Alternative Devices for Measuring Soil Moisture
https://www.dot.state.mn.us/research/TS/2013/201328TS.pdf
http://www.lrrb.org/PDF/201328.pdf

Performance-Based Measurement of Optimum Moisture for Soil Compaction
Part of the challenge achieving maximum field density in subgrade materials is transferring the optimal compaction and moisture content data from laboratory testing to the field. This research investigated the proficiency of four different instruments at accurately predicting moisture contents of three subgrade soils (loam, silt, silty/clay) commonly used in Minnesota roadway construction projects. The four instruments were; DOT600 (moisture content), WP4C dewpoint potentiometer (matric suction), the Button Heat Pulse Sensor (BHPS) (temperature rise vs. moisture content), and an exudation pressure test device. The DOT600 showed a strong correlation between the output period (measured in micro-seconds) and volumetric water content. The WP4C did not accurately measure matric suction for any of the loam, silt or silt/clay soils at suctions below 250 kPa. Published data shows that the matric suction of soils compacted at optimum moisture content is usually in the range of 200 – 300 kPa. The BHPS showed a strong correlation between measured temperature rise and water content but in its current configuration is not rigorous enough to withstand field conditions. The exudation pressure device was applied to soils compacted in a AASHTO T99 mold at various moisture contents. Water was exuded from the packed samples at pressures between 100 and 500 psi corresponding to AASHTO-T99 moisture contents of 10 to 25 %. Accurate moisture content readings from any of these instruments may not be as important as a more precise and simple calibration between the measurement units of the instrument and the optimum moisture content determined from the AASHTO T99 test.
Transport Database

Result <1.>
Title
Effect of Wetting-Drying Cycles on Mechanical Behaviour and Electrical Resistivity of Unsaturated Subgrade Soil.
Source
Advances in Civil Engineering. 2019. 2019(Article ID 3465327) 10p (Figs., Refs., Tabs.) Publisher
Hindawi Publishing Corporation
Publication Availability
Find a library where document is available URL
https://gcc01.safelinks.protection.outlook.com/?url=https%3A%2F%2Fdoi.org%2F10.1155%2F2019%2F3465327&amp;data=02%7C01%7Cqin.tang%40state.mn.us%7C7Cc39ecb7f9674442d71ea08d70541afdd%7Ceb14b04624c445198f26b89c2159828c%7C0%7C0%7C0%7C636983651995465919&amp;sd=0
Abstract
Compacted soil is widely used in road and railway subgrade, while alternation of seasons can cause fluctuations in moisture content of soil (i.e., wetting-drying cycles) and influence the performance of soil. In order to research the effect of wetting-drying cycles on mechanical behaviour and electrical resistivity of compacted unsaturated subgrade soil, wetting-drying tests considering different number and cyclic amplitude were conducted on compacted unsaturated clay specimens, and the electrical resistivity and unconfined compressive strength of soil were measured in this study. The AC (alternative current) two-electrode method was applied in the resistivity measurement. The experimental results show that increasing number and cyclic amplitude of wetting-drying cycles can both reduce the strength and electrical resistivity of the compacted unsaturated specimens. After 3-4 wetting-drying cycles, the strength and electrical resistivity tend to be constant value. The change of pore structure can be the key factor leading to the reduction of electrical resistivity of soil subjected to wetting-drying cycles and consequently causing the decrease of soil strength in the present study. Thus, the electrical resistivity can be adopted to indirectly assess the mechanical behaviour of unsaturated compacted soil after wetting-drying cycles.
Publication Year
2019

Result <2.>
Title
Investigation of the matric suction role on the curing mechanism of foamed asphalt stabilised mixtures.
Source
Road Materials and Pavement Design. 2019/4. 20(sup1) pp S365-S389 (Refs.) Publisher
Taylor & Francis
Publication Availability
Find a library where document is available URL
https://gcc01.safelinks.protection.outlook.com/?url=http%3A%2F%2Fovidsp.ovid.com%2Fovidweb.cgi%3FT%3DJS%26SC%3DY%26NEWS%3DN%26PAGE%3Dfulltext%26D%3Dtspt%26AN%3D01709539&amp;data=02%7C01%7Cqin.tang%40state.mn.us%7C7Cc39ecb7f9674442d71ea08d70541afdd%7Ceb14b04624c445198f26b89c2159828c%7C0%7C0%7C636983651995465919&amp;sd=0

