PARTNERSHIP FOR GEOTECHNICAL ADVANCEMENT

IOWA STATE UNIVERSITY

Soil Compaction Monitoring Technology

tech transfer summary

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

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MORE INFORMATION
www.ctre.iastate.edu/Research/detail.cfm?projectID=190237771

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Objective

Evaluate the new Caterpillar, Inc., (CAT) compaction monitoring technology's effectiveness in earthwork construction as a method control process (i.e., documentation of roller pass coverage) and in soil compaction as an end-result measurement (i.e., machine-soil interaction response).

Problem Statement

Measuring soil compaction during earthwork construction is a key element to ensure adequate performance of the fill. The current state of the practice relies 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 to ensure adequate compaction and proper moisture control. While providing relatively accurate information, these inspection approaches have several disadvantages:

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

Technology Description

To improve upon the traditional approaches of process control and spot tests, CAT has been developing compaction monitoring technology for determining real-time compaction results with 100 percent test coverage. The CAT compaction monitoring system consists of an instrumented roller with sensors to monitor machine power output in response to changes in soil-machine interaction. The compaction monitoring system is fitted with a differential global positioning system (DGPS) to monitor roller location in real time. Data are analyzed with newly developed computer algorithms, and the results are presented on a ruggidized computer monitor in the cab of the roller.

In contrast to other compaction monitoring and intelligent compaction systems that rely on the dynamic responses of vibratory rollers, CAT's compaction monitoring system uses machine drive power within the static or vibratory roller mode as a semiempirical measure of the compaction energy delivered to the soil. A compaction model based on laboratory compaction tests and statistical analysis algorithms relate the required compaction energy, compaction efficiency, and water content to the minimum target compaction value or density.

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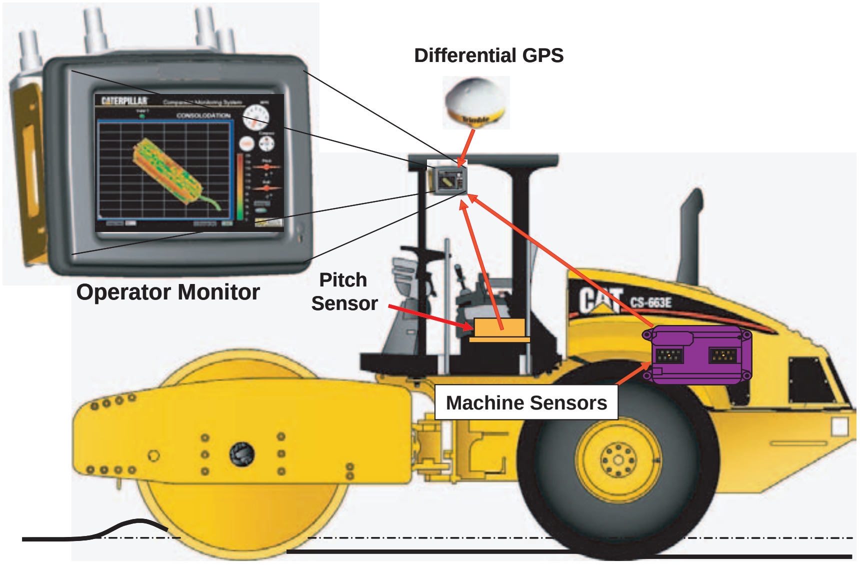
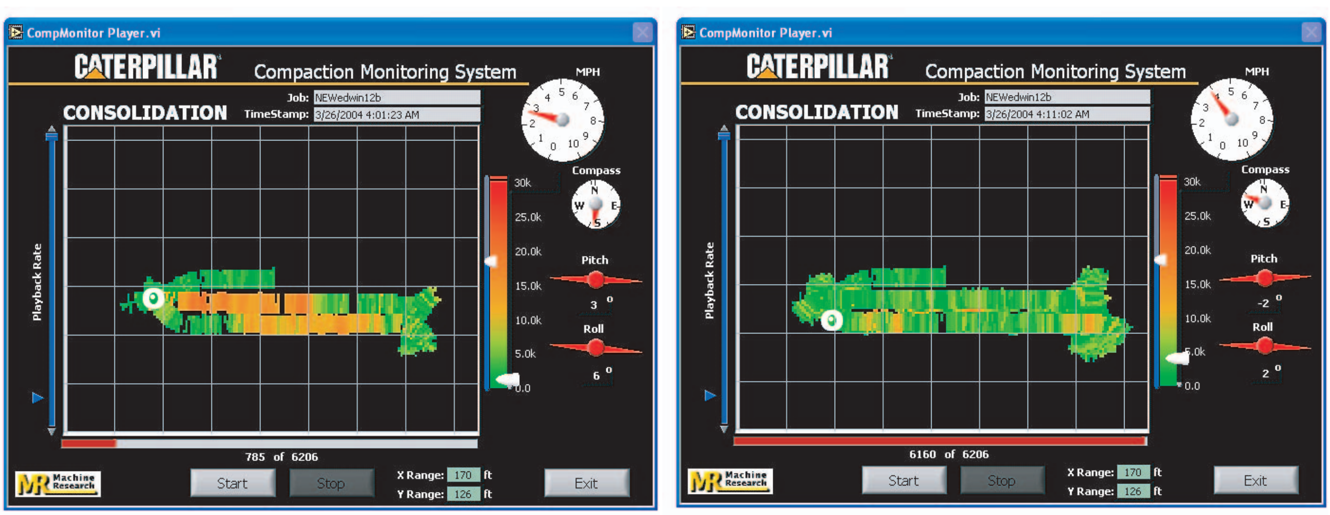
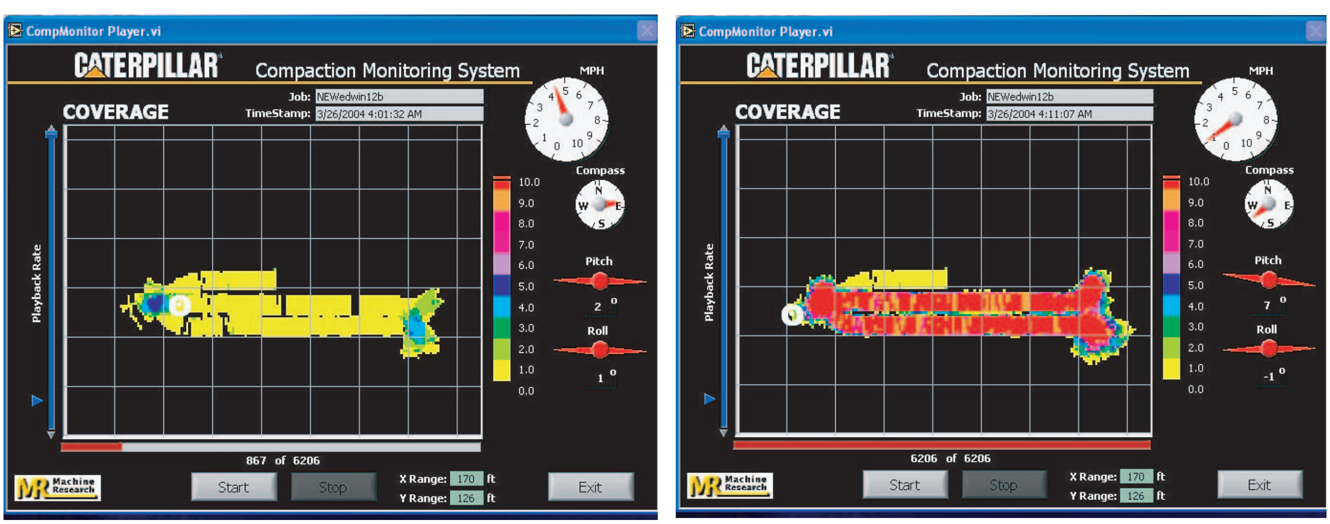


