TECH**NOTE**

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LTPP Analysis-Ready Datasets: New Features and Exciting Opportunities

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This document is a companion to the Federal Highway Administration report *Development and Use of the LTPP Analysis-Ready Materials Dataset* (FHWA-HRT-23-111).

BACKGROUND

The goal of the Long-Term Pavement Performance (LTPP) program is "to increase pavement life by the investigation of long-term performance. . . ." (FHWA 2015). One of the six objectives identified to support this goal was the establishment of a national pavement performance database. The LTPP program has been assembling a performance database since 1989, when data collection commenced. Today, the LTPP database is the world's premier source of data and information on pavement performance, but using the database is not necessarily easy. Typically, the data are distributed across multiple tables, making some data elements difficult to mine. Also, multiple values for a given data element make knowing which values to use difficult. Additionally, the data may need further interpretation to present meaningful results.

To address these challenges, the LTPP program undertook a process to generate analysis-ready datasets (ARDs) for all sections in the database so that data users did not have to spend effort wrangling data—i.e., finding, extracting, merging, and interpreting available data to develop an input dataset for analysis. These ARDs provide numerous benefits, such as simpler data handling, easier data analysis and data mining for trends, and descriptive data visualization.

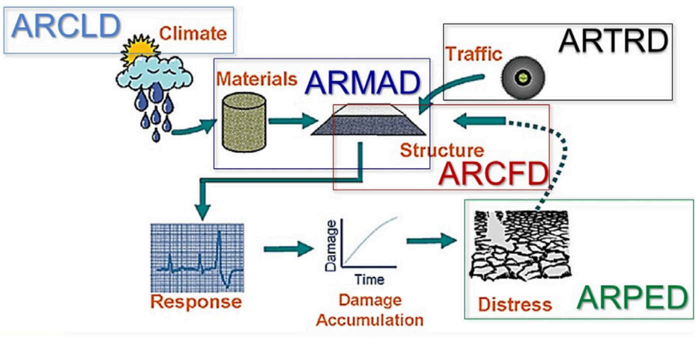
ANALYSIS-READY DATASETS

As illustrated in figure 1, pavement performance is affected by the separate and combined effects of the pavement structure (layer thicknesses, material properties, and construction features), traffic loadings (volumes and weights), and climatic conditions (moisture and temperature). Recognizing this, the LTPP program developed the following ARDs (FHWA 2023):

- Analysis-Ready Materials Dataset (ARMAD)—Thicknesses and material properties of each pavement layer for all LTPP test sections.
- Analysis-Ready Climate Dataset (ARCLD)—Data extracted from the Modern-Era Retrospective Analysis for Research and Applications 2 dataset, including hourly, daily, and monthly statistics for precipitation, temperature, wind, and humidity (NASA 2023).
- Analysis-Ready Traffic Dataset (ARTRD)—Input data needed by the AASHTOWare® Pavement Mechanistic-Empirical Design (PMED), annual time series truck volumes and axle loadings, and summary statistics for truck volumes (American Association of State Highway and Transportation Officials (AASHTO) 2020).

- Analysis-Ready Performance Dataset (ARPED)—Pavement surface distresses, international roughness index, rutting, and load transfer efficiency.
- Analysis-Ready Construction Features Dataset (ARCFD)—Transverse joint properties, shoulder properties, subsurface drainage information, and alignment of dowel bars.

Figure 1. Factors affecting pavement performance.



Source: FHWA.

The yardstick used to make ARD decisions was the Mechanistic-Empirical Pavement Design Guide (MEPDG), but the intended use of the ARDs goes well beyond just this guide (AASHTO 2020). The first dataset, ARMAD, was incorporated into LTPP Standard Data Release (SDR) 36 (FHWA 2022). This dataset was expanded in SDR 37 (FHWA 2023) to include data from the LTPP Specific Pavement Studies (SPS)-10 warm-mix asphalt experiment test sections, new laboratory materials testing data, and corrections to data issues. This SDR also incorporated the ARCLD, ARTRD, and ARPED, all of which are readily available via the LTPP InfoPave™ web portal (FHWA 2023). Additional information and correction of data issues are now being processed as part of SDR 38, which will be released in August 2024. This SDR will also incorporate the ARCFD.