Abstract
Moisture content is of great importance for foamed asphalt stabilised mixtures, since it influences mixing, compaction, curing process and the structural performance. The curing process, in which water evaporates, is responsible for the increase of the bearing capacity of foamed mixtures. Although different loading resistance mechanisms contribute simultaneously to the layer stiffness, the aim of this research is to evaluate the influence of matric suction in the stiffness of two foamed asphalt mixtures that have been used as base course materials in experimental test sections. Filter paper, X-ray microcomputed tomography and triaxial resilient modulus tests were conducted at four moisture conditions. The filter paper test indicated an increase in the matric suction when water evaporated from the specimen, which was validated by the reduction of the air voids measured with microcomputed tomography. From triaxial resilient modulus and matric suction results, it was observed that although other mechanisms might be dominating the loading resistance of foamed mixtures, the matric suction influences the stiffness of these materials.

Publication Year
2019

Result <3. >
Title
Permanent Deformation Characteristics of Coarse Grained Subgrade Soils Using Repeated Load Triaxial Tests.
Source
Conference Title: Eighth International Conference on Case Histories in Geotechnical Engineering (Geo-Congress 2019).
Publication Availability
Find a library where document is available URL

https://gcc01.safelinks.protection.outlook.com/?url=https%3A%2F%2Fdoi.org%2F10.1061%2F9780784482124.061&data=02%7C01%7Cqin.tang%40state.mn.us%7Ce9ecb7f9674442d71ea08d70541afdd%7Cebe14b04624c445198f26b89c2159828c%7C0%7C636983651995475903&amp;sdata=iligGcm0yedRaODEO1KxCSiifrMX00MgW133hb4S4dno3D&amp;reserved=0

Abstract
The resilient modulus (Mr) is used to represent the subgrade soil stiffness and is one of the key parameters for modeling pavement permanent deformation and subgrade rutting in the mechanistic-empirical pavement design guide (MEPDG).
However, soils having good resilient modulus may or may not have small permanent strains under repeated loading. Therefore, it is necessary to study both the resilient and permanent strain characteristics of subgrade soils under repeated loading. In this study, repeated load triaxial tests were performed following AASHTO T307 on remolded soil samples collected from different regions of South Carolina. The samples were prepared at optimum moisture contents (w<sub>opt</sub>) and +or-2% w<sub>opt</sub> and +or-2% w<sub>opt</sub>, Resilient modulus and permanent strains of subgrade soils were measured under different repeated deviatoric loads and confining pressures. Statistical models were developed to
correlate resilient modulus model parameters \((k_{\text{1}}, k_{\text{2}}, k_3)\) and permanent strain model parameters \((\alpha_1, \alpha_2, \alpha_3, \alpha_4)\) with soil index properties. Results showed that the compaction and optimum moisture content \((w\text{ and } w_{\text{opt}})\), percent passing No. 4 sieve \((P_4)\), maximum dry density \((\gamma_{\text{d}})\), uniformity coefficient \((C_u)\), liquidity index \((L_I)\), and specific gravity of soil \((G_s)\) have statistically significant effects on the resilient modulus model parameters and the permanent strain model parameters for South Carolina coarse grained soils. The correlation between \(M_r\) and permanent strain suggests that \(M_r\) is a satisfactory soil property to explain permanent deformation or rutting characteristics for the South Carolina soils studied herein. Thus, permanent deformation for these soils can be predicted from index properties using MEDPG with the developed resilient modulus model, or directly using the developed permanent strain model.

