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Field Evaluation of Nondestructive Tests in Measuring the Pavement Layers Density

H. Ziari, H. Behbahani, A. Izadi and H. Divandary
Faculty of Civil Engineering, Iran University of Science and Technology, Narmak, Tehran, Iran

Abstract: The aim of this study was field evaluation of nondestructive devices in measuring the density of road layers. Density may be considered as a reliable criterion for evaluating pavement quality and has a high level of importance in that it can ensure the proper performance of pavement at least prior the period of life-time. At present time, the most current and also accurate method to determine in-situ density of asphalt mixture is core sample method, however it has some disadvantages. As well as being costly and time consuming, core sample method causes some distress on the pavement surface and it is not possible to repeat the test for a specific location. In view of this, some attempts were made to develop new methods as alternatives for core sample method. And as such, nondestructive tests have grown into a huge area over the last few years. These tests including nuclear and nonnuclear nondestructive tests do not have the limitations of core sample method. In this study, field evaluation in a new constructed part of a highway was conducted using pavement quality indicator (PQI301) and Troxler nuclear gauge (Model HS-5001EZ). According to the results of validation tests for nondestructive devices (PQI and Nuclear devices), PQI device has sufficient reliability to determine density of asphalt mixture layer but Nuclear device is not reliable to determine density. The obtained results from validation of nuclear device revealed that it has sufficient reliability to determine density of soil layers. Also it was found that the role of calibration procedure in obtaining correct readings From PQI device is highly critical.

Key words: Core sample, PQI301, nuclear gauge, calibration, compaction

INTRODUCTION

Density can be characterized as one of the most important parameters in the design and implementation of asphalt pavement. Selection of an appropriate compaction level is highly critical to achieve the desired performance of pavement.

After spreading asphalt mixtures on the road bed, it should be compacted by rollers to achieve appropriate level of density. Before coming the nonnuclear nondestructive devices, there were only two methods to determine the density of fresh asphalt. The first, core sample method, a destructive method, is on the basis of coring and the second method employs a portable nuclear nondestructive device. Although, the first method is the most accurate method for determination of density, it is costly and time-consuming and is preferred to be applied as the last option. In this method, samples, first, should be sent to laboratory and since, it is likely that there is a notable distance between site and laboratory, it may take from 1 h to 1 day. In addition to the above, when the asphalt is still warm, the method does not provide the possibility to control the density during different stages of rolling process (Shane *et al*., 2004).

In recent years, the application of nondestructive tests has been increased, particularly to evaluate pavement quality and control the compaction process of pavement layers. Nuclear density gauge can be used to determine in-situ specific gravity and moisture content in accordance with ASTM D2922-D3017. For this purpose, this device employs emission of gamma-ray and neutron particles to compute specific gravity and moisture content, respectively. It offers two advantages over the constructive methods: the high speed and not being destructive. A significant amount of studies have been conducted on the results obtained from nuclear density gauge by different manufacturers. Site location, materials type and device model may have appreciable effects on the results (Khani, 2004). Nuclear density gauge is much faster and extremely cost-effective compared to core sample method, however, it is subjected to the following disadvantages: (1) use of a radioactive source requiring high adjustment and special training of experienced operators, (2) getting permit, renovation of equipment, technicians training and complicated operation. In order to overcome many of the disadvantages of nuclear density gauge, nonnuclear nondestructive device has been developed as a safer, lighter and more cost-effective

Corresponding Author: Amir Izadi, Faculty of Civil Engineering, Iran University of Science and Technology, Narmak, Tehran, Iran Tel: +982177240281 Fax: +982177240089

alternative (Karlsson, 2002). Also Karlsson (2002) found that water content (more than 15%) in asphalt layer effects on the instrument's reliability. Pedro Romero found in his study that, to measure density in the field, a calibration procedure that is mixture specific should be carried out and also indicated that it is necessary to correct for changes in moisture and temperature (Pedro Romero, 2002). Robert Schmitt found in his study that non-nuclear devices could be used for quality control, however they were not recommended for quality assurance or acceptance testing (Schmitt, 2006). This study is aimed at evaluating the performance of nondestructive devices using conducting field tests and statistical analysis of obtained results.

MATERIALS AND METHODS

In order to perform field studies and evaluate the performance of two nondestructive devices, namely PQI and nuclear, some tests were performed in 2008 at the specified segments of newly established Tehran-Pardis Freeway.

