Development of Soil Stiffness Measuring Device for Pad Foot Roller

COLORADOSCHOOLOFMINES
EARTH • ENERGY • ENVIRONMENT

Shawn C. Kimmel, Ph.D. Student and Michael A. Mooney, Professor

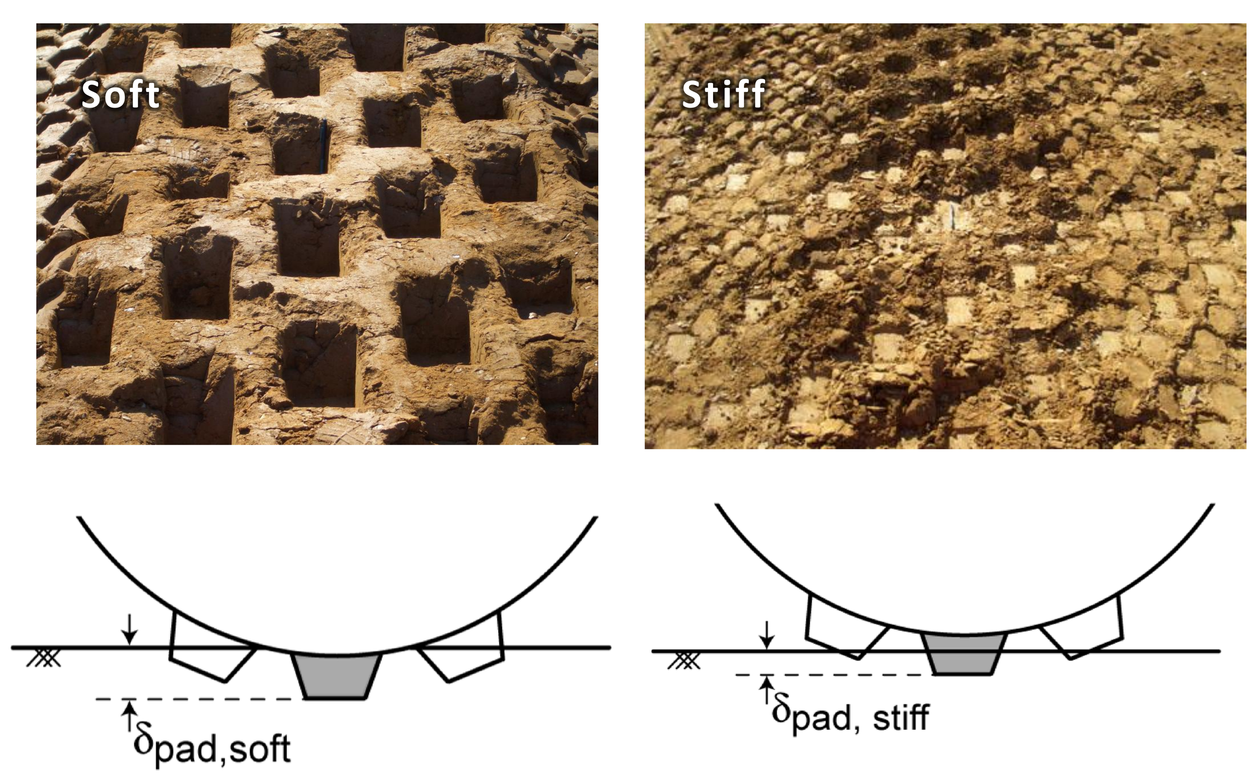
SmartGeo

Our motivation is to develop continuous, real-time measurement of soil stiffness during the compaction process

Pad foot rollers are used to compact or densify soil during the construction of roadways, earth dams, building foundations, etc. At present, quality assessment is performed periodically and only at 'spot' locations. In fact, less than 0.1% of the project is tested using current techniques. Our goal is to integrate the measurement of soil stiffness into the roller compactor to enable 100% assessment of the project material.

