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Project Title

Evaluation of Density and Moisture Testing for Granular Materials

University

South Dakota State University

Principal Investigators

Rouzbeh Ghabchi, Ph.D., A.M. ASCE
Assistant Professor
Department of Civil and Environmental Engineering
South Dakota State University
Phone: (605) 688-6333
Email: rouzbeh.ghabchi@sdstate.edu
ORCID: 0000-0002-3827-6315

Research Needs

Granular materials are widely used by the departments of transportation (DOTs) for construction of pavement structure such as base and subbase layers. While size distribution, shape parameters, texture, and the particles' mechanical properties largely affect the stiffness of the granular layer, achieved field density as a result of compaction remains the single most important parameter known to significantly influence the performance of a granular base subjected to traffic loads (Chen et al., 2018; Martin et al., 2017). Achieving field densities close to maximum dry density of the granular materials during the construction phase at the proper moisture content is of vital importance to pavement's performance and its longevity. Historically, South Dakota Department of Transportation (SDDOT), among several other DOTs, has been using the Ohio Highway Department's (OHD's) typical moisture/density curves (Joslin, 1958) for compaction quality control of granular materials and granular soils. However, the OHD curves were not developed for granular materials and use of them for granular materials was observed to result in error and inconsistencies between the lab and field-measured densities. Also, OHD curves were not originally developed for local materials and other repurposed materials such as recycled Portland Cement Concrete (PCC) and Reclaimed Asphalt Pavement (RAP) as aggregate base. Therefore, the OHD curves are being phased out by several DOTs including SDDOT. In response to a need for development of tests and procedures for compaction quality control of granular materials, a research project, namely Compaction Testing of Granular Material, was conducted by Jones and Weber (2019) at South Dakota State University (SDSU). In this study, the compaction control methods practiced by SDDOT were reviewed and as a result, recommendations in two major areas were made to improve the current practice as follows. (1) It was recommended to replace the OHD moisture/density curves by those developed as a part of Jones and Weber (2019); and (2) it was suggested to apply a strength-based method using the Dynamic Cone Penetrometer (DCP) instead of relative compaction which may widely vary in the field. However, a verification process needs to be carried out before the recommendations can be implemented. The verification process should cover two major areas as follows. (1) To ensure the applicability of the moisture/density curves developed by Jones and Weber (2019) over various materials and different geographical areas, the moisture/density curves are to be verified in full-scale side-by-side tests on pilot projects; and (2) the accuracy and applicability of the DCP as the strength-based method should be verified to determine and double-check correlations between DCP index and density. Also, the DCP test's repeatability, speed, operation convenience, safety, and limitations are to be determined. In response to these needs, the present study is being proposed to design an evaluation program to verify the moisture/density curves developed in SD2014-12 research project (Jones and Weber, 2019) and the suggested DCP method as the strength-based approach. Also, it is envisioned to make a number of recommendations and develop a specification for successful implementation based on observations made in this study. It is important to note that, the proposed specification will be developed only if this study shows that the DCP can be used as a strength-based method for screening the field compaction. In this case, the draft specification will establish the technical criteria based on the outcomes of the field DCP tests required for achieving the desired field compaction. Therefore, the scope of the proposed specification goes beyond the test procedure and will include pass/fail criteria based on the target relative densities.

Research Objectives

Specific objectives of the proposed study are as follows.

1. Design a field test program that will provide side-by-side comparison of the SDDOT moisture/density curves and the DCP test to current compaction testing methods during the 2020 construction season.
2. Based on results of the side-by-side comparison, evaluate the suitability of the SDDOT moisture/density curves and the DCP test as replacements for current granular material compaction acceptance.
3. Recommend specifications for using the SDDOT moisture/density curves and the DCP test in construction involving granular material compaction.

Research Methods

To this end, the proposed study will aim at designing an evaluation program through an effective research plan to verify the South Dakota moisture/density curves developed in SD2014-12 project (Jones and Weber, 2019) and the suggested DCP method as the strength-based approach. Additionally, if found to be applicable, a specification will be developed for effective implementation of the South Dakota compaction curves and conducting DCP test. Also, it is anticipated to make a number of practice-based recommendations for successful implementation of the aforementioned approach based on observations made in this study.

