Asphalt pavement compaction evaluation by Dielectric Profiling System

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ABSTRACT: The compaction quality achieved during construction significantly affects the performance of asphalt pavements and its longitudinal joints. Traditional quality assessment procedures rely primarily on pavement cores; coring is a surface-destructive, time-consuming, and costly process. More importantly, it provides limited coverage. Dielectric Profiling System (DPS) provides continuous compaction coverage and accurately predict as-constructed air voids non-destructively. This study highlights the benefits of DPS adoption for compaction assessment. DPS's can highlight low-density areas within a pavement lane both longitudinally and laterally. Such in-depth analysis enable highway agencies in accurately estimating pavement service lives. It can also enable optimization of maintenance needs focused on locations identified with compaction issues within a pavement lane. Using DPS for compaction quality assessment would encourage utilization of high-quality construction practice resultantly achieving durable and high performing asphalt pavements without risking overpayments for substandard quality.

1 INTRODUCTION

As-constructed air void content (or density) of the asphalt layer is a key indicator of the long-term performance of new and resurfaced flexible pavements. The impact of the achieved compaction levels during construction on asphalt mix performance has been researched since the 1960's (Goode and Owings, 1961). Previous studies have shown that a 1% decrease in as-constructed air voids is associated with an 8 to 44% improvement in fatigue performance and a 7 to 66% increase in rutting resistance of the asphalt layer (Aschenbrener et al., 2018). Every 1% increase in air void content of the compacted asphalt mat beyond 7% is estimated to reduce the pavement's service life by 10% (Linden et al., 1989). Thus, compaction is the most important construction-related factor directly related to achieved air voids and can enhance the durability of asphalt pavements (Hughes, 1989).

State highway agencies (SHAs) traditionally assess construction quality by determining the achieved compaction using pavement cores extracted in the field. However, this coring process is surface-destructive, labor-intensive, and costly. Using density gauges (nuclear and non-nuclear) provides a non-destructive way of assessing the achieved density. However, both cores and density gauges provide limited coverage. Either of these methods involves random sampling, increasing the risk of missing areas with compaction issues or reporting density from non-representative areas.

Density profiling system (DPS), a ground-penetrating radar (GPR) based device, has recently gained popularity due to its ability to assess asphalt compaction non-destructively during construction. DPS measures its dielectric values when rolled over a freshly laid asphalt layer, which can be directly related to as-constructed air voids (density). As opposed to the limited coverage of the traditional compaction assessment methods, DPS provides continuous dielectric profiles recording a value every 6 inches. Thus, it provides the equivalent of about 100,000 cores per mile compared to the spot tests (core or density gauges), aiding better monitoring and evaluation of as-constructed pavement density (Hoegh et al., 2020).

This paper demonstrates the benefits of using the DPS for pavement compaction assessment during the construction of asphalt pavements. It highlights the importance of the continuous coverage provided by the DPS and its possible usage in identifying critical locations for predicting pavement service lives and future maintenance requirements.

2 DATA SYNTHESIS

This study uses DPS dielectric data collected from four pavement projects constructed in Michigan between 2022 and 2023. The study used a PaveScan rolling density meter (RDM) v2.0 developed by Geophysical Survey Systems Inc. (GSSI) that used three GPR sensors mounted on a wheeled cart. The cart was strolled along 1000 ft sections at each project, measuring three dielectric profiles simultaneously with varying offsets from the centerline longitudinal joint. Testing at each pavement section typically involved three DPS passes measuring at least nine dielectric profiles along the width of the pavement lane on the surface asphalt layers. Table 1 shows the asphalt layer thicknesses and the mix details.

Table 1. Surface asphalt layer thickness and mix details.

Project	Surface layer thickness (in) & NMAS (mm)	Surface mix G_{mm}	Surface mix binder type & content (%)
US-23	1.5, 9.5 (SMA)	2.426	PG70-28P, 6.77
M-89	1.5, 9.5	2.455	PG64-28, 6.46
I-69	1.5, 9.5	2.505	PG64-28, 5.99
M-61	2.0, 9.5	2.477	PG64-28, 5.94

Note: NMAS= Nominal maximum aggregate size, P=Polymer modified, SMA=Stone Matrix Asphalt.