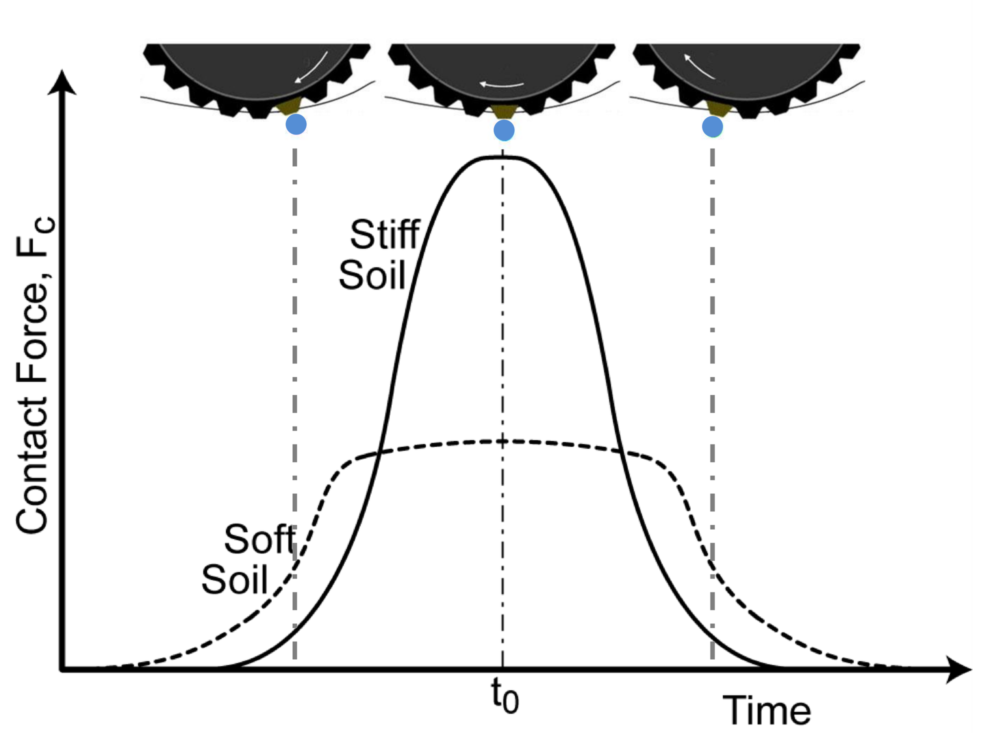
The premise is to measure the changing pad-soil interaction

As soil is compacted from loose and soft to dense and stiff, the pad-soil interaction changes. The force transmitted from each pad to the soil changes during compaction, as does the deformation, or indentation, of each pad. As shown below, the pad initially imprints the soil and eventually 'walks out.'



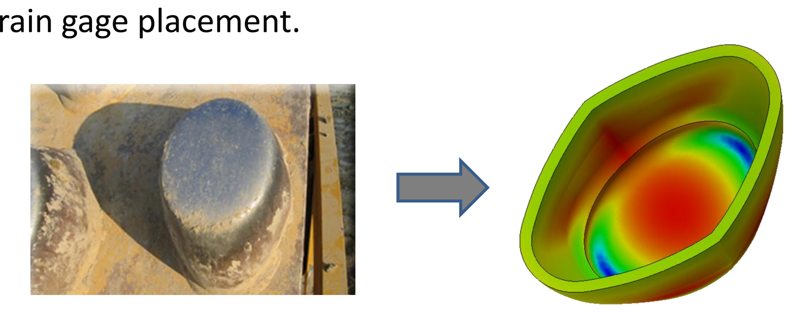
Capture and exploit the evolution of pad strain as soil is compacted