> *"The LTPP data continues to be invaluable to local MEPDG validation and calibration purposes, but now it has been made much simpler thanks to the LTPP ARDs," said Harold L. Von Quintus, P.E., Principal Engineer, Applied Research Associates, Inc., and subject matter expert in support of the LTPP ARD development effort.*

ARD IMPACTS

The following two examples illustrate the value of ARDs in reducing or eliminating data wrangling:

Example 1: Unbound Granular Resilient Modulus

The LTPP program has collected a significant amount of laboratory- and field-derived data. Those data, which are housed in the LTPP database, could be used to develop relationships between laboratory- and field-derived properties. However, concerns existed about whether the LTPP data could accomplish this task. As a result, researchers undertook National Cooperative Highway Research Program (NCHRP) Project 20-50(19) to evaluate the feasibility of using LTPP data to develop relationships between laboratory- and field-derived properties of unbound pavement materials (Serigos et al. 2019). The study concluded that while a substantial amount of testing had been carried out, a single laboratory-resilient modulus was not available for each unbound layer. Rather, the data consisted of 15 resilient modulus values corresponding to the 15 stress states (different bulk and confining pressures) specified in the test procedure (Simpson, Schmalzer, and Rada 2007).

To overcome the stated shortcoming, the equation in figure 2 was used to calculate the PMED design laboratory resilient modulus value as part of the ARMAD development effort. The k_1, k_2, and k_3 parameters in this equation were determined by fitting the best linear regression model through the resilient moduli for the 15 stress states. Bulk and confining pressures were established using the estimated values provided by Rao et al. (2012), which are based on layer type (base/subbase/subgrade), surface material type (asphalt concrete or portland cement concrete (PCC)), and layer thicknesses.

Figure 2. Equation. Calculation of resilient modulus.

$$Mr = k_1 P_a \left(\frac{\theta}{P_a}\right)^{k_2} \left(\frac{\zeta_{oct}}{P_a} + 1\right)^{k_3}$$

Where:

Mr = laboratory resilient modulus.
P_a = atmospheric pressure.
θ = bulk stress = $\sigma_1 + \sigma_2 + \sigma_3 = \sigma_d + 3\sigma_c$.
σ_1 = major principal stress.
σ_2, σ_3 = minor principal stress.
σ_c = confining stress.
σ_d = deviatoric stress = $\sigma_1 - \sigma_3 = \theta - 3\sigma_c$.
ζ_{oct} = octahedral shear stress = $(\sqrt{2}/3)\ \sigma_d$.
k_1, k_2, k_3 = model parameters.

Performing these tasks—computing k values, selecting bulk and confining pressures, and computing single resilient modulus—is not easy when dealing with thousands of unbound granular layers, which was the case in NCHRP Project 20-50(19), and consequently the reason the second phase of the study was not pursued (Serigos et al. 2019).

> *"In addition to the value to practitioners, ARDs will be a great resource for educators and students. Professors will be able to present real-world datasets of pavement structure, traffic, climate, and performance for students to analyze. Much more realistic and valuable than the 'toy' problems found in most textbooks," said Dr. Charles Schwartz, Philip J. Erdle Chair in Engineering Science, U.S. Air Force Academy, and subject matter expert in support of the LTPP ARD development effort.*

Example 2: Asphalt Concrete Air Voids

Air voids have a significant effect on asphalt pavement performance. Air voids that are too low can cause bleeding, rutting, and shoving. High air voids, on the other hand, can lead to an increased potential for water infiltration, accelerated oxidation, raveling, cracking, and rutting in the wheel path. To determine the effects of as-constructed air voids on pavement performance, NCHRP Project 20-50(18) (National Academy of Sciences, Engineering, and Medicine 2018) was conducted using data from the LTPP program. A major challenge in the study was establishing air voids for 426 LTPP test sections, many with multiple asphalt layers.