Calibration of PQI device before taking measurement operation: The role of calibration procedure in obtaining correct readings is highly critical. It should be noted that the calibration of the device for each project is necessary; therefore, Manufacture Company of PQI has presented different calibration method. In this study, normal method has been employed to calibrate the device. This is mainly due to the fact that other methods require density of unrolled asphalt mixture and prediction of the density of implemented mixture by experts as input data.

Five core samples as reference data were taken from asphalt mat and the densities of core samples were calculated. The results are shown in Table 1. The readings from PQI are represented in Table 2. From the results in Table 1 and 2 calibration process was done.

The results obtained from reading of density by PQI and coring devices are as follows:

- Mean of coring results: 2181 kg m^{-3}
- Mean of PQI reading: 2010 kg m^{-3}
- Difference between coring results and PQI reading: 171 kg m^{-3}

This modification value means that 171 should be added to Mean of PQI reading (Fig. 1).

Calibration of nuclear device before taking measurement (in asphalt layer): The nuclear device utilized in this study is HS-5001EZ and produced by TROXLER Ltd. If the difference between the results of successive measurement is minor, the device is calibrated and ready to be used.

Table 1: The obtained data from coring at five stations for device calibration

Sample No.	Weight at air (g)	Weight at water (g)	Bulk specific gravity (kg m^{-3})	Mean of core values (kg m^{-3})
1	692.6	375	2181	2181
2	860.3	466	2182	
3	725.4	394	2189	
4	760.9	411	2175	
5	667.0	361	2180	

Table 2: Readings of PQI device at five stations and different local positions (kg m^{-3})

Location	Location 1	Location 2	Location 3	Location 4	Location 5
Centre	1987	2002	2019	2025	1970
Location at 2 h	2008	2001	2015	2023	2026
Location at 4 h	2005	2019	2019	2006	2002
Location at 5 h	1996	2027	2017	2025	1985
Location at 10 h	2013	2025	2036	1988	2003
Total	10009	10074	10106	10067	9986
Mean	2002	2015	2021	2013	1997

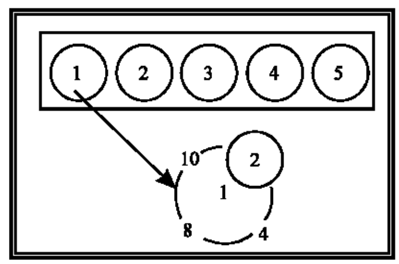

Fig. 1: Reading location layout and PQI measurement pattern

Field measurements on the asphalt layer: In this study, 10 sections with the width of 3.65 m that have been placed 7 m apart from each other were selected. Afterwards, 6 points were specified at each section and finally the density was computed for 60 points using two methods, namely nuclear and nonnuclear non-destructive methods (Fig. 2). The reading from each method is shown in Table 3 that in each section, 6 readings were done by both nuclear and PQI devices and one reading was done by coring device. Finally the density of asphalt mat was computed for 60 points to be enough for proper statistical analysis.

Field measurements on the soil surface: The density of subgrade layer was determined at the segment of Tehran-Pardis Freeway and the results are presented in Table 4, then, the density values obtained from sand bottle test have been utilized as a criterion for validation of outputs of nuclear device (Fig. 3).

