TECH**BRIEF**

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Research, Development, and Technology
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, VA 22101-2296

https://highways.dot.gov/research

Introduction to the LTPP Analysis-Ready Materials Dataset (ARMAD)

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FHWA Contact: Y. Jane Jiang (ORCID: 0000-0003-3982-2530), HRDI-30, 202-493-3149, jane.jiang@dot.gov

This document is a technical summary of the Federal Highway Administration (FHWA) report, *Development and Use of the LTPP Analysis-Ready Materials Dataset* (Afsharikia et al. Forthcoming). The release of this TechBrief coincides with the release of the first version of the Analysis Ready Materials Dataset (ARMAD) in the Long-Term Pavement Performance (LTPP) Standard Data Release (SDR) 36 via LTPP InfoPave™ in the summer of 2022 (FHWA 2022a). This TechBrief provides an introduction and overview of the ARMAD. The full report, which details the development and implementation of the dataset, will be issued later in 2022.

The LTPP database is the world's premier source of data and information on pavement performance. However, understanding and using the database is not necessarily an easy undertaking. For starters, the data are typically distributed across multiple tables in the database, making some data elements hard to mine. There are also multiple values for a given data element, making it difficult to know which value(s) to use. In addition, the data may have to be further interpreted to present meaningful results. Because of these challenges, the LTPP program has undertaken a process to generate analysis-ready datasets (ARDs), starting with the dataset detailed in this document—ARMAD (FHWA 2015). The ARMAD solves the stated challenges for the layer thicknesses and material properties of all test sections in the LTPP database with one exception—the Specific Pavement Studies (SPS)-10 warm-mix asphalt experiment test sections. Testing for these SPS-10 test sections is presently ongoing, and the results will be incorporated upon completion. Similarly, future planned ARDs—climatic conditions, traffic conditions, and performance data—will be incorporated into upcoming SDRs.

INTRODUCTION

The goal of the LTPP program is "to increase pavement life by the investigation of long-term performance of various designs of pavement structures and rehabilitated pavement structures, using different materials and under different loads, environments, subgrade soil, and maintenance practices" (FHWA 2015). The following six objectives were identified to support the goal:

- Evaluate existing design methods.
- Develop improved design methodologies and strategies for the rehabilitation of existing pavements.
- Develop improved design equations for new and reconstructed pavements.
- Determine the effects of (1) loading, (2) environment, (3) material properties and variability, (4) construction quality, and (5) maintenance levels on pavement distress and performance.
- Determine the effects of specific design features on pavement performance.
- Establish a national long-term pavement database to support Strategic Highway Research Program (SHRP) objectives and future needs (Manning 1986).

To accomplish the stated goal and objectives, the LTPP program undertook a study of the behavior of pavement test sections located on in-service roadways (FHWA 2015). These in-service pavement test sections are classified in the LTPP program under General Pavement Studies (GPS) and SPS. GPS consist of a series of studies on 976 in-service pavement test sections to examine specific features of existing pavement. SPS address specific variables involving new construction, maintenance treatments, and rehabilitation activities and comprises 1,605 pavement test sections. The sections are located throughout the United States and Canada (Elkins and Ostrom 2021).

Information about pavement material properties is a key component of all aspects of pavement engineering, including design, construction, quality control, maintenance and rehabilitation, and management. The pavement layer structure and material properties are fundamental requirements for the development of practical pavement performance models and inputs for pavement design, among other uses.

The LTPP program has a wealth of materials information and data. Nearly every test section in the program had materials sampling and testing conducted to determine the thickness and material types of the constituent layers. In addition, a well-structured laboratory materials-testing program was undertaken to further classify and characterize the layers. (See Simpson, Schmalzer, and Rada 2007 for the latest version of the LTPP project's laboratory materials testing and handling guide.)

However, there are limitations in the materials properties in the LTPP database, as follows:

- Data are distributed across dozens of tables in the LTPP database, making some data elements hard to mine.
- There are multiple property values for a given layer, making it difficult to know which representative value(s) to use.
- Materials characterization data are missing for a number of LTPP test sections.
- Data have to be further interpreted in many cases to achieve meaningful results.

OBJECTIVE AND SCOPE OF ARMAD

Prior to the implementation of ARMAD, the acquisition and interpretation of LTPP materials data characterization could potentially require expert-level knowledge of each LTPP experiment, material and protocol, and the pavement performance database, creating a significant barrier to implementation for practitioners and researchers. Consequently, an LTPP user needed to spend a substantial amount of time on a data-wrangling effort to find, extract, merge, and interpret the available data to develop a suitable analysis dataset. Therefore, the program developed a process to generate the LTPP ARMAD for each section and each layer for every construction period in the LTPP database. LTPP ARMAD solves the stated challenges, through the following processes:

- Consolidating the number of tables from many to a few for all material types.
- Identifying the essential set of material properties to characterize each material type.
- Developing representative materials characterization data for every section and every layer within the LTPP program.
- Interpreting the data to ensure meaningful engineering material properties are provided (such as subgrade resilient modulus).