Publication Year
2019

Result <4.>
Title
Improving the resilient modulus of a gypsum sand roadbed soil by increased compaction.
Source
International Journal of Pavement Engineering. 2019/4. 20(4) pp 432-438 (Refs.) Publisher
Taylor & Francis
Publication Availability
Find a library where document is available
URL
https://gcc01.safelinks.protection.outlook.com/?url=http%3A%2F%2Fdx.doi.org%2F10.1080%2F10298436.2017.1309190&data=02%7C01%7Cqin%40state.mn.us%7C00c9eb7f9674442d71ea08d70541afdd%7Ceb14b04624c445198f26b89c2159828c7C0%7C0%7C636983651995475903%7C00e7F%2FT8hJyOvRs3IRQfdky2AKXghBVvACK%2BqmcE%3D&amp;reserved=0
Abstract
A gypsum sand roadbed soil with about 28% gypsum content was tested in the laboratory for the resilient modulus (MR) and California bearing ratio (CBR) under four different compaction efforts. Twenty-eight pairs of CBR specimens were compacted at the optimum moisture content of modified AASHTO compaction. The first seven pairs were compacted using 10 blows/layer, while the second, third and fourth seven pairs were compacted using 30, 50 and 70 blows/layer, respectively. Each pair of the seven pairs was soaked for a certain period of time namely, 0 (unsoaked conditions), 4, 7, 15, 30, 60 and 120 days under the effect of 40 lbs (178 N) surcharge load. The nondestructive test for measuring MR using New Sonic Viewer was conducted before carrying out the CBR test. The travel times of compression and shear waves were measured to allow the calculation of the resilient modulus before and after each soaking period. The results show that the MR increases with increasing compaction effort but decreases significantly with increasing soaking period. The drops in the MR after 120 days of soaking were 38.7%, 36.84%, 33.53% and 29.15% for 10, 30, 50 and 70 blows/layer, respectively. The paper recommends the strong non-linear correlation developed between MR and CBR for soaked gypsum-rich roadbed sand.
Publication Year
2019
Title
Performance of an Instrumented Embankment Constructed with Lime-Treated Silty Clay During Four-Years in the Northeast of France.

Source
Transportation Geotechnics. 2018. (60 Refs.) Publisher Elsevier

Publication Availability
Find a library where document is available URL

Abstract
The soil-atmosphere interaction is investigated in a densely monitored large-scale embankment constructed with compacted lime treated soils in the Northeast of France. The field instrumentation covered spatial and temporal changes of the soil suction and moisture at predefined locations within the embankment, as well as meteorological data. This paper focuses on the field performance of a compacted lime-treated silty clay in the embankment system subjected to the natural variations of the environmental conditions, including temperature changes and wetting-drying cycles, in a continental climate. The used sensors provide continuous soil moisture measurements in good agreement with the soil suction measurements over a four-year monitoring period for the investigated embankment. Soil suction and corresponding soil moisture variations follow consistently a systematic annual and seasonal fluctuation at different depths. Monitoring and evaluation of the investigated embankment indicate stability of the lime-treated silty clay in relation to the weather conditions. As expected, maximum changes in suction occur at the interface between soil and atmosphere, near the ground surface. Even at the location of -0.75 m from the soil-slope face the soil-atmosphere interaction is noticeable in terms of daily soil suction and moisture measurements.

Publication Year
2018

Title
Intelligent Compaction of Soils--Data Interpretation and Role in QC/QA Specifications.
This report describes a study of intelligent compaction (IC) technologies, within the context of actual construction projects, for its potential as a component of INDOT's QC/QA for soils. The output from an IC-equipped roller compaction equipment is a real-time area mapping of the compacted lift stiffness as captured by the IC measure. Data was collected to evaluate the correlation between each of two IC measures—compaction meter value (CMV) and machine drive power (MDP)—and in situ embankment quality test measures, the chief in situ test being the dynamic cone penetrometer (DCP) test which INDOT uses for soil embankment acceptance testing. Researchers sought to understand how well the IC measures might assess embankment quality as currently evaluated by the in situ measures. Window-averaged IC measures were compared with the in situ DCP test points. For CMV, a variable correlation was found between the average CMV and DCP values from 74 in situ locations. Also, a limited head-to-head comparison of CMV and MDP with the in situ measures provided some indication that MDP should be studied further. Lessons were learned regarding the elimination of bias in future correlation studies, critical provisions to facilitate best data quality, and important aspects of data management. IC technology holds promise for monitoring the consistency of the soil compaction effort and flagging weak areas in real time during compaction operations. However, further insight is needed regarding the correlation of the DCP measure with both types of IC measures for various soil characterizations and field moisture conditions.

