USE OF PAVEMENT QUALITY INDICATOR (PQI)
FOR QUALITY CONTROL TESTING

Materials Engineering
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L. ADAMSON
Graduate Engineer

MAIN ROADS Western Australia
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CONTENTS

1. INTRODUCTION

In order to satisfy specifications, road construction contractors have to ensure that asphalt meets specified compaction levels by core sampling. The typical requirement is for ten cores per lot. Coring however is a destructive procedure which can result in weaknesses in the pavement. It is normally done once the pavement section is complete and results are not available until the next day at the earliest, complicating any corrective measures.

The introduction of non-nuclear density gauges into the pavement industry has opened up the possibility of using the devices for Quality Control measures to improve pavement quality and subsequently reduce the need for coring. This paper describes a preliminary investigation conducted with a non-nuclear density gauge on work undertaken on Contract 358/06, Reid Highway, from West Swan Rd to Roe Highway. The device trialled was the Pavement Quality Indicator 301 (PQI) produced by TransTech Systems, Inc.

2. NON-NUCLEAR DENSITY GAUGES

Non-nuclear density gauges work by sending an electrical sensing field into the pavement. The reading is influenced by the overall dielectric constant for the asphalt material, which is a combination of the dielectric constant of components in the pavement multiplied by their volumes. Because the dielectric constant for air is constant and the dielectric constant for hot mixed asphalt (HMA) is known over a narrow range, the density of a pavement can be calculated (Diefenderfer & Smith 2008).

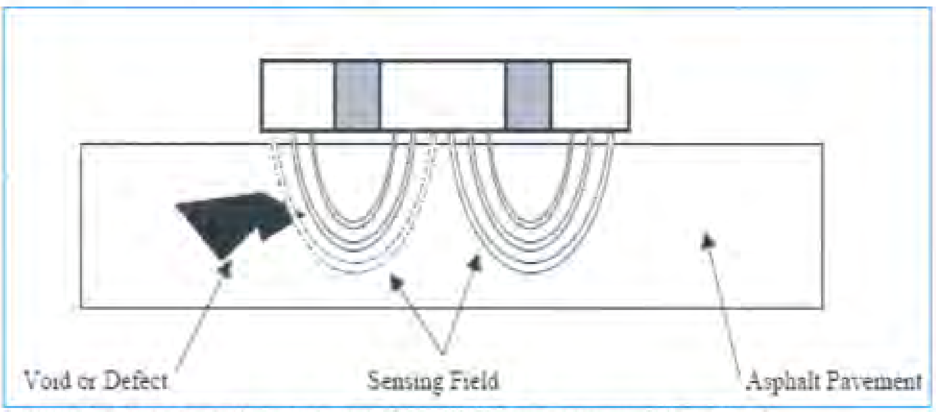


Figure 1: Cross-sectional view of base plate measurement method.

3. PREVIOUS STUDIES

Studies conducted by Williams have shown that paint, sand and water on the asphalt surface can impact on the readings obtained with non-nuclear density gauges, so it is important to ensure that they are removed or avoided. Williams noted that orientation of the gauge can also impact on readings, so a consistent orientation is recommended, preferably parallel to the direction of paving (Williams 2008). A detailed study by Kvasnak, Williams, Ceylan and Gopalakrishnan found several mix and project specific factors affect electromagnetic gauge readings and recommend utilizing a test strip in order to determine an appropriate adjustment factor (Kvasnak 2008).

When analysing the raw density readings Williams described the PQI as being relatively insensitive to actual changes in density, and required a calibration procedure that forced the detection of density fluctuations (Williams 2008). All other studies reviewed concurred with the need for a calibration procedure. Schmitt, Rao and Von Quintus found correlation between true density and raw non-nuclear density readings was optimal to develop accurate calibration factors (Schmitt et al 2007).

The majority of the researchers reviewed agreed that non-nuclear gauges in general are not an acceptable alternative to coring for Quality Assurance purposes (taken as acceptance testing). This is due to the number of environmental and project specific factors that can affect measurement accuracy. However most researchers agree that the PQI seems to be a suitable tool for Quality Control purposes (taken as process control) if it has been properly calibrated.

