matching inplace side roads, cut vertically to the bottom of the inplace surfacing or to the bottom of the new surfacing design, whichever is deeper, then transition at a 1:4 slope to the bottom of the recommended subgrade excavation.

8. Special Treatments

   Swamp Treatments

   Soils classified as slightly organic were discovered 65’ west of station 327+80 in the SB direction. This is also the site of a culvert extension. This site will require muck excavation to remove the organics. Crushed rock will be required under the culvert extension due to the expected water level.

9. Subcuts need to have outlets. If this is not feasible, the designer should contact the District 7 Materials Office for possible modifications. Polyethylene (PE) pipe outlets should be kept a minimum of 1 foot above the finished ditch grade. It is recommended that the drainage flow line be located 6.0 feet below the finished grade in cut areas, whenever possible. If this is not possible, contact the District Materials Office for further recommendations. It is recommended that ditches should be approximately 4.0 feet below the finished shoulder P.I. for the County Roads and 3.0’ for Township Roads.

10. It is understood that no replacement or extension of culverts with an opening greater than 80 square feet is part

of this project.

For treatment of any new centerline culverts with an opening less than 80 square feet, refer to the Road Design Manual cases 1-4 dated Dec. 1996.

11. Construct edge drains according to current design standards.

    The proposed headwall outlets shall be marked by the following method.

    The location of the headwall marking should be a point adjacent to the outside edge of the paved shoulder.

    A depression, 5” X 24” X 1/8” min., should be made at each headwall location and the depression shall promote drainage of surface water to the inslope.

    When an iron plate is used to construct the 1/8” depression, the thickness of the plate shall be ¼” min.

    The depression should be painted with white latex paint

    The placement and depression method shall be pre-approved by the Engineer.

    When feasible, provide for edge drain lengths to be kept to a maximum length of 250’.

12. Uniformly mixed soils are critical on this project and the second paragraph of 2105.3D shall be strictly enforced. Mixing of soils will be required to ensure uniformity.

13. Test Rolling - Test rolling will be required on T.H. 60 mainline.

14. Provide for granular borrow backfills at the following sites

NBL	123+66	129+88	Granular to 1645.0
NBL	182+46	187+46	Granular to 1641.0
NBL	257+00	258+75	Granular to 1648.0
NBL	309+70	310+25	Granular to 1618.0
SBL	127+06	130+35	Granular to 1645.0
SBL	182+54	186+34	Granular to 1641.0
SBL	256+80	258+33	Granular to 1648.0
SBL	327+53	329+37	Granular to 1600.0
CSAH 4	40+00	41+00	Granular to 1611.0

15. In Iowa provide for the removal of existing T.H. 60 consisting of 8" of bituminous 24' wide over 10-8-10 concrete 22' wide. The mainline was widened to 24' next to the concrete by placing a 2' wide 10" thick bituminous structure. Shoulders are 4-6' wide consisting of 3-6" of granular material.

In Minnesota provide for removal of existing T.H. 60 consisting of 6" of bituminous over 9-7-9 x 22' wide concrete.

16. Provide for the following T.H. 60 mainline structure in Minnesota:

Lift	**Thickness**	**Mix Designation**	**Compaction Method**
Concrete	8 in	15' joint spacing 1.25" epoxy coated dowels Protected Edge Design	NA
Permeable Base	4 in	Open Graded Aggregate Base	Quality Compaction
Base	5 in	Class 5 Aggregate Base	Modified Penetration Index Method
Subcut	3.5 ft	Select Grading Material	Specified Density

17. Use the standard water cement ratio specification. The w/c ratio for High Performance concrete or small jobs does not apply.

18. Provide for the following T.H. 60 mainline structure in Iowa:

Lift	Thickness	Mix Designation	Compaction Method
Concrete	10 in	15' joint spacing 1.25" epoxy coated dowels Protected Edge Design	NA
Permeable Base	4 in	Open Graded Aggregate Base	Quality Compaction
Base	12 in	Class 5 Aggregate Base	Modified Penetration Index Method
Subcut	2' 9"	Select Grading Material	Specified Density

19. Provide for the following T.H. 60 bituminous shoulder structure in Minnesota:

Design Period: 20 years	**Design BESAL's: NA**		**Design R-value: 13.2**
Lift	**Thickness**	**Mix Designation**	**Compaction Method**
Wear	4 in (*)	2360 SPWEB230B (58-28)	Maximum Density (**)
Base	4 in	Class 5 Aggregate Base	Modified Penetration Index Method
Sub-base	var. (9" max)	Class 3 Aggregate Base	Modified Penetration Index Method
Subcut	3.5 ft	Select Grading Material	Specified Density

(*) Place in two equal lifts.

(**) Shoulders 6' or narrower will be compacted by the Ordinary Compaction Method (as per 2350/2360 specification).

20. Provide for the following T.H. 60 bituminous shoulder structure in Iowa:

Design Period: 20 years	**Design BESAL's: NA**		**Design R-value: 13.2**
Lift	**Thickness**	**Mix Designation**	**Compaction Method**
Wear	6 in (***)	2360 SPWEB230B (58-28)	Ordinary Compaction (**)
Base	4 in	Class 5 Aggregate Base	Modified Penetration Index Method
Sub-base	var. (16" max)	Class 3 Aggregate Base	Modified Penetration Index Method
Subcut	2' 9"	Select Grading Material	Specified Density

(***) Place in three equal lifts.

Note: It is understood that the bituminous portion of the shoulders will be 4' wide. For aggregate shoulder outside of the 4' paved width use 6" of Class 1 and then the same structure as shown above below the bituminous.

21. Provide for the removal of County Road 52 and C.S.A.H. 4 which consist of an average 8” of bituminous. County Road 44 consists of 6” of bituminous.

22. Provide for County Road 44 (Iowa), County Road 52 (border road), C.S.A.H. 4 and T.H. 60 North Connection to Bigelow to be constructed with the following structure:

Design Period: 20 years		**Design BESAL’s: NA**	**Design R-value: 13.2**
Lift	**Thickness**	**Mix Designation**	**Compaction Method**
Wear	6 in (**)	2360 SPWEB340C (58-34)	Maximum Density
Aggregate	11 in	Class 5 Aggregate Base	Modified Penetration Index Method
Subcut	2.0 ft	Select Grading Material	Specified Density

(**) Place in three equal lifts.

23. Provide for the following aggregate structure for Township Road 330, Nystrom Road, the cross-over near station 155 in Iowa and farm entrances in Iowa:

Lift	**Width**	**Thickness**	**Mix Designation**	**Compaction Method**
Aggregate	var.	6 in	Class 5 Aggregate Base	Quality Compaction
Subcut	var.	2 feet	Select Grading Material	Quality Compaction

24. Field entrances in Iowa are to be constructed of Select Grading Material.

25. Tack coat uses and application rates - Provide for a tack coat between all bituminous lifts and at the edges where concrete and bituminous meet. The bituminous tack coat material shall be applied at a uniform rate of 0.03 to 0.05 gal/yd^2 between bituminous layers and 0.07 to 0.10 gal/yd^2 on concrete or milled bituminous surfaces prior to being overlaid. These application rates are for undiluted emulsions (as supplied from the refinery). The asphalt emulsion may be further diluted in the field in accordance with Mn/DOT Spec. 2357.

26. It is anticipated that local aggregate sources will be utilized on this project and no pits will be listed on the front page of the plans.

27. It is recommended that construction personnel tie in all subcut drains and edge drain outlets with GPS coordinates and provide to the proper Maintenance personnel to facilitate with future cleaning and maintenance.

cc :	M. Flygare	D7	K. Bloomgren	D7
	R. Sinn	D7	J. Garrity	MS 645
	C. Turgeon/G. Engstrom	MS 645	J. Geib	MS 645
	N. Sannes	MS 692	E. Buckley	MS 692
	T. Swanson	MS 692	D. Schwartz	MS 645
	C. Brakke	IA/DOT	B. Stanley	IA/DOT

Appendix D

TH 10 in Detroit Lakes (S.P. 0301-47) Specifications

S. P. 0301-47

(2105) (QC/QA) IC QUALITY COMPACTION (PILOT SPECIFICATION FOR GRANULAR TREATMENT)

All work shall be performed in accordance with Mn/DOT 2105 and 2106. Compaction requirements shall be performed in accordance with (QC/QA) IC Quality Compaction (Pilot Specification for Granular Treatment) as described below.

