Comparison Between Light Weight Deflectometer and Nuclear Density Gauge to Assess Compaction Quality of Base Layers

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Abstract

Compaction quality of base and subbase layers has a major effect on the overall performance of pavement structures. Therefore, it is important to ensure that base and subbase layers are compacted properly. Nuclear density gauge (NDG) is one of the most commonly used methods to measure density of compacted base and subbase layers. However, using nuclear-based equipment requires additional training, safety and environmental considerations, which require additional cost to maintain and operate the equipment. Recently, Light Weight Deflectometer (LWD) became a candidate for in-site assessment of compaction quality for base and subbase layers. LWD is a portable equipment, easy to operate, and practical to use for evaluating the stiffness of compacted granular materials. The aim of this research study was to investigate the feasibility of using LWD to assess compaction quality of base and subbase layers during construction. This paper compared measurements taken by a Troxler 3440 NDG and a ZFG 3.0 LWD for base layers during construction of pavement projects in Saskatchewan, Canada. The LWD was used to measure surface deflection as well as dynamic California Bearing Ratio (CBR_d). Results of this study were used to evaluate the correlation among CBR_d, dynamic deflection modulus (E_{vd}), and Field Dry Density (FDD) measurements.

Introduction

The depletion of high-quality aggregate sources in the Canadian prairie region force contractors to use pavement granular materials with higher percentage of fines. The high percentage of fines negatively impacts the material characteristics of base layers and consequently pavement performance. Therefore, premature pavement distresses are more likely to occur due to the poorer performance of base layers. Several studies showed that stiffness of granular materials is affected by several factors including stress state, material density, mineralogy of aggregate, water content, fine content, fine plasticity, and gradation. Lekarp et al. (2002) stated that the stiffness of granular materials has a direct proportional relationship with vertical stress and confining pressure. Barksdale and Itani (1994) reported that the density has a significant effect on the stiffness of granular materials. Barksdale and Itani (1994) noticed an increase of granular material stiffness with the increase of density at low stress levels, whilst this effect is less significant at higher stress level. Zaman et al. (1994) concluded that mineralogy of aggregates greatly impacts their resilient behaviour. Thompson (1989) reported a decrease of granular material stiffness with the increase of degree of saturation.

Quality Control (QC) and Quality Assurance (QA) in pavement projects is adapted to ensure conformity to regulations and standards. QC/QA is also used to validate the accuracy of selected design parameters in field. During construction, density measurements for base layers are part of the QC/QA process for pavement projects. Density can be measured using either core density measurement or Nuclear Density Gauge (NDG). Core density measurement, where a metal cylinder of known volume is hammered into the base layer to a depth of interest, is a destructive test that creates imperfections on the tested surface. Furthermore, Core density measurement is a time-consuming process that require further laboratory testing and does not produce test results in-situ to allow for immediate paving corrections. NDG is commonly used in Saskatchewan for measuring density of granular materials. NDG is a non-destructive testing gauge that offers an instant in-place test result. However, NDG needs proper precautions and training for operation and transportation as it uses radioactive materials that might be hazardous to the surrounding labors. Further complications could include strict licensing, relicensing and special storage requirements of the NDG. Hence, the need of using non-radioactive, non-destructive, accurate, and easy to use testing method is highly demanded.

In the recent decades, pavement design methodologies experienced a significant evolution shifting towards mechanistic-empirical approaches (NCHRP 2004). The mechanistic-empirical design approach encourages using modulus-based tests as an alternative for in-situ QC/QA (Rathje et al., 2006). Alshibli et al. (2005) and Baltzer et al. (2009) showed that Light Weight Deflectometer (LWD) measurements correlate with the plate load test, which is the traditional modulus-based test. To utilize the LWD test for QC/QA of base layers compaction, the correlation between LWD measurements and traditional compaction QA/QC tests (NDG) should be studied. This paper focuses on comparing the testing results of NDG and LWD performed on a newly constructed granular base layer. The data of this study were collected from two different projects under construction in Saskatchewan.

Experimental Program

This paper is part of ongoing research program that aims to characterize the behaviour of unbound granular base/subbase materials in Saskatchewan. The LWD and NDG tests were performed on two newly constructed road projects in Saskatchewan. The first project was Warman Intersection (Warman) project (near Saskatoon, SK) and the second was Highway 4 (HW4) project (near North Battleford, SK), as shown in Figure 1. The testing took place on the top surface of the base layer after the compaction process was completed. Further LWD and NDG tests will be performed on another two pavement projects (Highway 155 and Highway 7) that will take place in the construction season of 2019.

