Missouri Hwy 141 – Embankment, Box Culvert, and MSE Wall Fill – August 2010

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RESEARCH PROJECT TITLE
Earthwork Performance Specification Integrating Proof Mapping and Alternative In-Situ Testing – Demonstration Project Hwy 141, Chesterfield, MO

SPONSOR
SHRP 2 R07
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MORE INFORMATION
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Introduction

This demonstration project on Highway US141 in Chesterfield, MO, was initiated as a pilot project to evaluate new concepts for geotechnical performance specifications involving embankment and pavement foundation construction. This project was established through a partnership between the SHRP 2 R07 research team and Missouri Department of Transportation (MoDOT). Alternative in-situ testing methods and use of intelligent compaction (IC) technologies were investigated and compared to traditional quality assurance (QA) and quality control (QC) testing involving nuclear density-moisture testing. The IC systems used on this project included a Caterpillar CS-563E self-propelled smooth drum roller equipped with machine drive power (MDP) and compaction meter value (CMV) measurement technologies, and a prototype 815F soil compactor equipped with MDP technology. The machines were set up with real time kinematic (RTK) global positioning system (GPS), onboard display, and data documentation/software systems. The high accuracy RTK-GPS measurements were used to determine pass coverage and compacted lift thicknesses information and to analyze empirical correlations from spatially paired IC measurement values (IC-MVs) and in-situ point measurements.

The project involved constructing and testing several test areas consisting of silty clay embankment fill and crushed limestone aggregate used for MSE wall backfill or pavement subbase (i.e., Type 5 base). The IC-MVs were evaluated by conducting nuclear density-moisture content tests, dynamic cone penetration (DCP) tests to determine the California bearing ratio (CBR), plate load tests to determine the modulus of subgrade reaction (k-values), and rut depth from proof rolling with a loaded tandem axle dump truck.

The overall goals of the demonstration project were as follow:

- Study QA/QC testing technologies that improve test frequency and construction process control,
- Develop effective reporting, analysis, and evaluation protocols,
- Link mechanistic pavement design parameter values to construction monitoring,
- Development new concepts for earthwork performance specifications,
- Determine project specific correlations between IC-MVs and in-situ point measurements, and
- Evaluate the advantages/disadvantages of using IC technology for compaction operations.

IC Systems Overview

The rollers used in this study are shown in Figure 1. CMV technology uses an accelerometer mounted to the roller drum to create a record of machine-ground interaction. CMV is calculated using the acceleration data from fundamental and

Figure 1. Caterpillar CS-563E smooth drum roller (left) and Caterpillar 815F soil compactor (right)

second-order harmonics. Additional information about CMV is provided in White et al. (2011).

MDP relates to the soil properties controlling drum sinkage and uses the concepts of rolling resistance to determine the stresses acting on the drum and the energy necessary to overcome the resistance to motion. MDP values can be obtained in both vibratory and static compaction operation modes. Detailed information about MDP is reported in White et al. (2008).

The CMV and MDP measurements are reported at a frequency of about every 1 ft at the center of the roller drum width along with GPS coordinates and a time-stamp. An onboard display allowed the operators to view a color-coded map of pass coverage and IC-MVs in real time. After downloading the IC data from the compactor, the IC results could be viewed and shared using a software program provided by the roller manufacturer.

Test Results

Results from three areas are described in this technical brief: (1) box culvert backfill, (2) MSE wall backfill, and (3) embankment fill. Each of these areas presented unique challenges in terms of materials, QA/QC testing, and speed of construction.

Box Culvert Backfill

The box culvert area involved placement of silty clay fill material alongside a large cast-in-place double box culvert (Figure 2). Placement of materials alongside large boxes can be challenging due to the generally soft foundation conditions associated with drainage areas and the need to limit lateral stresses on the box during compaction.

Figure 2. Double box culvert test area at south end of project

Figure 3 shows the CS-563E final pass results in plan view and the cross section view of lift thickness for the six lifts of backfill material placed parallel to the box on the east side. Figure 4 shows the results of analysis of the pass coverage and lift thickness along the cross section parallel to the box. The average lift thickness was 0.88 ft and the average number of roller passes was 5.0. Based on the coefficient of variation (COV) results, pass coverage was more variable than lift thickness. Figure 5 shows the nuclear gauge density-moisture QA/QC results in the box culvert area indicating that the fill was generally wet of the optimum moisture content

