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Comparison of soil strength measurements of agricultural soils in Nebraska ☆

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ABSTRACT

In 2014 the University of Nebraska, Lincoln (UNL) was engaged in field testing program to investigate a soil moisture mapping system as a crop management tool. In conjunction with this work, the US Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory (ERDC-CRREL) deployed a team to perform soil characterization and strength measurements at three agricultural test sites. The primary objective was an investigation of the Lightweight Deflectometer (LWD) as a soil surface strength tool for the purposes of assessing bearing capacity of soft soils. The LWD measurements were performed with those from more "standard" tests, i.e. the Dynamic Cone Penetrometer, Cone Penetrometer, and Clegg Impact Hammer to determine if the LWD produced results that compared with these methods. The strength test data were also used to calculate California Bearing Ratio (CBR) values using existing equations in order to see if the different test methods produced similar CBR values that could in turn be used to predict the bearing capacity of the sites. The secondary objective was to compare the strength data with the corresponding soil water content data taken by UNL to determine if soil moisture was an indicator of soil strength.

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1. Introduction

In 2014 the University of Nebraska-Lincoln (UNL) undertook a field testing program to evaluate components of the Cosmic-Ray Soil Moisture Observing System (COSMOS) as a crop management tool for precision watering (Franz et al., 2015). COSMOS is a network of stationary neutron probes designed for long-term soil moisture monitoring (Zreda et al., 2012). The 2014 UNL program included continual measurements of soil moisture, or water, content with stationary Cosmic-Ray Neutron Probes (CRNP) installed at several test sites. In addition, reoccurring soil water content measurements were made with a the mobile or roving CRNP unit, and standard soil samples were taken for laboratory determination of water content as part of the calibration of the COSMOS system.

In conjunction with this work, in September 2014, the US Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory (ERDC-CRREL) deployed a team to perform soil characterization and strength measurements at three of the COSMOS sites. The primary purpose of ERDC-CRREL test program was to evaluate the Lightweight Deflectometer (LWD) as a potential soil surface strength measurement tool that could be used to assess the bearing capability of soft soils, an application that the LWD and its software were not specifically designed for. The LWD measurements were taken in conjunction with those from more "standard" test equipment, i.e. the Dynamic Cone Penetrometer (DCP), Cone Penetrometer, and Clegg Impact Hammer (CIH).

The LWD is portable version of the larger, typically trailer mounted, Falling Weight Deflectometer (FWD). It was developed to estimate the in-situ stiffness modulus of soils. The device is typ-

Abbreviations: a, loading plate diameter [mm]; *CBR*, California Bearing Ratio [%]; *CI*, cone index [psi]; *CIH*, Clegg Impact Hammer; *CIV*, Clegg Impact Value; d_0, deflection at the center geophone [mm]; *COSMOS*, Cosmic-Ray Soil Moisture Observing System; *CRNP*, Cosmic-Ray Neutron Probe; $d_0(r)$, deflection at the geophone located at distance r from the center of the plate; *DCP*, dynamic Cone Penetrometer or Dynamic Cone Penetrometer Index [mm/blow]; *E*, Young's modulus [MPa]; E_0, elastic modulus from the center geophone [MPa]; $E(r)$, elastic modulus from the geophone located at distance r from the center of the plate [MPa]; *f*, contact stress distribution factor; *FWD*, Falling Weight Deflectometer; *LWD*, Lightweight Deflectometer; *MC*, soil moisture content [g/g, %]; *r*, distance from the center of the plate [mm]; ν, Poisson's ratio of the soil; σ_0, stress under the plate [MPa].

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ically used for quality control/quality assurance and structural evaluation of mechanically compacted earthwork and pavement construction (Senseney and Mooney, 2010). With its proprietary software, the LWD is used to backcalculate the soil elastic modulus for known one- and two-layer stratigraphy from the deflection data measured by three geophones (seismic transducers); one at the center of the loading plate and two offset radially beyond the edge of the plate.

This paper compares the soil strength data collected by ERDC-CRREL during field testing performed at three Nebraska (NE) agricultural sites. A brief statistical analysis comparing the soil strength measurements from the different testing apparatus is included, as well as a comparison of California Bearing Ratio (CBR) values calculated from the data using existing equations from the literature.

In addition, the companion soil water content data collected by UNL was analyzed to see if a correlation between soil water content and strength was evident. The water content data was also applied to an existing soil strength model to see if that model gave valid results with new, differing site data where strength measurements were available for comparison. Both facets of the Nebraska field work add to efforts on the determination of in-situ soil strength, or bearing capacity, for use in ongoing remote site assessment work being conducted by ERDC-CRREL under various vehicle mobility programs.