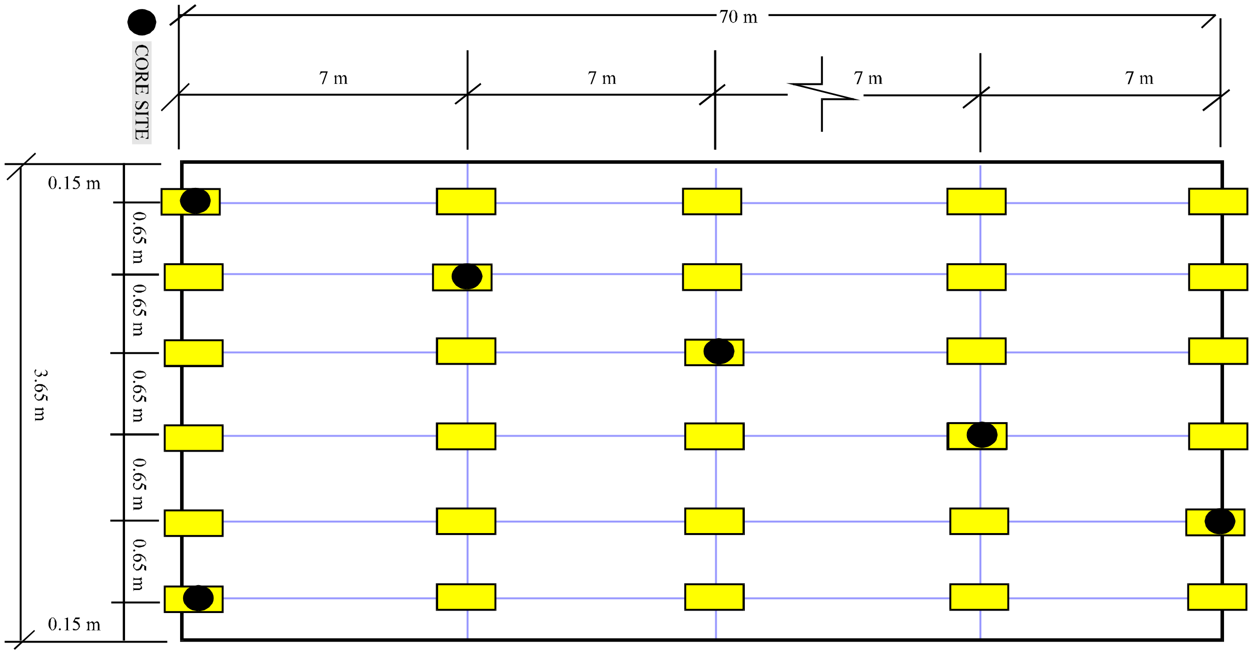

Fig. 2: Test section layer for asphalt layer density measuring

Table 3: Results of field measurements by three methods

Stations	Nuclear	PQI	Coring device
	($kg\ m^{-3}$)		
Station 1			
1	1956.3	2130	
2	1814.6	2197	2181
3	1669.8	2188	
4	2115.2	2141	
5	1980.1	2237	
6	2010.2	2181	
Station 2			
1	1710.8	2083	
2	2008.9	2177	2182
3	1814.8	2204	
4	2072.2	2157	
5	1940.5	2213	
6	1936.7	2140	
Station 3			
1	1673.6	2068	
2	1935.7	2160	
3	1694.3	2158	
4	1966.8	2183	2189
5	2131	2231	
6	1941.8	2172	
Station 4			
1	1909.2	2122	
2	1942.8	2150	
3	1912.3	2128	
4	1963	2224	
5	1991.3	2294	2182
6	2068.4	2213	
Station 5			
1	1910.8	2166	2181
2	2045.7	2200	
3	1809.8	2138	
4	2079.2	2226	
5	2099	2222	
6	1814	2166	2175
Station 6			
1	1941.4	2080	
2	1792.2	2139	2182
3	1801.2	2150	
4	1948.4	2188	
5	2079.9	2153	
6	2009	2073	
Station 7			
1	1695.2	2130	
2	1902.6	2138	
3	1757.4	2131	2174
4	2004	2172	
5	2061.1	2210	
6	1763.7	2143	
Station 8			
1	1751.5	2110	
2	2080.2	2091	
3	1978.9	2160	
4	1984.3	2149	2180
5	1985.5	2096	
6	2051.1	2090	
Station 9			
1	1603.3	2077	
2	1988.4	2095	
3	1858.7	2133	
4	2041.2	2233	
5	2090.5	2212	2175
6	2058.2	2237	
Station 10			
1	1618.6	2173	2181
2	2008.3	2149	
3	1846	2132	
4	2040	2184	
5	1999	2178	
6	1985.2	2180	2182

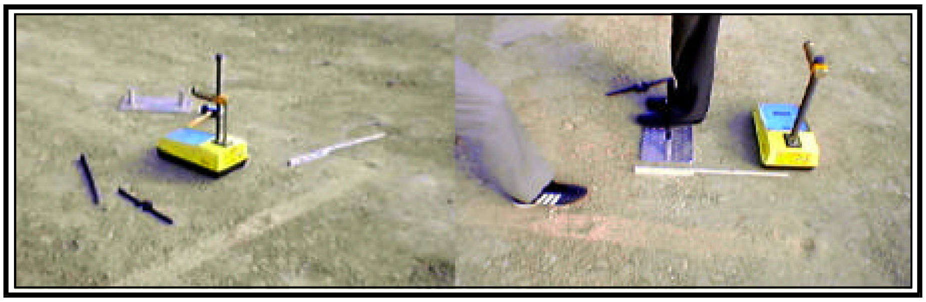

Fig. 3: Taking measurement for 20 points in soil sub grade layer using nuclear device

Table 4: Determination of density of soil layer using sand bottle test

Point No.	1	2	3	4	5
Density	1790	1794	1800	1810	1808

Table 5: Measures of density for 20 points in soil subgrade layer using nuclear device

Station	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
kg m^{-3}	1878	1829	1757	1810	1959	1910	1898	1738	1881	1914	1925	2015	1817	1777	1803	1779	1780	1835	1844	1811

Afterwards, determination of density by nuclear device has been made at 20 points with the interval of 50 cm and the results are shown Table 5.

