Construction and Building Materials 113 (2016) 824–834

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Accelerated assessment of quality of compacted geomaterials with intelligent compaction technology

Siddagangaiah Anjan Kumar [a,*], Raed Aldouri [b], Soheil Nazarian [b], Jimmy Si [c]

[a] *Department of Civil Engineering, Indian Institute of Technology Guwahati, India*
[b] *The University of Texas at El Paso, TX, USA*
[c] *Texas Department of Transportation, TX, USA*

HIGHLIGHTS

- An alternate approach to assess the compaction quality of geomaterials is proposed.
- The approach is based on quantifying the lift contribution to roller measurements.
- Influence of moisture variation on in-situ and roller measurements is investigated.

ARTICLE INFO

Article history:
Received 2 September 2015
Received in revised form 9 March 2016
Accepted 21 March 2016
Available online 26 March 2016

Keywords:
Intelligent compaction
Geomaterials
Modulus
Density
Moisture content

ABSTRACT

This paper presents the results of the assessment of several popular guidelines and test protocols for the practical use of intelligent compaction at construction sites. In addition to the timely data processing and analysis, other practical challenges that impede the wide use of the intelligent compaction are establishing criteria for high quality compaction and relations between the in situ and roller measurements. Several test strips with varying moisture contents were constructed and evaluated to determine the best strategy to select the target intelligent compaction values. Several in situ test devices (such as nuclear density gauge, lightweight deflectometer and dynamic cone penetrometer) were used to compare the compacted layer properties with roller measurements. Considering the inherent variability of the material properties and relations between the in situ and roller measurements, an alternate approach to building test sections for estimating the target intelligent compaction value was evaluated. The alternative approach is based on quantifying the lift contribution to the intelligent compaction value. The proposed approach seems to be a good compromise between achieving a high quality compacted layer and providing enough flexibility to contractors to use their know-how in expediting the construction process.

1. Introduction

The satisfactory performance of pavement structures depends on appropriate material selection, realistic design parameters and high construction quality. The quality assessment of compacted soils and bases is traditionally based on density and moisture content measurements at few random locations. An in situ spot test measurement cannot assess the quality of the compaction area comprehensively and cannot provide feedback to the operator during compaction process. One technique receiving interest in compaction quality management is the intelligent compaction (IC) technique. IC is a technique that continuously assesses the soil stiffness through roller parameters (frequency, amplitude and speed) integrated with global positioning system to provide a complete compaction and geographic information [7]. The compaction quality is estimated through the intelligent compaction measurement value (ICMV), which is basically derived from the vibratory drum and soil interaction relations or from the machine drive power required to propel the roller drum against the soil mass. One way of estimating the ICMV is to represent the roller and soil by the combinations of spring and dashpot models using force–displacement relations. Various proprietary technologies such as compaction meter value (CMV), vibration modulus (E_{vib}), machine drive power (MDP) etc., are adopted as ICMVs for implementing intelligent compaction technology [7].

Several groups (e.g. [1,17,5,11,7,4,3]) have investigated the advantages of the intelligent compaction. The most important advantages of the IC technology have been attributed to identifying

---

* Corresponding author.
E-mail addresses: sak@iitg.ernet.in (S. Anjan Kumar), raeda@utep.edu (R. Aldouri), nazarian@utep.edu (S. Nazarian), jimmy.si@txdot.gov (J. Si).

http://dx.doi.org/10.1016/j.conbuildmat.2016.03.117
0950-0618/© 2016 Elsevier Ltd. All rights reserved.

the weak spots, reducing the production variability and improving the uniformity of the compacted layers [5,6,4,12]. Many pilot studies geared toward understanding and implementing the IC technology have been carried out in the United States. However, to employ fully the IC technology in day-to-day compaction and quality control/quality assurance (QC/QA) operations, there are still obstacles and gaps that need to be explored and overcome [7]. Variations in the roller measurements due to soil heterogeneity, moisture variations, and insensitivity of roller measurements to underlying soil conditions, poor correlations between the in-situ and roller measurements are the challenging concerns explored by several researchers [16,18,19,8,5,6]. The variation in depth of influence between the in-situ and roller measurements and stress dependent nature of geomaterials have further complicated the implementation of IC [6,12].

