Field Evaluation of Compaction Monitoring Technology

tech transfer summary

This research aims to evaluate compaction monitoring technology for use in earthwork construction and quality control/quality assurance.

Objectives

Evaluate compaction monitoring technology developed by Caterpillar Inc. for use in earthwork construction and quality control/quality assurance practices.

- Investigate machine power for the full range of soil compaction.
- Describe variations in machine power observed during compaction in terms of soil density, strength, stiffness, and moisture content for a wide range of field conditions.
- Use laboratory data to derive a relationship between energy, density, and moisture content that can be used to relate machine power data to field measurements.
- Evaluate the mapping capabilities of the compaction monitoring technology at an earthwork project.

Problem Statement

Current practices for ensuring adequate compaction and proper moisture control rely primarily on process control (lift thickness and number of passes) and/or end-result spot tests using a nuclear moisture-density gauge or other devices. While providing relatively accurate information, these inspection approaches have several disadvantages:

- Process control requires continuous observation
- Spot test measurements cover only a small percentage of the fill volume (typically 1:1,000,000)
- Spot tests delay construction during testing and data analysis
- Process control and spot tests create potential safety hazards due to personnel in the vicinity of equipment

With recent developments in prototype compaction monitoring technologies, experimental research is developing relationships between roller sensor data and physical soil measurements (e.g., soil density, strength, stiffness). In practice, these technologies could allow compaction processes to be managed and controlled with results provided in real-time, thus improving quality, reducing rework, maximizing productivity, and minimizing construction costs.

PGA
PARTNERSHIP FOR GEOTECHNICAL ADVANCEMENT

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RESEARCH PROJECT TITLE
Field Evaluation of Compaction Monitoring Technology: Phase II (TR-495)

SPONSORS
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The Partnership for Geotechnical Advancement (PGA) is part of the Center for Transportation Research and Education (CTRE) at Iowa State University. The mission of the PGA is to increase highway performance in a cost-effective manner by developing and implementing methods, materials, and technologies to solve highway construction problems in a continuing and sustainable manner.

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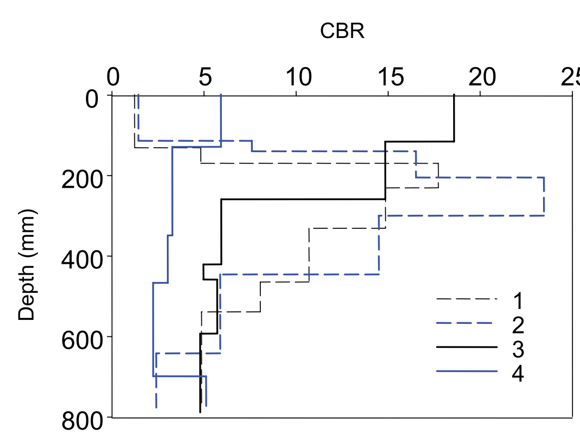
Implementation Readiness

Short-term objectives for implementing compaction monitoring technology into earthwork construction should include the following:

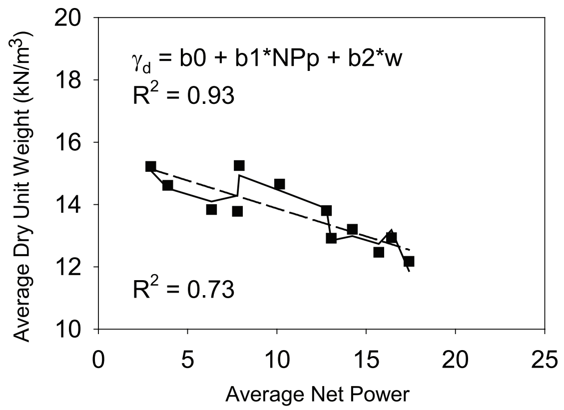
- Evaluate the technology with a perspective of geotechnical and materials performance.
- Demonstrate that the technology provides superior pavement performance.
- Document the cost savings associated with using compaction monitoring technology over conventional earthwork practices.

Immediate efforts should verify and document the reported benefits (maximized productivity, improved compaction and uniformity of pavement materials, identification of weak areas, improved depth of compaction, reduction in highway repair costs, etc.) with data to support any conclusions. Large-scale pilot projects that use side-by-side conventional compaction operations and compaction monitoring technology may provide the information needed to accomplish these tasks.