CAT compaction monitoring system

The basic premise of determining soil compaction from changes in equipment response is that mechanical energy to power the roller relates to the physical properties of the material being compacted. Laboratory compaction and strength tests show that correlating dry unit weight to the logarithm of compaction energy results in R^2 values of 0.8, and that by including water content in the multiple regression analysis, strength and stiffness can be predicted with R^2 values of 0.9 and 0.6, respectively.



Monitor output for machine energy after 1 (left) and 10 (right) roller passes



Monitor output for machine coverage after 1 (left) and 10 (right) roller passes

Evaluation of Technology

Pilot field studies were conducted at the CAT facilities in Peoria, Illinois, and on an actual earthwork project in West Des Moines, Iowa. At each site, reference in situ tests and surveys were conducted using conventional and currently accepted practices to provide a comparison to the new technology. Typical construction operations for all tests included the following steps: (1) aerate/till existing soil, (2) moisture condition soil with water truck (if too dry), (3) remix, (4) blade to level surface, and (5) compact soil using CAT roller instrumented with the compaction monitoring sensors and display screen. Test strips varied in loose lift thickness, water content, and length.

Spatial sampling requirements for spot field tests (e.g., cores samples, nuclear density gauge, dynamic cone penetrometer [DCP], Clegg impact hammer, and GeoGauge vibration tests) were determined using a statistical approach.

Field data on the compaction monitoring system were gathered and compared to field and laboratory measurement data using appropriate statistical analysis tools.

Engineering parameter correlations were developed for various moisture-strength-stiffness-compaction energy relationships that may be better indicators of performance than percent compaction alone.