The (QC/QA) IC QUALITY COMPACTION (PILOT SPECIFICATION FOR GRANULAR TREATMENT) Specification utilizes new technology and new equipment to measure the compaction and/or stiffness of the roadway embankment construction. If, in the opinion of the Engineer, the measurement of compactive effort resulting from the Pilot Specification herein does not accurately reflect the compaction and/or stiffness observed, the Engineer reserves the right to change the method of compaction measurement to Modified Penetration Index, Specified Density, or LWD as outlined elsewhere in the Mn/DOT Standard Specifications or these Special Provisions.

A. Description

This work shall consist of measuring the compaction parameters of the granular treatment with a smooth drum vibratory roller. The roller shall be equipped with a measurement and documentation system that allows for continuous recording of the roller location by the global positioning system and the corresponding compaction parameters.

The Contractor shall develop and implement a Project specific Quality Control Procedure for embankment construction that is based on Contractor IC compaction parameters, moisture testing and other Quality Control practices; and shall provide ongoing Quality Control data to the Engineer.

Compaction of all granular treatment used in embankment construction shall be obtained by the "(QC/QA) IC Quality Compaction (Pilot Specification for Granular Treatment)" method.

B. Definitions

Embankment Grading Materials

Are defined as all grading materials placed in the roadbed subgrade as indicated in the Plans. The embankment shall be the zone under the base, pavement and curb structures bounded by the roadbed slopes shown in the Plan or 1:1 slopes from the shoulder PI (point of intersection) (1.0 vertical to 1.5 horizontal slopes for fills over 10 meters **(30 feet)** in height).

Granular Treatment

Is defined as Granular Material (Mn/DOT 3149.2B1) and Select Granular Material (Mn/DOT 3149.2B2).

Quality Compaction

Is defined in Mn/DOT 2105.3F2 Quality Compaction (Visual Inspection) Method.

Quality Control

Is defined as a procedure whereby the Contractor develops, utilizes, and documents Quality Control activities that govern how the embankment is constructed on this Project.

Quality Assurance

Is defined as a procedure where the Engineer monitors the Contractor's Quality Control activities and performs assurance monitoring and/or testing for final acceptance of all embankment construction.

Intelligent Compaction (IC)

This process involves measuring and recording the time, location and compaction parameters of the granular treatment during the compaction process with a vibratory roller that is equipped with an accelerometer-based measuring system and a global positioning system.

Intelligent Compaction (IC) Roller

Rollers shall be vibratory rollers with an accelerometer-based measurement system and capable of recording the compaction parameter measurements.

Intelligent Compaction Test Pad

Is defined as a location where the Contractor shall demonstrate to the Engineer that the IC roller and the intelligent compaction instrumentation meet all the requirements of this specification. The Contractor and Engineer will agree on a location(s) within the Project to construct the IC test pad.

Intelligent Compaction – Compaction Target Value (IC-CTV)

The target compaction parameter reading obtained from control strips compacted with the IC roller for each type of granular treatment used on the Project. The IC-CTV is determined for specific drum amplitude; drum frequency, roller speed, and roller direction.

Proof layer

Is defined as a predetermined layer that requires Quality Control measurements by the Contractor and Quality Assurance measurements by the Engineer to ensure compliance with the IC & LWD Compaction Target Values prior to placing successive lifts.

Portable Light Weight Deflectometer (LWD)

Is a hand-operated device that uses a sensor to measure the deflection of the 200 mm **(8 inch)** flat plate, impacted by a falling weight to measure the stiffness of the granular treatment. The LWD shall have one sensor directly below the falling weight. The device measures the deflection and estimates the modulus based on the force required to generate a given deflection for the type of granular material.

Compaction Parameters

Includes modulus, stiffness or other compaction related parameters

Modulus Test Value

At each LWD test location, the LWD drop shall be repeated six (6) times without moving the plate. The first, second and third drops are designated as seating drops. The LWD Modulus Test Value shall be the average modulus estimated from the fourth, fifth and sixth drops in the testing sequence.

Portable Light Weight Deflectometer – Compaction Target Value (LWD-CTV)

The target modulus measurement for each type of embankment grading material determined by LWD testing on the control strip(s) constructed on this Project.

C. <u>Equipment Requirements</u>

C1. <u>Intelligent Compaction (IC) Roller</u>

The smooth drum Intelligent Compaction (IC) Roller shall weigh at least 10,800 kg **(24,000 pounds)** and be approved by the Engineer.

A smooth drum vibratory roller with an accelerometer-based measurement system is required for the compaction and recording of the compaction parameter measurements on the granular treatment.

Alternatively, rollers equipped with other dynamic measurement value systems may be utilized as approved by the Engineer.

C2. <u>Intelligent Compaction Instrumentation</u>

The IC roller shall be equipped with a location, measurement, and documentation system, which shall provide the results that:

1) Enhance the ability of the roller operator and Project inspection personnel to make real-time corrections to the compaction process.
2) Allow the Engineer to review the roller operators IC screen in the roller operator's cab, when requested.
3) Provide printed Plan-view color maps to the Engineer in a timely manner.
4) Provide comma delimited ASCII data files identified by fixed format filenames containing the date, time, and location of the proof layer to the Engineer in a timely manner.
5) Include the summary quality control parameters (roller compaction value (RCV)), which may be modulus, stiffness, or another index parameter; resonance meter value (RMV), which identifies unstable drum oscillation; and roller pass number (RPN), which is the number of passes at that location on that lift since initial material placement.
6) Include the roller parameters: travel direction, travel speed, horsepower, and total mass.
7) Include the drum parameters: static mass, width, diameter, frequency, peak vertical amplitude, peak vertical acceleration, and peak vertical force.
8) Include the position for each data record accurate to the frequency of the drum (x, y, z coordinates for each end of the drum in UTM NAD 1983 zone 15 N format).
9) Include a time stamp for each data point accurate to the frequency of the drum.

C3. Equipment Approval

Within 15 days after award of the Contract, the Contractor must provide the following information to the Engineer:

Intelligent Compaction Roller
Model:
Manufacturer:
Operating Weight:
Drum Width:
Drum Diameter:
Drum Mass:
Maximum Vertical Dynamic Force:
Roller Horsepower:

The Contractor shall make available an on-site equipment manufacturer's representative for construction of the initial control strip and as required or requested by the Engineer throughout the portion of the Project that which utilizes IC.

The Contractor will be required to complete a IC test pad to demonstrate that the roller and the intelligent compaction instrumentation meets all the requirements of this specification. The Contractor and Engineer will agree on a location(s) within the Project to construct the IC test pad. The IC test pad shall be on the Project site, using the granular treatment that will be used on the Project, and be in a location that demonstrates the ability of the system to fully function throughout the Project site. The IC test pad size and the lift thicknesses shall be the same as the control strip requirements or as otherwise determined by the Engineer. Portions of the Project that require using the IC roller shall not proceed until the IC roller meets all the specification requirements and is approved by the Engineer.

The IC test pad cannot be one of the required control strips.

C4. Testing Equipment

The Engineer may order the contactor to provide a Light Weight Deflectometer and/or electronic moisture meter or other moisture testing device with payment to be made as Extra Work.

C5. IC Roller Software Review

The IC roller manufacturer or Contractor shall supply the Agency with two (2) copies of the latest software to review the information obtained from the IC roller until the end of the Project. This is to allow the Engineer to see what the IC roller operator is seeing in the cab at the Project site and at the Engineer's office.

Construction Requirements

D1. Proof Layers

For granular treatment less than or equal to 750 mm **(2.5 feet)** in thickness, the proof layer shall be designated as the top of the granular treatment.

For a granular treatment more than 750 mm **(2.5 feet)** and less than 1.2 meters **(4 feet)** in thickness, the proof layers shall be designated as the midpoint and the top of the granular treatment thickness.

