NCHRP

REPORT 512

NATIONAL
COOPERATIVE
HIGHWAY
RESEARCH
PROGRAM

Accelerated Pavement Testing: Data Guidelines

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

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Accelerated Pavement Testing: Data Guidelines

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Subject Areas

Pavement Design, Management and Performance • Materials and Construction

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TRANSPORTATION RESEARCH BOARD

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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Applied Research Associates, Inc., ERES Consultants Division, conducted the research described herein. Dr. Jim W. Hall, Jr., was the principal investigator for the study.

Dr. Athar Saeed served as the project engineer and prepared this report with Dr. Hall. Mr. Richard N. Stubstad supervised the work at Consulpav International, and Mr. Erland Lukanen supervised the work at Braun Intertec Corporation. Dr. Vincent Janoo and Dr. Thomas D. White served as project consultants.

FOREWORD

By Amir N. Hanna
Staff Officer
Transportation Research Board

This report provides definition and guidelines to help agencies involved in accelerated pavement testing (APT) ensure proper interpretation of the data and facilitate their use by other agencies. Use of these guidelines will promote compatibility of data resulting from APT at different facilities and will provide an effective means for economically addressing issues of common concern, reducing duplication of research efforts, and enhancing the benefits of APT. The report is a useful resource for pavement and materials engineers, researchers, and others involved the accelerated evaluation of pavement materials, designs, and features.

The use of APT for determining pavement response and performance has increased in recent years, primarily because of its ability to apply wheel loads in a compressed time period, thus providing an expedited means of evaluating potential materials, designs, and features. However, the data collected and reported by the various APT facilities have often varied in definition and format, making it difficult for others to interpret and use. Therefore, research was needed to identify and develop definitions of the data associated with the tests performed by APT facilities and to recommend guidelines for data collection, storage, and retrieval. This information will help to ensure proper interpretation of the data and facilitate their use by other agencies, thus enhancing the benefits of APT results. NCHRP Project 10-56 was conducted to address this need.

Under NCHRP Project 10-56, “Accelerated Pavement Testing: Data Guidelines,” Applied Research Associates was assigned the objectives of (1) identifying and developing definitions of the data elements associated with APT and (2) recommending guidelines for their collection, storage, and retrieval. The research was limited to APT in which full-scale wheel loads are applied to full pavement structures by either machines or vehicles in a test facility, test track, or in-service pavement for the purpose of determining pavement response and performance in a compressed time period. To accomplish these objectives, the researchers reviewed relevant domestic and foreign literature; surveyed U.S. organizations that had active APT facilities as well as organizations that previously operated or planned future operation of APT facilities; and visited several U.S. facilities to acquire information on the current practices for use as a basis for developing acceptable definitions and rational guidelines.

The literature review and field visits revealed that 15 APT facilities were in operation in the United States in 2002. Tests were conducted at these facilities to address a variety of topics related to materials, design, construction, and life-cycle costs of pavements. The research also highlighted the operating characteristics of these facilities, the types of data being collected, and the practices for collecting, storing, and retrieving these data.

The research suggested the classification of data elements into seven categories—administrative, load application, pavement description, material characterization, environmental conditions, pavement response, and pavement performance—and provided definitions of the data elements included in each category. The research also recommended guidelines that address (1) the data elements and their definitions and (2) the data collection and storage requirements, and the research identified the test methods currently available for characterizing paving materials used in APT.

The information contained in this report will be particularly useful to agencies currently operating, or planning the operation of, APT facilities. These agencies should ensure compatibility of their databases with the recommended guidelines to facilitate the use of data from tests performed at different APT facilities in addressing issues of common concern.

CONTENTS

ACCELERATED PAVEMENT TESTING: DATA GUIDELINES

SUMMARY

Over the years, more and more highway agencies have used accelerated pavement testing (APT) as a means of evaluating potential construction materials, pavement designs, and other pavement-related features. Of primary concern in APT is the application of a significant traffic volume in a reasonable length of time and at an acceptable cost to produce measurable deterioration. APT is generally defined as the application of wheel loads to specially constructed or in-service pavements to determine pavement response and performance under a controlled and accelerated accumulation of damage in a short period of time. The research being reported is concerned with APT in which full-scale wheel loads are applied to full pavement structures by machines or vehicles in a test facility, at a test track, or on an in-service pavement. APT facilities have several advantages over in-service pavements:

- APT facilities provide a safer environment for the researchers and the traveling public (tests on in-service highways often involve safety hazards).
- Tests can be conducted more quickly and in a more controlled manner.
- The number of wheel load applications can be controlled accurately, and loads can be positioned at desired locations.
- Different factors can be evaluated simultaneously.