Source
2018/2. 21p

Publication Availability
Find a library where document is available URL

https://gcc01.safelinks.protection.outlook.com/?url=https%3A%2F%2Fdoi.org%2F10.5703%2F1288284316645&amp;data=02%7C01%7Cqin.tang%40state.mn.us%7C39ecb7f9674442d71ea08d70541afdd%7Ceb14b04624c445198f26b89c2159828c%7C0%7C636983651995475903&amp;data=jGY5%2BvWTFgqbqmMMyblooEesjn3wz8g33GJGNSBMTU3D&amp;reserved=0

Abstract
This report describes a study of intelligent compaction (IC) technologies, within the context of actual construction projects, for its potential as a component of INDOT's QC/QA for soils. The output from an IC-equipped roller compaction equipment is a real-time area mapping of the compacted lift stiffness as captured by the IC measure. Data was collected to evaluate the correlation between each of two IC measures—compaction meter value (CMV) and machine drive power (MDP)—and in situ embankment quality test measures, the chief in situ test being the dynamic cone penetrometer (DCP) test which INDOT uses for soil embankment acceptance testing. Researchers sought to understand how well the IC measures might assess embankment quality as currently evaluated by the in situ measures. Window-averaged IC measures were compared with the in situ DCP test points. For CMV, a variable correlation was found between the average CMV and DCP values from 74 in situ locations. Also, a limited head-to-head comparison of CMV and MDP with the in situ measures provided some indication that MDP should be studied further. Lessons were learned regarding the elimination of bias in future correlation studies, critical provisions to facilitate best data quality, and important aspects of data management. IC technology holds promise for monitoring the consistency of the soil compaction effort and flagging weak areas in real time during compaction operations. However, further insight is needed regarding the correlation of the DCP measure with both types of IC measures for various soil characterizations and field moisture conditions.

Publication Year
2018

Link to the Ovid Full Text or citation
https://gcc01.safelinks.protection.outlook.com/?url=http%3A%2F%2Fovidsp.ovid.com%2Fovidweb.cgi%3FT%3DY%26NEWS%3DN%26PAGE%3Dfulltext%26D%3Dtspt%26AN%3D01683057&amp;data=02%7C01%7Cqin.tang%40state.mn.us%7C39ecb7f9674442d71ea08d70541afdd%7Ceb14b04624c445198f26b89c2159828c%7C0%7C636983651995475903&amp;data=82zO7FSO7q3RyZjyXcGJMkEqUPbqy%2FRIgj8fobZDgVs%3D&amp;reserved=0

Result <7.>

Title
Strength characteristics of dune sand stabilized with lime-silica fume mix.

Source
International Journal of Pavement Engineering. 2018/10. 19(10) pp 874-882 (Refs.) Publisher Taylor & Francis

Publication Availability
Find a library where document is available URL

https://gcc01.safelinks.protection.outlook.com/?url=http%3A%2F%2Fdx.doi.org%2F10.1080%2F10298436.2016.1215677&amp;data=02%7C01%7Cqin.tang%40state.mn.us%7C39ecb7f9674442d71ea08d70541afdd%7Ceb14b04624c445198f26b89c2159828c%7C0%7C636983651995475903&amp;data=RMNCbGT%2B5%2FQkep3Vmntnq3y2knqzPta4nAmz8DtGtksU3D&amp;reserved=0
Abstract

While more than half the land surface of Iraq consists of deserts covered mainly with sand dunes, little research has taken place to study the characteristics and the behaviour of sand dunes. The growth of economy, demography and building activities in Iraq necessitates carrying out geotechnical investigations for the dune sand. The purpose of the present work is to assess the suitability of sand dunes as subgrade layer for carrying roads and rail foundations. An extensive laboratory testing programme was carried out to study the geotechnical properties and the behaviour of sand dunes. Sand dune samples were collected from a region in Baiji area in Salah-Aldeen governorate, North of Iraq, and in situ field density of the soil was measured by sand-cone test. The tests include moisture content, classification tests, compaction tests, relative density and direct shear test. Chemical tests and X-ray diffraction analyses were also carried out.