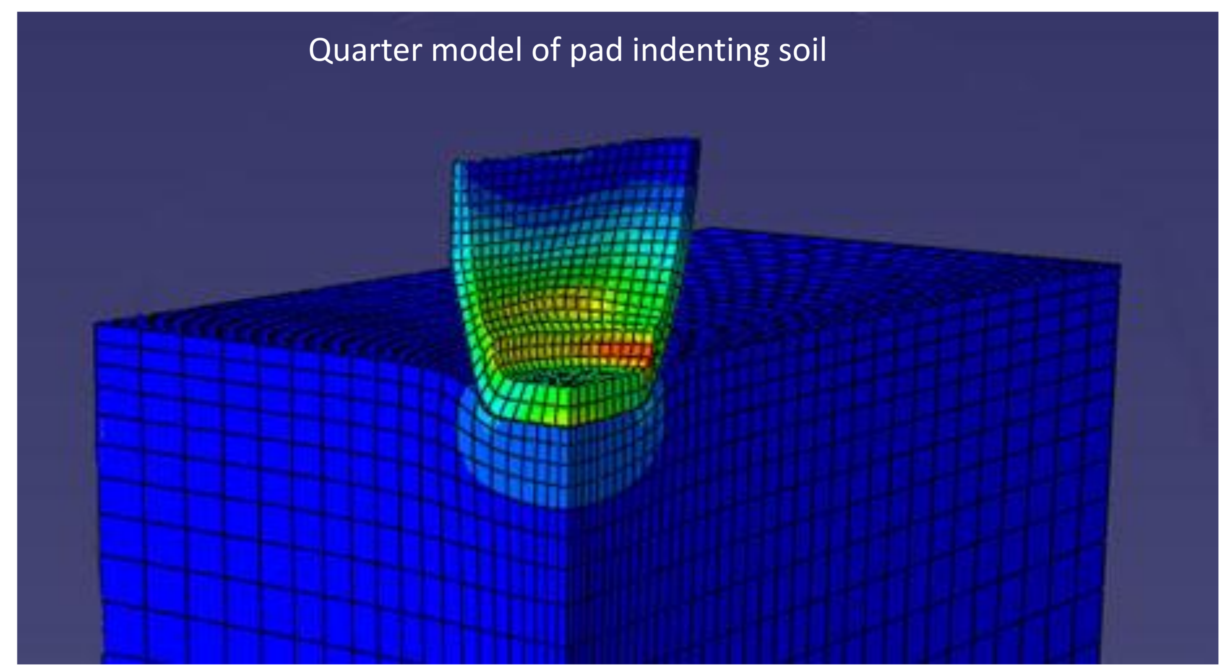
By instrumenting individual pads, we can capture the force distribution imparted on the pad as it rolls through the soil. As the soil stiffens due to compaction, the force imparted to the soil changes both in magnitude and shape.



Computational modeling to investigate pad-soil interaction

We use finite element analysis (Abaqus©) to gain insight into how pad strain varies spatially and in time under various soil and loading conditions. FEA results are used to inform strain gage placement.





Pads were instrumented with strain gages, and a lab apparatus was used to investigate pad strain distribution

Individual pads were instrumented with a suite of strain gages at locations identified through FEA modeling. Individual strain gages and strain gage rosettes were placed to measure side wall and bottom face normal strains. Instrumented pads were investigated in a controlled laboratory setting through vertical loading into a variety of prepared soil beds. In addition to measuring the evolution of each strain component during loading, surface and subsurface deflections, as well as pad-soil contact pressure, were measured.