4. PURPOSE AND SCOPE

The purpose of Main Roads conducting this study was to determine a suitable calibration method for the PQI meter for use as a Quality Control tool. The initial phase will involve comparing the readings obtained using the PQI non-nuclear density gauge with core density measurements obtained from the asphalt contractor. A field study of a full depth asphalt project has been used to obtain the data. The study to date has been restricted to comparing base course and intermediate course PQI readings with core density measurements. The analysis will include comparisons by percent difference, correlation analysis, hypothesis testing of offset values and comparing mean compaction.

5. CALIBRATION

A number of methods are available for use in calibrating non-nuclear impedance gauges. A correlation approach, drawn from preceding investigations, was adopted as it was favourably evaluated by the researchers reviewed. The other two methods used in this phase of the study are based on the core calibration method outlined in the PQI meter operating guide, and in accordance with AASHTO Standard Method of Test for Density of In-Place Hot-Mix Asphalt (HMA) Pavement by Electronic Surface Contact Devices, AASHTO Designation TP 68-04, Method C.

To determine a calibration factor using the correlation method the relationship between the raw PQI data and the core density measurements was graphed. A trend line was then fitted to the data to establish the level of correlation. A high degree of correlation is required for an accurate calibration factor.

For the procedure outlined in the PQI meter operating guide, five locations were chosen within a 3m by 1m plot and PQI readings were taken at each location for a five reading average density, following the pattern shown in Figure 2 below.

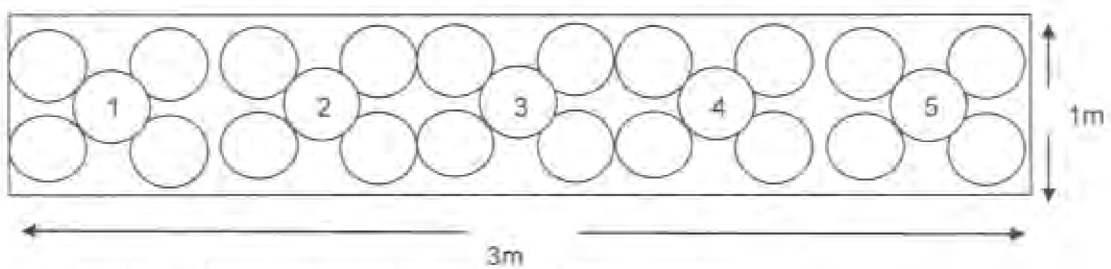


Figure 2: PQI reading location layout for calibration readings

Cores were then taken within the central circles for comparison. An offset value was calculated from the average differences in the gauge and core densities based on the five readings.

The other method of calibration explored was similar to the method outlined above whereby the offset was derived from the average differences in the gauge and core densities, however all core density measurements and corresponding PQI readings taken across the lot were used to determine the offset.

6. DATA COLLECTION

The asphalt mixes tested were produced and placed in Perth, Western Australia, during January and February of 2010. The mixes were supplied by the same asphalt provider and all mix designs complied with MRWA specifications.

Surface preparation was according to AASHTO TP 68-04 which involved ensuring no visible moisture was present on the surface of the asphalt, and where surface debris or paint was evident it was brushed clear or avoided. The PQI meter was used in the five reading average mode with readings taken parallel to the direction of paving.

Testing on the full depth asphalt project on the Reid Highway Extension was performed on asphalt mix layers overlying a crushed limestone sub-base, consisting of:

- 20mm MRWA base course placed at a thickness of 70mm
- three layers of 20mm MRWA intermediate course placed at a thickness of 75mm for each layer

The selection of layer type is required as part of the initial calibration of the PQI unit along with depth settings for layer thickness. To allow for construction tolerances, and ensure the PQI meter only determined the density for the layer of interest, each layer was tested at an instrument setting of 10mm less than the specified thickness.

Preliminary testing was done by lot basis with five readings taken for calibration and coring, nine readings taken for comparison and coring, and a further nine readings for comparison only as shown in Figure 3. All test locations were selected randomly across the lot.