The LTPP ARMAD integrates the material properties of several categories of pavement layers:

- Asphalt concrete (AC) materials.
- Portland cement concrete (PCC) materials.
- Unbound granular base/subbase, stabilized base/subbase, and subgrade materials.
- Other layer materials such as surface treatments and engineering fabrics.

The scope of this effort was to identify an essential set of material properties for each pavement layer type, assemble and process the data of those material properties, assess the percentage of missing values in the selected material properties gathered from the LTPP database, impute or assume missing material properties, and populate the LTPP ARMAD. In addition, a quality indicator was assigned to each material property to ensure that users can understand the method used to obtain the material property and, hence, the associated data quality.

LTPP MATERIALS TESTING PROGRAM SYNOPSIS

The details regarding the GPS and SPS materials sampling and testing programs can be reviewed through the documents in the Resources section of this TechBrief. For a description of each experiment, please see the *Long-Term Pavement Performance Information Management System (IMS) User Guide*, pages 4 (GPS) and 5 (SPS), which are available on the homepage of LTPP InfoPave at https://infopave.fhwa.dot.gov/ (Elkins and Ostrom 2021; FHWA 2022a).

GPS Test Sections

A typical materials sampling plan for a GPS section is shown in figure 1. In general, materials were sampled from both the approach and leave ends. Therefore, for each layer, there were at least two samples/specimens taken and tested, one from the approach end and one from the leave end. Destructive sampling within test section limits would violate LTPP practices because it would interfere with long-term performance trends.

It is important to note that, with one exception (GPS overlays after 1989), the test results for the GPS sections represent different ages of the pavement and were not taken at the time of construction, because these sections were in-service test sections that were not constructed specifically for the LTPP program.

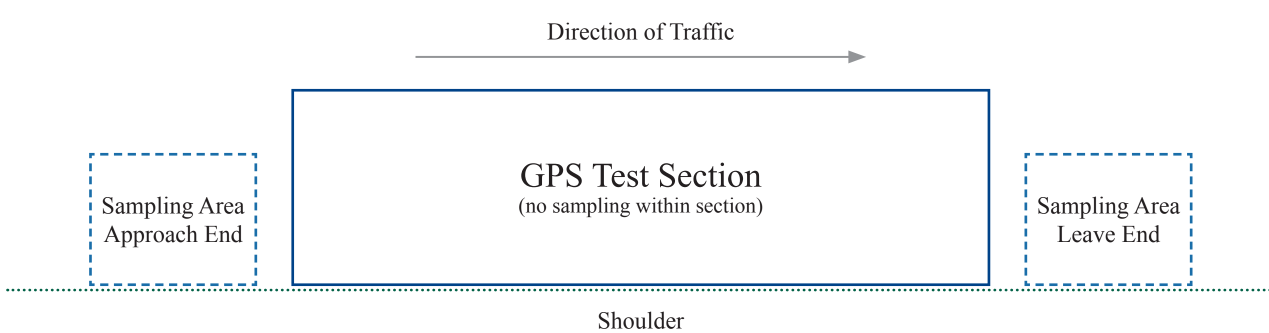
SPS Test Sections

For SPS-1, -2, -5, -6, -7, -8, -9, and -10, which consist of multiple co-located test sections, a different approach was taken. In general, for SPS projects (besides SPS-3 and SPS-4), several samples of the different layers and materials were extracted, tested, and then used to represent the entire project. For example, for unbound materials, three samples (sometimes more or less depending on the individual project) were taken. These samples were tied to a particular test section as illustrated in figure 2. In this example, three bulk samples of the subgrade and dense-graded aggregate base were taken within the project adjacent to sections 1, 4, and 5 and 6. Testing from these three locations was then tied to the other SPS test sections. For bound layers, a specimen was typically obtained and tested for each layer for each test section, and the full suite of materials tests was conducted at each location. For several SPS projects, the materials were sampled and tested during the construction process.

For each individual SPS project site (besides SPS-3 and SPS-4), the LTPP program developed customized materials sampling and testing plans, which can be downloaded from https://infopave.fhwa.dot.gov/Reports/Library (FHWA 2022b).