RESULTS

Analysis of obtained results from different methods and presenting some practical approaches for the optimal use and reduction of error: The obtained results from measurement of PQI and nuclear devices at the edges of segments were lower than that of at the medium of segments. The same result was observed in the conducted research by North Carolina Department (Shane *et al*., 2004). SPSS Software has been applied to analyze data for the purpose of validation of non-destructive devices.

The function used for conducting statistical test is called test statistic and varies in different conditions. In what follows, the relevant test statistic to each test is introduced. In parametric tests like T-student test, some assumptions are made concerning population distribution. For instance, T-student test is on the basis of this assumption that the societies will follow normal distribution. T-student test aimed to obtain a better understanding of unknown parameters of statistical society is normally employed to evaluate the differences between means of two societies which are under analysing. Since, the distribution of considered population is not known in nonparametric tests, accordingly, t-student test can not be applied, because it is based on the normal distribution. In such conditions, nonparametric Mann-Whitney test may be used instead. The other difference between parametric and nonparametric test is that nonparametric tests employ median in lieu of mean so as to compare societies. The T-test used to compare means of normal societies is strongly dependent on the hypothesis of equality of variances and normal distribution of statistical society. Therefore, different solutions to this problem have been proposed in the literature. One way to solve this problem is to use equivalent nonparametric tests. It should be mentioned that nonparametric tests investigate the differences between two societies through evaluation of differences between median of two societies.

Analysis for validation of PQI and nuclear devices in the asphalt layer: Comparison of two statistical societies in the parametric tests is based on the means of these two societies. Since, the considered societies in the current research follow normal distribution, thus, parametric tests (T-test in this research) was employed to compare two societies.

If the amount of significant level (sig) in the test output is less than 0.05, it can be concluded that the assumption of equality of two societies is not valid with the probability of 95%. On the other hand, if amount of significant level (sig) is more than 0.05, then with the probability of 95%, the two societies are close to each other.

In accordance with the above results in Table 6, the measured values by PQI and coring devices did not represent significant difference with the probability of 95%. However, the measured values by nuclear and coring devices showed sensible difference with the probability of 99%.

Table 6: Output of SPSS software for validation of PQI and nuclear devices using core sampling results as precise values

Paired samples statistics	Mean	N	SD	SE mean
Pair 1				
PQI	2173.00	40	43.8	6.9000
Core	2179.84	40	4.8	0.7623
Pair 2				
Nuclear	1955.87	40	116.7	18.4600
Core	2179.84	40	4.8	0.7600

Paired samples correlations	N	Correlation	Sig
Pair 1			
PQI and Core	40	0.202	0.210
Pair 2			
Nuclear and core	40	0.014	0.931

				99% confidence Interval of the difference				
Paired samples test	Mean	SD	SE mean	Lower	Upper	t	df	Sig. (2-tailed)
Pair 1								
PQI and Core	-6.81	43.1	6.80	-25.3	11.63	-1.0	39	0.324
Pair 2								
Nuclear and core	-224.00	116.8	18.46	-274.0	-174.00	-12.1	39	0.00

Practical hints for reduction of error and optimal application of PQI device:

- It should be noted that PQI has appropriate capability to identify points with improper compaction such as edges or places with insufficient compaction
- It is recommended to avoid taking measurement at the edges. This is due to the fact that density at these points is lower than other points and accordingly it causes some error in the calculations
- Do not contact with device during measurement, because it causes some errors in the reading of the device
- Rainy weather and high moisture content of pavement may result in error in the reading of PQI device
- PQI device should be calibrated according to the type of asphalt before starting operation
- Although, there are different types of calibration methods including empirical methods, it may be advisable based on the experiences of executive team to employ normal which is on the basis of comparison with coring results (the most precise method for determination of density). In other words, since other methods require density of unrolled asphalt mixture and prediction of density of implemented mixture by experts as input data and considered sites often do not meet the above requirements, thus, normal method is proffered

Validation of nuclear device to measure density of soil layers: The sand bottle test has been run five times to properly determine density of subgrade layer. Then, measurement was made by nuclear device for 20 times through using direct distribution method. According to the results of sand bottle test (Table 4), it can be concluded that these data do not follow normal distribution (five observations is not sufficient for judging whether the society is normal or not), whereas, nuclear data follows normal distribution with the possibility of 95%.