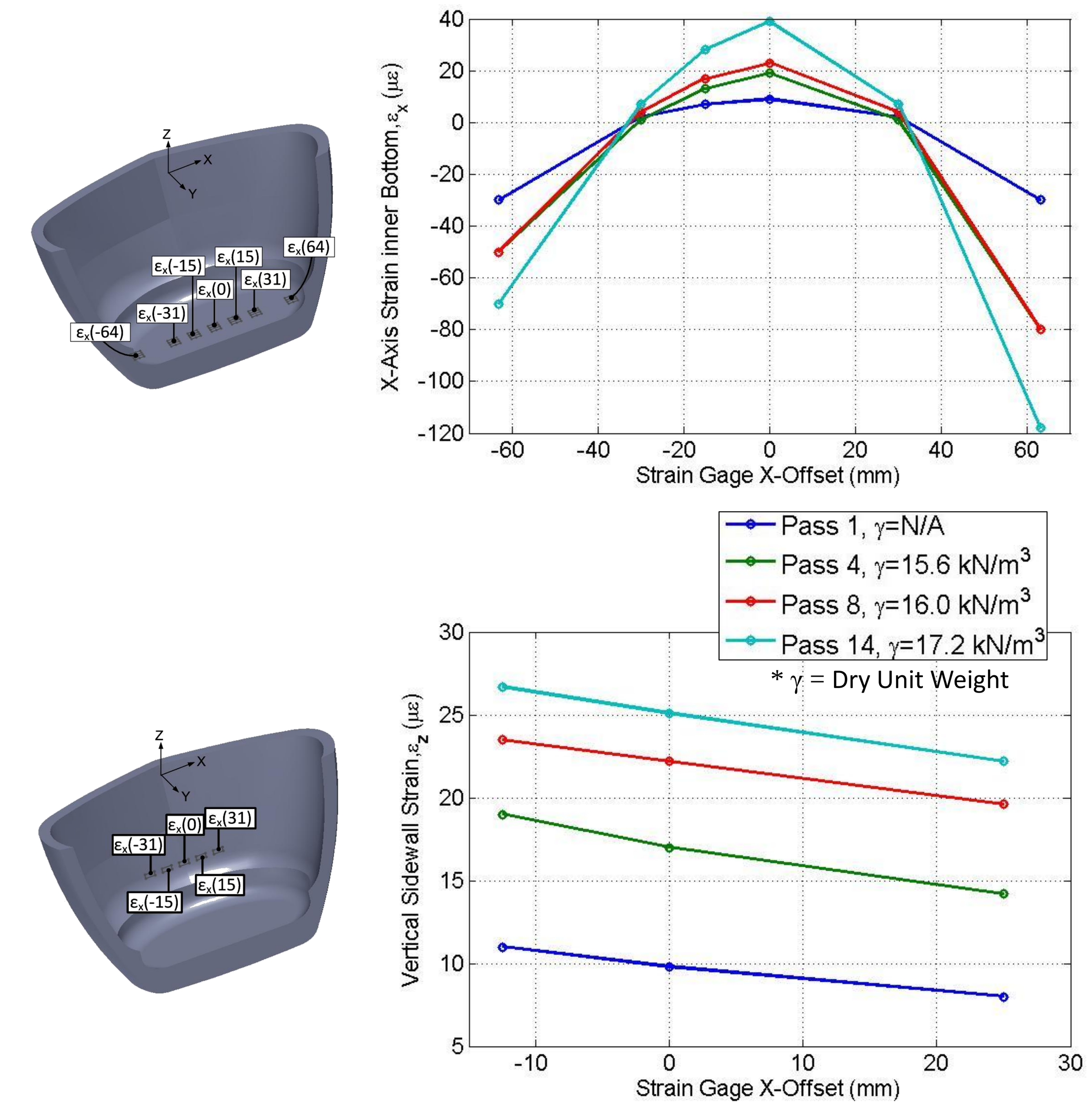
Wireless instrumented pads were tested on a roller in field tests

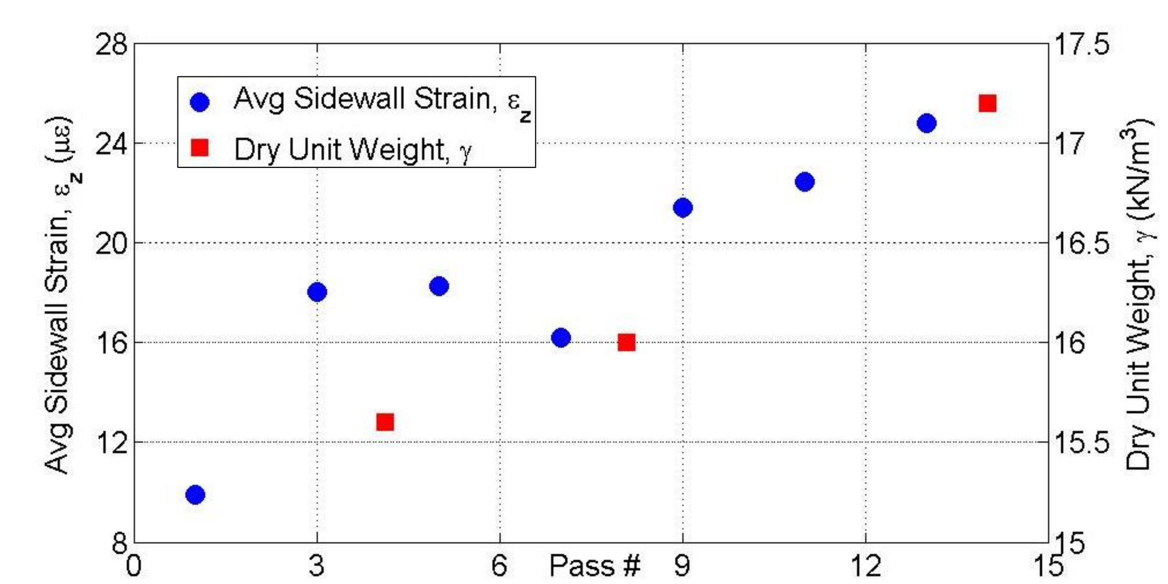
Nine instrumented pads were welded to the drum of a Caterpillar roller. The pad sensors were wired to signal processing boxes in the drum of the roller, which transmit data wirelessly to a computer in the cab of the machine.