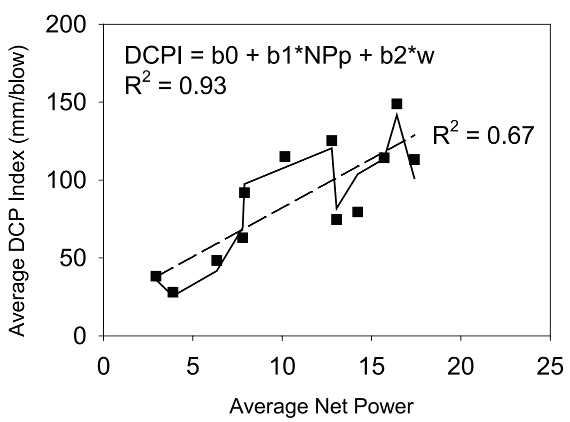
Compaction monitor showing areas of unstable subgrade (red)



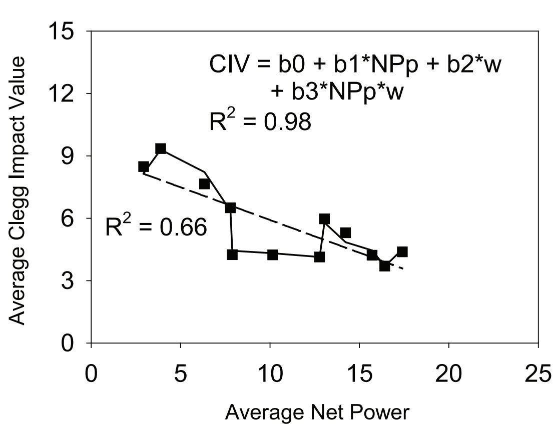
DCP strength profiles for corresponding points shown above. Results show that red areas from monitor are areas of weak subgrade



Relationship between dry unit weight and machine power for topsoil



Relationship between dynamic cone penetrometer (DCP) index and machine power for topsoil



Relationship between Clegg impact value and machine power for topsoil

Technology Description

The following results were collected from controlled test sections compacted with a prototype CP-533 vibratory padfoot roller. Sensors attached to the roller measured machine drive power, and newly developed computer algorithms analyzed the data to determine soil compaction. Soil compaction was then displayed in real time on a ruggidized computer monitor placed in the cab of the roller.

Prototype CP-533 roller

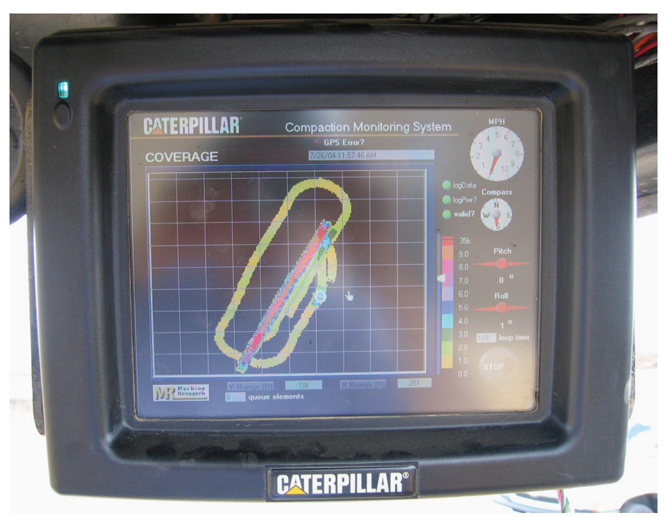
The concept of using machine drive power to indicate soil compaction derives from more general models of vehicle-terrain interaction. To determine the net power required to propel the machine through the uncompacted fill layer, the machine power associated with sloping grade, acceleration, gravity, and internal machine losses is subtracted from the machine's total power output. The remaining net power thus represents only the machine power associated with changes in the soil's physical properties (i.e., density, strength, and stiffness). These changes indicate soil compaction.

The machine used in this research was set up to provide 100% test coverage using information on the number of roller passes and machine drive power results. To do this, monitoring sensors attached to the compaction machine used a differential global positioning satellite system to determine machine location.