3 COMPACTION ASSESSMENT

3.1 *DPS calibration*

The recorded dielectric values require calibrating a model for converting into air voids. This study used the core-free calibration method developed by Hoegh et al., which requires compacting gyratory pucks in the laboratory (Hoegh et al., 2019). Using an empirical model from a recent study (Eqn. 1), the dielectric-air void relationship was calibrated for each project's asphalt mix (Haider et al., 2023). Figure 1 shows the calibrated relationships for US-23 and M-61. The figures display the 95% confidence (CB) and prediction bands (PB) for the model (Av-P) and measured puck air voids (Av-O). It also shows measured air voids of the pavement cores extracted during testing for validation. The horizontal error bars display the allowable ±0.08 dielectric measurement variability per AASHTO PP98-19 (AASHTO, 2019). The vertical error bars indicate a 1% air void measurement tolerance per MDOT quality assurance procedures (MDOT, 2020). The figure shows that the coreless calibration predicts air voids with reasonable accuracy as represented by the core data.

$$AV = \frac{0.20}{1 + \left(\frac{e}{c}\right)^b} + \frac{0.0008}{(e-1)} \quad (1)$$

where AV = air voids (%); ε = asphalt dielectric value; and b,c = regression coefficients.

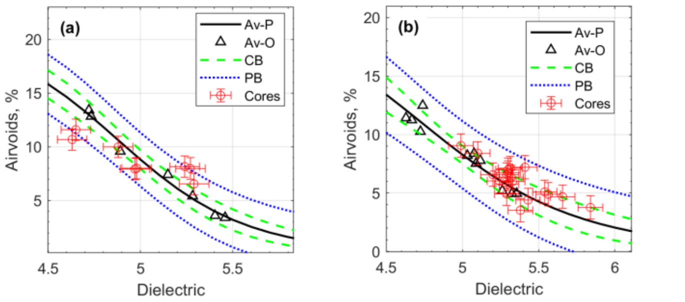

Figure 1. The calibrated dielectric-air voids relationship and its core validation: (a) US-23 SMA, (b) M-61.

3.2 *As-constructed compaction evaluation*

Figure 2 compares dielectric values at various offsets from the longitudinal joint on US-23. DPS measurements covered the full 1000 ft lane's width on the unconfined side and a shorter segment (142 m) on the confined side. Dielectric values on the unconfined side are mostly 5.6 or lower, with many below 4.8 at a 0.5 ft offset, indicating lower compaction. Conversely, the confined side shows values mostly between 4.8 and 5.6. This highlights the impact of joint type and construction conditions on compaction, with unconfined joints having lower values.

Examining the asphalt mat's dielectric data (excluding the two outer offsets) along the pavement lane reveals significantly lower dielectric values across the width in the final 400 ft section (right side of the plot). This suggests that the latter portion of the pavement was not compacted as consistently as the first half. This compaction difference is translated into significant air void differences, as illustrated in Figure 3. The mat's air voids range between 8% to over 12%, while the unconfined joint (i.e., at 0.5 ft offset) has over 12% air voids for the majority of the sections' length. The air voids are below 8% on the confined side of the joint, with limited data showing void content between 8% and 12%.

Figures 4 and 5 display box plots of the dielectric and predicted air voids data for US-23. These figures demonstrate that the paving conditions and type of joint affect the achieved compaction, as shown in Figures 2 and 3. While the dielectric values next to the pavement edges are lower for the unconfined side of the joint, they are relatively higher on the confined side. Consequently, the confined joint side has lower air voids and better compaction than the unconfined side. For a joint to be acceptable, its air voids must be within 2% of the mat's density (Kandhal and Mallick, 1996). This corresponds to a dielectric difference of about 0.14 (mat minus joint) based on the US-23 project-specific calibration model, given that 8% air voids in the mat are considered acceptable, yielding a dielectric of 5.057. Hence, 10% air voids are acceptable in the joint, corresponding to a 4.921 dielectric value. However, dielectric values for the unconfined joint show a significantly greater difference than the 0.14 threshold compared to measurements farther from the joint.

Lateral variations in pavement compaction within the lane are evident from the mat's dielectric values. Although these values are consistently higher than those at the unconfined joint, the measurements at 8.5 ft and 12.5 ft offsets exceed the acceptable dielectric threshold of 5.057 for 8% air voids. Such detailed compaction analysis is crucial for identifying critical areas of lower density that may affect the pavement's long-term performance and require focused periodic maintenance.

Figures 6 and 7 show the boxplots for predicted air void values for the M-89 and I-69 projects. Similar to the compaction on US-23, the confined joint on M-89 shows air voids comparable to the asphalt mat. For this project, a 5.141 dielectric value corresponds to 8% air voids; 4.956 equals 10% air voids. Figure 6 indicates that air voids remain below 8% throughout the lane across all offsets. The compaction variability reveals that, aside from the outer shoulder joint (14.5 ft offset), most air void levels seen in Figure 6 are between 5% and 7%.