Representative base material samples were collected for laboratory investigations and characterization tests such as sieve analysis and Standard Proctor compaction (Proctor) tests. Eight samples were collected from HW4 project and six samples were collected from Warman project for sieve analysis tests to determine the gain size distribution curves. The gradation test results for HW4 and Warman projects are shown in Figures 2 and 3, respectively. Figures 2 and 3 indicate that the used base materials in both projects were quite uniform in gradation. Furthermore, Proctor tests were performed on base layer material samples collected from both projects. Proctor tests were performed to determine the maximum dry density (MDD) and the optimum moisture content (OMC) for the collected samples. The results of Proctor tests for both projects are shown in Table 1.

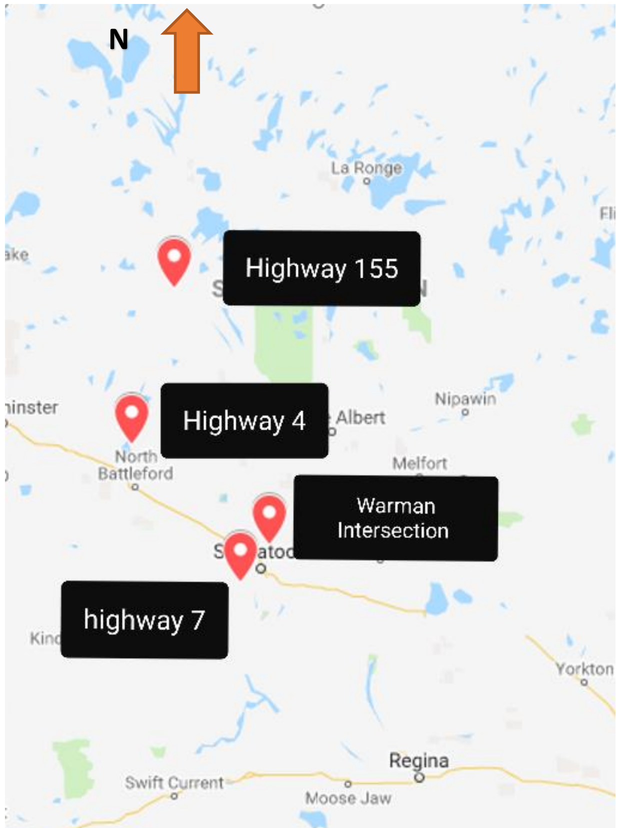

Figure 1: project locations for LWD and NDG tests (Google Maps, 2019).

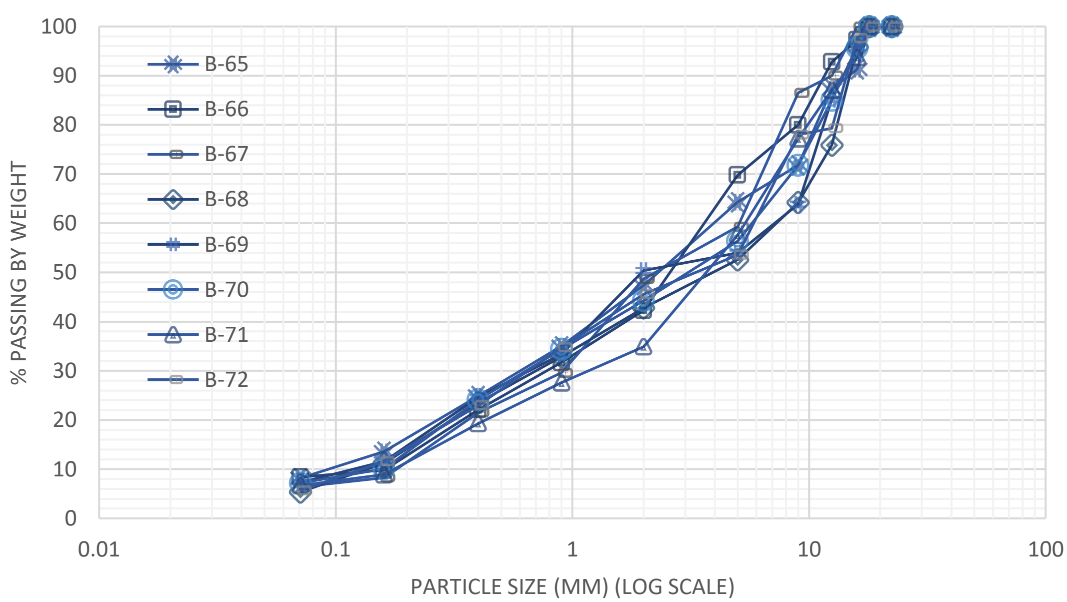

Figure 2: Sieve analysis results of field samples of HW4 project.