This research was conducted to (1) identify and develop definitions of data elements associated with APT and (2) recommend guidelines for data collection, storage, and retrieval. Pertinent national and international literature was reviewed to determine the state-of-the-practice in APT, with emphasis on APT facilities located in the United States. A questionnaire was then sent to APT facilities in the United States to gather information on facility administration, APT machine loading characteristics, pavement test programs, material characterization, environmental and climatic data, instrumentation installed, pavement response to load, pavement performance, construction and postmortem testing, and data documentation and storage. The survey showed that state departments of transportation operate six APT facilities, universities operate five, the U.S. Army Corps of Engineers operates two, the Federal Highway Administration operates one, and a private firm operates one. The survey was followed by visits to most of the APT facilities to supplement the collected information.

The literature review results, the survey data, and information gathered during APT facility visits were used to identify and define data elements. The data elements were categorized as follows:

- Administrative—administrative details of a particular APT facility or a particular study/experiment being conducted at the facility.
- Load application—wheel loadings applied to a test pavement and the characteristics of the applied loads.
- Pavement description—information on pavement type, pavement construction, and geometric details.
- Material characterization—information about material type, composition, stiffness, strength, and test methods.
- Environmental conditions—information (primarily temperature and moisture) about the “above” and “within” pavement conditions.
- Pavement response—deflections, stresses, or strains measured at the pavement surface or within the pavement structure when subjected to a given load or when subjected to changes in temperature and moisture.
- Pavement performance—information on various types of pavement surface distress, pavement smoothness, and longitudinal and transverse (rutting) profiles.

Data can be collected manually, semi-automatically (generated electronically or mechanically but recorded manually), or automatically (data generated and recorded electronically). Administrative data are usually collected manually, whereas pavement response data collection is more automated.

The most common data storage medium is paper—written information (such as tables) filed in folders and stored in cabinets. Electronic storage devices range from simple floppy disks to more complex optical disks and flash memory cards. Electronic text files and spreadsheets are used for small data amounts, and dedicated databases are mostly used for large quantities of data. The method used for data storage and retrieval depends on the type and quantity of data. Storage capacity, cost, performance, reliability, and manageability must be considered when selecting a data storage and retrieval system.

Finally, guidelines for APT were prepared to facilitate sharing of data among researchers. These guidelines delineate data elements related to APT and their definitions, describe information on state-of-the-art data storage and retrieval systems, provide recommendations and specifications for a database, and propose data collection frequencies.

CHAPTER 1

INTRODUCTION

BACKGROUND

Accelerated pavement testing (APT) is the application of wheel loadings to specially constructed or in-service pavements to determine pavement response and performance under a controlled, accelerated accumulation of damage (*1*). However, this project only dealt with APT in which full-scale wheel loads are applied to full-scale pavements by machines or vehicles in a test facility, at a test track, or on an in-service pavement.

Many agencies use APT facilities to evaluate construction materials, pavement designs, and other aspects of pavement performance. Of primary concern in APT is its application of a sufficient traffic volume, in a reasonable length of time, and at an acceptable cost to produce measurable response or deterioration. The acceleration of damage in testing can be achieved by an increased rate of load application, increased load magnitude (loads greater than the pavement design load), modification of loading characteristics, reduced pavement thicknesses, imposed adverse environmental conditions, or a combination of these factors. Application of traffic loads at an increased rate is the most desirable means of inducing pavement damage. Even with accelerated loading, it is often not practical to test for high volumes of design load. It is important that the APT conditions do not differ significantly from actual in-service conditions so that the APT produces pavement distress types similar to those observed on in-service pavements.

The performance data collected and reported by various APT facilities are not readily comparable; data are generally facility specific and often project specific. Differences in definitions of test parameters and the format in which data are collected, recorded, and stored make it difficult for others to interpret and use the data, leading to duplication of efforts. Therefore, significant benefits can be achieved by establishing uniform guidelines for both data collection and archiving test results. NCHRP Project 10-56 was conducted to address this need.