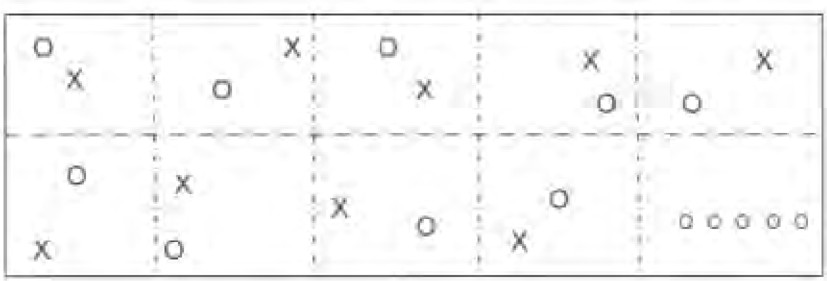


Figure 3: Example test layout for lot testing.

O – Core and PQI sites
X – Additional PQI sites

Density readings with the PQI were recorded by staff of MRWA Materials Engineering Branch and cores were taken and analysed by the asphalt contractor. The coring locations on the Reid Highway Extension were stipulated by MRWA for direct comparison between core densities and PQI measurements.

7. RESULTS AND DISCUSSION

Results have been stored on TRIM File 09/5494 within the Main Roads document management system.

7.1 Percent Difference

The percent difference between the raw PQI data and the core density measurements were determined by the following method.

$$\%\ difference = \left| \frac{Raw\ PQI\ value - Core\ density}{Core\ density} \right|$$

These values were then used to determine the average percent difference and standard deviation of the data. The results shown in Table 1 reveal that the PQI readings are approximately 20% lower than the core densities. While the difference in the two values is quite large, the low standard deviation indicates that the difference is consistent.

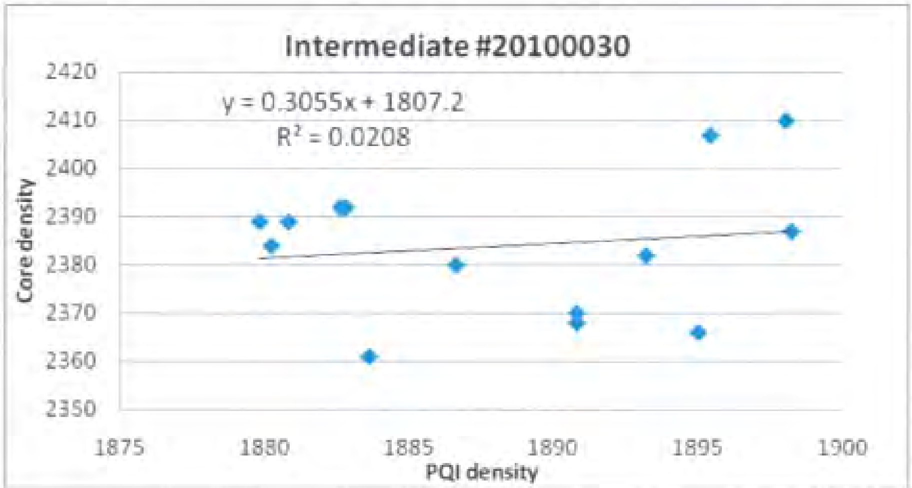
Table 1: Average % difference and standard deviation based on absolute values.

Project			
Reid Highway	**Average % difference**	**Standard deviation**	**Number of sites**
Base course			
Sample # 20100029	20.85	0.81	23
Intermediate course			
Sample # 20100030	20.79	0.52	14
Sample # 20100061	20.43	1.19	14
Sample # 20100070	19.70	0.83	14

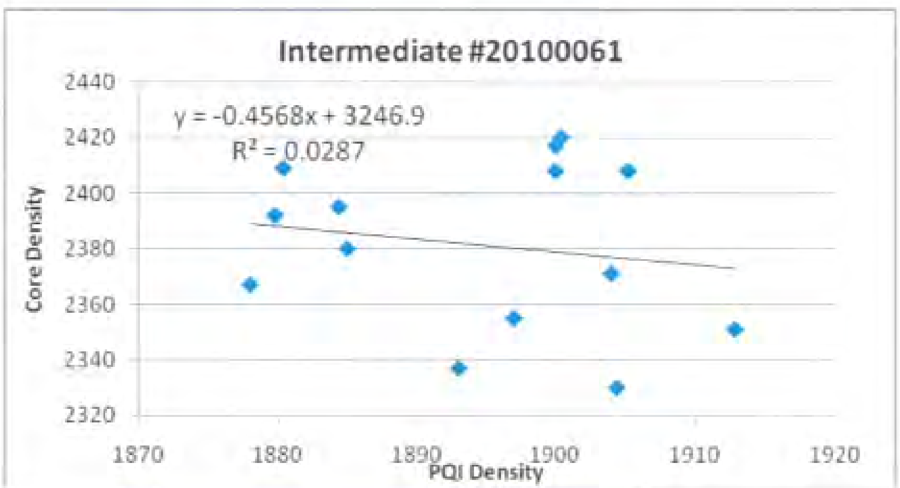
A slope correction factor may have been necessary if the findings had shown a greater variation across the samples. The results however suggest that it would be reasonable to adopt an additive shift alone to correct the raw PQI readings to reflect core density measurements.