2. Test sites

The three agricultural field sites for the UNL/ERDC-CRREL study were in the vicinity of Lincoln, NE. Sites 1 and 2 were to the west of Lincoln near York, NE. These two sites were located 2.9 km (1.9 miles) apart. Site 3 was 90 km (56 miles) to the northeast near Mead, NE. Soil samples for the characterization of the site soils were taken from a soil test pit dug near the center of the testing area. Standard grain size analysis and soil classification tests were performed on these samples. Climatologically, May to September 2014 was relatively wet with 772 mm [30.4 in. (in.)] of precipitation between April 20 and September 20. Widespread irrigation use only occurred between late July and mid-August 2014.

2.1. Site 1 – Irrigated Corn

Site 1 was a circular corn field that employed a center pivot irrigation system. The field had been recently harvested and cut corn stalks remained; the field was scattered with dried corn debris. The surface was uneven with visible shallow imprints from tractor tires. Site 1 had received a total irrigation depth of 94 mm (3.7 in.) between late July and mid-August (Franz et al., 2015) The previous week a significant amount of rainfall had occurred and standing water remained on areas of the field. Soil classification tests performed on samples from the test pit excavated at Site 1 classified the field soil as a lean clay (CL) to a depth of 0.6 m (m) (24 in.). The United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) Web Soil Survey (WSS) classified the site soil as Hasting silt loam (USDA, 2016).

2.2. Site 2 – Irrigated Soybean

Site 2 was a circular soybean field that also employed a center pivot irrigation system. Fig. 1 shows the irrigation equipment and the UNL COSMOS CRNP and the general site conditions at Site 2. The field was densely vegetated with row planted soybean. Site 2 received a total irrigation depth of 82.6 mm (3.25 in.), also between late July and mid-August (Franz et al., 2015). Surface water was encountered due to the rain fall previous to the field work. The soil at Site 2 was also classified as CL. The USDA NRCS WSS soil classification was Hasting silt loam with Fillmore silt loam (USDA, 2016).

2.3. Site 3- Rain Fed Soybean

Site 3 was a rectangular soybean field with no irrigation system. The site was densely vegetated with row planted soybean. Again the soil at this site was classified as CL, making the soils at all three sites very similar from an engineering perspective. The USDA NRCS WSS soil classification was Tomek and Fillmore silt loams with Yutan silty clay loam (USDA, 2016).

3. Test program

Each site was tested in a radial pattern emanating from a central point as shown in Fig. 2. Test points were located using a Garmin GPS 18x PC system. For Site 1 and Site 2 the center point was the pivot point of the irrigation system. The pattern consisted of transects, with 0 degrees being north and transects proceeding clockwise from 0 degrees, to 60, 120, 180, 240 and 300 degrees. Strength testing and soil water content sampling along each transect took place at 25, 75 and 200 m (m) [82, 246 and 656 feet (ft)] from the center point, on areas clear of vegetation between the corn or soybean plant rows. The soil test pits used to take samples for soil characterization were located near the center points as were the LWD measurement locations. Test points are identified by the transect and distance from the center, i.e. 120 degrees 75 m (120 deg 75 m).

The test plan at Site 3 was different than that used at the other two sites. The Site 3 plan involved transects at 0, 30, 60, 90, 135 and 180 degrees with the starting transect to the southeast as opposed to due north to avoid instrumentation already installed at Site 3. Spacing of test points along each transect remained at 25, 75 and 200 m (82, 246 and 656 ft).

It was the intent of the study to run each standard test device (DCP, CI and Clegg) at all 18 points of the radial test pattern. An additional point near the soil test pit, located at the center of the pattern, and some duplicate tests were also included. The LWD, however, was only used at four to six points near the soil test pit. Additionally, soft surface conditions (no reading registered by the equipment) limited the CIH data at Site 2 to five points.

As part of the CRNP calibration UNL collected undisturbed soil samples using a split corer 30.48 cm (one foot) in length and 5.08 cm (2 in.) in diameter with stainless steel liners per Zreda et al. (2012). Samples were taken at 5 cm (2 in.) intervals to a depth of 30 cm (12 in.) from the 18 radial strength testing locations. No samples were taken at the test pit locations (i.e. point 0 deg 0 m). From these samples oven dried gravimetric soil water contents were determined in g/g, as a percent (Franz et al., 2015).

3.1. Dynamic Cone Penetrometer

The DCP test apparatus and procedures are given in ASTM/D6951M-09 (2015). The DCP is used heavily by the United States Air Force (USAF) for evaluation of bearing capacity and soil strength profiles for both paved and unsurfaced airfields. The 8 kg (17.6 lb) sliding drop hammer and the standard 60 degree, 20 mm (0.787 in.) diameter cone tip were used. The soil strength was determined by measuring the penetration of the cone into the soil after each hammer drop. This value was recorded in millimeters per blow and is known as the DCP Index. In this study the DCP measurements were taken to a depth of one meter (1000 mm [40 in.]).