



In Altoona, Iowa highway ramp project, Caterpillar machine drive power (MDP) technology on CS74B soil compactor found compaction discontinuities that may not have been located by accelerometer-based IC dirt rollers.

Down to the Dirt

Intelligent and new technologies are revolutionizing soil compaction.

Intelligent compaction – matched with more productive operational control systems – is revolutionizing the commonplace world of dirt rolling.

Yesterday's slow-but-steady soil compactor now communicates with satellites, logs performance, saves fuel, pollutes less and is more productive. It's all done natively, at the push of buttons or on a cab-mounted touch screen.

And the clunky onboard computers and GPS receivers that were the hallmarks of earlier intelligent compaction systems have been replaced with modular systems that minimize costs as they permit GPS receivers to be transferred from roller to roller and even from soil to asphalt compactors.

An intelligent soil compaction system will include continuous assessment of mechanistic soil properties (e.g., stiffness, modulus) through roller vibration monitoring, automatic feedback control of vibration amplitude and frequency, and an integrated global positioning system to provide a complete

geographic information system-based record of the earthwork site, according to National Cooperative Highway Research Program Report 676, *Intelligent Soil Compaction* (2010).

"Intelligent compaction equipment measures and records the quality of compaction during the compaction process," says John Siekmeier, senior research engineer, Minnesota DOT, at this year's Transportation Research Board (TRB) presentation. "The compactor's force changes in real time to increase compaction where needed, while preventing over-compaction. The equipment uses a global positioning system to create a map that shows the quality of compaction across the entire surface of each lift."

The Federal Highway Administration (FHWA) has been quarterbacking research in soil and asphalt intelligent compaction. Intelligent compaction (IC) devices offer a number of advantages for highway projects, according to FHWA, including:

- **Optimized labor deployment and construction time.**

Contractors can roll the right amount of material with the right amount of compactive effort on each pass to ensure long-term performance.

- **Reduced compaction costs and maintenance requirements.** The flexibility to make fewer passes to achieve the correct compaction level minimizes fuel use and equipment wear and tear.

- **Ability to make midcourse corrections.** Adjusting during compaction of one layer before additional layers are put over it ensures subsurface problems do not affect the entire road surface, and

- **Ability to maintain** construction records. Data from the IC, along with GPS or differential global navigation system satellite (DGNSS) coordinates of compaction activity, can be downloaded into construction quality databases and stored for future reference.

For both single-drum soil compaction, and double-drum asphalt compaction, intelligent compaction usually is accelerometer-based, with the gauge located on the roller frame.

For each manufacturer's system, FHWA requires the following:

- An intelligent compaction measurement value (ICMV)
- A GPS-based documentation system
- An onboard color-coded display
- A surface temperature measurement system for asphalt rollers only, and
- Raw data that are Veda-compatible.

Veda 2.1 is a map-based tool for viewing and analyzing geospatial data, and is the software around which all IC activity revolves. Veda can import data from various intelligent compaction equipment to perform editing, data layering, point testing and analysis; Veda displays compaction information in easy-to-read formats, including graphs and maps.

Veda's functionality includes viewing and analyzing IC and other related

geospatial data. You can overlay the data onto a map of the site, perform various statistical analyses and create reports.

IC data flow consists of data collection, data transfer and data processing. Now, data analysis options have been en-

hanced with a new Veda export function, which exports recorded data in a standardized format required today for documentation purposes on many construction sites in North America. Read more about Veda or download the program at intelligentcompaction.com.

Correlating Measurement Values

To date, manufacturers have been unable to relate the measurement of buildup of stiffness beneath a drum to an actual density value; instead they use their own measurement values for stiffness and are trying correlate stiffness data acquired during intelligent compaction activity with nationally accepted density specifications. For example, today Bomag calls its stiffness measurement value Evib; Caterpillar/Trimble, the CMV; Hamm/Wirtgen, the HMFV; and Sakai, the CCV.

This inability to directly relate stiffness measurement values

from the accelerometer or other process to actual engineering values stands in the way to use of IC for soil compaction for quality assurance or acceptance.