The objectives of this study will be achieved through field measurements and a lab testing program. The field testing program consists of side-by-side comparison of the SDDOT moisture/density curves and the DCP test to current compaction testing methods during the 2020 construction season. This is proposed to be achieved first by summarizing the existing literature including technical reports, specifications, journal papers, and conference proceedings as well as the SD2014-12 final report (Jones and Weber, 2019). Then, based on the literature review and in close consultation with project's technical panel (which will be formed in close collaboration with SDDOT), a testing program tentatively consisting of a combination of DCP and Nuclear Density Gage (NDG) measurements and their comparison with sand cone measurements will be planned and test sites for construction season 2020 will be identified. In this process, the current practice used for testing compaction and South Dakota compaction curves will be used and compared side-by-side. Based on results of the side-by-side comparison, the suitability of the SDDOT moisture/density curves and the DCP test as replacements for current granular material compaction acceptance will be evaluated. This will be achieved by analyzing the collected field data and literature review. The DCP test results will be analyzed side-by-side with the relative density results and the Penetration Index Values' (PIV) capability in capturing the compaction adequacy in conjunction with the moisture/density curves developed as a part of SD2014-12 project (Jones and Weber, 2019) will be evaluated. One hypothesis is that the moisture/density curves developed in SD2014-12 project accurately deliver the relative density (null hypothesis). The plausibility of this hypothesis will be tested by conducting a statistical analysis. Based on outcomes of the statistical analysis, test repeatability and the technician's feedback on speed, operation convenience, and safety the technical competency and the suitability of the test methods will be summarized. The summary will also include the recommendations of the research team on the efficiency and practicality of the test method. The important observations during execution of the field tests, including the DCP test's repeatability, speed, operation convenience, safety, and limitations as well as other findings related to verification of the South Dakota's moisture/density curves will be compiled and summarized. If the DCP test is found to be suitable for screening the compaction, the DCP test repeatability will be evaluated through repeating the DCP tests at least on five close locations of the same sublot for each test site. Standard deviation and coefficient of variation for each set of the PIV measurements will be determined and used to evaluate the repeatability of the DCP test. If the DCP test is found to be suitable for screening the field densities, a draft specification will be developed based on the outcomes of aforementioned methodology. The specification will be finalized based on the comments and suggestions received from the project's technical panel. It is important to note that, the proposed specification will be developed only if this study shows that the DCP can be used as a strength-based method for screening the field compaction. In this case, the draft specification will establish the technical criteria based on the outcomes of the field DCP tests required for achieving the desired field compaction. Therefore, the scope of the proposed specification goes beyond the test procedure and will include pass/fail criteria based on the target relative densities.

Expected Outcomes

The outcomes of this study will provide research-based information to assist pavement engineers and DOTs in making decisions for updating the testing methodologies used for in-situ acceptance of the compacted granular bases. More specifically, it will help determine the efficacy and suitability of using two methods, namely the density curves (SD2014-12) and DCP test for screening of the compaction for granular bases. If the study finds that one or both methods can be suitable for implementation, specification(s) for using the SDDOT moisture/density curves and/or the DCP test in construction involving granular material compaction will be developed and recommended. It is critical to note that the results may indicate none of the aforementioned methods is suitable for evaluation of the compaction quality of the granular materials. Also, this project will be instrumental to improving the testing capabilities and research infrastructure at SDSU in the area of pavement materials.

Relevance to Strategic Goals

The expected outcomes of this project are directly related to the USDOT strategic goal, namely State of Good Repair. The proposed project aims to promote application of precise, quick, and reliable methods for in-situ density measurement of granular base, subbase, and subgrade layers of a pavement's structure. Achieving field densities close to maximum dry density of the granular materials during the construction phase at the proper moisture content is of vital importance to pavement's performance and its longevity. Outcomes of this project, after implementation, are expected to result in pavements with a longer life and a need for lesser costly repairs.

Educational Benefits

This project will provide an excellent learning opportunity for both graduate and undergraduate students. A graduate student will be working on this project as a GRA. The results of this study will be used to provide materials for his/her thesis. Outcomes of this study will be blended with learning experience of students in the classroom. More specifically it will be used for selected lectures in the CEE 765: Pavement Design and CEE 411/511/L: Asphalt Materials and Mix Design courses.