Silica fume (SF) and lime-silica fume (L-SF) mix have been used for stabilising and their effects on the sand dunes were investigated. A grey-coloured densified SF is used. Four percentages are used for lime (0, 3, 6 and 9%) and four percentages are used for SF (3, 6, 9 and 12%) and the optimum percentage of SF is mixed with the percentages of lime. Several tests are made to investigate the soil behaviour after adding the lime and SF. It was found that L-SF caused an increase in the angle of internal friction \( \phi \) and cohesion \( c \). Higher cohesion was reached; 10 kPa with higher percentage of 6% \( L + 12\% \) SF. In addition, the angle of internal friction increases with increasing the maximum dry density, where the values of the angle of internal friction ranged between 35 degrees and 41 degrees.

Publication Year
2018

Link to the Ovid Full Text or citation
https://gcc01.safelinks.protection.outlook.com/?url=http%3A%2F%2Fovidsp.ovid.com%2Fovidweb.cgi%3FT%3DJS%3C%26C%3DY%26NEWS%3D3%26PAGE%3Dfulltext%26D%3Dtsp%26AN%3D01680020&data=02%7C01%7Cqin.tang%40state.mn.us%7Cc39ecb7f9674442d71ea08d70541afdd%7Ceb14b04624c445198f26b89c2159828c%7C0%7C0%7C636983651995475903%26sdata=ltx9xvo7ql3qtUesRnsITVHhqX4aNUhhX%2FtZ0iHuEE%3D%26reserved=0

Result <8.>

Title
Effect of soil particle and pore orientations on sound velocity.

Source
Innovative Infrastructure Solutions. 2018/12. 3(1) p 37 (Refs.) Publisher
Springer Publishing

Publication Availability
Find a library where document is available URL
https://gcc01.safelinks.protection.outlook.com/?url=http%3A%2F%2Fdx.doi.org%2F10.1007%2Fs41062-018-0140-9&data=02%7C01%7Cqin.tang%40state.mn.us%7Cc39ecb7f9674442d71ea08d70541afdd%7Ceb14b04624c445198f26b89c2159828c%7C0%7C0%7C636983651995475903%26sdata=mGphaqK%2BOc9YnIn1N2yu6dmVrqUclJkdZg8lCVRlWac4%3D%26reserved=0

Abstract
The main purpose of compressing soil dams, highway constructions, bridge abutments and fillings behind retaining walls is to increase the bearing capacity, reduce consolidation settlement and permeability of clayey soils. However, the soil particles and pore orientation could be somehow anisotropic due to a compaction-induced anisotropic structure. Orientations of particles, pores and other constituents during compaction of a mixed mica schist clayey soil with fly ash were studied to investigate how soil structure, and in turn, sound velocity change during compaction of a cohesive soil at different moisture contents on all three sides at three are perpendicular to each other. Ultrasonic sound velocity measurements of the cube samples compressed in the optimum water content were investigated perpendicular to each other. The results showed that the ultrasonic sound velocity decreased in the compression direction of the soil samples,
namely the overall degree of preferred orientation increases as opposed to the compression direction. On the other hand, the overall degree of preferred horizontal orientation increases and ultrasonic sound velocity decreases.

Publication Year
2018

Link to the Ovid Full Text or citation
https://gcc01.safelinks.protection.outlook.com/?url=http%3A%2F%2Fovidsp.ovid.com%2Fovidweb.cgi%3FT%3DSJ%26SC%3DY%26NEWS%3D%26PAGE%3Dfulltext%26D%3Dtspt%26A%26D%3D01669596&data=02%7C01%7Cqin.tang@state.mn.us%7C39eb7f9674442d71ea08d70541afdd%7Ceb14b04624c445198f26b89c2159828c%7C0%7C0%7C36983651995475903%3D&amp;sdata=SUR9l%2BhID9bSCpbS%2Fkd2yZ5gcmqHr2uAqX70T%2FRI3fY%3D&amp;reserved=0

Result <9.>

Title
Comparison of Laboratory and Field Test Results for Granular Bases.
Source
Publication Availability
Find a library where document is available URL
https://gcc01.safelinks.protection.outlook.com/?url=http%3A%2F%2Fdx.doi.org%2F10.1061%2F9780784480441.040&amp;data=02%7C01%7Cqin.tang@state.mn.us%7C39eb7f9674442d71ea08d70541afdd%7Ceb14b04624c445198f26b89c2159828c%7C0%7C0%7C36983651995475903%3D&amp;sdata=xqTxTGkZs%2FV1CzydQDlvaXsvBCfUXkM5f9InuteWgk%3D&amp;reserved=0