"Consistently reliable correlation between intelligent compaction measurement values (ICMV) and in situ density readings have not been established," says FHWA's Michael Arasteh, Office of Technical

Services, Baltimore, at a workshop in January 2014. "On many projects, there has been a 'relationship' between ICMV and density," he adds, but the firm, reliable link is not yet there.

However, IC can be used as a quality control tool, Arasteh says, adding "Contractors can use IC capabilities to improve their compaction process."

IC techniques [usually] use accelerometers mounted on the frame of the roller to gather and analyze the vibrations of the roller during compaction, write Manik Barman, Moeen Nazari, Syed Asif Imran, Sesh Commuri and Musharraf Zaman, College of Engineering, University of Oklahoma-Norman; Fares Beainy, Volvo Construction Equipment, Shippensburg, Pennsylvania; and Dharamveer Singh, Indian Institute of Technology Mumbai, in their 2014 Transportation Research Board paper, Application of Intelligent Compaction Technique in Real Time Evaluation of Compaction Level during the Construction of Subgrade.



On the Cat Compaction Control display in-cab, operators often configure green color to indicate areas where the target is met and red color to indicate areas that do not meet the target.

Photo courtesy of Caterpillar Paving Products



Photo courtesy of Wirtgen America Inc.

In-cab HCQ Tablet PC shows exact location of passes and degree of compaction reached in color-coded format.

“These vibrations are then processed using modern signal processing techniques to estimate the stiffness of the material being compacted,” they write. “Global positioning system receivers are used to record the location of the roller at each instant and these readings are used to provide as-built maps showing process information such as number of roller passes, roller path, and subgrade stiffness in real-time to the operator.”

Access to compaction quality in real-time will enable the roller operator to detect and correct any soft spots on the subgrade, and thereby improve the quality of construction, Barman, Nazari, Imran, Commuri, Zaman, Beainy and Singh say. “IC techniques can help in improving the productivity of the crew by reducing the amount of rework, improving the overall compaction quality of the subgrade, and leading to a lower long-term maintenance cost of the pavement,” they write.

IC systems can collect and analyze the roller vibrations to estimate the level of compaction of the pavement, but the use of these in the quality control of subgrade compaction is still under investigation, the authors write. “Existing IC technology provides a measure of stiffness in terms of a Roller Measurement Value (RMV),” they say. “Research is still underway to establish good correlations between RMV [their term for the ICMV] and the stiffness estimated by the conventionally available equipment such as falling weight deflectometers and dynamic cone penetrometers and laboratory resilient modulus.”

In work supported by Volvo Construction Equipment, Shippensburg, Pennsylvania, and the Oklahoma Transportation Center, the ability of the Oklahoma University-developed

Intelligent Asphalt Compaction Analyzer [IACA] in evaluating the resilient modulus of subgrade compaction was investigated.

Two full-depth asphalt pavement construction projects were considered and the use of the IACA during the compaction of stabilized subgrade was studied. In both these projects, it was verified IACA can predict subgrade resilient modulus with a reasonable accuracy.

While the IACA was designed to estimate the density/dynamic modulus of asphalt pavements during compaction, the present study showed that the IACA could be used to determine resilient modulus of stabilized subgrade soils with minimal modification.

The IACA can detect changes in the stiffness of the subgrade, they say. Further, for an assumed stress state of the soil, the calibrated IACA can estimate resilient modulus with an accuracy that is suitable for field quality control applications.

The extension of the IACA from asphalt to soil compaction was initially studied during compaction of subgrade soils at four different sites. The performance was then determined at the two sites.

“While the results are promising, it’s prudent to point out that the tests so far have focused on cementitious stabilized subgrades,” Barman, Nazari, Imran, Commuri, Zaman, Beainy and Singh say. “Additional tests for different soil types and additives are required to fully validate this technology. Research is underway to verify the ability of the IACA to identify and rectify under compacted regions on the prepared subgrade.”

MDP Alternative to Accelerometers

The Cat Compaction Control system is featured on new Cat soil compactors, tandem vibratory compactors and pneumatic rollers, and is one element of a suite of intelligent compaction technologies.