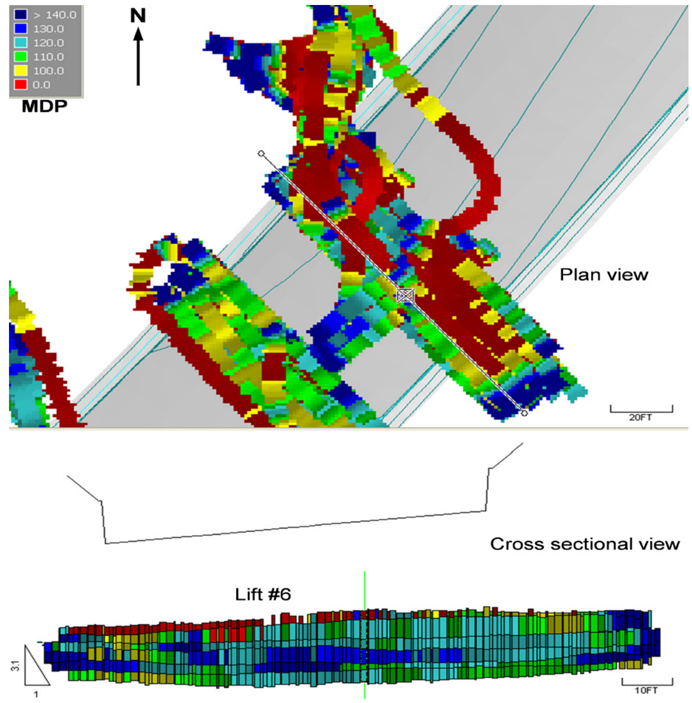

Figure 3. Lift #6 mapping in box culvert test area

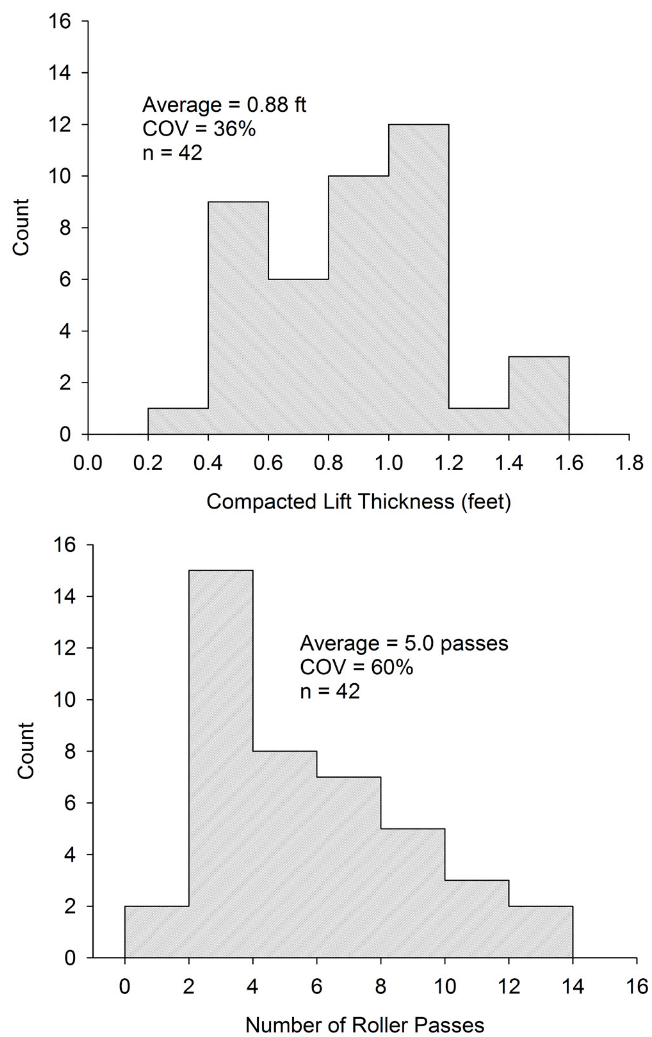

Figure 4. Results of compacted lift thickness and number of roller passes at several locations in box culvert fill test area after completing lift #6