For a granular treatment equal to or greater than 1.2 meters **(4 feet)** in thickness the proof layers shall be successive 600 mm **(2 foot)** layers in thickness from the bottom and up to the top of the granular treatment.

The designation of proof layers is general in nature and may require modification by the Engineer to meet Project specific embankment heights. The proof layers do not change control strip and production maximum lift thickness requirements, but are the designated layers in the granular treatment where acceptance testing is performed.

IC compaction parameter measurements shall be recorded continuously on all proof layers of granular treatment by the IC roller. The LWD Modulus Test measurements shall be recorded on all proof layers of granular treatment. The Contractor shall give the Engineer timely notification of proof layer testing so that this activity may be observed and tested by the Engineer for acceptance.

D2. Quality Control/Quality Assurance (QC/QA)

D2a. Contractor Quality Control (QC) Requirements

The Contractor shall utilize the data gathered from the control strip construction to develop a Quality Control Procedure for granular treatment. This procedure shall detail how Quality Control will be accomplished, including, but is not limited to, identifying IC equipment and procedures, collecting and reporting IC compaction parameter measurement results, ensuring uniformity of the granular treatment, confirming acceptable moisture and compaction parameter results on granular treatment lifts between proof layers, determining the anticipated number, pattern and speed of roller passes to obtain optimum compaction parameter results on all layers, not just the proof layers, and other items that may contribute to an effective Quality Control Procedure.

The Quality Control Procedure shall include any corrective construction actions that may be required as a result of Quality Control measurements, such as adding water and/or drying soils, re-compacting non-compliant granular soils or other corrective actions that have been undertaken.

The Contractor shall perform all IC compaction parameter measurements required by the approved Quality Control Procedure, and shall modify construction operations so that acceptable compaction results are obtained. The Contractor shall also document all Quality Control IC compaction parameter results, Quality Control activities and corrective construction actions taken as a result of the Quality Control measurements to meet the requirements of this specification with a Weekly Quality Control Report in a format acceptable to the Engineer. The documentation shall be submitted to the Engineer for acceptance on a weekly basis.

As part of the Quality Control Procedure, the Contractor shall perform moisture content tests on the granular treatment at a minimum of 1 per 3,000 cubic meter (CV) **[1 per 4,000 cubic yards (CV)]** for compliance. The Contractor moisture content tests may be performed by a Project calibrated electronic moisture meter, reagent method, burner method, oven dry method, or other gravimetric methods as approved by the Engineer. The Engineer may perform additional moisture content tests.

D2b. Agency Quality Assurance (QA) Requirements

The Engineer will observe the final compaction recording pass of the IC roller on each proof layer, review and approve the Contractor's Quality Control data documenting acceptable compaction results submitted in the form of the Weekly Quality Control Report and perform companion and verification LWD and moisture testing.

The Engineer will also perform a companion LWD Modulus Test and a moisture content test at the minimum rate of one (1) LWD Modulus Test Value measurement per proof layer, per 300 meters **(1,000 feet)** for the entire width of embankment being constructed during each operation.

The Contractor shall provide a relatively smooth uniform surface that has been shaped to approximate line and grade of each proof layer for the purpose of taking all LWD Modulus Test Value measurements at the required locations for this specification, with no direct compensation made therefore. The Contractor shall make the proof layer surface available for Quality Assurance testing in a safe condition on an ongoing basis, or within 24 hours of the completion of compaction activities.

For acceptance of compaction at each proof layer during general production operations, all segments of the granular treatment shall be compacted so that at least 90% of the IC compaction parameter measurements are at least 90% of the applicable corrected IC-CTV prior to placing the next lift. The Contractor shall re-compact (and dry or add moisture as needed) all areas that do not meet these requirements. Additional IC compaction parameter measurements shall be taken for acceptance of the re-compacted areas.

If localized areas have an IC compaction parameter measurement of less then 80% of the corrected IC-CTV, the Contractor shall re-compact (and dry or add moisture as needed) these areas to at least 90% of the IC-CTV prior to placing the next lift.

If a significant portion of the grade is more than 20% in excess of the selected corrected IC-CTV, the Engineer will re-evaluate the selection of the applicable control strip corrected IC-CTV. If an applicable corrected IC-CTV is not available, the Contractor shall construct an additional control strip to reflect the potential changes in compaction characteristics.

If the Engineer determines that the Contractor appears to be performing acceptable compaction efforts, but the IC compaction parameter measurements consistently do not meet the applicable corrected IC-CTV, the Engineer will re-evaluate the selection of the applicable control strip corrected IC-CTV. If an applicable corrected IC-CTV is not available, the Contractor shall construct an additional control strip to reflect the potential changes in compaction characteristics.

The Engineer may perform additional LWD Modulus Tests and moisture content tests in areas that visually appear to be non-compliant, or as determined by the Engineer.

Each LWD Modulus Test Value taken shall be at least 90% but not more than 120% of the corrected LWD-CTV obtained on the proof layer of the applicable control strip prior to placing the next lift. The Contractor shall re-compact (and dry or add moisture as needed) all areas that do not meet these requirements. Additional LWD Modulus Test measurements shall be taken for acceptance of the re-compacted areas.

Final Acceptance will be determined when the following criteria are met:

1) The final compaction parameter measurement pass observed by the Engineer meets the requirements of this specification.

2) The Contractor has submitted Weekly Quality Control Reports documenting that acceptable compaction results were obtained for all embankment construction.

3) All Quality Assurance tests taken by Mn/DOT meet specification requirements.

4) The Engineer has reviewed the IC compaction related parameter measurements taken on all proof layers and approved the Weekly Quality Control Reports.

D3. Control Strip

The Contractor shall construct compaction control strips to determine the Intelligent Compaction Target Value (IC-CTV) for each type and/or source of granular soil. Additional control strips shall be constructed for materials with observable and/or quantifiable variations in material properties that affect the IC-CTV, as determined by the Engineer.

The compaction of the control strip shall be limited to the compaction produced by the IC roller approved for use on the Project by the Engineer. No other compactive equipment shall be utilized to achieve compaction during the construction of the control strip.

It is anticipated that the IC-CTV and LWD-CTV for the granular treatment may be moisture sensitive to some degree. Therefore, to determine the moisture sensitivity correction for the IC-CTV and LWD-CTV, a control strip shall be constructed at or near each extreme of 65% and 95% of optimum moisture. This data will be utilized to produce a Correction Trendline showing a linear relationship of the IC-CTV and LWD-CTV at different moisture contents.

The control strip shall be at least 100 meters **(300 feet)** long and at least 10 meters **(32 feet)** wide at the base, or as determined by the Engineer. The lift thicknesses for the control strip and the constructed embankment shall be limited to the maximum lift thickness allowed in Mn/DOT 2105.3E. The total thickness of each control strip shall equal the planned granular treatment thickness being constructed. The total thickness of each control strip shall be a maximum of 1.2 m **(4.0 feet)**.

Both the Contractor and the Engineer will save a material sample from each control strip for comparison to the embankment material being compacted during QC/QA procedures in order to determine the applicable control strip IC-CTV.

The costs of constructing the control strips for each identifiable different type and/or source of grading material, for each material with observable and/or quantifiable variations in material properties, including but not limited to, moisture content, gradation, texture, and silt & clay content, that affect the IC-CTV, or for each compaction method, shall be part of the work required for this specification with no direct compensation made therefore.