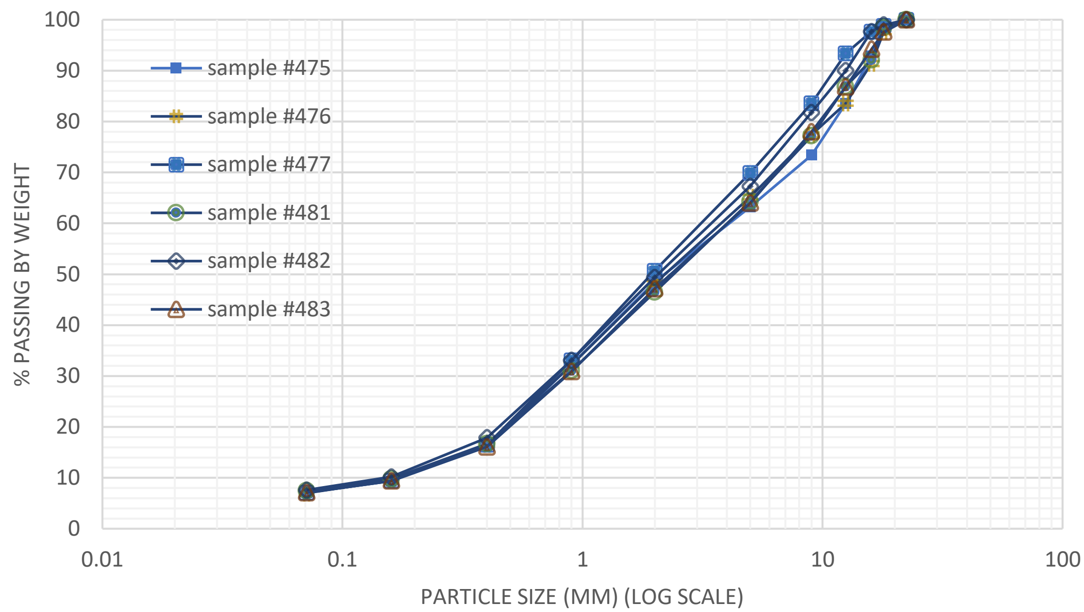

Figure 3: Sieve analysis results of field samples of Warman project.

Table 1: Proctor test results.

HW4 project		Warman project	
OMC (%)	MDD (kg/m^3)	OMC (%)	MDD (kg/m^3)
7.2	2232	7.1	2228

Nuclear Density Gauge In-situ Testing

The NDG is the most commonly used method to determine material FDD and Moisture Content (MC) by departments of transportation in North America (Rathje, 2006). In this study, the compaction quality was measured using a Troxler 3440 NDG in both Warman and HW4 projects. NDG functions by emitting radiation from two separate radioactive sources into the tested material (Nazzal, 2014). The first radioactive source emits Cesium-137 (gamma radiation) into the tested depth of material. Then, detectors read the reflected radiation to determine the wet density of the material. The other radioactive source emits americium/ beryllium high-energy neutrons to collide with the hydrogen atoms presented in the water molecules. The thermal neutron detector presented in the NDG device counts the retarded neutrons so the gauge can calculate MC in the tested sample. By subtracting MC from the material wet density, FDD of the material can be determined (Nazzal, 2014).

The NDG was used to evaluate the compaction quality of the base layer by contractors. For HW4 project, a 250-meter strip of the road was tested with 25-meter intervals between testing locations. For Warman project, a 380-meter strip of the road was tested with different interval lengths between testing locations. The evaluation was based on comparing the resulting density and MC with the maximum/optimum values determined from Proctor tests. Figure 4 presents the dry density data collected by NDG and comparing it with the MDD determined from Proctor test for HW4 and Warman projects. As shown in Figure 4, the measured dry density values varied between 2226 and 2276 kg/m^3 for HW4 project and between 2231 and 2245 kg/m^3 for Warman project. The NDG MC data was measured after the final roller pass as presented in Figure 5. By comparing the measured MC with OMC, it can be noticed that the material compaction was at the dry side of the OMC for both projects.