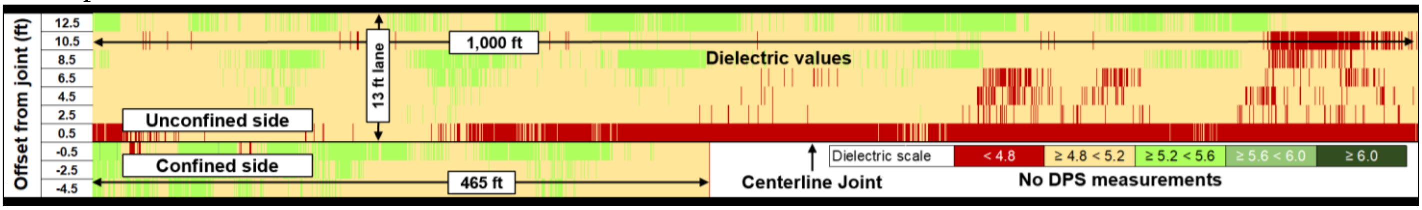

Figure 2. Recorded dielectric data heat maps at different offsets from the centerline joint on either side – US-23 SMA project

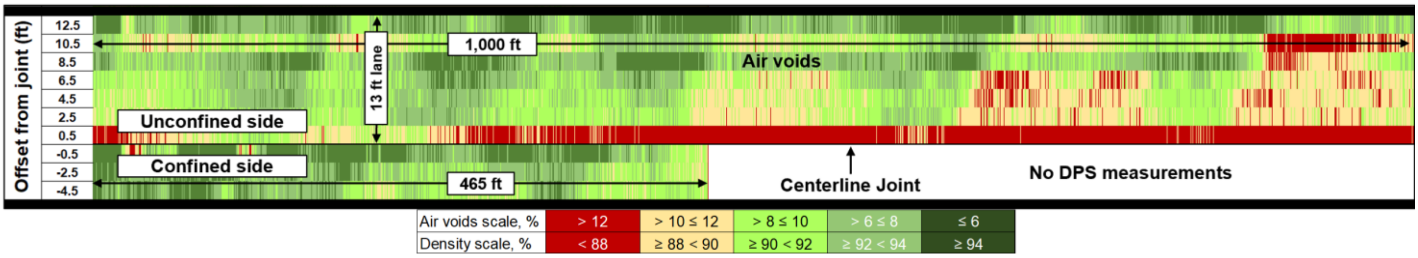

Figure 3. Predicted air void heat maps at different offsets from the centerline joint on either side – US-23 SMA project.

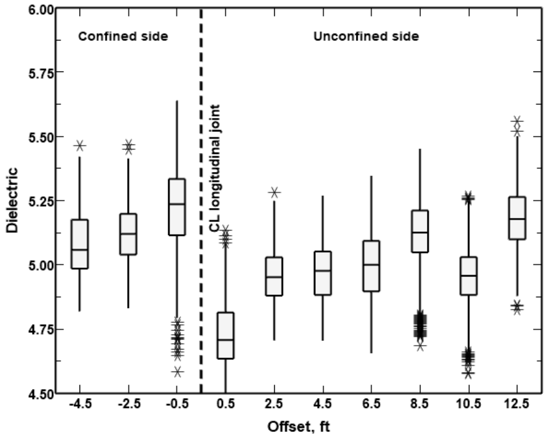

Figure 4. Box plots displaying recorded dielectric values at varying offsets on US-23.

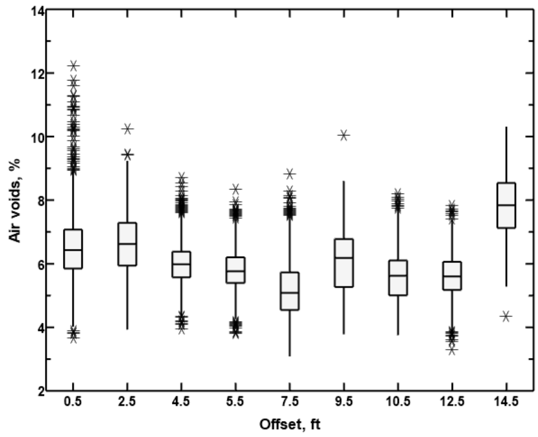

Figure 6. Box plots displaying predicted air voids at varying offsets on M-89 (confined centerline joint).