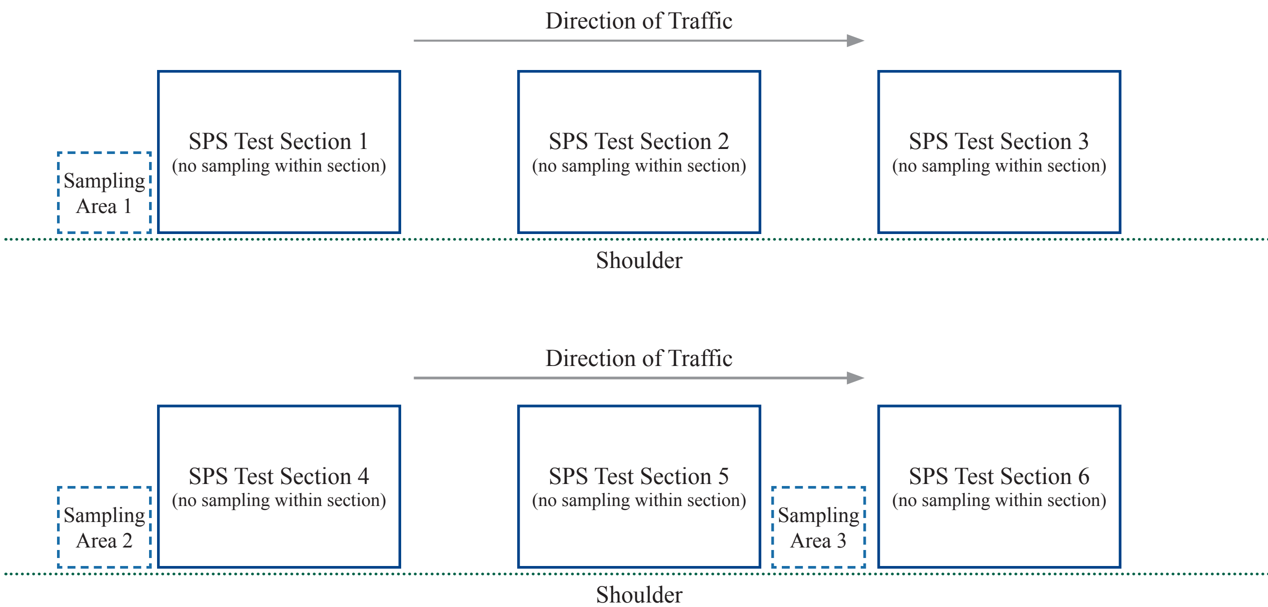
For SPS-3 and -4 projects, there was no sampling or testing of the layers because these were maintenance experiments, and only the surface of the pavement was of concern. However, each SPS-3 and -4 site generally had a GPS test section near it. Typically, the material properties measured for the GPS section were used for the SPS-3 and -4 test sections, as illustrated in figure 3.

Figure 1. Illustration. Typical sampling plan for an LTPP GPS test section.



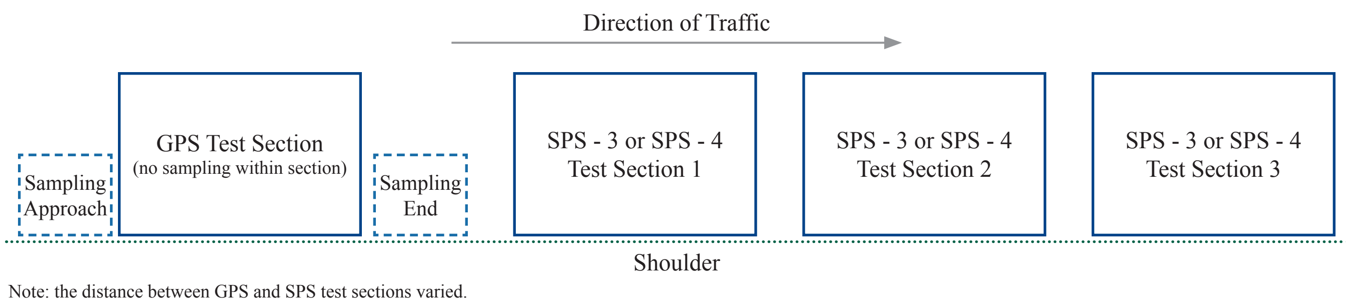
Source: FHWA.

Figure 2. Illustration. Example of unbound materials sampling plan for an LTPP SPS project.



Source: FHWA.

Figure 3. Illustration. Typical sampling plan for an LTPP SPS-3 or -4 project.



Source: FHWA.

DEVELOPMENT PROCESS

The ARMAD was developed by using a phased approach by material type in the following order:

1. Unbound granular base, subbase, and subgrade materials.
2. PCC materials.
3. AC materials.
4. Stabilized (chemically treated) materials.
5. Other layer material types, such as surface treatments and engineering fabrics.