Key Findings

- The CAT compaction monitoring system has a high level of promise for use as a quality control/quality assurance (QC/QA) tool.
- Soil compaction may be evaluated with relatively good accuracy using machine energy as an indicator, with the advantage of 100 percent coverage with results in real time.
- Field spot measurements of density, moisture content, strength (DCP), and stiffness (Clegg impact hammer) show a high level of promise for the soil compaction technology with strong correlations to the machine energy output (correlation R^2 values over 0.9 for certain field conditions).
- To determine relationships between machine energy from the compaction monitoring system and various field measurements (density, DCP, and Clegg impact value), multiple linear regression analyses were performed. R^2 of these models indicate that compaction energy accounts for more variation in dry unit weight than DCP index or Clegg impact values. Including water content in the regression analyses greatly improves the R^2 models for DCP index and Clegg hammer, indicating the importance of water content on strength and stiffness.

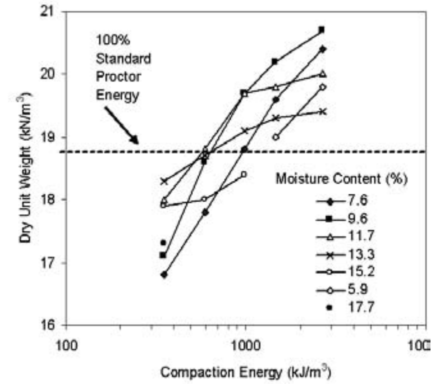
R^2 values comparing machine power to measured in situ properties from correlation

Models	Machine Power
DD = Power	0.8324
DD = log(Power)	0.8620
DD = MC + log(Power)	0.9336
CIV = Power	0.4693
CIV = log(Power)	0.4573
CIV = MC + log(Power)	0.9726
MDCP = Power	0.3838
MDCP = log(Power)	0.3757
MDCP = MC + log(Power)	0.9065

Notes:
DD = dry density
CIV = Clegg impact value
MC = moisture content
MDCP = mean dynamic cone penetrometer

Implementation Benefits

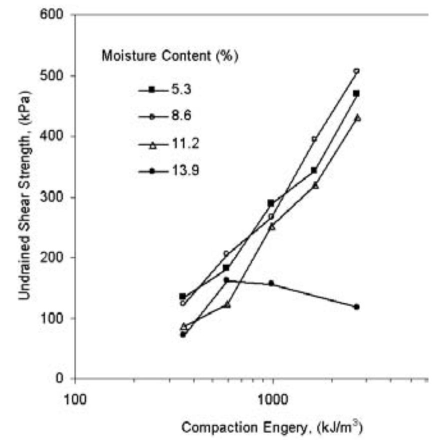
- Real-time compaction results with 100 percent test coverage
- Areas of poor compaction identified in real time
- Necessary changes in rolling pattern made immediately by roller operator
- Reduced construction delays for post-process inspections
- Better controlled compaction process
- Improved quality
- Compaction requirements met the first time
- Reduced necessary rework
- Improved productivity
- Reduced costs
- Improved safety due to reduction of people on the ground for inspection measurements



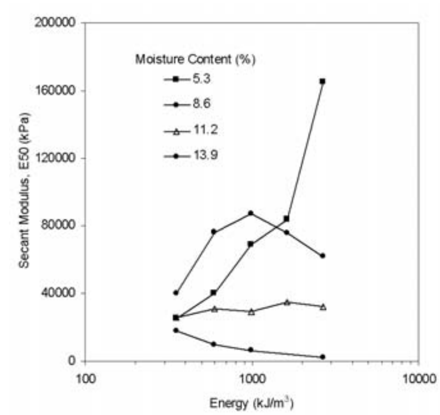
Influence of compaction energy on dry unit weight as a function of moisture content

Additional Research Needs (Phase II)

- The computer algorithms used to develop the compaction monitoring output need to be evaluated. A better understanding of the algorithms is necessary to better explain the results obtained, develop more effective future experiments, and produce more consistent results. Some modifications may be necessary.
- Additional controlled experiments are recommended before full-scale field testing. These experiments could investigate the effects of varying the soil type, lift thickness, moisture content, slope, and direction.
- Additional field trials are necessary to expand the range of correlations to additional soil types, roller configurations and speeds, lift thicknesses, water content, and other field conditions.
- The new compaction monitoring technology should be compared to existing compaction equipment and methods. Additional new technologies should be evaluated as they are developed.
- New detailed QC/QA guidelines/specifications for earthwork construction will need to be developed with a framework in statistical analysis, considering data variability and reliability. The specifications are likely to be divided into method versus end-result specifications. The method specification will consider process control operations including the number of passes of the roller and lift thickness. The end-result specification will likely involve test strip construction and validation with spot tests. Because the compaction monitoring system provides 100 percent test coverage, statistic procedures need to be developed to evaluate variability of data sets. Further, it is possible that incentive type specifications (i.e., owners pays based on achieved quality) could be developed similar to the paving industry.
- The transferability of the compaction monitoring technology to hot-mix asphalt compaction could be evaluated.



Relationship between undrained shear strength and compaction energy as a function of moisture content



Relationship between secant modulus and compaction energy as a function of water content