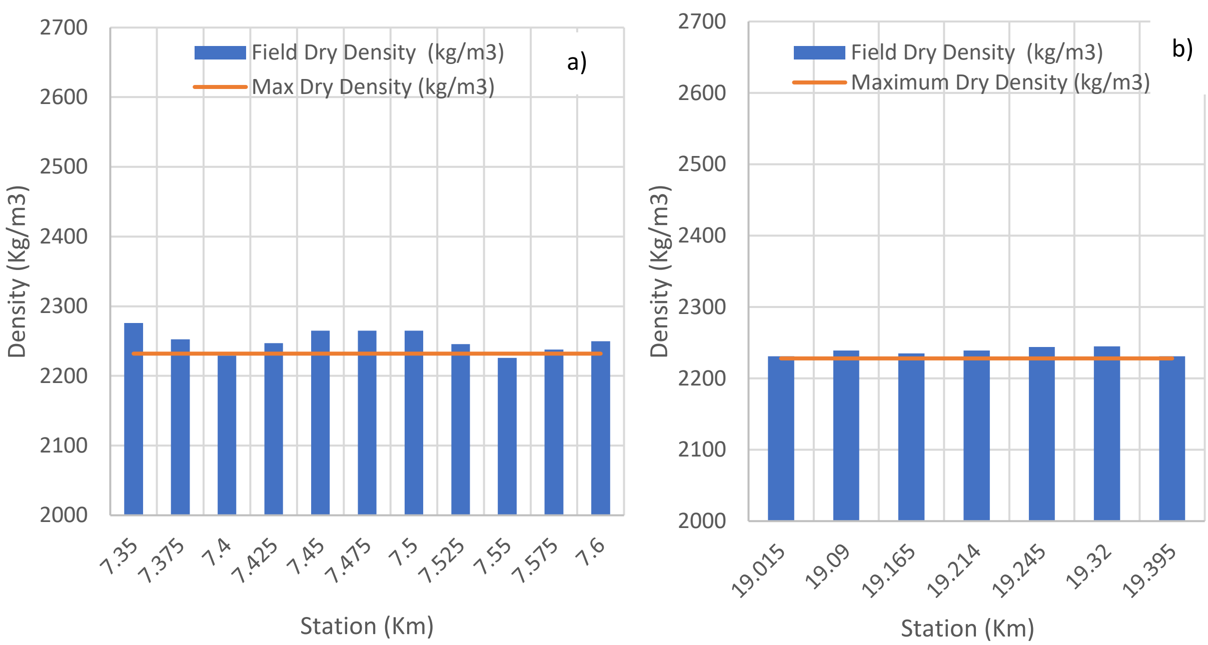

Figure 4: Field dry density data collected by NDG vs MDD determined from Proctor test for (a) HW4 project and (b) Warman project.