RESEARCH OBJECTIVE

The research was conducted to identify and develop definitions of data elements associated with APT and to recommend guidelines for data collection, storage, and retrieval. Because of the growth of the number of APT facilities, vast amounts of data associated with APT are being generated; standardized definitions and guidelines will ensure proper interpretation of the data and facilitate their use by other agencies, thus enhancing the benefits of APT results.

SCOPE OF STUDY

The research included the following tasks:

1. Review *NCHRP Synthesis of Highway Practice 235* (*1*) and other domestic and foreign literature, research findings, and current practices relevant to the use of APT facilities;
2. Identify and define the terms and data elements associated with APT;
3. Document current practices for collecting, storing, and retrieving APT data; and
4. Prepare guidelines that address the collection, storage, and retrieval of data associated with APT.

RESEARCH APPROACH

The research approach included a literature search and a survey. *NCHRP Synthesis of Highway Practice 235* (*1*) helped identify data sources and active and planned APT programs. The inventory of domestic APT programs was updated through a brief literature review and personal contact with operating agencies. A questionnaire was sent to all APT facilities in the United States to seek information on administrative and technical details of the testing programs, including methods for applying the load, characteristics of the loading device, geometrics of the pavement test sections, pavement material properties, pavement instrumentation, data collected, methods for collecting data (including recording equipment), test methods and test procedures, and methods of data storage and retrieval. Follow-up visits were then made to obtain information on how the APT data have been used and to determine if the data from other APT facilities have been combined with these data to enhance their use.

Based on the results of the literature review, questionnaire, and visits to APT facilities, a list of data elements pertaining to APT was developed. Definitions and methods/procedures for collecting, storing, and retrieving each data element were assembled to produce the guidelines.

CHAPTER 2

ACCELERATED PAVEMENT TESTING: STATE OF THE PRACTICE

The objectives of this research were to identify and define data elements associated with APT facilities and recommend guidelines for their collection, storage, and retrieval. To accomplish these objectives, the researchers performed the following activities:

1. Identification of all active and planned APT facilities;
2. Review of literature pertaining to APT facilities, data elements, data collection methods, and data storage processes and media;
3. Survey of active and planned APT facilities using a questionnaire;
4. Visits to APT facilities to clarify and augment previously gathered information.

NCHRP Synthesis of Highway Practice 235 (*1*) provided information on sources of data and active and inactive APT programs. APT facilities considered in this research are listed in Table 1. Of the fifteen facilities studied, five are operated by universities, six by state departments of transportation (DOTs), three by federal agencies (two by the Department of Defense and one each by the Federal Highway Administration), and one by a private firm (although funding for the research was initially provided by the FHWA and subsequently by the NCHRP).

RESULTS OF LITERATURE REVIEW

Published literature and other information sources were reviewed to determine the current practices of APT users regarding data collection and data storage. Key sources included the Transportation Research Information Services (TRIS), the National Technical Information Service (NTIS) databases, the resources of the Grainger Engineering Library at the University of Illinois, and the technical library at the U.S. Army Engineer Research and Development Center (ERDC) in Vicksburg, Mississippi.

PURPOSE OF APT PROGRAMS

Although each APT facility has its own objectives, all APT facilities provide pavement engineers with a means to study pavement-related issues within a short period of time; they provide quick and reliable test results using cost-effective research for evaluation of pavement performance. Examples of the purpose and objectives of some of the APT studies include the following:

- Evaluations of load damage equivalency, remaining life and impact on rehabilitation techniques, new pavement materials, and truck component pavement interactions by the TxMLS (*2*). Several related investigations have been conducted since the program was launched in 1995 (*3*, *4*).
- Evaluation of quality control/quality assurance (QC/QA), structural design, construction practices and specifications, overlay design and construction, and long-life pavement rehabilitation by CAL/APT (*5*, *6*, *7*).
- Development of performance-related specifications (PRSs) for asphalt concrete (AC) pavements and field verification of the Superpave hot mix asphalt (HMA) design procedure by the WesTrack (*8*)
- Aid in developing of mechanistic-empirical (ME) pavement design methods and addressing issues specific to the interactions of climate, soil, and traffic in cold regions by Mn/ROAD (*9*, *10*).
- Evaluation of pavement design, construction, evaluation, and maintenance of military airfield, roadways, and other operating surfaces by the U.S. Army Corps of Engineers (USACE) research laboratories (*11*).