The development process for each type of material entailed the following steps:

1. Selecting material properties—selection of the properties to be included in the LTPP ARMAD.
2. Data discovery—determination of the location of the source table(s) housing the data in the LTPP database and the extraction of data for each test section and layer.
3. Deriving representative values—a decision tree was used to derive such values.
4. Populating the LTPP database—the material properties data were populated in the LTPP database.
5. Disseminating data—the final dataset was disseminated via the LTPP InfoPave web portal (FHWA 2022a).

Selecting Material Properties

The development of the LTPP ARMAD began with identifying the key pavement layer material properties by layer type (Afsharikia et al. Forthcoming). The ARMAD contains an essential set of material properties necessary to characterize each layer and effectively analyze pavement performance or calibrate pavement performance models, specifically (but not exclusively) the American Association of State Highway Transportation Officials (AASHTO) Pavement Mechanistic-Empirical (ME) software (Afsharikia et al. Forthcoming, AASHTO 2020). The criteria for the selection of these properties are described in the following sections.

Fundamental Material Properties

Fundamental material properties such as thickness, material type, gradation, volumetric properties, and so forth were included in the dataset.

Importance to Pavement Performance Analyses

To direct the focus of this work to the most important material characteristics, the material properties inputs for the AASHTO *Mechanistic-Empirical Pavement Design Guide* (MEPDG) analysis and performance models were considered (AASHTO 2020). LTPP data are often used for calibrating MEPDG distress prediction models or for MEDPG performance analysis (Afsharikia et al. Forthcoming; AASHTO 2020). These material properties are grouped based on the pavement layer material categories mentioned previously (PCC, AC, etc.).

Usefulness in Computing Other Data Elements

Some of the fundamental material properties, such as AC dynamic modulus and resilient modulus for unbound granular base/subbase, were not measured on every pavement section due, in most cases, to limited resources for performing laboratory tests. In the absence of laboratory test results, correlation equations and/or prediction models provide an alternative for estimating these properties based on other material properties. The ARMAD also contains correlated material properties, which are useful in calculating missing properties and developing newer correlation equations (Afsharikia et al. Forthcoming).

Key Properties Availability

The list of key material properties selected for representation in the ARMAD is presented in table 1 (Afsharikia et al. Forthcoming). A review of the LTPP database was conducted to identify the availability of each selected material property. The results are shown in the third column of table 1, which indicates whether a given material property is measured by the LTPP program. Notably, even if a material property is measured by the LTPP program, there are still some layers where the indicated material property will be missing for a given class of experiments (GPS or SPS), individual experiments, or test sections.

Table 1. List of key material properties.

Category	Material Element	Availability in LTPP Database
Unbound base/ subbase/ subgrade materials	Layer thickness	Yes
	Material type	Yes
	Poisson's ratio	Yes
	Resilient modulus	Yes
	Soil classification (gradation and Atterberg limits)	Yes
	Compaction characteristics (optimum moisture content and maximum dry density)	Yes
	Specific gravity	Yes
	Resilient modulus and parameters	Yes
	Saturated hydraulic conductivity	Yes
PCC mixture	Layer thickness	Yes
	Material type	Yes
	Poisson's ratio	No
	Modulus of rupture	Yes
	Modulus of elasticity	Yes

Table 1. List of key material properties. (Continued)		
Category	**Material Element**	**Availability in LTPP Database**
PCC mixture	Compressive strength	Yes
	Tensile strength	Yes
	Coefficient of thermal expansion	Yes
	Mixture properties (unit weight, water-to-cement ratio)	Yes
	PCC shrinkage	No
	Thermal conductivity	No
	Heat capacity	No
	PCC zero-stress temperature	No
	Surface shortwave absorptivity	No
	Steel in concrete properties (diameter, depth, spacing, etc.)	Yes
AC mixture and asphalt-treated layers	Layer thickness	Yes
	Material type	Yes
	Poisson's ratio	Yes
	Asphalt binder complex shear modulus (G^*) and phase angle (δ)—set of values at different frequencies and temperature to create master curve	Yes
	Binder type	Yes
	Viscosity	Yes
	Dynamic modulus (E^*)—set of values at different temperatures and frequencies to build a master curve	Yes
	Tensile strength	Yes
	Creep compliance	Yes
	Volumetric properties (unit weight, bulk specific gravity, maximum specific gravity, aggregates specific gravity, air voids, binder content, VMA, VFA)	Yes
	Aggregate gradation	Yes
	Thermal conductivity	No
	Heat capacity	No
	Aggregate coefficient of thermal contraction	No
	Surface shortwave absorptivity	No
Chemically stabilized materials	Layer thickness	Yes
	Material type	Yes
	Poisson's ratio	No
	Aggregate type	Yes
	Treatment type and details	Yes

Table 1. List of key material properties. (Continued)

Category	Material Element	Availability in LTPP Database
Chemically stabilized materials	Heat capacity	No
	Thermal conductivity	No
	Resilient/elastic modulus	No
	Compressive strength	Yes
Surface treatments and engineering fabrics	Layer thickness	Yes
	Material type	Yes

VFA = voids filled with asphalt; VMA = voids in the mineral aggregate.