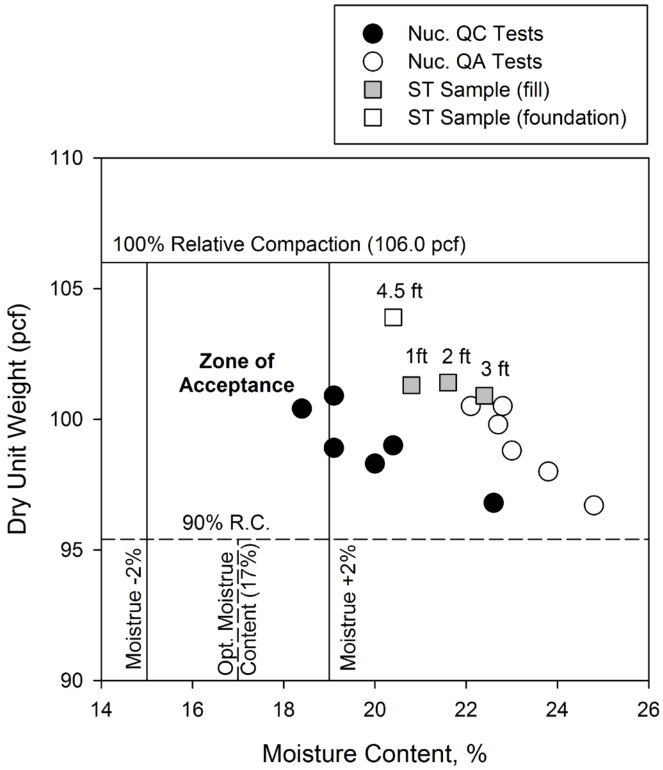

Figure 5. Box culvert backfill QA/QC nuclear gauge test results and independent Shelby tube samples at selected depths adjacent to box culvert

and that the QC moisture content measurements were consistently lower than the QA moisture content measurements. All QA/QC measurements were performed at the same location. Moisture contents from Shelby tube samples are shown as an independent check.

After completing the box culvert study, the roller operator was informed of the results and asked to use the onboard IC computer display to complete two roller passes in the area west of the box culvert. As shown in Figure 6, the roller operator achieved a uniform pass coverage. These results demonstrate how process control and pass coverage documentation can be effectively achieved with an IC system.

MSE Wall Backfill

A portion of the multi-tiered MSE wall area was compacted with the CS-563E IC roller. Due to the larger aggregate particle size (3+ in.), use of a nuclear gauge is not suitable for inspection. Inspection therefore was conducted by visually monitoring lift thickness and pass counting. According to the specifications used on this project, only light compaction equipment was allowed within 3 ft of the wall face to minimize lateral earth pressures. IC compaction was used in parallel to the traditional visual method to record pass coverage and roller position relative to the MSE wall.

Figure 7 shows the panels and backfill for one tier of the MSE wall. Figure 8 shows IC results from CMV and RMV (resonant meter value) measurements and locations of dynamic cone penetration (DCP) tests. The CMV results in this area were generally high and ranged from 25 to 70. In portions of this area, the RMV values were high (> 6) indicating that the vibratory roller was starting to bounce, which is a result of very stiff to hard well compacted material. The DCP results (Figure 9) show that the area within 3 ft of the MSE wall is less compacted (based on the CBR profile) compared to the material subjected to rolling, where CBR values > 50 at depths of 8 in. (200 mm) and deeper. Application of IC to MSE wall backfill compaction provided value in terms of pass coverage and location information and indicated the strength/stiffness of the compacted material.

Embankment Fill

Several areas within the sandy clay embankment fill areas were compacted with the CS-563E and 815F rollers. Near the south end of the project, a large area was mapped with both IC rollers, and various QA/QC tests were performed to evaluate the ability of the IC machines to identify areas of non-compliance (i.e., areas of wet fill material). Figure 10 shows an area approximately 70 ft wide by about 700 ft long that was mapped with the CS-563E IC roller. The variation in color of the MDP values helped identify areas of wet soil conditions (see MDP scale in upper left corner and notes on w%). Static plate load tests were conducted in this test area at several locations based on the variations observed on the MDP map and confirmed soft and wet areas of non-compliance.

Correlation analysis of plate load test results and MDP values demonstrated that a positive correlation for k-values less than about 100 pci (Figure 11) is possible. In contrast, the CMV values were not sensitive to variations in k-values. The lack of correlation for CMV to k-values is primarily due to material being at the low end of the CMV measurement range (i.e., CMV < 10). Other studies have shown that for CMV > 10, correlations do exist between CMV and plate load test results (White et al. 2011). Figure 12 shows the results of the QA/QC nuclear density-moisture gauge testing and that the material is highly variable. Figure 13 shows the 815F MDP mapping results for the same area along with plate load test deflections at the same stress level and moisture content measurements. Compared to the CS-563E roller IC-MVs, the 815F MDP map shows similar geospatial variations in ground stiffness.

To better understand how the 815F results relate to traditional proof rolling with a loaded tandem axle dump truck (Figure 14), several areas along the extent of the project were proof rolled and compared to the MDP results at selected locations. Figure 15 shows the project areas selected for proof testing. The results from this exercise demonstrated that the MDP values can be correlated to both rut depth (Figure 16) and k-values (Figure 17). A MDP target value of 123 was selected from the rut depth and plate load test results for IC production mapping conducted by the contractor. MDP results were also correlated to CBR profiles to a depth of about 30 in. Compared to the QA/QC nuclear density-moisture results, however, the MDP values were poorly correlated.