To explore how pad strain evolves during compaction, the roller was used to compact prepared test beds of different soil types at different moisture contents. Standard compaction tests were conducted to monitor soil compaction.

Pad strain magnitudes increase with compaction

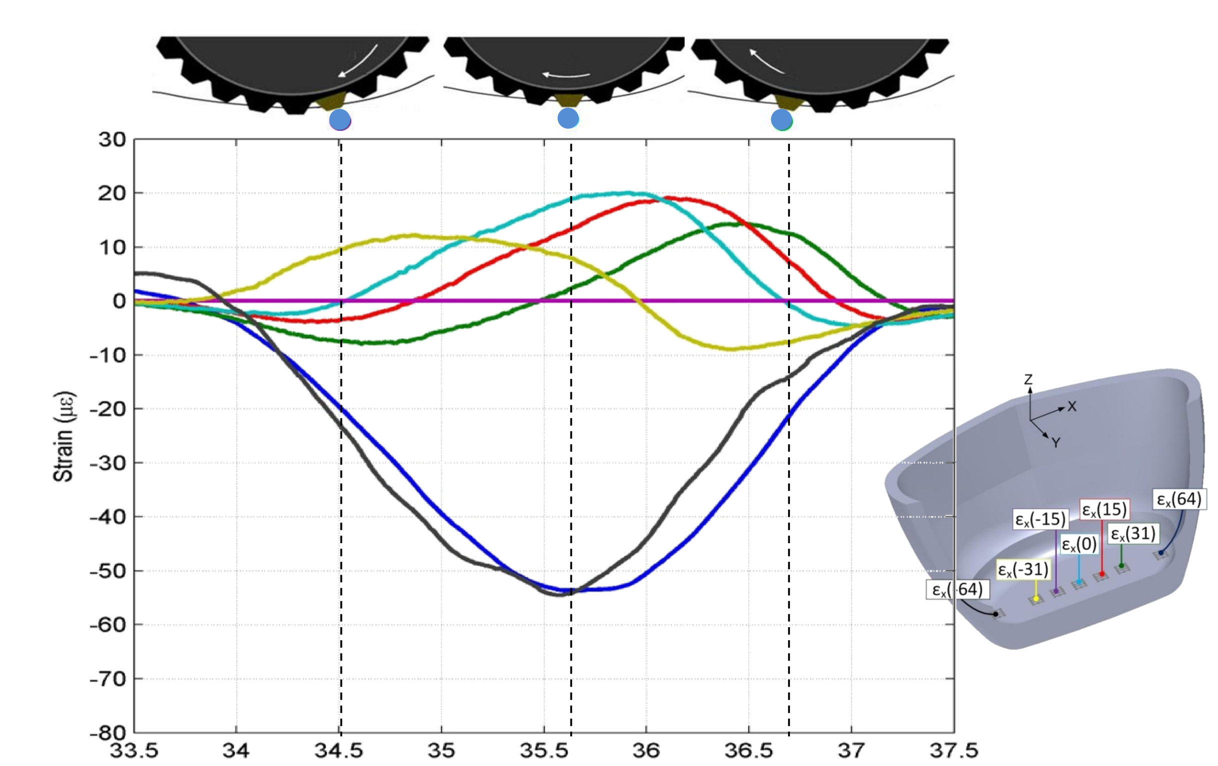
During field testing in granular soils, pad strains increased at all gage locations as the soil underwent compaction. As shown below, during successive roller passes over the soil that serve to densify the soil, the magnitudes of bottom face strain increase significantly. Sidewall strains also increase significantly, and correlate well with the increase in the density of the soil.





