<table>
<tr>
<td>
Author
Thomas Karlsson
Skanska Asphalt and Concrete
Technology Region – VTO South
380 30 ROCKNEBY

Date: January 31, 2002

An SSIJF-financed development project (no. 1040)
</td>
<td>
Evaluation of the PQI

Pavement Quality Indicator
</td>
</tr>
</table>

SKANSKA

Contents

1 Summary

The Pavement Quality Indicator (PQI) is a device that is used to provide a quick indication of whether the degree of compaction is sufficient when laying pavements. The instrument has been tested in a number of contracts, in a comparison with the current, standard technology.

The scope of the project has been intentionally limited, in line with the objective.

It was not the intention to introduce an instrument to replace conventional quality control. For this reason, some long-term comparative tests and their associated statistical evaluations have not been carried out.

Instead, the purpose was to investigate the supplier's contention that the PQI is a simple and quick method of carrying out effective production checks in the initial stage of the laying process. For those who are interested in how the measurement technology works, a simple description has been included.

The instrument is obviously used frequently in the US, and there are several references that confirm that the instrument is a very effective means of checking quality when laying pavements. According to the information we have, the system has been sold in 12 countries, and 145 units have been sold. The spread in the US alone has been rapid, and only nine months after its introduction, the PQI 135 is being used in 35 states.

The experience we have acquired during the project indicates that:

- The instrument is easy to use.
- There are no transport restrictions.
- A limited amount of training is required.
- It is lightweight.
- Several measurements can be taken in a short time.
- You receive a quick indication of whether there is insufficient compaction.
- You receive a quick indication of whether the screed is being compacted unevenly, which enables corrections to be made in good time.

The limitations of use are discussed in point 10.

2 The project group

The project group consisted of:

Thomas Karlsson	Skanska Sverige AB, Project Manager
Nils Eneland	National Road Administration, Southern Region
Bo Sävinger	Ballast Väst
Per-Olof Ohlsson	Skanska Sverige AB

3 Background

In the past, when you wanted to check the bulk density under the asphalt mat, you would choose between three methods:

- Core samples
- Stationary point-measurement using an isotope meter (nuclear technology)
- Rolling density gauge (nuclear technology)

All of these methods suffer from certain limitations.

It can take a relatively long time to obtain the results from core samples, due to much longer transport times to the laboratory and the time needed to complete some stages in the analysis methods.

The other methods have the disadvantage that, because the equipment contains a radioactive source, it is automatically subject to transport restrictions, and every user has to undergo special training. Heavy lifting is also involved.

As a result, the core sample method is often used instead, despite the longer time taken to obtain the results. This leads to the danger that checking will be neglected in the initial stages, and that the paving will have been completed before corrective measures can be taken.

The above situation means that there is a need in the market for an instrument that is easy to use and which provides a quick indication if the compaction is inadequate.

The Pavement Quality Indicator (PQI) is manufactured by Trans Tech Systems Inc. (USA). When this report was written, there was nothing equivalent on the market. The British name, PDM (Pavement Density Meter) was used in the project application to the Swedish Building Industry Development Fund. As it appears that production takes places solely in the US, I have chosen to use the name PQI.

4 General description of the PQI

The PQI weighs approximately 15.5 lb (7 kg). The equipment measures bulk density, using the technique described below. It also measures the temperature using an IR sensor. The water content is also measured; the reason for this is explained in section 5. The equipment is battery driven. The battery lasts for a normal working day, and can then be recharged overnight.

Just as with the systems that use the nuclear technology, the PQI also has simple algorithms. They relate the bulk density to another density measurement, e.g. the Marshall bulk density. In this way, you can obtain a read-out of the degree of compaction. Alternatively, you can enter the compaction density as a reference, and obtain a numerical value. The cavities in the mat are then 100 minus the value on the display.

You can also choose a measurement value to use as a reference. You obtain this value by measuring a test surface, where you have full control over the number of passes. Another method is to use the value you obtain immediately after laydown as a reference. Experience has shown that the degree of compaction obtained is around 80 % of the Marshall value.

No matter which method you choose as a reference, the basic principle involves a parallel displacement of the curve. This procedure should be seen as away of obtaining measurements that are around 100. This is probably of educational value, as it is simpler to gain acceptance for a requirement that values below 98, for example, are not acceptable.