Data Discovery

The next step was to determine data availability in the LTPP database by GPS and SPS experiment. The basis for selection of the layers to be populated was the LTPP layering table, TST_L05B. The TST_L05B table was selected as the base table because it has already gone through a section-by-section layering reconciliation process and is the most representative source of information for layer thickness, material type, and material classification. The layer thickness for the LTPP ARMAD was derived directly from table 1.

To retrieve data for an available material property from the LTPP database, the tables containing the indicated property were selected. The LTPP IMS User Guide was used extensively to identify the relevant LTPP source data tables (Elkins and Ostrom 2021).

For each material property indicated as available, a preliminary list of the appropriate LTPP tables was developed; then, each property and each table were evaluated to identify the tables with the most representative value to include in the dataset. This selection varied based on the material property that was evaluated. Finally, the table with the most representative values was selected along with secondary tables, if they existed.

Deriving Representative Values

After the tables were selected, a decision tree was developed for each material type and data availability scenario to use as a basis to code the algorithms for developing the representative values. Statistical models were used to evaluate the variability and select the most representative values or predict missing values. These decision trees are explained further in the final report.

For engineering fabric layers and other treated material layers (such as surface treatments), no laboratory testing was conducted, and only the representative thickness, material code, and layer description were populated directly from the TST_L05B table.

Populating the LTPP Database

The final data and metadata resulting from this effort were stored in the LTPP database. For each material type, two new tables were created: the primary data table, ANALYSIS_TST_* (where * = the material type such as AC, PCC, etc.) and the data support table, ANALYSIS_TST_*_SUPPORT. The metadata contain the data dictionary, table dictionary, and a description of field codes.

*Primary Data Table: ANALYSIS_TST_**

Each ANALYSIS_TST_* table contains the representative layer properties for all relevant LTPP GPS and SPS layers. This table can be used by practitioners and researchers as the LTPP representative value for each data element and pavement test section.

Data Support Table: ANALYSIS_TST_*_SUPPORT

The ANALYSIS_TST_*_SUPPORT table contains data statistics and the number of samples tested for each representative layer and layer property. The purpose of this table is to inform the user about the variability and the method that was used to populate ARMAD. For each material property, the table contains the average, median, minimum, maximum, standard deviation, coefficient of variation (COV), number of samples used in the calculation, and the source variability code of the value, as appropriate.

Data Tables

Table 2 lists the tables created in the PPDB. The collective set of tables contains more than 1 million records.

Contents of Each ARMAD Material Property Table

In general, the contents of each material property table include a description of the section and the layer type by section layer. Specifically, the contents include information that identifies a specific layer in a test section. The contents also include information on all material properties for each given layer, as shown in table 1. Thereby, the user can determine and use all of the materials information derived for ARMAD for each layer of the test section. These tables will likely be of primary interest to researchers because they provide the most representative value for a given material property, as guided by the ARMAD subject matter experts to the LTPP program. These tables should be considered as an ARD.

Contents of Each ARMAD Support Table

In general, the contents of each material support table include a set of key fields that identify the layer within the section and the State, provide a description of the layer, and provide the basis for the material property value. The support table also includes the minimum, maximum, average, median, standard deviation, COV, and sample count for each material property, as applicable. The user can merge the support table with the ARMAD material property table by using the set of key fields to further filter the data.

The data element, which is termed REP_CODE_SOURCE_VARIABILITY in the ANALYSIS_TST_*_SUPPORT tables, is very important because it informs the user about the relative quality of the individual material property. A one- or two-character code comprises the element. The first character shows the data source, as

Table 2. List of tables created for ARMAD in the LTPP database.

Table Name	Description
ANALYSIS_TST_UNBOUND	Representative properties of unbound base, subbase, and subgrade materials.
ANALYSIS_TST_UNBOUND_SUPPORT	Support information for the unbound base, subbase, and subgrade material properties.
ANALYSIS_TST_PCC	Representative properties of PCC materials.
ANALYSIS_TST_PCC_SUPPORT	Support information for the PCC material properties.
ANALYSIS_TST_AC	Representative properties of AC materials.
ANALYSIS_TST_AC_SUPPORT	Support information for the AC material properties.
ANALYSIS_TST_AC_ESTAR	AC dynamic modulus data generated from an analysis study (Kim et al. 2011). There is presently no support table.
ANALYSIS_TST_AC_CREEP_COMP	AC creep compliance testing properties.
ANALYSIS_TST_AC_CRCOM_SUPPORT	Support information for the AC creep compliance values.
ANALYSIS_TST_ACT	Representative properties of asphalt-treated base and subbase testing materials.
ANALYSIS_TST_ACT_SUPPORT	Support information for the asphalt-treated base and subbase material properties.
ANALYSIS_TST_PCT	Representative properties of cement-treated base and subbase materials.
ANALYSIS_TST_PCT_SUPPORT	Support information for cement-treated base and subbase materials.
ANALYSIS_TST_TR	Representative properties of treatment layers.