For soil compactors, the basic system provides compaction measurement using either compaction meter value (CMV) or machine drive power (MDP) technology, with the ability to boost the system with GPS mapping capability. For tandem vibratory rollers and pneumatic compactors, the system provides pass-count information and GPS mapping.

MDP, a machine-integrated soil compaction measurement technology, is available on new Cat B-Series soil compactors, and is unique in that it measures compaction with the vibe system on or off. MDP measures rolling resistance as an indication of soil stiffness, Cat says. It measures closer to the depth that the machines are able to compact. It also measures

closer to lift thickness. The measurements are less impacted by the dampening effect of cohesive soils, so it can be used on padfoot machines.

Cat Compaction Control, whether using CMV or MDP measurement, can also use a GPS to provide positioning information to map pass count, coverage and compaction measurement details. These data can be stored for review at a later time. Contractors at several jobsites around the world, including Greece, Germany and an interstate on-off ramp being built by McAninch in Altoona, Iowa, have been testing it.

Machine drive power is not a breakthrough in how machines compact, the maker says. Instead, MDP evaluates the rolling resistance without an accelerometer.

“It gives an indication of soil stiffness by measuring the rolling resistance on the drum,” says Loïc Le Bellec, regional sales support consultant for Caterpillar Paving Products. “It correlates the fact that the looser the material is, the harder it is for the drum to roll over the pile of material in front of it.”

That resistance provides an indication of soil stiffness and load-bearing strength, and whether compaction is adequate to hold the road, parking lot, building or whatever is planned for the site.

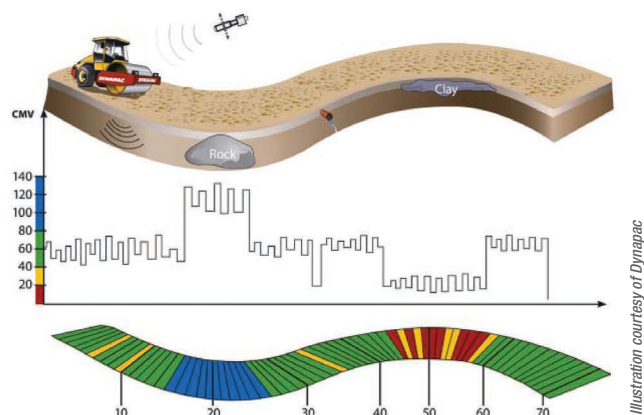
MDP, a proprietary technology developed by Caterpillar, works on all soil types, including cohesive. It can enable a compactor to act as a proof roller, even when not vibrating. It can eliminate multiple passes of a compactor, and deliver considerable cost savings with them, the maker says.

“Uniformity has always been an issue,” says Cat Paving Products. “Is the entire site compacted the same way, or are there areas of structural weakness? Uniformity matters because weak areas ultimately become failures. That means going back and making costly repairs. Historic methods of testing can only provide a snapshot, and are no guarantee of uniformity. Typically only 1 percent of the jobsite is tested.”

That has left compaction experts to search for uniformity by other means. Among those experts is Dr. David White of Iowa State University. White has spent years studying soil compaction, and months gathering data at the Altoona jobsite.

Among his most important findings is that MDP is a good indicator of soil stiffness, load-bearing strength or the ability for the compacted soil to resist deflection on a consistent basis, across the entire jobsite.

In Iowa, the on-off ramp in Altoona proved a great testing ground for intelligent compaction and MDP, demonstrating the ease of preventive measures, compared with costly post-construction repairs.



Dynapac Compaction Analyzer (DCA) supplies compaction control data with full area coverage for documentation and analysis.

Operator Eddy Butler went to work on the ramp, viewing real-time results on an easy-to-use monitor display on the Cat CS74B soil compactor, outfitted with Cat Compaction Control, including MDP. A green area on the display meant the area had been covered and the targets had been met. A red area indicated a potential problem. Butler had seen green most of the time, but when he made two passes over an area and still saw red, he knew an adjustment had to be made.