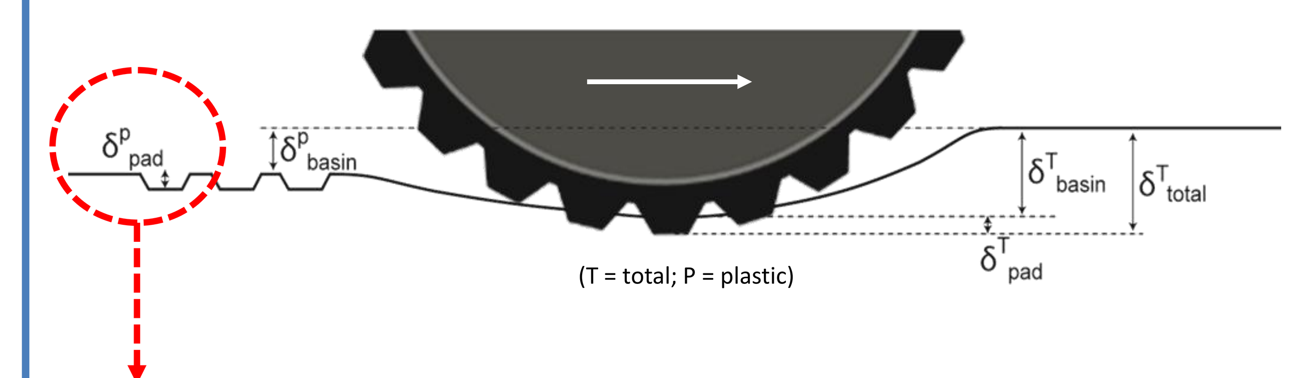
Strain behavior in pad during rolling shows complex waveforms

Some bottom face strain gages experience purely tension or compression, while others see a cyclic strain response as a pad rolls through the soil. The waveforms are used to determine pad orientation. More importantly, we are exploring the nature of these waveforms as the soil is compacted. The goal is to identify and exploit waveform features that provide information about compaction and soil stiffness.



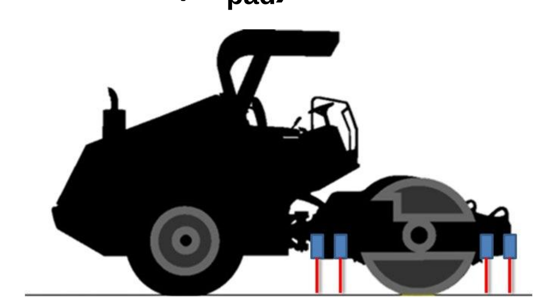
Advance a methodology to measure pad foot deformation

Measuring deformation is a critical to compaction monitoring and soil stiffness estimation. The overall deformation of the soil is decomposed into a number of elastic and plastic components as depicted below. Some are easier to measure than others, but information about each elastic and plastic component advances the measurement system.