Technology Transfer

In a close collaboration with the South Dakota Local Transportation Assistance Program (SDLTAP), the findings of this project, after completion, will be presented during South Dakota Annual Asphalt Conference. This is a very well attended conference which allows broader participation by pavement engineers, asphalt industry, SDDOT personnel, NAPA members, and others. Moreover, research papers will be published, and presentations will be delivered at conferences and other occasions for effective dissemination of findings of this study. Toward building a stronger transportation workforce, a major component of MPC mission and vision, we plan to blend research ideas and innovations in classroom.

Work Plan

The proposed work plan consists of five major tasks as follows:

Task 1 – Literature Review: Substantial literature review on this topic has already been compiled by Jones and Weber (2019) and Siekmeier et al. (2009). The literature review of the foregoing reports will be expanded to capture the findings of the recent studies relevant to the objectives of the project. As a result, the important aspects of implementation and validation of moisture/density curves and the DCP including but not limited to specifications, application, evaluation, performance, and testing will be summarized and included in the final report.

Task 2 – Design a Comprehensive Field Test Program: The literature review summary in conjunction with project technical panel's input will be applied for designing a comprehensive field test program for side-by-side comparison of the SDDOT moisture/density curves and the DCP test to current compaction testing methods. It is proposed to measure field densities using the NDG test, DCP test, and sand cone method at project's test sites on granular materials. It is important to ensure compliance of all the candidate site materials with the definition of granular materials as per AASHTO M 145 (AASHTO, 2015). Also, a sieve analysis test and an Atterberg limit test will be conducted on the materials in accordance with the AASHTO T 27 (AASHTO 2018) and AASHTO T 89 (AASHTO 2017), respectively, and their classification be determined according AASHTO M 145 (AASHTO, 2015). Although final decision on the locations of the test sites will be made after discussion with project's technical panel.

In view of the material mineralogies and types and to cover different regions, at least 10 sites (tentatively 15 sites) are anticipated to be tested. In addition to testing conventional granular materials, effort will be made to include recycled concreate aggregate (RCA) and reclaimed asphalt pavement (RAP) in the testing program. Each test site will consist of side-by-side test sections of a granular material layer compacted by target unit weights obtained from implementing Type C OHD curves (SDDOT, 2015) and South Dakota compaction curves developed as a part of SD2014-12 project (Jones and Weber, 2019). Additionally, DCP, NDG and sand cone density tests are proposed to be conducted on insufficiently compacted materials, as well. This will help examine the effectiveness of the developed methodology in capturing the problematic compaction and development of correlations between field densities and PIV measurements. In addition to field tests, laboratory testing will be used as an additional measure for verification purpose. Most importantly, the laboratory measurements, namely PIV, gradation parameters such as percent fines, coefficient of uniformity (Cu), coefficient of curvature, (Cc), and diameters corresponding to 60% passing (D60), 30% passing (D30), and 10% passing (D10) as well as the liquid limit (LL), plastic limit (PL), plasticity index (PI), and consistency index (CI) of the material fraction passing a No. 40 sieve will be correlated with the relative density of the compacted granular materials by developing a regression model. These datapoints will also be used for verification of field measurements and will be treated as reference measurements with high confidence levels. Also, the criteria and analyses needed to evaluate the use of the SDDOT moisture/density curves and the DCP test will be developed and finalized by implementing the project's technical panel's input.

Task 3 – Observe Initial Testing and Analyze Reported Field Test Data to Verify the Field Test and Evaluation Program and Identify Needed Improvements: After receiving the technical panel's approval, the research team, in coordination with the project's technical panel, will visit a number of project test sites to observe initial testing efforts and record important observations relevant to practicality, speed, convenience, ease of testing, variability and other important aspects of the field testing. Also, the reported data collected from the initial field tests will be analyzed. Based on this analysis, the test repeatability and the technician's feedback on speed, safety and operation convenience will be summarized. The final recommendations on suitability of the candidate test method(s) will be made after discussing the compiled memo with the technical panel and incorporating technical panel's input. In addition to field observations, the SDSU research team will conduct tests in the laboratory. For verification purpose, it is proposed to conduct a gradation test and Proctor test in the laboratory on the materials collected from job sites. Also, a soil/aggregate test box will be fabricated in the laboratory at SDSU and the collected materials will be compacted using a power vibratory rammer to the relative density levels reported from the field testing. Then, the PIV of the compacted material in the test box will be determined using a DCP device. Also, a comparison will be made between the gradations before and after compaction for different type of materials of various mineralogy. This will provide an extra number of precise data points as control points. Also, it will let the research team evaluate the effect of the gradation on effectiveness of using density tests and moisture/density curves.