To assess the effectiveness of the MDP target value to field control compaction quality, the contractor operated the machine for several months and used this target value to create compaction reports. Figure 18 is an example of a compaction report showing isolated areas of non-compliance (i.e., MDP values < 123). In this production area, the compaction report provided the following information: (1) 77% of the area met the minimum requirement;

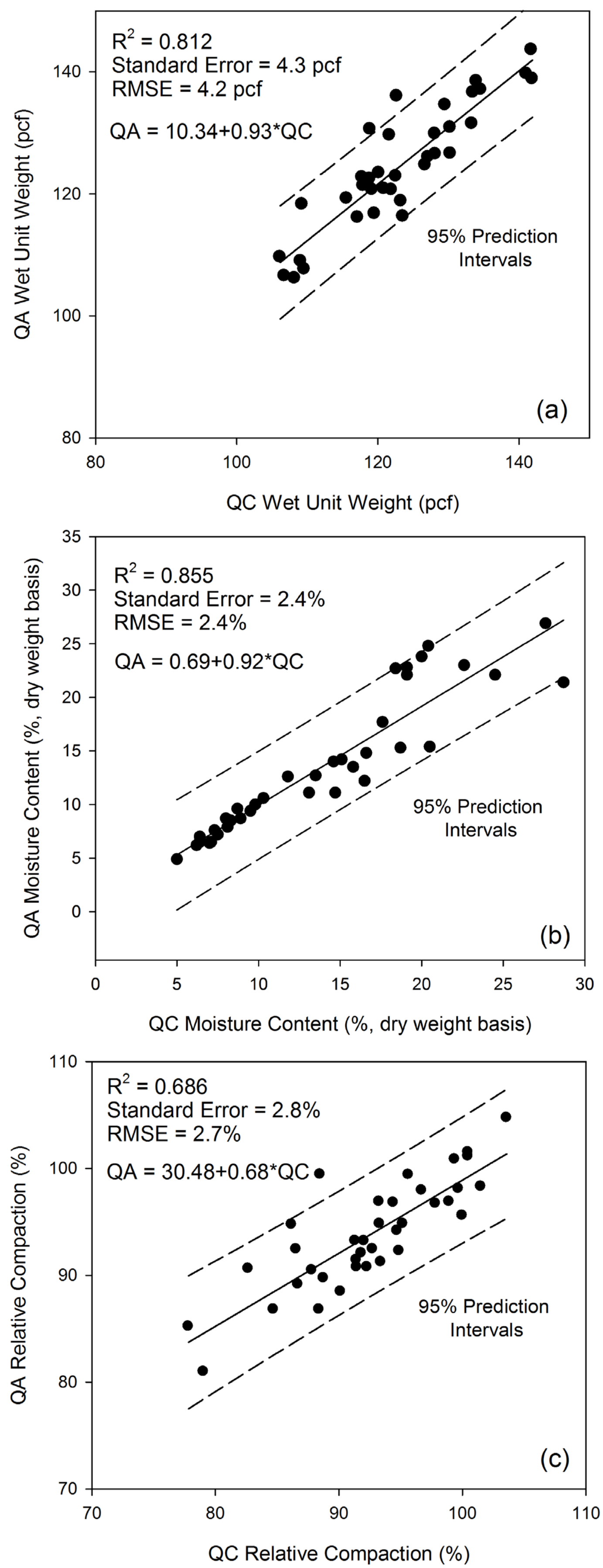

Figure 20. Comparison and calculations of measurement error for QA/QC nuclear density-moisture gauge results for CS-563E test areas (n = 36) (a) wet density, (b) moisture content, (c) relative compaction

Exit Interviews

This project created an opportunity to evaluate new technologies and develop performance specification strategies for earthworks. On November 12, 2010, the SHRP 2 R07 research team set up exit interviews to gain knowledge of how QA/QC field personnel and roller operators involved in the testing viewed the use of IC technology and the alternative in situ testing technologies. The following captures the results of the interview.

Questions:

1. What is your experience with impression of using the IC equipment to date?
2. How do you see the IC information being used in a QC plan?

- Response from Dave Dwiggins (815F operator, Fred Weber Inc.): “I like the technology. It helps me know where to focus where more compaction work is needed as well as knowing when it is good. It could speed up operations by not having to guess on what is going to pass.”
- Response from Nancy Leroney: (project inspector, MoDOT): “Neat thing to be involved with new tests. I find it very interesting. It could save time and money by knowing when the soil passes. I would love to eliminate the nuclear testing.”
- Response from Bill Stone, PE (research administrator, MoDOT): “MoDOT is looking for a technology that both MoDOT and the construction industry can utilize during Quality Assurance / Quality Control that can provide information with more uniform coverage of compaction data than traditional methods with an outcome being the elimination of nuclear density testing. Intelligent compaction appears to fit that role of providing number of passes and stiffness of material over the entire project area rather than a few point locations and will give information that is more closely linked with current design methods with mechanistic properties of the aggregate, soil, and pavement.”

References

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