D4. Control Strip Construction

a. The Contractor and Engineer will agree on a location(s) within the Project to construct the control strip(s).

b. After the layer below the granular treatment has been compacted, the Intelligent Compaction roller shall be used to record the compaction parameters of the layer prior to placing the granular treatment. The data shall be utilized as an Intelligent Compaction Base Map to determine uniformity of the embankment grading materials and to identify any inherent soft spots.

c. Place the granular treatment in lifts. The lift thicknesses for the control strip shall be limited to the maximum lift thickness allowed in Mn/DOT 2105.3E.

d. The Contractor shall make repeated compaction passes on each lift, using a roller pattern approved by the Engineer, with continuous compaction parameter measurements being recorded by the IC roller. The optimum value is reached when additional roller passes do not result in a significant increase in the compaction parameter values on that lift, as determined by the Engineer.

e. The Engineer will perform LWD Modulus Test Value measurements on each layer at three (3) separate LWD test locations spaced at least 25 meters **(75 feet)** apart, or as modified by the Engineer.

f. Repeat c. to e. until it has reached the proof layer.

g. The Engineer will perform Light Weight Deflectometer (LWD) Modulus Test measurements tests at each proof layer at three (3) separate LWD test locations spaced at least 25 meters **(75 feet)** apart, or as modified by the Engineer.

h. The proof layer LWD-CTV will be the average of the LWD Modulus Test Values at the three (3) LWD test locations measured on the designated proof layer(s) during construction of the control strip. LWD Modulus Test Value measurements at additional locations may be taken on the proof layer(s) and included in the calculation of the average LWD-CTV as determined by the Engineer. The proof layer LWD-CTV's obtained from the control strips that were constructed at each moisture content extreme, will be used to determine the LWD-CTV Correction Trendline.

i. The proof layer Intelligent Compaction-Compaction Test Value (IC-CTV) will be the optimum value obtained from the Intelligent Compaction stiffness measurements on the designated test layer during construction of the control strip. The optimum value is reached when additional passes do not result in a significant increase in stiffness values, as determined by the Engineer.

j. Repeat c. to f. until the next proof layer is reached and repeat g. to i..

The proof layers in the control strip construction are general in nature and may require modification by the Engineer to meet specific Project conditions.

D5. Moisture

At the time of compaction, both for the construction of the test pad and during production, the moisture content of the granular materials shall be not less than 65% or more than 95% of Optimum Moisture. The Engineer will determine the Optimum Moisture by the Standard Proctor Density Method.

The Contractor shall add water and blend as needed to meet the moisture requirements. The Engineer may order the application of additional water for compaction if necessary. If any embankments are constructed with materials that contain excessive moisture, the Contractor shall dry or replace it with material having the required moisture content._

Additional water ordered by the Engineer, or efforts to dry materials or replace soils that are excessively wet which are taken by the Contractor to meet Quality Control procedures or otherwise ordered by the Engineer, will not be considered extra work, but shall be considered part of the work required for this specification with no direct compensation made therefore.

D6. Production Requirements

The Contractor shall provide at least one IC instrumented roller during embankment construction. Additional rollers that are utilized may be non-instrumented, but the IC roller must be the final roller used to obtain compaction on the proof layers. When using non-instrumented rollers, the actual compaction efforts, such as number of passes, type of drum, moisture content, and speed of the roller during compaction shall be shown in the Quality Control Procedure as determined by the information gathered during control strip construction. The Weekly Quality Control Report shall indicate how these requirements are met on embankments compacted with non-instrumented compactors.

The bottom of the subcut or fill shall be compacted by Quality Compaction prior to the start of placing the granular treatment.

After the layer below the granular treatment has been compacted, the Intelligent Compaction roller shall be used to record the compaction parameters of the layer prior to placing the granular treatment. This data shall be utilized as an Intelligent Compaction Base Map to determine uniformity of the embankment grading materials and to identify any inherent soft spots.

In the event embankment construction is suspended prior to completion to a proof layer elevation, the area shall be re-compacted prior to resuming embankment construction in the partially completed embankment area.

Compaction and mixing efforts shall be complete and uniform, to the greatest extent practical, from bottom to top of all roadbed embankments, and for the entire length and width of the roadbed embankment.

(2105) (QC/QA) IC QUALITY COMPACTION (PILOT SPECIFICATION FOR NON-GRANULAR MATERIALS)

All work shall be performed in accordance with Mn/DOT 2105 and 2106. Compaction requirements shall be in accordance with (QC/QA) IC Quality Compaction (Pilot Specification for Non-Granular Materials) as described below.

The (QC/QA) IC QUALITY COMPACTION (PILOT SPECIFICATION FOR NON-GRANULAR MATERIALS) Specification utilizes new technology and new equipment to measure the compaction and/or stiffness of the roadway embankment construction. If, in the opinion of the Engineer, the measurement of compactive effort resulting from the Pilot Specification herein does not accurately reflect the compaction and/or stiffness observed, the Engineer reserves the right to change the method of compaction measurement to Specified Density or LWD, as outlined elsewhere in the Mn/DOT Standard Specifications or these Special Provisions.

A. Description

This work shall consist of measuring the compaction parameters of the non-granular materials with a vibratory roller. The roller shall be equipped with a measurement and documentation system that allows for continuous recording of the roller location by the global positioning system and the corresponding compaction parameters.

The Contractor shall develop and implement a Project specific Quality Control Procedure for embankment construction that is based on Contractor IC compaction parameters, moisture testing and other Quality Control practices; and shall provide ongoing Quality Control data to the Engineer.

Compaction of all non-granular materials used in embankment construction shall be obtained by the “(QC/QA) IC Quality Compaction (Pilot Specification for Non-Granular Materials)” Method.

B. Definitions

Embankment Grading Materials

Are defined as all grading materials placed in the roadbed subgrade as indicated in the Plans. The embankment shall be the zone under the base, pavement and curb structures bounded by the roadbed slopes shown in the Plan or 1:1 slopes from the shoulder PI (point of intersection) (1.0 vertical to 1.5 horizontal slopes for fills over 10 meters **(30 feet)** in height).

Non-Granular Materials

Is defined as all materials except, Granular Material (Mn/DOT 3149.2B1) and Select Granular Material (Mn/DOT 3149.2B2).

Quality Compaction

Is defined in Mn/DOT 2105.3F2 Quality Compaction (Visual Inspection) Method.

Quality Control

Is defined as a procedure whereby the Contractor develops, utilizes, and documents Quality Control activities that govern how the embankment is constructed on this Project.

Quality Assurance

Is defined as a procedure where the Engineer monitors the Contractor's Quality Control activities and performs assurance monitoring and/or testing for final acceptance of all embankment construction.

Intelligent Compaction (IC)

This process involves measuring and recording the time, location and compaction parameters of the non-granular treatment during the compaction process with a vibratory roller that is equipped with an accelerometer-based or other measuring system and a global positioning system.

Intelligent Compaction (IC) Roller

Rollers shall be vibratory rollers with an approved compaction measurement system and capable of recording the compaction parameter measurements.

Intelligent Compaction Test Pad

Is defined as a location where the Contractor shall demonstrate to the Engineer that the IC roller and the intelligent compaction instrumentation meet all the requirements of this specification. The Contractor and Engineer will agree on a location(s) within the Project to construct the IC test pad.

Intelligent Compaction – Compaction Target Value (IC-CTV)

The target compaction parameter reading obtained from control strips compacted with the IC roller for each type of non-granular material used on the Project. The IC-CTV is determined for specific drum amplitude; drum frequency, roller speed, and roller direction.

Proof layer

Is defined as a predetermined layer that requires Quality Control measurements by the Contractor and Quality Assurance measurements by the Engineer to ensure compliance with the LWD Compaction Target Values prior to placing successive lifts.

Portable Light Weight Deflectometer (LWD)

Is a hand-operated device that uses a sensor to measure the deflection of the 200 mm (**8 inch**) flat plate, impacted by a falling weight to measure the stiffness of the non-granular material. The LWD shall have one sensor directly below the falling weight. The device measures the deflection and estimates the modulus based on the force required to generate a given deflection for the type of non-granular material.

Compaction Parameters

Includes modulus**, stiffness or other compaction related parameters**

Modulus Test Value

At each LWD test location, the LWD drop shall be repeated six (6) times without moving the plate. The first, second and third drops are designated as seating drops. The LWD Modulus Test Value shall be the average modulus estimated from the fourth, fifth and sixth drops in the testing sequence.

Portable Light Weight Deflectometer – Compaction Target Value (LWD-CTV)

The target modulus measurement for each type of embankment grading material determined by LWD testing on the control strip(s) constructed on this Project.

C. Equipment Requirements

C1. Intelligent Compaction (IC) Roller

The Intelligent Compaction (IC) Roller shall be a smooth drum or pad foot vibratory roller weighing at least 10,800 kg **(24,000 pounds)** and be approved by the Engineer.

A smooth drum vibratory roller with an accelerometer-based measurement system is required for the compaction and recording of the compaction parameter measurements on the non-granular embankment.