Butler had been working in a soil with heavy clay content, and an accelerometer-based instrument would have had difficulty finding the trouble, Cat says. Butler realized the red probably resulted from too much moisture. He switched from the compactor to a tractor and disk and spent about 15 minutes turning the soil so it would dry more quickly.

Then it was time to take another pass with the CS74B. The screen turned green, and Troxler density samples later confirmed the target had been achieved. “We’ve not been wrong yet about whether we would pass a test,” Butler says.

Global Positioning Systems

The land-based global positioning system used by most manufacturers offers real-time kinematic (RTK) precision via a GPS base station, GPS radio and roller-mounted receiver and a GPS rover, all connected by radio signals.

Hamm, however, eschews this system’s setup by using the proprietary, subscription-based OmniSTAR HP system, which should provide location precision of up to 4 inches (10 cm) directly from the differential global navigation system satellites (DGNSS), operating in real time and without the need for local base stations or telemetry links. This eliminates the need to set up and move the base station and rover as work progresses.

With the HCQ Navigator (for Hamm Compaction Quality), Hamm was one of the first manufacturers to launch a compaction measurement and documentation system. The system links measurement data from various sensors on the rollers with the position information obtained via GNSS (global navigation satellite system) receivers. The HCQ Navigator utilizes these data to determine the progress of compaction for all rollers in a group in real time. A compaction map visualizes the status for the roller drivers and site management.

At the core of the application is a rugged panel touch-screen PC with USB interface. This computer provides processing power as well as a monitor and data storage facilities. It is based on military standards, has a fully enclosed metal case and is protected against water and vibrations.

The differential global navigation system receiver in a heavy-duty version with magnetic feet only takes seconds to mount on the roller. This device receives the satellite signals, along with a DGNS correction signal. Licenses for these signals are available in different accuracy classes by subscription.

The HCQ Navigator retains the GPS signal for up to 16 hours even after the machine is shut down; this eliminates wait time for system initialization when starting work, after breaks, at the start of shifts, etc. When compacting under bridges or in locations with radio shadowing, sensors combine with the intelligent software to bridge over insufficient GPS signals for up to one minute.

The HCQ Indicator measures the stiffness of soil beneath the drum, and consists of an accelerometer inside the drum, a processor and a display. Based on these data, the processor calculates the HMV (Hamm measurement value) – indicating the degree of compaction derived from the measured signals – and displays this value to the driver in the cab.

A WLAN data network can be used to interconnect a group of rollers so they can exchange measurement results continuously. Each of the roller operators can watch the current progress of the group's work, e.g. the number of passes by all of the rollers or the temperature.

During the compaction process, the panel PC shows the operator how stiffness is progressing. Separate graphics depict, for example, the number of completed passes or the current asphalt temperature, and the operator has the ability to monitor two of these functions simultaneously on the split screen.

Dynapac's Compaction Analyzer

Advance mapping of a construction site sounds daunting, but preconstruction mapping is recommended for many IC applications. Project test strips are often calibrated in order to correlate the compaction index or stiffness/moduli values to conventional in situ measurements such as material modulus or density.

The *Dynapac Compaction Analyzer* (DCA) and GPS allow operators to make a pre-compaction pass to chart ground conditions. The pass determines the properties of the material to be compacted, and also reveals weak areas before compaction begins.

Dynapac's documentation system is built up in three levels. At the basic level there is the compaction meter. This can then be expanded with increasingly advanced documentation tools in the form of computers mounted on the roller with different positioning systems.

The compaction meter consists of a sensor/accelerometer, a processor, and a display. The sensor registers the vibratory movement of the roller and this information is then transferred to the processor, where it is analyzed. This information is presented on the display as the CMV, or compaction meter value.

DCA registers all the CMV data and allows the operator to see the compaction results on the computer screen. On the basis of experience or an existing calibration, the CMV limiting value can be used for each separate compaction job. The DCA will then indicate precisely which areas require additional compaction.

The company's *CompBase* software provides detailed compaction planning and production data for machines working in unbound materials. The project manager can input machine model, material type, thickness and degree of compaction desired. ❖