The depth of the measurement can be set within two ranges:

1. 0 – 1 in (0 – 2.5 cm) (shallow mode)
2. 1 – 2 in (2.5 – 5 cm) (deep mode)

Mode 2 should normally be used for Swedish conditions.

You can set the type of mat, based on the particle size, as follows:

Top:	0.3 – 0.6 in (9 –16 mm)
Intermediate:	0.6 – 1.0 in (16 – 25 mm)
Base:	1.0 – 1.4 in (25 – 35 mm)

5 Measurement technology

If you want to explore the measurement technology in greater depth than is described here, you should contact the manufacturer. A full understanding of the details of the technology requires a considerable knowledge of physics, particularly electrical technology. However, I will attempt to provide/give a general outline of the measurement procedure.

The technology works by measuring the electrical impedance, in order to give a measurement of the bulk density. The electrical impedance of the mat is in turn a measure of the dielectric constant of the mat. This is an expression of the ability of the material to store electrical energy.

The dielectric constant varies for different materials:

Air	1
Stone + bitumen	5 – 6
Water	80

Because water has such a high dielectric constant, it provides an indirect measurement of the water content. This indirect measurement is obtained by measuring the phase angle of the electrical field. Because water is the only component that affects the phase angle markedly, an indirect measurement of the water content is obtained.

In order to provide the required phase angle, the DC battery drives an AC generator.

The equipment then automatically adjusts the measurement of the bulk density, in light of the results. This correction of the measurement is essential for the technology to work, due to the considerable influence the water has on the measurements.

Beneath a normal mat of hot-mix asphalt, the water content (water from the roller) is 5 – 6 %. The instrument is designed to be able to correct the measurement if the water content is below 15 %.

A high degree of compaction means a low air content. The dielectric constant will then be higher, as will be the bulk density. By eliminating the influence of water, the measurement will reflect the composition of the actual mat.

An IR sensor measures the temperature. The measurement is processed by a microprocessor, which corrects the bulk density. This correction is necessary, as without it, measurements at the same point, but at different surface temperatures, would give different results.

The procedure for taking measurements is illustrated in Appendix 1.

6 Procedure for taking measurements

The equipment is turned on by pressing the "ON" button. The measurement range and reference bulk density are entered. The unit is then placed on the mat and the measurement appears immediately on the display. There is no delay in obtaining the reading, as is the case with the systems that use the nuclear technology (calibration for ambient conditions).
This means that the number of measurements that can be taken per minute is limited only by how quickly the operator can move the unit. It is also quite possible to take right – center – left readings of the strip before the roller returns for another pass. There is also time to note the bulk density and degree of compaction (plus the water content and temperature if you are interested in them). The unit has a data outlet, if you want to transfer the readings to a PC.

The instrument should not be disturbed while it is taking a measurement, otherwise the reading will be affected.

The measurement is displayed in lb/cu-ft or kg/m^3.

7 Repeatability of measurements

In order to check the repeatability, the PQI was placed at a fixed point. Measurements were taken every 30 seconds for 10 minutes. 20 identical readings were obtained, indicating that the instrument is totally stable (as long as you don't touch it during the measurement process).

An instrument that uses a radioactive source has a much poorer repeatability, unless the measurement times are very long. This is natural, as the gamma radiation emitted by the isotope is not constant, but random. The author's personal experience is that measurement times of at least four minutes are required to achieve something approaching a repeatable value.

With the PQI technology, we chose to leave the instrument in the same place and take repeated readings (every 30 seconds). The reason for this, of course, is that if the instrument is moved, a different reading is obtained. It is well known that the bulk density can vary over a very short distance, whatever method of checking is used. In order to check the repeatability, therefore, the instrument must be in the same place.

8 The influence of the surface structure on PQI readings

When using units that use nuclear technology, the surface structure influences the readings. In general, the bulk density figure is lower than that obtained from a core sample from the same point. The size of the discrepancy varies with the coarseness of the surface structure. It is possible to compensate for this to some extent, by sealing the surface with dry filler or with filler slurry. However it is not possible to compensate fully, except in the case of mats with a very fine surface structure.