7.2 Correlation

Studies conducted by Diefenderfer and Smith (2008) have shown that the relationship between core density measurements and PQI readings can be used to calibrate the PQI meter if there is a high degree of correlation between the results. The values obtained from the PQI meter for both the single reading mode and the five sample average mode were plotted on a scatter plot against the core densities to determine the degree of correlation (Table 2). Figures 4a, 4b and 4c show the correlation between core density measurements and the PQI meter five sample average mode using data from the Reid Highway site.



(a)



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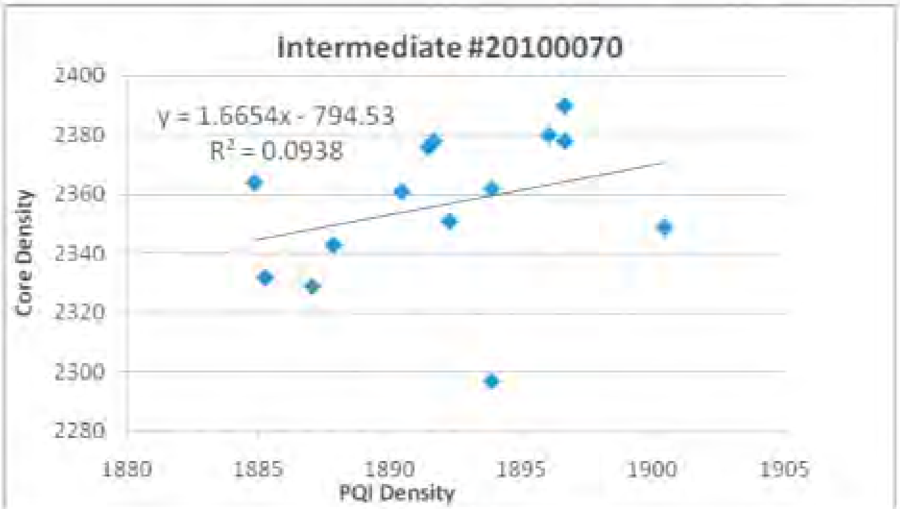

(c)

Figure 4: Correlation charts for intermediate course on Reid Highway: (a) coring reference #20100030, (b) coring reference #201000610 and (c) coring reference #20100070

Figures 4 shows that the values obtained with the PQI on the Reid Highway Extension project had a poor correlation with the values determined from the core samples.

Previous studies by Kvasnak had indicated that a correlation using the single reading mode was suitable for quality control, and Diefenderfer & Smith found the single reading mode provided a better device-to-device comparison. However as can be seen in Table 2, when the values for the PQI using both the single reading mode and the five sample average mode were analysed, the correlation with the core samples was very low in both instances.

Table 2: PQI and core correlation.

	Correlation - r^2	
	One reading	Five reading average
Base course		
Sample # 20100029	0.2158	0.1884
Intermediate course		
Sample # 20100030	0.0066	0.0208
Sample # 20100061	0.0251	0.0287
Sample # 20100070	0.01918	0.0938

Based on the correlation results it was determined that the relationship between the core densities and the PQI readings was too weak to be used for calibration purposes.

7.3 Offset

After considering the correlation and percent difference analysis the offset method was considered the most appropriate to correct the raw PQI data. Two methods were considered as means of achieving an accurate offset. The first was by using the core calibration method described in the PQI manual, with the difference between five core sample densities and the corresponding PQI readings being used to calculate an average offset. The second method adopted was by averaging the difference between all of the core sample densities within a single lot and the corresponding PQI readings to calculate the offset. As can be seen in Table 3 the offset values differed slightly.