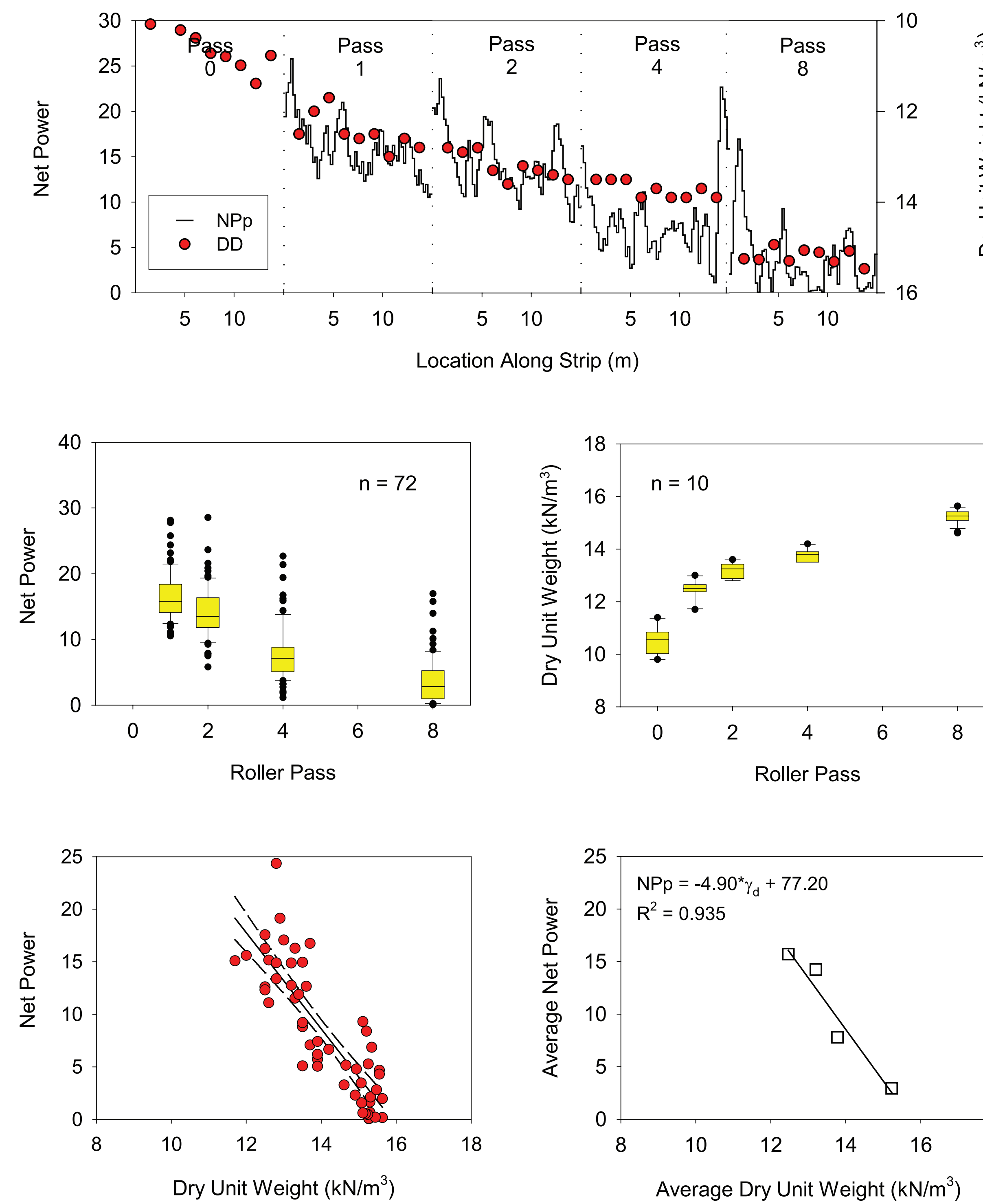
In essence, this research used the compaction machine as a measuring device to help control the compaction process and ensure that compaction requirements were met the first time. Theoretically, the compaction process can thus be controlled to improve quality, reduce rework, maximize productivity, and minimize costs.

Key Findings

- A compaction model was developed using laboratory test data that predicts dry unit weight from compaction energy and moisture content. The model is independent of soil type.
- Strong correlations were observed between averaged machine power and field measurement data, characterizing machine–soil interaction. The relationships are based on the compaction model derived from laboratory data.
- By including both moisture content and moisture–energy interaction (i.e., machine power) terms in a regression analysis, higher correlation coefficients were observed than were found using only machine power as a linear regression term.
- Dry density predictions from machine net power data were often more accurate than predictions of soil strength or stiffness, since the initial model was derived from density data.
- Correlation coefficients (R^2) were consistently higher for thicker lifts than for thin lifts, indicating that the depth influencing machine power response exceeds the representative lift thickness encountered under field conditions.
- All data for cohesive soils were combined, and soil fines content and plasticity index were used as statistically significant regression parameters to produce models that were independent of cohesive soil type.
- Caterpillar Inc. compaction monitoring technology identified localized areas of an earthwork project with weak or poorly compacted soil. The soil properties at these locations were verified using in situ test devices.



Number of roller passes presented in real time to machine operator



Machine power measurements with corresponding nuclear density measurements