Several approaches have been proposed to improve the correlations between the in-situ and roller measurements using multivariate analyses [16,15]. The use of geostatistics in IC as a process control tool will be more meaningful than just spot tests for demonstrating the spatial variability of compaction and depicting soft/hard areas that can be targeted for repeated compaction or rework White et al. [17]. documented the use of geostatistics in effectively characterizing the uniformity and spatial variability of compacted layers. Petersen et al. [10] and Vennapusa et al. [14] reported similar findings.

Considering the inherent material heterogeneity and variations in production process the main motivation of the study presented here include:

- to investigate the influence of moisture variation on the sensitivity of the in-situ and roller measurements,
- to evaluate the effectiveness of using test strips for developing target values,
- to establish more conveniently the criteria for high-quality compaction and explore relations between in-situ and roller measurements, and
- to develop alternate approaches to assess the compaction quality using lift contribution and existing ground conditions.

2. Methodology

The flow chart in Fig. 1 presents the methodology adopted in the study. To achieve the objectives of the study, comprehensive field and laboratory activities were carried. The local soils and bases from the sites were selected for laboratory testing and evaluation first. The second step of the process consisted of extensive performance-based laboratory tests to determine the relationship between the laboratory and field results, to establish target modulus and also to use appropriate constitutive material properties in the structural analyses.

3. Experimental sections and materials

Two test sections were selected. The index properties, classifications and moisture density relations for the relevant geomaterials are given in Table 1. Two comparable subgrades (Subgrades A and B) and a base material were evaluated at the first site. Subgrade C was evaluated at the second site. The subgrade layers at the two sites were compacted using a combination of sheep-foot and smooth-drum roller. This roller combination was selected due to the plastic nature of the soils (see Table 1). Commercially available IC retrofit kits, with accelerometer, GPS and data acquisition, were setup on the smooth-drum rollers (see Fig. 2).

4. Laboratory modulus testing program

Combined with the regular index and moisture density testing, the resilient modulus (MR) tests were performed on the laboratory specimens according to AASHTO T 307-03 test protocol. Three sets of specimens [one set at the optimum moisture content (OMC), one set dry of OMC and the third set wet of OMC] were compacted as per AASHTO T 99 for each subgrade material. All specimens were nominally 100 mm in diameter and 200 mm in height. The granular base materials specimens, were also prepared in the same fashion but in the dimensions of 150 mm by 300 mm. The frequency of the MR load applications was 1 Hz with 0.1 s load time and 0.9 s rest period. The specimens were subjected to 100 cycles of load pulses of varying axial and confining stress levels and the resilient strains were estimated for each stress level from the last five cycles. Fig. 3 illustrates the variations in the representative MR modulus with moisture content for each soil. The measured moduli decrease drastically when the specimens were prepared wet of their corresponding OMCs.

5. Field testing program

The field-testing program consisted of constructing and monitoring three experimental test sections at three different moisture contents of 0.8 OMC, OMC and 1.2 OMC. The goals of those activities were (1) to establish the variability of different test methods under field conditions, and (2) to evaluate the effectiveness of using test strips for developing target ICMVs.

The following activities were carried out at each test bed:

- modulus-based nondestructive testing (NDT) in conjunction with the IC roller measurements on underlying layer to establish the variability of the foundation layer,
- material sampling before compaction for laboratory investigations,
- monitoring changes in density, modulus and IC roller values with the number of passes during compaction,
- testing a number of points with each NDT device, nuclear density gauge (NDG) and IC roller shortly after compaction.

In addition to these control test sections, similar activities were also carried out on one day of the production at the first site where the procedures were less controlled.

6. Roller data processing and analysis

The IC roller data collection varied according to the speed of the roller but on average, a data point was collected every 1 ft. The software package VEDA [2,3], which is available freely to process and analyze the data collected from the roller and other in situ measurements, is available to the industry. Two of VEDA's limitations at the time of this study were that it did not separate the data from different passes and was not compatible with all sensor data collected in this study. As such, the data were imported into the ArcGIS software. Once in ArcMAP, the data points with either NULL or zero CMV values or no locational information were removed. An algorithm was developed to automate part of the processing and analysis as shown in Fig. 4. The workflow for analyzing the data started by separating the data from different roller passes for each section (dry, wet and OMC) for each day and for all three sections of both sites. The data were gridded using kriging technique and generating a mask using minimum bounding geometry box. The two outputs were passed through an extraction by mask to get the raster data cut out around the data points. Finally the roller