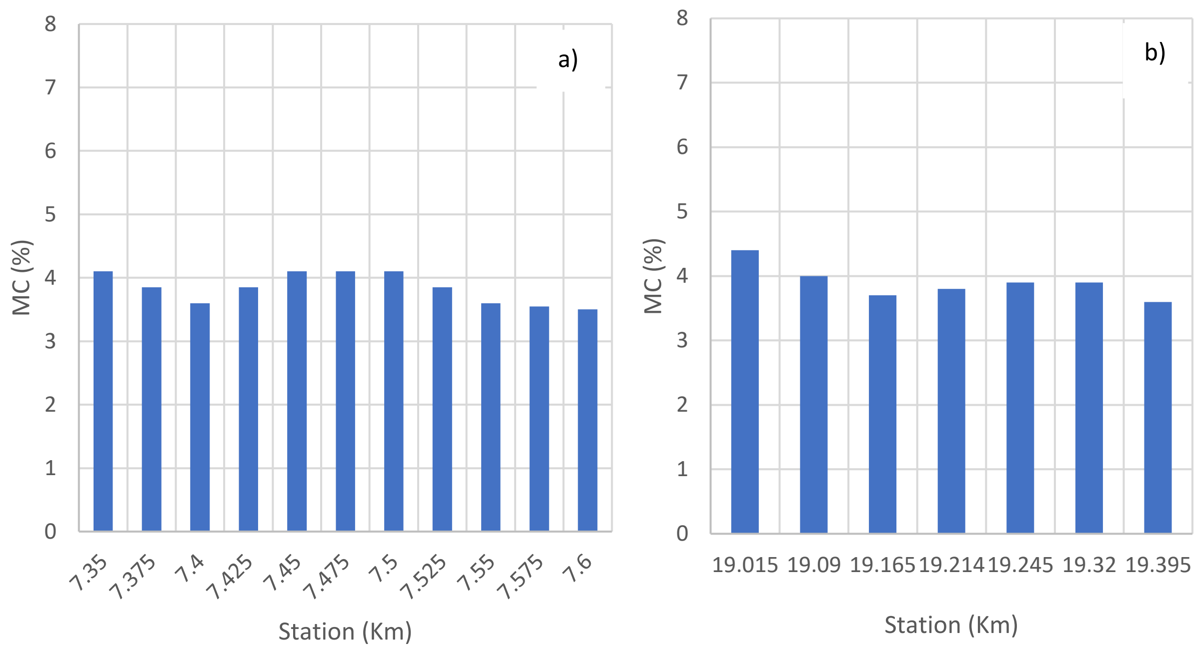

Figure 5: Field MC data collected by NDG vs optimum MC determined from Proctor test for (a) HW4 project and (b) Warman project.

Light Weight Deflectometer In-situ Testing

The LWD is a moduli-based device that is being widely used to evaluate the granular material stiffness and compaction. It can measure the surface deflection after applying an impulse load from a standard height. A ZFG 3.0 LWD device (Figure 6) was used in this study to measure the Dynamic Deflection Modulus (E_{vd}) of the base layer. After measuring E_{vd}, another testing attachment was used to measure the Dynamic Field CBR (CBR_d) (Figure 7), which replaces the traditional LWD loading plate.

The LWD working mechanism is based on two assumptions; 1) the material intended to be tested is a uniform elastic medium, 2) the applied pressure from the loading plate is uniform (Landge et al., 2017). After the falling weight impact is applied on the loading plate, the surface deflection can be measured using the accelerometer sensor installed at the bottom of the LWD (Nazzal, 2014). E_{vd} can be mathematically calculated through an in-built computer program using the following equation (Alshibli et al., 2005):

$$E_{vd} = \frac{k(1 - v^2)qr}{w_{ave}}$$

Where: k is the rigidity factor of the plate (which equal π/2), v = Poisson's ratio of the material, q = maximum contact pressure measured by an embedded load cell, r = plate radius, and w_{ave} = average deflections from three deflection readings for three LWD drop tests.

For CBR_d, it is mathematically calculated through an in-built computer program using the following equation (Zorn, 2011):

$$CBR_d = 87.3*S^{0.59}$$

Where: S is the deflection measured by LWD with the CBR_d attachment (in mm).

A ZFG 3.0 LWD was used to carry out both. The E_{vd} and CBR_d tests were conducted at the same stations evaluated by the NDG and along the shoulder of the road with minimum offsets to avoid changes in material characteristics affected by the former tests. Figure 8 presents E_{vd} and CBR_d data collected by LWD for both HW4 and Warman projects.