Table 2. List of tables created for ARMAD in the LTPP database. (Continued)

Table Name	Description
ANALYSIS_TST_TR_SUPPORT	Support information for treatment layer types.
ANALYSIS_TST_EF	Representative properties of engineering fabric layers.
ANALYSIS_TST_EF_SUPPORT	Support table for engineering fabric layers.

shown in table 3. The second character, when present, characterizes the representative source code variability. If the second character is not present, it means the variability is unknown or not applicable.

The specific value for each classification is described as follows:

Measured Values—Code A

These properties were directly measured by using standard testing in the LTPP program. Two primary scenarios were available:

- Layers with one specimen tested per layer: The table was populated with the single measured value.
- Layers with more than one specimen tested per layer: The layer was evaluated to determine whether all tests were representative. If they were, an average or median (depending on data dispersion) was used. If not, then available data were assessed to determine the best value based on technical expertise and logic.

Table 3. Data source code descriptions.

Data Source Code	Description
A	Properties directly measured in the LTPP program by using field or laboratory materials sampling and testing.
B	Properties calculated by using measured parameters and assumed conditions.
C	Properties expanded to similar sections in an LTPP experiment by using the PROJECT_LAYER_CODE.
D	Properties estimated by using statistical methods and typical models.
E	Properties adopted from inventory or maintenance/rehabilitation data.
F	Properties estimated by basing them on the MEPDG or other reliable sources.

For layers with a single measurement, a second character of S (for single) was added to the data source code resulting in AS. Material properties with two or more measurements were divided into low COV and high COV, based on an identified threshold appropriate for the property and material type. A second character of L (for low COV) or H (for high COV) was added to the data source code, resulting in AL or AH. If the variability was unknown or not applicable, a second character was not added to the data source code. The approach described in this paragraph was also used for the remaining data source codes (i.e., B to F).

Calculated Values—Code B

These properties were calculated by using measured parameters and assumed conditions. In some cases, materials testing was conducted but a final, representative value was not contained in the LTPP database. As an example, the unbound resilient modulus test has values for up to 15 stress sequences. The test was purposefully developed this way to ensure that users could derive their own resilient modulus values at a specified bulk stress. However, for the purposes of the ARMAD, one value was desired, and thus it was calculated assuming typical bulk stress values for different layers.

Expanded Values—Code C

In this case, the material properties for a given section are expanded from an adjacent LTPP section using the PROJECT_LAYER_CODE. Since SPS projects consist of multiple test sections, a "project-level layering structure" was developed to keep track of pavement layering and test results from various test sections. The ultimate purpose of the project-level layering was to set up an accounting system that could be used to link material tests for a given pavement layer in a particular section to other similar materials throughout the project (Simpson, Schmalzer, and Rada 2007). Therefore, the PROJECT_LAYER_CODE is an SPS project-level layer identifier and allows layers in different test sections on the same SPS project with the same material properties to be identified (Elkins and Ostrom 2021). In some cases, such as in the SPS-3 and -4 test sections, the materials on the test sections were not themselves sampled. The material properties may be derived from an adjacent GPS test section that was sampled and tested, because SPS-3 and -4 test sections typically had GPS test sections nearby.

Imputed Values—Code D

Imputed values are properties that are estimated by using engineering models or statistical methods. For example, the gradation of unbound materials not tested was imputed by deriving the mean percent passing of sieves, based on layers with the same material type in the LTPP database. The appropriateness of the gradation was then checked by comparing the imputed values against the derived mean percentages for the same material type.

Inventory Values—Code E

In some cases, inventory data were used, such as when testing was not conducted or when a material test did not otherwise have a value for a given layer. Inventory data are gathered from agency records or agency specifications or from reported maintenance/rehabilitation data. These data were used on a case-by-case basis.

Assumed Values—Code F

Default values from the AASHTO Pavement ME Design software were used for values for which there were no data in the LTPP IMS (Afsharikia et al. Forthcoming; AASHTO 2020). This classification does not have a COV designation because these are assumed values, so they are one-character values.