To address this challenge, percent air voids (and many other material properties) were calculated as part of the ARMAD development effort for the LTPP asphalt pavement layers by comparing a test specimen's bulk specific gravity (G_{mb}) with its theoretical maximum specific gravity (G_{mm}) and assuming the difference is due to air. To determine the air voids of a particular section, the equation given in figure 3 was used:

Figure 3. Equation. Calculation of percent air voids.

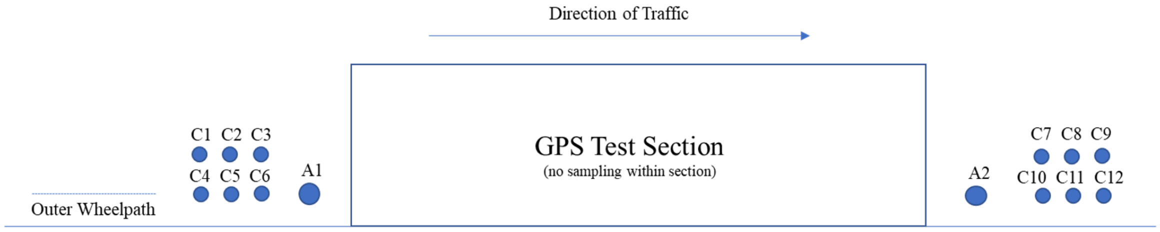
$$\%Air\ Voids\ =\ \left((G_{mm}-G_{mb})/G_{mm}\right)\times 100\%$$

In addition to this equation, data users should be familiar with the LTPP materials sampling as illustrated in figure 4 for a General Pavement Studies (GPS) test section. For this test section, 4-inch cores were drilled and obtained at the C locations in the outer wheel path (C4–C6 and C10–C12) and in the midlane (C1–C3 and C7–C9). Six-inch cores were taken from the A1 and A2 locations. The C-type cores were used to measure G_{mb}, and the A-type cores were used to measure G_{mm}. Accordingly, the approach used by ARMAD was to combine the individual core results from C1–C3 with the A1 result and the individual core results from C4–C6 with the A1 result to obtain wheel path and midlane air voids for one end of the section, which results in six air void values per asphalt layer tested. The results of the other test section end were developed in a similar fashion, resulting in a total of 12 air void values per asphalt layer tested. Ultimately, the average of the test section ends was used to determine the air voids for each asphalt layer.

For those not intimately familiar with the LTPP database and the materials sampling and testing plans, generating air void content values for hundreds of LTPP asphalt test sections, many with multiple asphalt layers, might be daunting.

> *"In the mid-2000s, I struggled with LTPP data wrangling and filling data gaps. The data were needed to perform the modeling in the FHWA High-Performance Concrete Paving (HIPERPAV6) software (Chang et al. 2008), which calculates the progression of the concrete's strength gain and develops stresses at the early age after placement. The model inputs include materials, pavement structural information, construction, and environmental conditions. Today's ARDs would have saved me a tremendous amount of time and effort," said Dr. George Chang, P.E., Director of Research, The Transtec Group, Inc., and subject matter expert in support of the LTPP ARD development effort.*

Figure 4. Illustration. Depiction of sampling for asphalt layers for a GPS test section (Afsharikia, Rada, and Groeger 2022).



Source: FHWA.

CONCLUSION

The ARDs will save LTPP data users thousands of data-wrangling hours in the coming years, allowing them to focus instead on their data analyses. Moreover, the data contained in the ARDs is easily accessible via the LTPP InfoPave application (https://infopave.fhwa.dot.gov/), which has been the primary mode for LTPP information dissemination for close to a decade.(4) Given their value, the LTPP program anticipates it will continue to work on the development of ARDs. Much of the effort will be spent incorporating new data into the existing ARDs or making corrections to the existing ARDs, as needed. Creating new ARDs is also possible and is routinely evaluated by the LTPP program. ARD suggestions that LTPP data users may have are welcomed and encouraged; please submit ideas via ltppinfo@dot.gov.

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