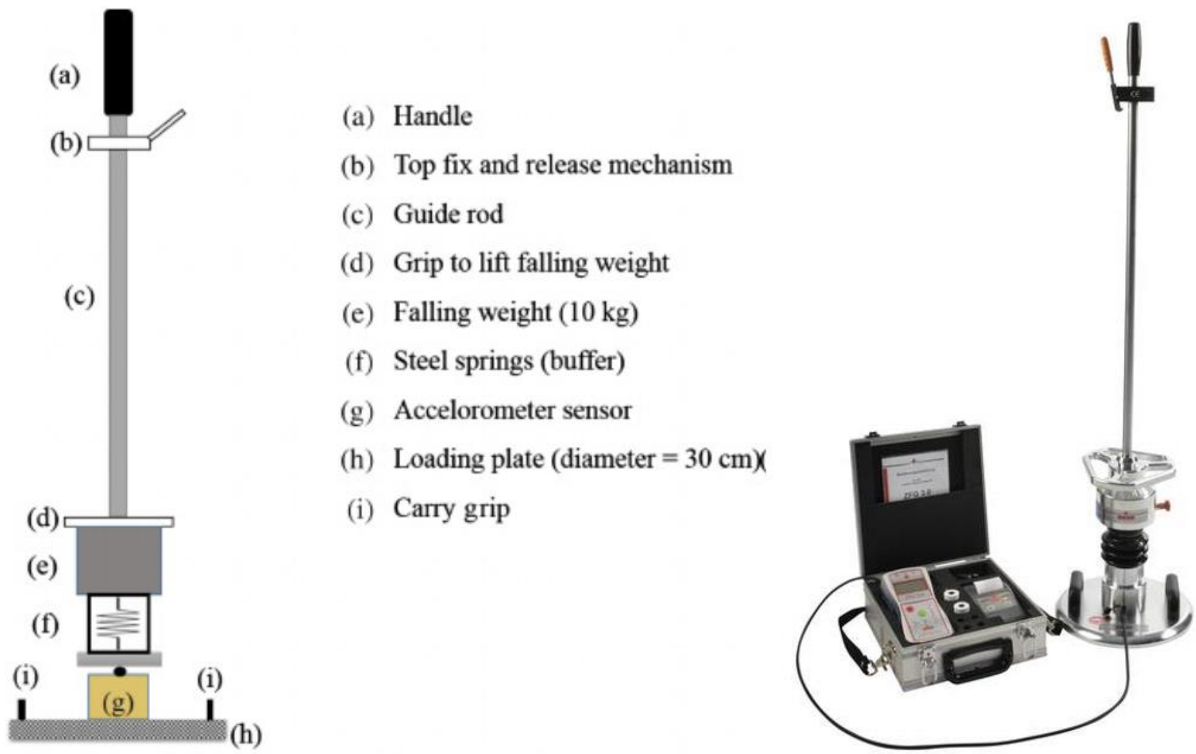

Figure 6: The ZFG 3.0 LWD components (Zorn,2018).

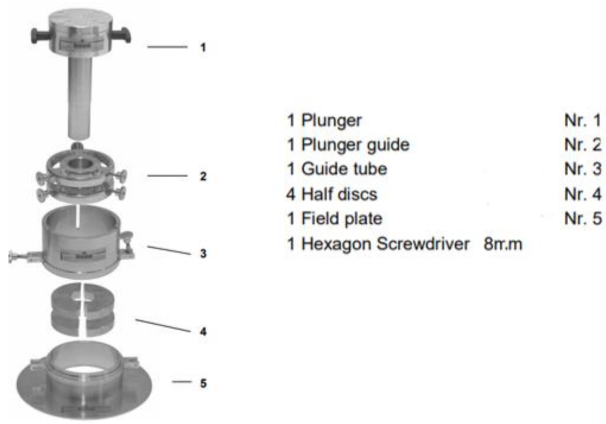

Figure 7: CBR$_d$ attachment (Zorn,2018).