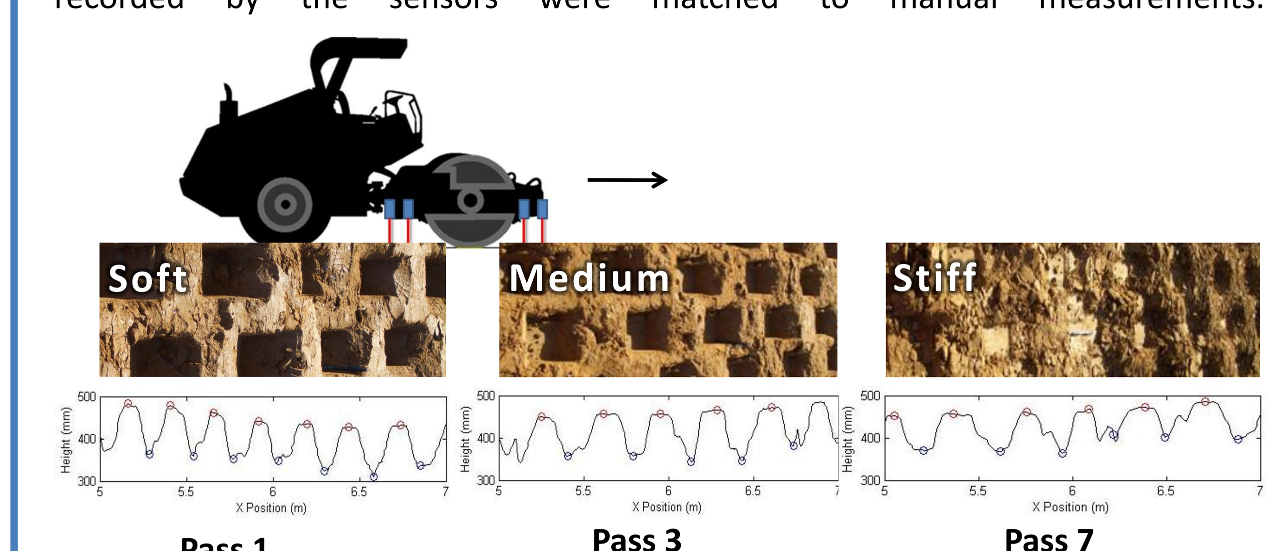
Laser measurement of pad indentions in the soil (δ^P_{pad})

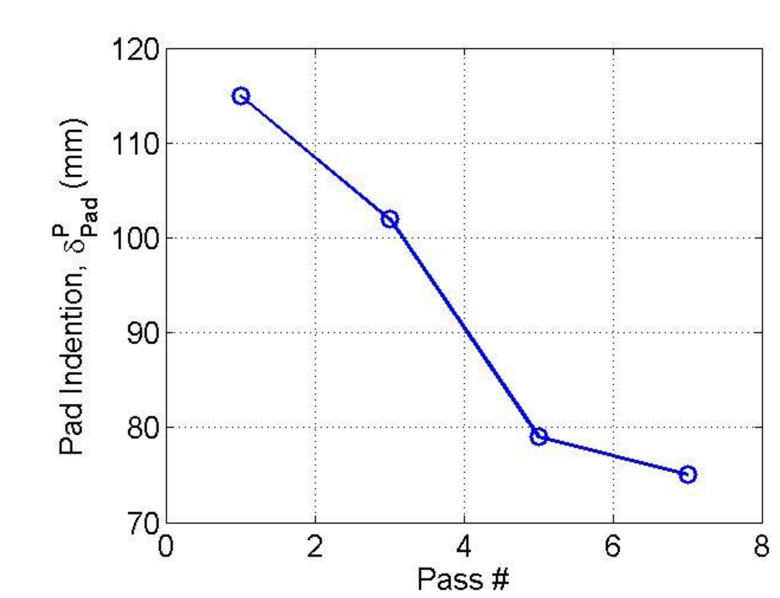
Laser sensors were mounted to the frame of the roller to measure the depth of pad indentions in the soil. Optical sensing was chosen because it is a proven technology for providing high accuracy, high sampling rate distance measurements.



Laser sensors are able to detect pad indentions

Laser data clearly shows troughs and peaks from pad indentions. The values recorded by the sensors were matched to manual measurements.





Conclusions & Future Research

In this research, we have developed a pad-based measurement system and demonstrated the sensitivity of the system to compaction and soil stiffness. A laser-based deformation measurement system has been developed. The padfoot roller measurement system has been implemented and tested in the field. A wireless data acquisition system was developed for field implementation. Continuing research seeks to better define and understand the relationships between pad strain waveforms and soil compaction and stiffness, as well as advance the measurement of additional components of soil deformation. In addition, considerable field implementation on active construction sites is planned.

Acknowledgements

Funding for this research is provided by the FHWA Exploratory Advanced Research Program (No. DTFH61-07-H-00036). Additional support is provided by the National Science Foundation (IGERT). The participation of industry partners Caterpillar and Case Construction, as well as the Colorado Department of Transportation and the Denver Transit Construction Group is gratefully appreciated.