Abstract
The performance of a flexible pavement depends, to a large extent, on the mechanical characteristics such as stiffness and deformation resistance of its base layer. The laboratory static triaxial compression tests are common to estimate these mechanical characteristics. The resilient modulus tests are the other laboratory tests that are also gaining popularity. These laboratory tests are usually augmented with field tests such as the plate load, lightweight deflectometer or dynamic cone penetration tests. Since the methods of compaction and testing are different, one can anticipate that the mechanical characteristics measured in the laboratory and in the field are different even at the same moisture content and density. In this paper, the relationships among the laboratory and field mechanical characteristics of a common base with different fines contents and moisture contents are evaluated, reported and discussed.

Publication Year
2017

Link to the Ovid Full Text or citation
https://gcc01.safelinks.protection.outlook.com/?url=http%3A%2F%2Fovidsp.ovid.com%2Fovidweb.cgi%3FT%3DSJ%26SC%3DY%26NEWS%3D%26PAGE%3Dfulltext%26D%3Dtspt%26A%26D%3D01686960&data=02%7C01%7Cqin.tang@state.mn.us%7C39eb7f9674442d71ea08d70541afdd%7Ceb14b04624c445198f26b89c2159828c%7C0%7C0%7C36983651995475903%3D&amp;sdata=UySJqtmZgk9SxYTqLy6DTzH48GSMJCdeegQ5p3XFQc%3D&amp;reserved=0

RIP Database
Rapid Field Detection of Moisture Content for Base and Subgrade
http://swutc.tamu.edu/research/new-research/0-6676/
Water content in pavement materials plays a critical role both in construction and performance. During the construction phase, the water content influences compaction; in performance, water content significantly influences strength, modulus, and permanent deformation characteristics. While efforts exist to link design and construction by accepting compacted materials based on modulus, these efforts historically have been hindered due to the dependence of modulus on water content. For modulus-based acceptance to be implementable, companion water content measurements are necessary at the time of acceptance testing. Although the nuclear gauge can provide water content measurements in the field, restrictions and licensing requirements make the use of that gauge somewhat burdensome to agencies; test procedures are needed using rapid, accurate, non-nuclear moisture-measurement methods. To make the possibility of modulus-based acceptance an implementable reality by including nonnuclear moisture measurement, this project will: (1) Evaluate and rank non-nuclear techniques for measuring water content in soils and bases used in pavement construction. (2) Develop test procedures in the Texas Department of Transportation (TxDOT) format for measuring water content with non-nuclear methods. (3) Produce a training workshop and training materials. (4) Produce a training DVD.


Description: Compaction of earth materials for roadway construction is the primary activity to build embankment and to prepare subgrade, subbase, base, and stabilized layers of highways. Current standards of state highway agencies require contractors to build uniform material layers, without dependable means to continuously quantify and verify the degree of compaction. The implementation of intelligent compaction (IC) technology has the potential to provide continuous, real-time measurements for quality control/quality acceptance (QC/QA) of compaction. Specifically, Roller Integrated Compaction Monitoring (RICM) [i.e., IC or Continuous Compaction Control (CCC)] uses rollers equipped with sensors that record location and layer stiffness. Current IC technology depends solely on the roller measurement values (MVs), which represent a composite value of compacted layers within a zone of influence, approximately 1 m (3.3 ft) in depth. MVs are influenced by variation in layer thickness, moisture, layer stiffness, machine vibration, drum-soil interaction, etc. The inability to associate the contribution of these variables on MVs is an obstacle for implementing IC technology in construction acceptance. Overcoming this obstacle requires a better understanding of the mechanical properties of earth materials governing IC compaction.

The objective of this research is to develop procedure(s) that measure the mechanical properties of earth materials to facilitate the adoption of dynamic and static compaction using IC technologies for field acceptance. Earth materials include unbound aggregates, and both coarse and fine grained soils.