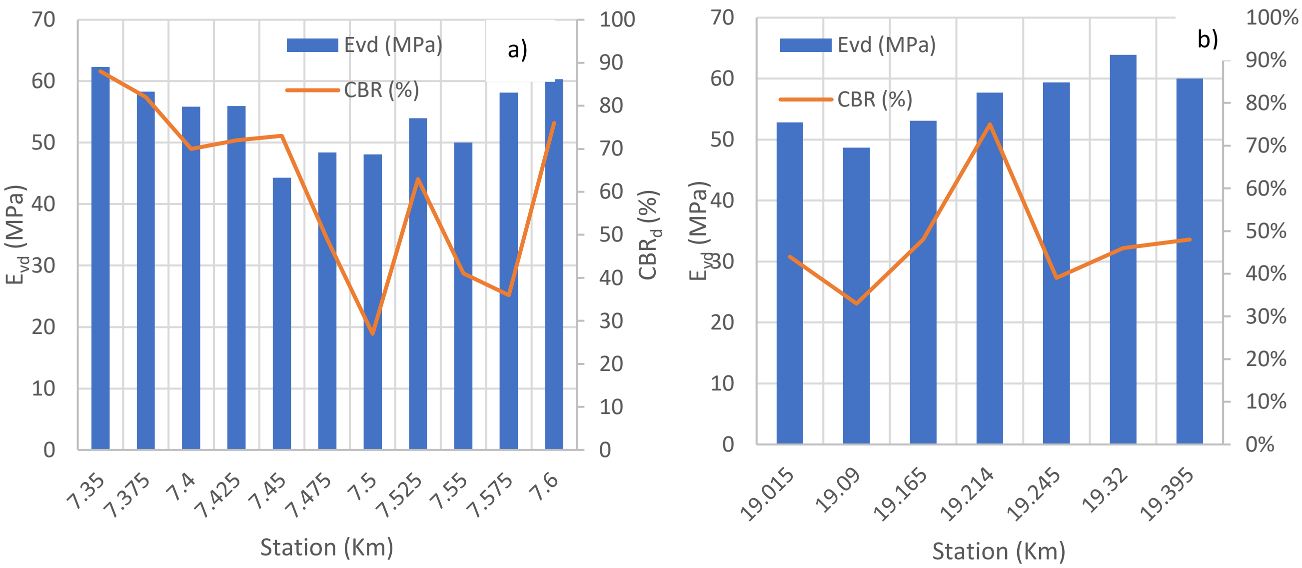

Figure 8: E$_{vd}$ and CBR$_d$ data collected by LWD for (a) HW4 project and (b) Warman project.

Discussion

As the two sites had relatively similar material characteristics (Table 1 and Figures 1 & 2), the tests data of both HW4 and Warman projects were combined to study the correlation between the tested parameters. Figure 9 compares E_{vd} measured by LWD and the NDG measurements of FDD at the same locations. As shown in Figure 9, E_{vd} and FDD had a significant scattered correlation even over a narrow range of values. The poor correlation between E_{vd} and FDD also was supported by the associated coefficient of determination (R^2) values from the linear regression analyses. The same poor correlation was noticed when CBR$_d$ measured by LWD was compared with the NDG field dry density measurements at the same locations (Figure 10).

Previous research studies developed an understanding about interpreting the contribution of several factors that could affect the modulus-based in-situ test results. Meehan et al. (2012), Tehrani and Meehan (2010), and Sawangsuriya et al. (2008) proved that MC and material density of compacted granular material has a high influence on the measured in-situ modulus values. The dependency of MC and material density can be mathematically addressed using multivariate regression analysis. A multivariate regression analysis was performed to include the effect of FDD and MC (independent variables) on E_{vd} and CBR_d values (dependent variables). Table 2 shows the effect of including the MC observed by NDG on R^2 values for both E_{vd} and CBR_d. Comparing the R^2 values reveals the importance of including MC to interpret E_{vd} and CBR_d data. Although the correlations of E_{vd} with FDD and CBR_d with FFD were poor, a notable increase in the R^2 values was obtained when including MC in the regression analysis.

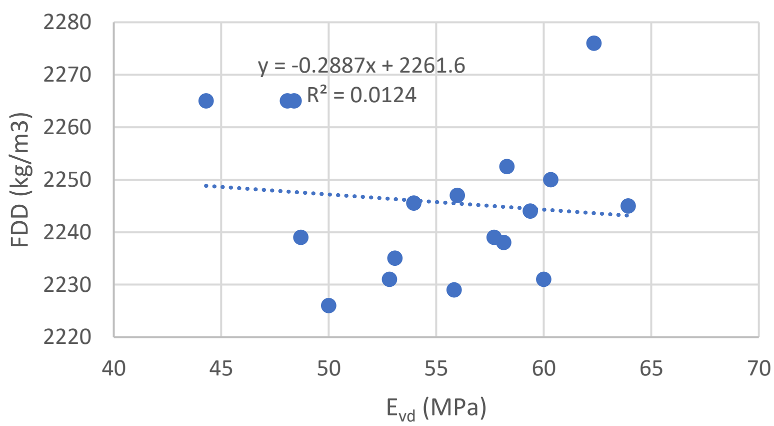

Figure 9: E_{vd} Vs. FDD results of HW4 and Warman projects combined.

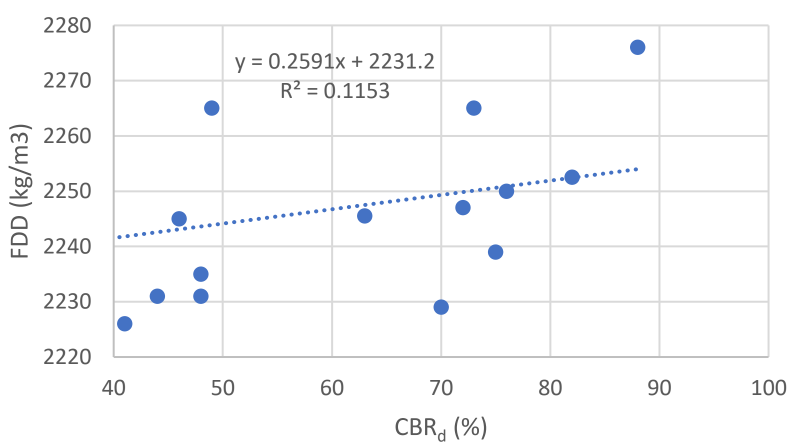

Figure 10: CBR_d Vs. FDD results of HW4 and Warman projects combined.