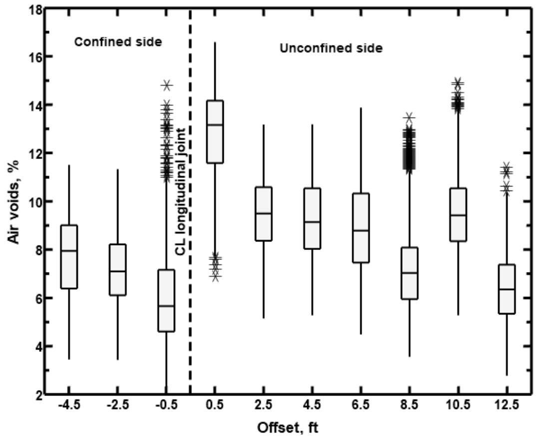

Figure 5. Box plots displaying predicted air voids at varying offsets on US-23.

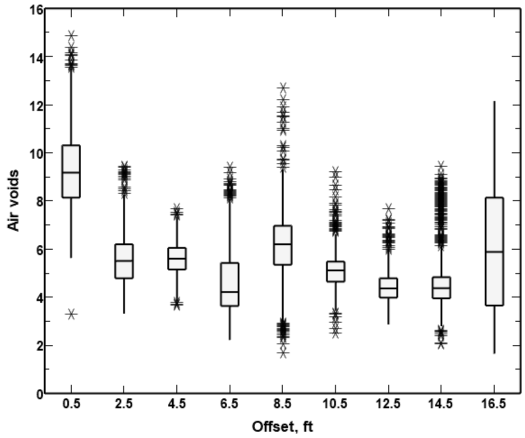

Figure 7. Box plots displaying predicted air voids at varying offsets on I-69 (Echelon-paved).

The I-69 project was constructed using the echelon paving method. Except for the dielectric values measured 0.5 ft from the shoulder joint, all the other values surpassed 5.110 (i.e., 8% air voids), indicating air voids between 4% and 8% throughout the 1000 ft lane on the I-69 project (Fig. 7). This consistency reflects the echelon paving method's effectiveness in achieving proper and consistent compaction; maintaining acceptable air void levels across the lane.

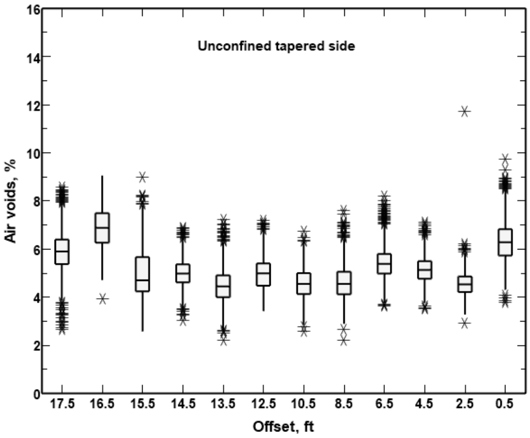

Figure 8. Box plots displaying predicted air voids at varying offsets on M-61.

Figure 8 shows the predicted air voids for the M-61 project that was constructed with a notched wedge/tapered centerline joint. For this project's asphalt mix, 8% of the air voids result from a 5.027 dielectric value, and 10% of the air voids align with a dielectric value 4.828. The tapered construction method resulted in higher compaction, reflected by elevated dielectric values. The predicted air voids consistently ranged between 4% and 6% across both lanes on either side of the joint. Figures 2 through 8 demonstrate the benefit of the DPS's continuous compaction coverage capability, allowing for extensive air voids (density) analysis, which is impossible with conventional spot-test-based methods. With such a detailed compaction analysis, one can predict future pavement performance variations. Additionally, highway agencies can identify locations with sub-par compaction levels within a pavement that may require focused preventive maintenance throughout the pavement's service life.

4 CONCLUSIONS AND RECOMMENDATIONS

Traditional compaction quality assurance processes primarily rely on cores that offer limited spatial coverage, risking overpayment for sub-par quality in the field. The DPS is a better alternative to the spot-test-based compaction assessment procedures since it provides continuous, comprehensive compaction coverage and accurately estimates as-compacted air voids. This study highlighted the benefits of DPS's usage for compaction quality evaluation. Note that the economic viability of DPS application might vary depending on the project scope (i.e., low budget project).

- DPS provides thorough compaction coverage and can highlight under-compacted and low-density areas across the pavement lane longitudinally and laterally.
- Such in-depth compaction assessment enables SHAs to estimate pavement service lives accurately.
- It can also aid SHA in optimizing maintenance efforts by focusing on identified locations with compaction issues.
- Given the critical role of compaction quality in asphalt pavement performance, quality assurance methods should transition from current spot-test-based approaches to DPS.
- Adopting DPS will promote high-quality construction practices, enabling the achievement of durable asphalt pavement with longer-lasting performance without risking overpayments for substandard quality.

5 REFERENCES

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