Description: Water content in pavement materials plays a critical role both in construction and performance. During the construction phase, the water content influences compaction; in performance, water content significantly influences strength, modulus, and permanent deformation characteristics. While efforts exist to link design and construction by accepting compacted materials based on modulus, these efforts historically have been hindered due to the dependence of modulus on water content. For modulus-based acceptance to be implementable, companion water content measurements are necessary at the time of acceptance testing. Although the nuclear gauge can provide water content measurements in the field, restrictions and licensing requirements make the use of that gauge somewhat burdensome
to agencies; test procedures are needed using rapid, accurate, non-nuclear moisture-measurement methods. To make the possibility of modulus-based acceptance an implementable reality by including nonnuclear moisture measurement, this project will: (1) Evaluate and rank non-nuclear techniques for measuring water content in soils and bases used in pavement construction. (2) Develop test procedures in the Texas Department of Transportation (TxDOT) format for measuring water content with non-nuclear methods. (3) Produce a training workshop and training materials. (4) Produce a training DVD.


Description: In the United States, the current state of practice for quality control of soil compaction is based upon measurements of soil density and soil moisture content at the time of compaction. The current approach that is used in the State of Delaware compares measurement of in situ soil density and moisture content with measurements of soil density and moisture content obtained from a standard-energy compaction test approach (1-Point Proctor Compaction). Measurement of in situ soil density and moisture content are typically obtained via measurements from Nuclear Density Gauges (NDGs). NDG test equipment uses a nuclear-based approach to obtain radioactive counts that are correlated to soil densities and moistures. The results of NDG test exhibit significant scatter when compared to previous in-situ density test standards (e.g. sand cone tests, "water balloon" tests, etc). Nonetheless this equipment has become the accepted industry standard for quality control of soil compaction, because tests are much faster and easier to perform than other density-based quality control tests. In addition to inherent inaccuracies with NDG test results, there are significant regulatory compliance issues that are present when dealing with NDG test equipment. The NDG itself contains radioactive material, which is heavily regulated by the Nuclear Regulatory Council. This regulation necessitates strict protection standards for employees working with this equipment (mandatory day-long training for all staff using the equipment, mandatory use and monitoring of nuclear dosimeter badges, significant security procedures related to storage of nuclear material/equipment, in-house Nuclear Compliance Regulatory officers, etc). Particularly for large-scale NDG operations, such as those at the DOT, these nuclear regulatory issues can present a significant obstacle to smooth day-to-day operations, and compliance can be difficult. New equipment that uses an electrically-based approach for measuring in situ soil density and moisture content has recently become available. This Electrical Density Gauge (EDG) equipment does not contain any nuclear material, and consequently does not have the same regulatory obstacles that are present with NDG. Additionally, this equipment may allow for more accurate measurements of in situ density and moisture content than those that are currently being made with the NDG (the accuracy of this equipment as compared to NDG is currently unknown). Electrical density gauges have the potential to replace nuclear density gauges for field evaluation of in situ soil density and moisture. Consequently, a study of the accuracy and effectiveness of the Electrical Density Gauge for compaction control of Delaware soils is needed. The program of research proposed will provide the necessary information to assess the benefits of this technology for the DOT.