A pad foot vibratory roller with an approved compaction measurement system is required for the compaction and recording of the compaction parameter measurements on the non-granular embankment.

Alternatively, rollers equipped with other dynamic measurement value systems may be utilized as approved by the Engineer.

C2. Intelligent Compaction Instrumentation

The IC roller shall be equipped with a location, measurement, and documentation system, which shall provide the results that:

1) Enhance the ability of the roller operator and Project inspection personnel to make real-time corrections to the compaction process.
2) Allow the Engineer to review the roller operators IC screen in the roller operator's cab, when requested.
3) Provide printed Plan-view color maps to the Engineer in a timely manner.
4) Provide comma delimited ASCII data files identified by fixed format filenames containing the date, time, and location of the proof layer to the Engineer in a timely manner.
5) Include the summary quality control parameters (roller compaction value (RCV)), which may be modulus, stiffness, or another index parameter; resonance meter value (RMV), which identifies unstable drum oscillation; and roller pass number (RPN), which is the number of passes at that location on that lift since initial material placement.
6) Include the roller parameters: travel direction, travel speed, horsepower, and total mass.
7) Include the drum parameters: static mass, width, diameter, frequency, peak vertical amplitude, peak vertical acceleration, and peak vertical force.
8) Include the position for each data record accurate to the frequency of the drum (x, y, z coordinates for each end of the drum in UTM NAD 1983 zone 15 N format).
9) Include a time stamp for each data point accurate to the frequency of the drum.

C3. Equipment Approval

Within 15 days after award of the Contract, the Contractor must provide the following information to the Engineer:

<u>Intelligent Compaction Roller</u>
Model:
Manufacturer:
Operating Weight:
Drum Width:
Drum Diameter:
Drum Mass:
Maximum Vertical Dynamic Force:
Roller Horsepower:

The Contractor shall make available an on-site equipment manufacturer's representative for construction of the initial control strip and as required or requested by the Engineer throughout the portion of the Project that which utilizes IC.

The Contractor will be required to complete a IC test pad to demonstrate that the roller and the intelligent compaction instrumentation meets all the requirements of this specification. The Contractor and Engineer will agree on a location(s) within the Project to construct the IC test pad. The IC test pad shall be on the

Project site, using the granular treatment that will be used on the Project, and be in a location that demonstrates the ability of the system to fully function throughout the Project site. The IC test pad size and the lift thicknesses shall be the same as the control strip requirements or as otherwise determined by the Engineer. Portions of the Project that require using the IC roller shall not proceed until the IC roller meets all the specification requirements and is approved by the Engineer.

The IC test pad cannot be one of the required control strips.

C4. Testing Equipment

The Engineer may order the contactor to provide a Light Weight Deflectometer and/or electronic moisture meter or other moisture testing device with payment to be made as Extra Work.

C5. IC Roller Software Review

The IC roller manufacturer or Contractor shall supply the Agency with two (2) copies of the latest software to review the information obtained from the IC roller until the end of the Project. This is to allow the Engineer to see what the IC roller operator is seeing in the cab at the Project site and at the Engineer's office.

D. Construction Requirements

D1. Proof Layers

For non-granular materials less than or equal to 300 mm **(1 foot)** in thickness, the proof layer shall be designated as the top of the non-granular treatment.

For non-granular materials greater than 300 mm **(1 foot)** in thickness, the proof layers shall be successive 300 mm **(1 foot)** layers in thickness from the bottom and up to the top of the non-granular materials.

The designation of proof layers is general in nature and may require modification by the Engineer to meet Project specific embankment heights. The proof layers do not change control strip and production maximum lift thickness requirements, but are the designated layers in the non-granular materials where acceptance testing is performed.

IC compaction parameter measurements shall be recorded continuously on all proof layers of non-granular materials by the IC roller. The LWD Modulus Test measurements shall be recorded on all proof layers of non-granular materials. The Contractor shall give the Engineer timely notification of proof layer testing so that this activity may be observed and tested by the Engineer for acceptance.

D2. Quality Control/Quality Assurance (QC/QA)

D2a. Contractor Quality Control (QC) Requirements

The Contractor shall utilize the data gathered from the control strip construction to develop a Quality Control Procedure for non-granular materials. This procedure shall detail how Quality Control will be accomplished, including, but is not limited to, identifying IC equipment and procedures, collecting and reporting IC compaction parameter measurement results, ensuring uniformity of the non-granular materials, confirming acceptable moisture and compaction parameter results on non-granular material lifts between proof layers, determining the anticipated number, pattern and speed of roller passes to obtain optimum compaction parameter results on all layers, not just the proof layers, and other items that may contribute to an effective Quality Control Procedure.

The Quality Control Procedure shall include any corrective construction actions that may be required as a result of Quality Control measurements, such as adding water and/or drying soils, re-compacting non-compliant non-granular materials or other corrective actions that have been undertaken.

The Contractor shall perform all IC compaction parameter measurements required by the approved Quality Control Procedure, and shall modify construction operations so that acceptable compaction results are obtained. The Contractor shall also document all Quality Control IC compaction parameter results, Quality Control activities and corrective construction actions taken as a result of the Quality Control measurements to meet the requirements of this specification with a Weekly Quality Control Report in a format acceptable to the Engineer. The documentation shall be submitted to the Engineer for acceptance on a weekly basis.

As part of the Quality Control Procedure, the Contractor shall perform moisture content tests on the non-granular materials at a minimum of 1 per 3,000 cubic meter (CV) **[1 per 4,000 cubic yards (CV)]** for compliance. The Contractor moisture content tests may be performed by reagent method, burner method, oven dry method, or other gravimetric methods as approved by the Engineer. The Engineer may perform additional moisture content tests.

D2b. Agency Quality Assurance (QA) Requirements

The Engineer will observe the final compaction recording pass of the IC roller on each proof layer, review and approve the Contractor's Quality Control data documenting acceptable compaction results submitted in the form of the Weekly Quality Control Report and perform companion and verification LWD and moisture testing.

The Engineer will also perform a companion LWD Modulus Test and a moisture content test at the minimum rate of one (1) LWD Modulus Test Value measurement per proof layer, per 300 meters **(1,000 feet)** for the entire width of embankment being constructed during each operation.

The Contractor shall provide a relatively smooth uniform surface that has been shaped to approximate line and grade of each proof layer for the purpose of taking all LWD Modulus Test Value measurements at the required locations for this specification, with no direct compensation made therefore. The Contractor shall make the proof layer surface available for Quality Assurance testing in a safe condition on an ongoing basis, or within 24 hours of the completion of compaction activities.

The Engineer may perform additional LWD Modulus Tests and moisture content tests in areas that visually appear to be non-compliant, or as determine by the Engineer.

Each LWD Modulus Test Value taken shall be at least 90% but not more than 120% of the corrected LWD-CTV obtained on the proof layer of the applicable control strip prior to placing the next lift. The Contractor shall re-compact (and dry or add moisture as needed) all areas that do not meet these requirements. Additional LWD Modulus Test measurements shall be taken for acceptance of the re-compacted areas.

Final Acceptance shall be determined when the following criteria are met:

1) The Contractor has submitted Weekly Quality Control Reports documenting that acceptable compaction results were obtained for all embankment construction.

2) All Quality Assurance tests taken by Mn/DOT meet specification requirements.

3) The Engineer has reviewed the IC compaction related parameter measurements taken on all proof layers and approved the Weekly Quality Control Reports.

D3. Control Strip

The Contractor shall construct compaction control strips to determine the Intelligent Compaction Target Value (IC-CTV) and Portable Light Weight Deflectometer Compaction Target Value (LWD-CTV) for each type and/or source of non-granular materials. Additional control strips shall be constructed for materials with observable and/or quantifiable variations in material properties that affect the IC-CTV & LWD-CTV, as determined by the Engineer.

The compaction of the control strip shall be limited to the compaction rollers used on the Project.

The IC roller shall be used to map the bottom of the control strip and at the proof layer thickness.