Task 4 – Evaluate the Suitability of the SDDOT Moisture/Density Curves and the DCP Test as Replacements for Current Granular Material Compaction Acceptance: In the course of the execution of the study, results will be compiled and analyzed as they are being received applying an incremental approach in order to assess the suitability of the SDDOT moisture/density curves and DCP for granular material compaction acceptance. For this purpose, two hypotheses related to the suitability of the density curves (SD2014-12) and PIV will be set and evaluated. One hypothesis is that the moisture/density curves developed in SD2014-12 project accurately deliver the relative density (null hypothesis). The other null hypothesis to be tested will be that the PIV is capable of accurately predicting the relative density. In both cases (density curves as per SD2014-12 and the PIV), the density measurements obtained by using the sand cone and NDG will be used as the benchmark values for further analyses. The plausibility of these hypotheses will be tested by conducting statistical methods. Also, a regression model will be developed to correlate the measured PIV and predicted relative density values using the density curves as per SD2014-12 with those measured in the field using NDG and sand cone techniques. In addition, the research team and the technical panel will make effort to spot any abnormalities in the test results and take necessary actions to find the root cause of any sort of errors. It should be noted that, a number of strategies applied to reduce errors cannot eliminate them completely. For detecting the data abnormalities and addressing them (data cleaning) the sources and types of possible errors should be tracked proactively during site selection, testing process, measurement, recording and after measurement and during converting the hand-written records to digital format.

Task 5 – Summarize the Results of Testing and Evaluation: The outcomes of the Tasks 3 and 4 will be summarized and presented to the project's technical panel as a separate memorandum. It will include the observations and improvements made to the testing plan as a part of Task 3 as well as the data analysis results carried out as a part of Task 4. The research team may revise the submitted memorandum, after receiving the technical panel's input.

Task 6 – Develop Specification Language for Use of the SDDOT Moisture/Density Curves and the DCP Test in Construction Involving Granular Material Compaction: Based on the outcomes of the literature review, the proposed test procedure, observations made during testing, data collection, and outcomes of the test results analysis, regression models developed to correlate the DCP data with other material properties as discussed earlier, a draft specification language for use of the SDDOT moisture/density curves and the DCP test in construction involving granular material compaction will be developed and presented to the project's technical panel for review and feedback. The specification will identify the testing method, and then according to the gradation parameters and possibly the Atterberg limits of the portion passing a No. 40 sieve will specify what PIV values need to be achieved for a compacted material to pass or fail. The draft specification will cover all technical aspects of the testing, methods, materials, and reporting requirements as well as the required techniques and methodologies for conducting the DCP tests and reporting. Currently, procedures, methods, and supplemental specifications for conducting the DCP tests are compiled and are available as a part of the Appendix A in the final report of the SD2014-12 project (Jones and Weber, 2019).

Task 7 – Analyze Test Results, Summarize the Findings, and Report: After completion of the testing program, findings of this study will be compiled and analyzed. Important findings will be summarized and reported as project's interim and final reports.

Task 8 – Outreach and Technology Transfer Initiatives: It is proposed to present the findings of this project after completion to a broad audience with the help of SDLTAP through South Dakota Annual Asphalt Conference and South Dakota Local Road Conference. These are very well-attended conferences which allow broader participation by pavement engineers, asphalt industry, South Dakota Department of Transportation's personnel, NAPA members, and others. In addition, research papers will be published, and presentations will be delivered at national conferences and other occasions for effective dissemination of findings of this study. Toward building a stronger transportation workforce, a major component of MPC mission and vision, it is planned to blend research ideas and innovations in classroom.

Project Cost

Total Project Costs:	$78,324
MPC Funds Requested:	$38,335
Matching Funds:	$39,989
Source of Matching Funds:	South Dakota Department of Transportation

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