Since, the assumption of equality of variance of two societies can not be met with the probability of 95%, therefore employing parametric t-student test is not justified. Hence, equivalent nonparametric t-student test, namely Mann-Whitney was utilized. The main difference between parametric and nonparametric tests lies in that the assumption of normal distribution of data is not required in the nonparametric tests. In recent years, these methods have been dramatically widespread and this is because of type of society distribution which is not often given. It should be mentioned that nonparametric tests evaluate the differences between two societies through assessing the difference between the median of two societies.

The output of Mann-Whitney test which is aimed at evaluating the difference between median of two statistical societies (in the current study: sand bottle method and nuclear device) revealed that the value of sig (0.126) is greater than 0.05 and accordingly the assumption of median equality of two statistical societies is reasonable with the probability of 95%. Moreover, other qualified nonparametric tests also confirmed the above finding.

In Table 7, the validation of the obtained results from nuclear device using nonparametric Mann-Whitney, Moses and Kolmogorove tests are illustrated. In all tests, it is assumed that null hypothesis implies equality of medians of two statistical societies (the results of sand bottle and nuclear methods) and the opposite hypothesis represents non-equality of medians. Hence, the obtained

Table 7: Output results relevant to nonparametric mann-whitney, moses and kolmogorove tests as alternatives for t-student test

Mann-whitney test	Group	N	Mean rank	Sum of ranks
Measurements	Nuclear	20	14.13	282.5
	Sand bottle	5	8.50	42.5
	Total	25	-	-
Test statistics				Values
Mann-whitney U				27.500
Wilcoxon W				42.500
Z				-1.529
Asymp. Sig (2-tailed)				0.126
Exact sig (2*(1tailed sig))				0.129
Moses test		Group		N
Measurements		Nuclear		20
		Sand bottle		5
		Total		25
Test satatistics				Values
Observed control				25
Group span sig (1-tailed)				1
Trimmed control				23
Group span sig (1-tailed)				1
Outliers Trimmed from each End				1
Two-sample kolmogorov-smirnov test			Group	N
Measurements			Nuclear	20
			Sand bottle	5
			Total	25
Test statistics				Values
Most extreme absolute				0.650
Differences positive				0.250
Differences negative				-0.650
Kolmogorov-smirnove Z				1.300
Asymp. sig (2-tailed)				0.068

results indicated that nuclear device can be considered a reliable method to determine density of soil layers.

DISCUSSION

Based on the results of statistical hypothesis testing in this study, use of the PQI model 301 for both Quality Control (QC) and Quality Acceptance (QA) testing is sufficient but it found that calibration should be done to achieve accurate results. Numerous studies on the suitability of non-nuclear pavement density gauges for QC and QA testing of pavements were reviewed. Most of these studies have concluded that non-nuclear gauges are suitable for contractor QC but not recommended for QA. Also It was found that the PQI appears to be an acceptable alternative to the nuclear gauge for density profiling, even if not calibrated (Sargand *et al*., 2005). A study prepared by the University of Utah indicated that, Calibration of these devices to local materials and conditions is critical to obtain accurate results. Whenever practical, the calibration should be done using a test section (Pedro Romero, 2002).

The following conclusions are drawn from the results of this study:

- According to the results of validation tests for PQI and Nuclear devices, indicated that PQI device has sufficient reliability to determine density of asphalt mixture but nuclear device is not reliable to determine density
- Due to the negative difference between mean measurements of nuclear and coring devices, it can be concluded that the measured values by nuclear method are lower than that of by core sample method with the probability of 99 % and include zero. While, this difference for nuclear and core sample method does not include zero and is negative. Hence, the validation results of PQI and nuclear devices indicated that contrary to nuclear device, PQI device has sufficient reliability to determine density of asphalt mixture
- The obtained results from validation of nuclear device revealed that it has sufficient reliability to determine density of soil layers
- It should be noted that PQI has appropriate capability to identify points with improper compaction such as edges. It is recommended to avoid taking measurement at the edges. This is because the density at these points is lower than other points and accordingly it causes some error in the calculations
- PQI device should be calibrated according to the type of asphalt before starting operation
- Although, there are different types of calibration methods including empirical methods, it may be advisable based on the experiences of executive team to employ normal which is on the basis of comparison with coring results (the most precise method for determination of density). In other words, since other methods require density of unrolled asphalt mixture and prediction of density of implemented mixture by experts as input data and considered sites often do not meet the above requirements, thus, normal method is proffered
- The required time for calibrating the Nuclear device is much affected by type of project and used materials (asphalt, soil)
- Finally, it is also noteworthy that the most precise and reliable method to determine the pavement layers density is core sample method

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