It is anticipated that the IC-CTV and LWD-CTV for the non-granular materials may be moisture sensitive to some degree. Therefore, to determine the moisture sensitivity correction for the IC-CTV and LWD-CTV, a control strip shall be constructed at or near each extreme of 65% and 95% of optimum moisture. This data will be utilized to produce a Correction Trendline showing a linear relationship of the IC-CTV and LWD-CTV at different moisture contents.

The control strip shall be at least 100 meters **(300 feet)** long and at least 10 meters **(32 feet)** wide at the base, or as determined by the Engineer. The lift thicknesses for the control strip and the constructed embankment shall be limited to the maximum lift thickness allowed in Mn/DOT 2105.3E. The total thickness of each control strip shall equal the planned non-granular material thickness being constructed. The total thickness of each control strip shall be a maximum of 1.2 m (4.0 feet).

Both the Contractor and the Engineer shall save a material sample from each control strip for comparison to the embankment material being compacted during QC/QA procedures in order to determine the applicable control strip IC-CTV.

The costs of constructing the control strips for each identifiable different type and/or source of grading material, for each material with observable and/or quantifiable variations in material properties, including but not limited to, moisture content, gradation, texture, and silt & clay content, that affect the IC-CTV, or for each compaction method, shall be part of the work required for this specification with no direct compensation made therefore.

D4. Control Strip Construction

a. The Contractor and Engineer will agree on a location(s) within the Project to construct the control strip(s).

b. After the layer below the non-granular material has been compacted, the Intelligent Compaction roller shall be used to record the compaction parameters of the layer prior to placing the non-granular materials. The data shall be utilized as an Intelligent Compaction Base Map to determine uniformity of the embankment grading materials and to identify any inherent soft spots.

c. Place the non-granular materials in lifts. The lift thicknesses for the control strip shall be limited to the maximum lift thickness allowed in Mn/DOT Specification 2105.3E.

d. The Contractor shall make repeated compaction passes on each lift, using a roller pattern approved by the Engineer. The optimum value is reached when additional roller passes do not result in a significant increase in the compaction parameter values on that lift, as determined by the Engineer.

e. The Engineer will perform LWD Modulus Test Value measurements on each layer at three (3) separate LWD test locations spaced at least 25 meters **(75 feet)** apart, or as modified by the Engineer.

f. Repeat c. to e. until it has reached the proof layer.

g. The Engineer will perform Light Weight Deflectometer (LWD) Modulus Test measurements tests at each proof layer at three (3) separate LWD test locations spaced at least 25 meters **(75 feet)** apart, or as modified by the Engineer.

h. The proof layer LWD-CTV will be the average of the LWD Modulus Test Values at the three (3) LWD test locations measured on the designated proof layer(s) during construction of the control strip. LWD Modulus Test Value measurements at additional locations may be taken on the proof layer(s) and included in the calculation of the average LWD-CTV as determined by the Engineer. The proof layer LWD-CTV's obtained from the control strips that were constructed at each moisture content extreme, will be used to determine the LWD-CTV Correction Trendline.

i. The proof layer Intelligent Compaction-Compaction Test Value (IC-CTV) will be the optimum value obtained from the Intelligent Compaction stiffness measurements on the designated test layer during construction of the control strip. The optimum value is reached when additional passes do not result in a significant increase in stiffness values, as determined by the Engineer.

j. Repeat c. to f. until the next proof layer is reached and repeat g. to i..

The proof layers in the control strip construction are general in nature and may require modification by the Engineer to meet specific Project conditions.

D5. Moisture

At the time of compaction, both for the construction of the test pad and during production, the moisture content of the non-granular materials shall be not less than 65% or more than 95% of Optimum Moisture. The Engineer will determine the Optimum Moisture by the Standard Proctor Density Method.

The Contractor shall add water and blend as needed to meet the moisture requirements. The Engineer may order the application of additional water for compaction if necessary. If any embankments are constructed with materials that contain excessive moisture, the Contractor shall dry or replace it with material having the required moisture content._

Additional water ordered by the Engineer, or efforts to dry materials or replace soils that are excessively wet which are taken by the Contractor to meet Quality Control procedures or otherwise ordered by the Engineer, will not be considered extra work, but shall be considered part of the work required for this specification with no direct compensation made therefore.

D6. Production Requirements

The Contractor shall provide at least one IC instrumented roller during embankment construction. Additional rollers that are utilized may be non-instrumented, but the IC shall be used to record the compaction parameters on the proof layers. When using non-instrumented rollers, the actual compaction efforts, such as number of passes, type of drum, moisture content, and speed of the roller during compaction shall be shown in the Quality Control Procedure as determined by the information gathered during control strip construction. The Weekly Quality Control Report shall indicate how these requirements are met on embankments compacted with non-instrumented compactors.

The bottom of the subcut or fill shall be compacted by Quality Compaction prior to the start of placing the non-granular materials.

The Intelligent Compaction roller shall be used to record the compaction parameters of the bottom of the subcut or fill prior to placing the non-granular materials. This data shall be utilized as an Intelligent Compaction Base Map to determine uniformity of the embankment grading materials and to identify any inherent soft spots.

In the event embankment construction is suspended prior to completion to a proof layer elevation, the area shall be re-compacted prior to resuming embankment construction in the partially completed embankment area.

Compaction and mixing efforts shall be complete and uniform, to the greatest extent practical, from bottom to top of all roadbed embankments, and for the entire length and width of the roadbed embankment.

(2105) LWD QUALITY COMPACTION (PILOT SPECIFICATION)

All work shall be performed in accordance with Mn/DOT 2105 and 2106. Compaction requirements shall be performed in accordance with LWD Quality Compaction (Pilot Specification) as described below.

LWD QUALITY COMPACTION METHOD

The Engineer will develop LWD-CTV's (Portable Light Weight Deflectometer – Compaction Target Values), from control strips constructed by the Contractor. The Engineer will perform LWD testing on the proof layer(s) of embankment being constructed, as described elsewhere in this specification, for acceptance of compaction.

DEFINITIONS

The term "roadbed embankment materials" as used in this specification shall mean any granular, select granular, select granular modified, or non-granular grading soils (borrow or select grading soils) to be placed in the roadbed subgrade as indicated in the Plan. The roadbed shall be the zone under the base, pavement and curb structures bounded by the roadbed slopes shown in the Plan or 1:1 slopes from the shoulder PI (point of intersection) (1.0 vertical to 1.5 horizontal slopes for fills over 10 meters **(30 feet)** in height).

"Granular Treatment" shall be defined as the designed uniform thickness of granular material immediately below the aggregate base.

"Select Grading Soils" may include granular or non-granular grading materials.

"Quality Compaction" shall be as defined in Mn/DOT 2105.3F2 Quality Compaction (Visual Inspection) Method.

"LWD" is the Portable Light Weight Deflectometer. This device is hand operated and takes measurements of the deflection of compacted soil that is impacted by a falling weight. The LWD shall have one sensor directly below the falling weight. The device measures a deflection and estimates a modulus based on the force required to generate a given deflection for that soil type.

"Modulus Test Value". At each LWD test location, the LWD drop shall be repeated six (6) times without moving the plate. The first, second and third drops are designated as seating drops. The LWD Modulus Test Value shall be the average modulus estimated from the fourth, fifth and sixth drops in the testing sequence.

"LWD-CTV" is the Compaction Target Value, which is the target modulus measurement for each grading material type determined by LWD testing on the control strip(s) constructed on this Project.

"Proof layer" shall be defined as a predetermined layer that requires LWD Modulus Test Value measurements by the Engineer to ensure compliance with the Compaction Target Value prior to placing successive lifts.

COMPACTION REQUIREMENTS

LOCATION	METHOD
Bottom of subcuts, excavations, and embankment foundations.	Quality Compaction
All roadbed embankments (including stabilizing aggregate if needed)	QC/QA IC Quality Compaction (Granular or Non-Granular)/LWD
Embankment outside of the roadbed	Quality Compaction
Embankment adjacent to retaining walls (not part of the roadbed)	Quality Compaction
Aggregate Bedding under drainage structures	Modified DCP
Culvert and Sewer Trench Backfill	Modified DCP
Backfill under roadbed near structures including granular bridge approach treatments	Modified DCP

EQUIPMENT REQUIREMENTS FOR CONTROL STRIP CONSTRUCTION

(A) Pneumatic-Tired Roller

Pneumatic-tired roller shall be self-propelled and weigh a minimum 22.7 metric tons (**25 tons**) or 111 kg/cm (**616 pounds/inch**) of rolling width. The tire arrangement shall be such that compaction will be obtained over the full width of the roller with each pass.