A schematic of the classification system is shown in table 4. In general, as the code goes from A to B to C, and so forth, the less confidence there is in the value; however, for all cases, the best value was selected for a particular layer and particular material property.

Tracking Changes in Pavement Structure Over Time

Each time an LTPP test section's characteristics change because of rehabilitation treatments or the application of maintenance treatments, the section is assigned a new construction number (CN) in the TST_L05B table. When a pavement section is first accepted into the LTPP program, it is assigned a CN of 1. The CN is incremented by one for each successive maintenance or rehabilitation event. It was necessary to assign material properties to all layers in the section for all construction events to perform the LTPP ARMAD process (Afsharikia et al. Forthcoming).

Disseminating Data

The LTPP program uses InfoPave to disseminate data and information to users. This data portal can be accessed at https://infopave.fhwa.dot.gov/ (FHWA 2022a). The PPDB tables explained previously can be found in the Data hub under Standard Data Release in LTPP InfoPave at https://infopave.fhwa.dot.gov/Data/StandardDataRelease/ (FHWA 2022c).

The data are also available in the LTPP InfoPave portal under the Data Selection and Download section at https://infopave.fhwa.dot.gov/Data/DataSelection (FHWA 2022d). This download method enables users to access an easy-to-use intuitive interface to select and download data of their choosing.

INTENDED USE OF THE ARMAD

The ARMAD is the end product of a materials data-wrangling effort for the LTPP database to facilitate future work by LTPP data users and researchers (Afsharikia et al. Forthcoming). The ARMAD has many uses in the engineering profession. As mentioned previously, the ARMAD is a consolidated summary of the vast amount of material properties information contained in the LTPP database, along with inputted and calculated values. These material properties were selected based on the standard engineering properties needed to classify layers and properties needed to calibrate and run pavement performance and design software, with a focus specifically on the AASHTO Pavement ME software (AASHTO 2020).

Examples of the types of studies that can be performed with the ARMAD dataset include the following (Afsharikia et al. Forthcoming):

- Developing a materials dataset for a selection of test sections as part of a broader pavement research study.
- Conducting materials data studies of in-service pavements.
- Developing correlations and prediction models (regression, machine learning, etc.) between material properties.
- Using the values contained in the ARMAD to perform pavement materials analysis, including laboratory to field comparisons and advanced materials testing analysis (resilient modulus, dynamic modulus).
- Using the material properties for local calibration of the MEPDG (AASHTO 2020).
- Evaluation of the impact of material properties on pavement maintenance and rehabilitation.

As with any dataset, caution should be exercised with these data, and the assumptions made to populate the dataset should be fully understood prior to using it. The dataset is a compilation of many data tables and

Table 4. Classification system used for REP_CODE_SOURCE_VARIABILITY field.

DATA SOURCE GROUP	DESCRIPTION	DATA SOURCE CODE	SUB-GROUPS	REP_CODE_ SOURCE_ VARIABILITY
Measured	Properties directly measured by using standard testing in LTPP program.	A	Variability unknown or not applicable	A
			More than one measured value with low COV	AL
			More than one measured value with high COV	AH
			Single value measured	AS
Calculated	Properties calculated by using measured parameters and assumed conditions.	B	Variability unknown or not applicable	B
			Calculated from more than one measured parameter with low COV	BL
			Calculated from more than one measured parameter with high COV	BH
			Calculated from one measured parameter	BS
Expanded	Properties expanded to similar sections in an LTPP experiment by using the PROJECT_ LAYER_CODE.	C	Variability unknown or not applicable	C
			More than one measured value from similar sections, low COV	CL
			More than one measured data from similar sections, high COV	CH
			One data point from similar sections	CS
Imputed	Properties estimated by using statistical methods and typical engineering models.	D	Variability unknown or not applicable	D
			Imputed from more than one measurement with low COV	DL
			Imputed from more than one measurement with high COV	DH
			Imputed from one measured value	DS
Inventory	Properties adopted from inventory representing agency typical practices.	E	Variability unknown or not applicable	E
			Inventory median for more than one value with low COV	EL
			Inventory median for more than one value with high COV	EH
			Inventory single value	ES
Assumed	Properties estimated by basing them on the MEPDG or other reliable sources.	F	Assumed values	F

data values, including directly measured, calculated, expanded, imputed, derived from inventory data, and assumed. Ultimately, the purpose of developing the ARMAD—using the best assumptions and algorithms known to LTPP at this time—was to eliminate much of the data-wrangling effort commonly done by researchers to make LTPP data extraction easier.