Table 3: Average difference calculated for offset value.

	Average difference		
Reid Highway Project	**Five cores**	**All cores**	**Number of core sites**
Base course			
Sample # 20100029	476	497	23
Intermediate course			
Sample # 20100030	504	496	14
Sample # 20100061	495	487	14
Sample # 20100070	482	465	14

To determine which offset value related best to the core density measurements a paired t-test was conducted on the raw PQI data and both sets of amended data. The t-test was conducted to determine if the density obtained using the PQI was statistically different from the density obtained from the cores (Table 4).

The hypothesis that the difference between both density values is zero was tested at a 95% confidence level, therefore a significance level of $\alpha = .05$ was used. A p-value less than 0.05 is significant and therefore the results can be considered to be statistically different.

Table 4: Comparing the significance of the PQI readings with core density measurements by calculating p-Values for the paired t-test for the different offset values.

	p-values		
Reid Highway Project	**Raw PQI data with no offset**	**Five cores offset**	**All cores**
Base course			
Sample # 20100029	4.8E-33	0.0017	1
Intermediate course			
Sample # 20100030	5.8E-28	0.0627	0.937
Sample # 20100061	2.3E-20	0.3782	0.984
Sample # 20100070	6.6E-19	0.0205	0.938

As can be seen from Table 4 a very low p value was returned for the raw PQI data, clearly indicating the need for an adjustment factor before comparisons with the core density measurement can be made. The p values obtained for the five core offset were improved, however for the basecourse sample and third intermediate sample the core and PQI data cannot be compared as they would be considered to be statistically different. The offset determined from the average of all cores gave the best result indicating that there was no significant difference between the adjusted PQI data and the core density measurements.

7.4 Mean compaction

Using the offset determined from the average of all cores to adjust the PQI data comparisons were then made between the mean compaction levels achieved. The reference Marshall Density was used to determine the percentage compaction of the core samples and the adjusted PQI measurements by the following method.

$$\%\ compaction = \left| \frac{adjusted\ PQI\ data}{Marshall\ Density} \right| *100$$

The mean compaction and standard deviation was then determined for the core density measurements and the adjusted PQI data (Table 5).

Table 5: Mean compaction and standard deviation for PQI and core measurements.

Reid Highway Project	Mean Compaction %		Standard deviation %		Number of readings	
	PQI	Core	PQI	Core	PQI	Core
Base course						
Sample # 20100029	97.9	98.1	0.54	1.12	43	23
Intermediate course						
Sample # 20100030	99.1	99.1	0.28	0.60	23	14
Sample # 20100061	99.6	99.7	0.47	1.26	23	14
Sample # 20100070	98.6	98.6	0.31	1.05	23	14

The mean compaction results from the PQI readings corresponded well with the mean compactions achieved for the core samples. The standard deviation for the PQI meter was less than the standard deviation for the cores, however both were very low and indicate a high level of consistency in reporting of compaction levels achieved for the asphalt.
These results also help to confirm the offset.

8. CONCLUSIONS

The study was limited to determining a calibration method suitable for 20mm basecourse and 20mm intermediate course. It is recognised that further research will need to be conducted to determine a suitable method for other asphalt mix designs.
From the first phase of the study it has been concluded that the offset method using an additive shift has given the best correlation with the core densities for the asphalt mixes trialled.

9. RECOMMENDATIONS

Using the calibration method established, compare corrected PQI densities taken on a lot basis with core density to investigate comparison for QC purposes.

Suggested procedure;

1) Determine calibration offsets for 14mm intersection mix and 20mm intermediate course (for full depth asphalt) on Great Northern Highway Project, Herne Hill as outlined above. The location of the 10 calibration readings will be the same as the 10 core sites. The offset value will be based on the difference between the PQI readings and the 10 core density measurements.
2) Using the calibration offset determined calibrate the PQI meter
3) Take 20 random PQI readings per lot on subsequent layers of 14mm and 20mm mixes.
4) Compare PQI results (after adjustment by the offset value determined) for subsequent layers with the core density results for comparison. The location of the core sites should not be the same as the PQI readings.

Given that the above approach gives favourable results, trial test procedure on DGA, SMA and OGA wearing courses.

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