(B) Smooth Drum or Padfoot Vibratory Roller

The vibratory roller shall weigh at least 11,300 kg (**25,000 pounds**).

(C) Compaction Equipment for Miscellaneous Embankment Areas

The compactor for miscellaneous embankment areas, including, but not limited to, embankment adjacent to structures, structure bedding and trench backfill, shall be a plate compactor, jumping jack, or self propelled roller as is most appropriate and approved by the Engineer. Using a backhoe bucket for compaction will not be acceptable. Thinner lifts may be required to determine optimum LWD-CTV values during control strip compaction.

(D) Light Weight Deflectometer (LWD)

Mn/DOT will maintain an approved LWD equipment list. The actual equipment used must meet the minimum functionality of the equipment shown in the approved LWD equipment list.

CONTROL STRIP CONSTRUCTION - LWD-CTV

(A) Roadbed Embankment

The Contractor shall construct compaction control strips to determine the LWD Compaction Target Value (LWD-CTV) for each identifiable different type and/or source of grading material. Additional control strips shall be constructed for materials with observable and/or quantifiable variations in material properties that affect the LWD-CTV, as determined by the Engineer.

It is anticipated that the LWD-CTV for all grading materials will be moisture sensitive to some degree. Therefore, to determine the moisture sensitivity correction for the LWD-CTV, a control strip shall be constructed at or near each extreme of 65% and 95% of optimum moisture, but within the required range, as specified in Section S-57.7. This data will be utilized to produce a Correction Trendline showing a linear relationship of the LWD-CTV at different moisture contents.

The Engineer will save a material sample from each control strip for comparison to the embankment material being compacted during acceptance procedures in order to determine the applicable control strip LWD-CTV.

Each control strip shall be at least 100 m **(300 feet)** long and at least 10 m **(32 feet)** wide at the base, or as otherwise determined by the Engineer. The total thickness of each granular treatment control strip shall equal the planned granular treatment thickness being constructed. The total thickness of each select grading soils control strip shall be a maximum of 1.2 m **(4.0 feet)**.

Each control strip for select grading soils shall be constructed on an excavated surface that is compacted with Quality Compaction procedures prior to the start of the control strip compaction activities. Each control strip for granular treatments shall be constructed on top of a previously constructed control strip from select grading soils, or on top of an excavated surface similar to what will be encountered in actual construction. This surface shall be compacted with Quality Compaction procedures prior to the start of the control strip compaction activities.

The following requirements for designation of proof layers in the control strip construction are general in nature and may require modification by the Engineer to meet Project specific embankment heights. All embankment construction, including control strip construction, shall be constructed in accordance with the maximum lift thicknesses specified in Mn/DOT 2105. The proof layers do not change control strip and production maximum lift thickness requirements, but are the designated layers in the constructed embankment where acceptance testing is performed.

For granular treatments more than 0.75 m **(2.5 feet)** in thickness, the proof layers of the control strip shall be designated as the midpoint and the top of the planned granular treatment thickness. For granular treatments less than or equal to 0.75 m **(2.5 feet)** in thickness, the proof layer of the control strip shall be designated as the top of the planned thickness.

For select grading soils, the proof layers of the control strip shall be designated as the 0.6 m **(2.0 foot)** thickness of embankment and the 1.2 m **(4.0 foot)** thickness.

During construction of the control strip, the Contractor shall make repeated compaction passes on each lift using a roller pattern approved by the Engineer. The Engineer will perform LWD Modulus Test Value measurements between **each** compaction pass at three (3) separate LWD test locations spaced at least 25 m **(75 feet)** apart, or as modified by the Engineer. When additional roller or compactor passes do not result in a significant increase in modulus values on that lift, as determined by the Engineer, the next lift shall be placed.

The proof layer LWD-CTV will be the average of the optimum LWD Modulus Test Values at the three (3) LWD test locations measured on the designated proof layer(s) during construction of the control strip. The optimum value is reached when additional passes do not result in a significant increase in modulus values, as determined by the Engineer. LWD Modulus Test Value measurements at additional locations may be taken on the proof layer(s) and included in the calculation of the average LWD-CTV as determined by the Engineer. The proof layer LWD-CTV's obtained from the control strips that were constructed at each moisture content extreme, will be used to determine the LWD-CTV Correction Trendline.

The costs of constructing the control strips for each identifiable different type and/or source of grading material, for each material with observable and/or quantifiable variations in material properties, including but not limited to, moisture content, gradation, texture, and silt content, that affect the LWD-CTV, or for each compaction method, shall be part of the work required for this specification with no direct compensation made therefore.

(B) Miscellaneous Embankment Areas

The above section regarding control strip construction for roadbed embankment, including proof layer designations, shall apply for miscellaneous embankment areas, except as modified below:

The miscellaneous embankment area control strip shall be the first miscellaneous embankment area constructed. Additional control strips shall be constructed for materials with observable and/or quantifiable variations in material properties that affect the LWD-CTV, and for each method of compaction, as determined by the Engineer. Only one control strip per type is required. The Engineer will perform LWD measurements at two (2) test locations, spaced at least 6 m **(20 feet)** apart after each compaction pass within the miscellaneous embankment area. When additional compactive effort does not result in a significant increase in the Modulus Test Value, as determined by the Engineer, or when that portion of the embankment is considered acceptable by specified density testing or Modified Penetration Index, the next lift may be placed.

The proof layer LWD-CTV will be the average of the Modulus Test Value measurements of the two (2) LWD test locations obtained on the proof layer during construction of the miscellaneous embankment area control strip.

The Correction Trendline for moisture sensitivity will be determined by the Engineer based on either the roadbed control strip data or historical data.

As an alternative, the LWD-CTV for the miscellaneous embankment area may be the LWD-CTV determined from comparative LWD Modulus Test Value measurements taken on compacted embankments considered acceptable by specified density testing or Modified Penetration Index.

MOISTURE REQUIREMENTS

At the time of compaction, both for the construction of the control strip(s) and during production compaction, the moisture content of the portion of the embankment materials that are to be compacted under LWD Quality Compaction requirements shall be not less than 65% or more than 95% of Optimum Moisture as determined by the Standard Proctor Density Method. The Standard Proctor Density will be determined by the Engineer.

The Contractor shall add water, and /or perform blending as needed to meet the moisture requirements. The Engineer may order the application of additional water for compaction if necessary. If any embankments are constructed with materials that contain excessive moisture, the Contractor shall dry or replace it with material having the required moisture content.

Additional water ordered by the Engineer, or efforts to dry materials or replace soils that are excessively wet will not be considered extra work, but shall be considered part of the work required for this specification with no direct compensation made therefore.

The Engineer will perform moisture tests as needed to determine the moisture content for compliance with the moisture requirements of this specification. Moisture tests will be performed by a Project calibrated electronic moisture meter, reagent method, field moisture oven, oven dry method, or other gravimetric methods as approved by the Engineer. The rate of moisture testing shall be the minimum of that shown in the Schedule of Materials Testing for Specified Density testing. Additional moisture tests may be performed as determined by the Engineer.

ACCEPTANCE PROCEDURES

The Engineer will perform LWD Modulus Test Value measurements on the designated proof layers of each embankment material for acceptance as needed to ensure compliance with these specifications.

(A) Roadbed Embankment - Acceptance Procedures

Compaction and mixing efforts shall be complete and uniform from bottom to top of all roadbed embankments, and for the entire length and width of the roadbed embankment.

The following requirements for designation of proof layers in the acceptance procedures are general in nature and may require modification by the Engineer to meet Project specific embankment heights. All embankment construction shall be constructed in accordance with the maximum lift thicknesses specified in Mn/DOT 2105. The proof layers do not change control strip and production maximum lift thickness requirements, but are the designated layers in the constructed embankment where acceptance testing is performed.