RESOURCES

The following resource documents are useful in understanding the LTPP material characterization program. These documents are downloadable from https://infopave.fhwa.dot.gov/Reports/Library (FHWA 2022b):

- FHWA. 1994. *Specific Pavement Studies, Material Sampling and Testing Requirements for Experiment SPS-1: Strategic Study of Structural Factors for Flexible Pavements.* Washington, DC: Federal Highway Administration.
- FHWA. 1994. *Specific Pavement Studies, Material Sampling and Testing Requirements for Experiment SPS-2: Strategic Study of Structural Factors for Rigid Pavements.* Washington, DC: Federal Highway Administration.
- FHWA. 1996. *Specific Pavement Studies, Material Sampling and Testing Requirements for Experiment SPS-9A: SUPERPAVE Asphalt Binder Study.* Washington, DC: Federal Highway Administration.
- FHWA. 2015. *The Long-Term Pavement Performance Program.* Report No. FHWA HRT-15-049. Washington, DC: Federal Highway Administration.
- NAS NRC. 1991. *Field Material Sampling and Testing Guide SHRP-LTPP Guide for Field Materials Sampling, Testing, and Handling.* Operational Memorandum No. SHRP-LTPP-OG-006. Washington, DC: United States National Academies of Sciences (NAS), National Research Council (NRC).
- NAS NRC. 1991. *Specific Pavement Studies, Material Sampling and Testing Requirements for Experiment SPS-5: Rehabilitation of Asphalt Concrete Pavements.* Operational Memorandum No. SHRP-LTPP-OM-014. Washington, DC: National Academy of Sciences, National Research Council.
- NAS NRC. 1991. *Specific Pavement Studies, Material Sampling and Testing Requirements for Experiment SPS-6: Rehabilitation of Jointed Portland Cement Concrete Pavements.* Operational Memorandum No. SHRP-LTPP-OM-019. Washington, DC: National Academy of Sciences, National Research Council.
- NAS NRC. 1991. *Specific Pavement Studies, Material Sampling and Testing Requirements for Experiment SPS-7: Bonded Portland Cement Concrete Overlays.* Operational Memorandum No. SHRP-LTPP-OM-020. Washington, DC: National Academies of Sciences, National Research Council.
- NAS NRC. 1992. *Specific Pavement Studies, Material Sampling and Testing Requirements for Experiment SPS-8: Study of Environmental Effects in the Absence of Heavy Loads.* Operational Memorandum No. SHRP-LTPP-OM-030. Washington, DC: National Academy of Sciences, National Research Council.
- Simpson, A. L., P. N. Schmalzer, and G. R. Rada. 2007. *Long-Term Pavement Performance Project Laboratory Materials Testing and Handling Guide.* Report No. FHWA-HRT-07-052. Washington, DC: Federal Highway Administration.

REFERENCES

Afsharikia, N., J. Groeger, L. Garner, B. Ostrom, and G. Rada. Forthcoming. *Development and Use of the LTPP Analysis-Ready Materials Dataset.* Washington, DC: Federal Highway Administration.

AASHTO. 2020. *Mechanistic-Empirical Pavement Design Guide: A Manual of Practice*, 3rd ed. Washington, DC: American Association of State Highway and Transportation Officials.

Elkins, G. E., and B. Ostrom. 2021. *Long-Term Pavement Performance Information Management System User Guide.* Report No. FHWA-HRT-21-038. Washington, DC: Federal Highway Administration.

FHWA. 2015. *The Long-Term Pavement Performance Program.* Report No. FHWA HRT-15-049. Washington, DC: Federal Highway Administration.

FHWA. 2022a. "LTTP InfoPave" (web page). https://infopave.fhwa.dot.gov/, last accessed March 1, 2022.

FHWA. 2022b. "LTTP InfoPave: Library" (web page). https://infopave.fhwa.dot.gov/Reports/Library, last accessed March 1, 2022.

FHWA. 2022c. "LTTP InfoPave: Data: Standard Data Release" (web page). https://infopave.fhwa.dot.gov/Data/StandardDataRelease/, last accessed March 1, 2022.

FHWA. 2022d. "LTPP InfoPave: Data: Data Selection" (web page). https://infopave.fhwa.dot.gov/Data/DataSelection, last accessed March 1, 2022.

Kim, Y. R., B. Underwood, M. Sakhaei Far, N. Jackson, and J. Puccinelli. 2011. *LTPP Computed Parameter: Dynamic Modulus.* Report No. FHWA-HRT-10-035. Washington, DC: Federal Highway Administration.

Manning, D. G. 1986. *Strategic Highway Research Program Research Plans, Final Report.* Washington, DC: Transportation Research Board of the National Research Council.

Simpson, A. L., P. N. Schmalzer, and G. R. Rada. 2007. *Long-Term Pavement Performance Project Laboratory Materials Testing and Handling Guide.* Report No. FHWA-HRT-07-052. Washington, DC: Federal Highway Administration.

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