Description: Is continuous sensing of soil properties during static pad foot roller compaction achievable? A new pad-based, roller-integrated system for real-time measurement of the elastic modulus of fine- and mixed-grain soils is the goal of "Development of Soil Stiffness Measuring Device for Pad Foot Roller Compactor," a project of the Federal Highway Administration's (FHWA's) Exploratory Advanced Research (EAR) Program. Initiated in 2008, the study is being conducted by the Colorado School of Mines with the participation of roller manufacturers and the Colorado and
Minnesota Departments of Transportation. Most embankment and subgrade soils are best compacted statically using pad foot rollers, yet none of the intelligent compaction systems in use measures stiffness or elastic modulus during static compaction. The estimation of soil modulus is important because subgrade modulus is the key parameter used in pavement design and in performance-based quality assurance. In this study, researchers are modeling a breakthrough approach and developing a prototype system to continuously measure soil modulus through its relationship with the contact force-displacement response of individual roller pads. Such a system, if accurate and reliable, would be significantly superior to the current practice of spot testing perhaps less than 1 percent of a compacted area. Measuring Pad Contact Force and Soil Deflection The system under development employs the changing relationship between pad contact force and deflection that occurs as soil is compacted. This change is illustrated in roller "walk out": as the soil stiffens, individual pads on the roller penetrate the soil less, causing the roller to "walk" out of the soil. Individual pads bear more contact force relative to the drum but are in contact with the soil for less time. By fitting several adjacent pads on standard pad foot rollers with load cells to gather data and by fusing the contact force-time history data from multiple pads, researchers can infer deflection. These contact force and deflection data feed into an algorithm that extracts soil modulus. During the research, tactile pressure sensors on the pads and ultra-sonic proximity sensors on the roller frame are being used to verify pad deflection calculations and further develop the measurement approach. Small-scale tests, using rollers from different manufacturers, are collecting data from three soil types at three moisture levels. Analysis of these field data will inform and refine the model. Ultimately, information from the system will be integrated via wireless communication with onboard global positioning system mapping software and documentation systems, enabling the roller operator to "see" the state of the soil. Real-time graphical feedback offers many benefits: documented quality control over 100 percent of the compacted area; elimination of unnecessary passes; identification of "weak" spots; accelerated (less costly) construction. The quality assurance team will have documentation of soil modulus throughout the compaction area on which to base its decisions.

https://rip.trb.org/view/1228498

Description: The lack of control over the uniformity of moisture content is a leading cause of problems experienced by industry in effective compaction control of earth fill materials. Current measurement techniques for determination of moisture content generally involve spot tests that can be time consuming, unreliable and do not provide adequate coverage. Recent advances in non-destructive evaluation technologies, especially near infrared reflectance spectroscopy (NIRS), and data analysis techniques (e.g., multivariate analysis and Bayesian statistics) show significant promise in obtaining necessary information that could significantly advance field moisture control for earthwork construction by increasing the coverage area in lieu of spot tests, providing measurements that are accurate, and speeding up the inspection process and providing real-time results in computer format. Research is needed to identify suitable technologies, evaluate them for robustness and accuracy in a wide range of soil types; develop data analysis and output algorithms and create onboard machine equipment; and launch technology.


Description: Compaction of embankment, subgrade, and base materials is a significant portion of state highway construction budgets and is critical to the performance of highway pavements. Heterogeneity of earth materials, variability in equipment and operators, and difficulty in maintaining uniform lift thickness and prescribed moisture content combine to make desired earthwork compaction difficult to achieve. Current quality-control and quality-
assurance testing devices—such as the nuclear gage, the dynamic cone penetrometer, the stiffness gauge, and the lightweight falling weight deflectometer—are typically used to assess less than one percent of the actual compacted area. In addition each of these testing devices measures values unique to the device. Intelligent soil compaction has the potential to improve infrastructure performance, reduce costs, reduce construction duration, and improve safety. Intelligent soil compaction involves: (a) continuous assessment of mechanistic soil properties (e.g., stiffness, modulus) through compaction-roller vibration monitoring; (b) continuous modification of roller vibration amplitude and frequency, and (c) an integrated global positioning system to provide a complete GIS-based record of the earthwork site. Research findings in Europe and in the United States have shown that soil stiffness and modulus can be assessed through vibration of the compaction roller drum and that continuous monitoring, feedback, and automatic adjustment of the compaction equipment can significantly improve the quality of the compaction process. Standard specifications for the application of intelligent compaction systems in the United States are needed. Such specifications should build on existing specifications and experience gained in Germany, Switzerland, Finland, Sweden, Japan, and other countries. The objectives of this research are to determine the reliability of intelligent compaction systems and to develop recommended construction specifications for the application of intelligent compaction systems in soils and aggregate base materials.

Web

Soil Moisture Measurement

Device Comparison for Determining Field Soil Moisture Content

Laboratory Performance of Five Selected Soil Moisture Sensors Applying Factory and Own Calibration Equations for Two Soil Media of Different Bulk Density and Salinity Levels
https://www.mdpi.com/1424-8220/16/11/1912/pdf

Design and Test of a Soil Profile Moisture Sensor Based on Sensitive Soil Layers
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5981356/

ASCE

Variability of Moisture Content Measurement Devices on Subgrade Soils

Conference Information
Geo-Congress 2014
February 23-26, 2014