The selection of the applicable corrected LWD-CTV shall be by visual comparison, or other acceptable comparison method, of the material properties of the embankment being constructed and the material properties of saved material samples from the control strip construction.

For granular treatments more than 0.75 m **(2.5 feet)** in thickness, the proof layers shall be designated as the midpoint and the top of the planned granular treatment thickness. For granular treatments less than or equal to 0.75 m **(2.5 feet)** in thickness, the proof layer shall be designated as the top of the planned thickness. The corrected LWD-CTV for each proof layer shall be determined from the Correction Trendline obtained on the corresponding proof layer (i.e. midpoint or top) of the applicable control strip and the actual moisture content of the embankment at the time of acceptance testing.

For granular bridge approach treatments constructed in conjunction with the general roadbed embankment construction, the proof layers shall be designated as every 0.6 m **(2.0 foot)** layer in thickness of the constructed embankment. With the exception of the first 0.6 m **(2.0 foot)** layer of thickness of embankment constructed, the corrected LWD-CTV for all proof layers will be determined from the Correction Trendline obtained on the 1.2 m **(4.0 foot)** layer in thickness of the applicable control strip and the actual moisture content of the embankment being constructed. The first 0.6 m **(2.0 foot)** proof layer (measured from the embankment bottom) shall be tested for acceptance using the corrected LWD-CTV determined from the Correction Trendline obtained on the 0.6 m **(2.0 foot)** proof layer of the applicable control strip. For granular bridge approach treatments constructed separately from general roadbed embankment construction, refer to the miscellaneous embankment area requirements.

For select grading soils, the proof layers shall be successive 1.2 m **(4.0 foot)** layers in thickness from the bottom of the embankment up, plus the top of the planned select grading soils thickness. If the top of the select grading soils is within 1.5 m **(5.0 feet)** of the previous proof layer, the next proof layer shall be the top surface instead of at the next 1.2 m **(4.0 foot)** increment. If the planned select grading soils thickness is less than 1.2 m **(4.0 feet)**, the proof layer shall be designated as the top of the planned select grading soils thickness. The corrected LWD-CTV for <u>all</u> proof layers shall be determined from the Correction Trendline obtained on the 1.2 m **(4.0 foot)** layer of the applicable control strip and the actual moisture content of the embankment at the time of acceptance testing, unless the planned select grading soils thickness is less than 0.75 m **(2.5 feet)**. In that case, the corrected LWD-CTV shall be determined from the Correction Trendline obtained on the 0.6 m **(2.0 foot)** layer of the applicable control strip and the actual moisture content of the embankment at the time of acceptance testing.

The Contractor shall provide a relatively smooth uniform surface that has been shaped to approximate line and grade of each proof layer for the purpose of taking all LWD Modulus Test Value measurements at the locations chosen by the Engineer, as part of the work required for this specification with no direct compensation made therefore. The Contractor shall make the proof layer surface available for LWD testing in a safe condition on an ongoing basis, or within 24 hours of the completion of compaction activities.

LWD Modulus Test Value measurements will be taken on all proof layers of embankment construction, at a minimum rate of three (3) LWD Modulus Test Value measurements per proof layer, per testing lot. Each testing lot will be 300 m **(1000 feet)** in length for the entire width of embankment being constructed during each operation, or as modified by the Engineer. Additional LWD Modulus Test Value measurements may be taken at random locations, including on the surface of all intermediate lifts as well as on the surface of the proof layers, to verify compaction results or at specific areas that visually appear to be poorly compacted.

In the event embankment construction is suspended prior to completion to a proof layer elevation, the Engineer may test the surface of the partially completed testing lot for acceptance within 24 hours of the suspension of compaction activities. In the event acceptance is not achieved at this time, the partially completed testing lot shall be re-compacted prior to resuming embankment construction in the partially completed testing lot.

For acceptance of compaction at each proof layer during general production operations, all segments of the embankment shall be compacted so that each LWD Modulus Test Value taken within a testing lot is at least 90% of the applicable corrected LWD-CTV prior to placing the next lift. The Contractor shall re-compact (and dry or add moisture as needed) all areas that do not meet these requirements. Additional LWD Modulus Test Value measurements shall be taken for acceptance of the re-compacted areas.

If a significant number of LWD Modulus Test Values are more than 20% in excess of the selected corrected LWD-CTV, the Engineer shall re-evaluate the selection of the applicable control strip corrected LWD-CTV. If an applicable corrected LWD-CTV is not available, the Contractor shall construct additional control strips to reflect the potential changes in compaction characteristics.

If the Engineer determines that the Contractor appears to be performing acceptable compaction efforts, but the LWD Modulus Test Values consistently do not meet the applicable corrected LWD-CTV, the Engineer will re-evaluate the selection of the applicable control strip corrected LWD-CTV. If an applicable corrected LWD-CTV is not available, the Contractor shall construct additional control strips to reflect the potential changes in compaction characteristics.

(B) <u>Miscellaneous Embankment Areas - Acceptance Procedures</u>

The above section regarding acceptance procedures and acceptance criteria for roadbed embankment construction shall apply for miscellaneous embankment areas, except as modified below:

The corrected LWD-CTV for each proof layer tested for acceptance shall be determined from the Correction Trendline obtained from applicable control strips and the actual moisture content of the Miscellaneous Embankment Area at the time of acceptance testing. The acceptance criteria for Miscellaneous Embankment Areas shall be the same as specified for Roadbed Embankment. The testing rates are as follows:

1. <u>Trench Construction</u>

    LWD Modulus Test Value measurements will be taken on all proof layers of trench backfill tested for acceptance, at a minimum rate of one (1) LWD Modulus Test Value measurement per proof layer, per length of trench that is being constructed during each stage of trench construction, or as modified by the Engineer. If the length of the trench is 150 m **(500 feet)** or more for a single stage, a minimum of one (1) LWD Modulus Test Value measurement shall be taken for each 150 m **(500 feet)** of trench.

2. <u>Culvert Treatments or other Tapered Construction</u>

    For the portion of the embankment that is as thick as, or thicker than, the proof layer, LWD Modulus Test Value measurements will be taken on all proof layers of treatment backfill tested for acceptance, at a minimum rate of one (1) LWD Modulus Test Value measurement per proof layer, per treatment that is being constructed during each stage of construction, or as modified by the Engineer. If the length of the treatment is 150 m **(500 feet)** or more for a single stage, a minimum of one (1) LWD Modulus Test Value measurement shall be taken for each 150 m **(500 feet)** of treatment length.

    For miscellaneous embankment areas that require tapered construction, such as frost heave treatment runouts or other tapered embankments, compaction of the portion of the embankment that is less than the minimum proof layer thickness shall be accepted or rejected based on the visual inspection method.

3. <u>Granular Bridge Approach Treatments and Other Embankment Adjacent to Structures</u>

    This section applies when embankment adjacent to structures is constructed separately from the roadbed embankment construction.

The proof layers will be designated as every 0.6 m **(2.0 foot)** layer in thickness of the constructed embankment. LWD Modulus Test Value measurements will be taken on all proof layers tested for acceptance of embankment adjacent to structures, at a minimum rate of one (1) LWD Modulus Test Value measurement per proof layer, per structure, or as modified by the Engineer.

With the exception of the first 0.6 m **(2.0 foot)** layer of thickness of embankment constructed, the corrected LWD-CTV for all proof layers will be determined from the Correction Trendline obtained on the 1.2 m **(4.0 foot)** layer in thickness of the applicable control strip and the actual moisture content of the embankment at the time of acceptance testing. The first 0.6 m **(2.0 foot)** proof layer (measured from the bottom of the embankment) shall be tested for acceptance using the corrected LWD-CTV determined from the Correction Trendline obtained on the 0.6 m **(2.0 foot)** proof layer of the applicable control strip and the actual moisture content of the embankment at the time of acceptance testing.

For miscellaneous embankment areas that require tapered construction, such as granular bridge approach treatments or other tapered embankments, compaction of the portion of the embankment that is less than the minimum proof layer thickness shall be accepted or rejected based on the visual inspection method.

TESTING EQUIPMENT

The Engineer may order the contactor to provide a Light Weight Deflectometer and/or electronic moisture meter or other moisture testing device with payment to be made as Extra Work.