In order to get an indication of whether the PQI technology has the same tendency, some simple tests were carried out on an AG 16 mat. We simply compared the readings from the PQI with and without filler. With this type of asphalt, the value for bulk density with filler is approximately 0.6 lb/cu-ft (10 kg/m^3) higher than without filler. This indicates that, without a sealing of filler, the instrument gives a reading that is approximately 0.5 % lower, on a fairly dense mat.

This is not surprising, as the air gap between the instrument and the mat would be expected to influence the reading (see point 5). The influence of other types of mat (e.g. ABS) will probably be even greater, if systematic tests were carried out on large areas.

It would be reasonable to ask if this seriously limits the practicability of the PQI. The Author's opinion is that this is not the case. It should be borne in mind that the PQI is designed to provide a quick indication of whether sufficient rolling has been done or not in a real compaction situation, in order to provide information to ensure the final quality of the mat.
The intention is not to provide a measurement that replaces traditional quality control (in the National Road Administration's nomenclature).

Another way of expressing the objective is that the PQI can be used to give better control over production, resulting in a more even and higher quality mat.

9 Comparisons between PQI and other methods

Appendices 3 and 4 contain the results of measurements from contracts with different types of mat. You can also find a lot of results at www.transtech.com.

10 Limitations of the equipment

Limited research has been carried out into remixing, where a large proportion of the existing mat is mixed with a small amount of new asphalt. The results show water contents of 15 %, and this is definitely at the limit of the instrument's reliability.

Water levels at least as high can also be expected if measurements are taken on older, existing mats in normal Swedish moisture conditions. This would be particularly true if measurements were taken in separation areas.

A comprehensive manual (in English) is supplied with the unit.

APPENDIX 3

Measurements with the PQI

Comparison with nuclear technology (surface sealed with dry filler) and core samples. The surface was sealed with C22, but this was not done with the PQI. Points 1 – 10 are 10 different points.

Mat: 1.6 in (40 mm) AG 16

No.	PQI	% of C 200	% of FAS 427	Seaman C 200	% of FAS 427	FAS 427
1	2250	97.8	95.2	2300	97.3	2363
2	2300	100.3	96.0	2293	97.7	2347
3	2290	100.1	97.0	2288	96.9	2362
4	2248	96.5	95.1	2282	96.5	2365
5	2247	96.3	93.5	2334	97.1	2404
6	2280	97.1	95.0	2347	97.8	2401
7	2280	102.2	99.8	2230	97.6	2285
8	2269	100.2	96.5	2284	96.4	2370
9	2203	97.6	93.7	2257	96.0	2350
10	2234	100.9	97.6	2215	96.7	2280
Mean		99.1	96.1		97.0	

Comparison between PCI/C200/Core Samples

Mat:

Point no.	PQI	C200	Core samples
1	2390	2264	
2	2390	2293	
3	2380	2281	
4	2385		
Mean	2381	2278	2340

Point no.	PQI	C200	Core samples
1	2303		
2	2333		
3	2289		
4	2293		
5	2310		
Mean	2308		2310

Point no.	PQI	C200	Core samples
5	2324	2307	
6	2267	2282	
7	2380	2322	
Mean	2314	2304	2385

Point no.	PQI	C200	Core samples
6	2331		
7	2295		
8	2296		
9	2327		
10	2324		
Mean	2315		2312

Point no.	PQI	C200	Core samples
8	2316		
9	2339	2278	
10	2327	2310	
11	2314	2301	
Mean	2324	2280	2342

Point no	PQI	C200	Core samples
11	2351		
12	2314		
13	2320		
14	2320		
15	2320		
Mean	2327		2293

Proposed procedure for checking mat compaction

Please note that the following is a proposal. The user is free, of course, to carry out the tests in the way that best suits his purpose. There are no hard and fast rules, but the important thing is that you are sure that the testing procedure you use is effective.

The measuring points on the strip are arranged as follows. In this example, the strip is 14 ft 9 in (4.5 m) wide. If the strip is wider, you will need more measuring points. You should try to have no more than 3 ft (1 m) between the measuring points.

Suggested measurement frequency

Time	Section			
Etc.				

The reason for having more frequent measurements at the beginning is to obtain a quick check of the compaction of the screed.