Table 2: the effect of including MC observed by NDG on R^2 values for both E_{vd} and CBR_d

R^2 Values			
E_{vd} Vs. FDD		***CBR_d Vs. FDD***	
MC Included	*MC not Included*	*MC Included*	*MC not Included*
0.1486	0.0124	0.1963	0.1153

Findings

This paper presented and compared the results of Light Weight Deflectometer (LWD) and Nuclear Density Gauge (NDG) tests to assess the compaction quality of pavement base layers. Tests were performed at two newly constructed road projects in Saskatchewan (Warman and HW4 projects). To simulate the construction practice, all tests were performed on already compacted base layers. The following findings were observed from the testing results:

- The LWD test results correlated poorly to the NDG results.
- Based on multivariate regression analysis, MC was found to be a significant parameter that affects the correlation between the NDG with LWD test results.

The test results presented in this paper were conducted on a similar type of base materials with limited amount of data. The data in this paper is part of ongoing research that will include testing different types of base layer materials in Saskatchewan. The presented analysis in this paper will be refined and updated when more field-testing data is available.

References

Alshibli, K, Abu-Farsakh, M, and Seyman, E. (2005). “Laboratory Evaluation of the Geogauge and Light Falling Weight Defletometer as Construction Control Tools.” Journal of Materials in Civil Engineering, Vol. 17 (5): 560-569.

Baltzer, S., Hejlesen, C., Korsgaard, H. C., and Jakobsen, P. E. (2009). “Practical use of light weight deflectometer for pavement design,” Proceedings of the 8th International Conference on Bearing Capacity of Roads, Railways and Airfields (BCR2A-09), University of Illinois at Urbana - Champaign, Champaign, Illinois, June 29 - July 2, 2009, 859-868.

Barksdale, R. D., & Itani, S. Y. (1994). Influence of aggregate shape on base behaviour. Transportation Research Board, (1227), 171–182.

Indexed, S., Gupta, S., Patni, S., Shahare, P., & Tech, M. (2017). Relationship between Field CBR and Dynamic Deflection Modulus for BC. 8(3), 546–553.

Lekarp, F., Isacsson, U., & Dawson, A. (2002). State of the Art. II: Permanent Strain Response of Unbound Aggregates. Journal of Transportation Engineering, 126(1), 76–83. https://doi.org/10.1061/(asce)0733-947x(2000)126:1(76)

Meehan, C. L., Tehrani, F. S., and Vahedifard, F. (2012). “A Comparison of Density-Based and Modulus-Based In Situ Test Measurements for Compaction Control,” Geotechnical Testing Journal, Vol. 35 (3): 387-399.

Meehan, C. L., Tehrani, F. S., and Vahedifard, F. (2012). “A Comparison of Density-Based and Modulus-Based In Situ Test Measurements for Compaction Control,” Geotechnical Testing Journal, Vol. 35 (3): 387-399.

Nazzal, M. (2014). National Cooperative Highway Research Program (NCHRP) Synthesis 456P: Non- Nuclear Methods for Compaction Control of Unbound Materials. Transportation Research Board, Washington, DC. DOI: 10.17226/22431

Rathje M, E. (2006). “Evaluation of Non-Nuclear Methods for Compaction Control.” Texas Department of Transportation, Center for Transportation Research at the University of Texas at Austin, Austin, TX.

Sawangsuriya, A., Edil, T. B., and Bosscher, P. J. (2008). “Modulus-suctionmoisture relationship for compacted soils.” Canadian Geotechnical Journal, Vol. 45 (7): 973-983.

Thompson M., 1989. Facteurs Affecting the Resilient Moduli of Soil and Granular Materials. Proc. Workshop on Resilient Modulus testing, State of Practices, Oregon State, University, Corvallis.

Zaman M., Chen D.-H. & Laguros J.G, 1994. Resilient Moduli of Granular Materials. Journal of Transportation Engineering, 120(6): 967-988.