DATA COLLECTED AT APT FACILITIES

Collection and analysis of test-related data (for example, load application, test section description, material characteristics, environment, pavement response, and pavement performance) is essential for developing meaningful conclusions and recommendations. At the same time, administrative data that identify the unique features of a particular APT facility (for example, funding agency, test agency, goals and objectives, type and location of the facility, and key people involved) are also useful. APT data reported in the literature are divided into seven categories pertaining to the following elements:

- Administrative
- Load application

TABLE 1 APT facilities

Facility Name and Location	Facility Designation	Owner Agency
Advanced Transportation Research and Engineering Laboratory (ATREL); Rantoul, IL	ATREL	University of Illinois at Urbana-Champaign
Caltrans Accelerated Pavement Testing (CAL-APT) Heavy-Vehicle-Simulator (HVS) Program; Richmond, CA	CAL-APT	California Department of Transportation
U.S. Army Cold Regions Research and Engineering Laboratory (CRREL), Frost Effects Research Facility; Hanover, NH	CRREL-HVS	Cold Regions Research and Engineering Laboratory
FHWA Pavement Test Facility (PTF); McLean, VA	FHWA-PTF	Federal Highway Administration
Florida-Accelerated Pavement Testing and Research Facility[a] (APTRF); Gainesville, FL	FL-APTRF	Florida Department of Transportation
Indiana DOT/Purdue APT Facility; West Lafayette, IN	INDOT/Purdue	Indiana Department of Transportation
Kansas-Accelerated Pavement Testing (APT); Manhattan, KS	KS-APT	Kansas State University
Louisiana Transportation Research Center (LTRC) Pavement Research Facility (PRF); Port Allen, LA	LTRC-PRF	Louisiana Transportation Research Center
Minnesota Road Research Project (Mn/ROAD); Minneapolis, MN	Mn/ROAD	Minnesota Department of Transportation
National Center for Asphalt Technology (NCAT) Pavement Test Track (PTT); Auburn University, AL	NCAT-PTT	National Center for Asphalt Technology
Ohio-Accelerated Pavement Loading Facility (APLF); Lancaster, OH	OH-APLF	Ohio University/Ohio State University
Penn State (PS) Pavement Durability Facility[b] (PDF); College Park, PA	PS-PDF	Pennsylvania State University
Texas Mobile Load Simulator (TxMLS); Austin, TX	TxMLS	Texas Department of Transportation
U.S. Army Corps of Engineers Waterways Experiment Station (WES) HVS; Vicksburg, MS	WES-HVS	Engineers Research and Development Center
WesTrack[c]; Reno, NV	WesTrack	Nevada Automotive Test Center

[a] under construction, [b] inactive facility, [c] not in operation

- Pavement description
- Material characterization
- Environmental conditions
- Pavement response
- Pavement performance

Administrative Data

Administrative data describe and document the test program being conducted. These data include facility name and location, owner/operator, key personnel, project/program name and objectives, test start date, and timeframe. Complete administrative data were not available in all cases.

Load Application Data

APT load application data relate to the load as applied during a particular project and may not represent the full load application capability of the particular APT system. Load application data reported in the literature are listed in Table 2. Typical examples of the load application data of some of the APT studies are discussed below.

Pavement Description Data

Pavement description data elements include information about pavement type, pavement construction, and geometric details. The objectives of a particular test dictate the collection of specific pavement-related data. Table 3 provides examples of pavement description data elements reported in the literature.

Material Characterization Data

Material characterization data are obtained from established tests and occasionally from tests under development. These data pertain to materials used in a test pavement and include descriptions of the characterization methodologies and test results, such as the following:

- Physical description data (for example, density, water content, cement content, asphalt content, and void ratio)
- Strength data (for example, cohesion, angle of internal friction, shear strength, Marshall stability, and modulus of rupture)

TABLE 2 Examples of reported APT-related load application data elements

Load Application Data Element	Explanation of Data Element	APT FACILITY	
		CAL-APT (*5, 7*)	CRREL-HVS (*11*)
Loading device	Method of load application	Dual or single standard size truck tires	Single/dual aircraft or vehicle tires
Load magnitude	Value of applied load	Can load up to 200 kN, usually loaded at 40-100 kN	20-111 kN, -200 kN (C141 aircraft)
Load monitoring	Method of monitoring load	Static (hydraulic pressure gage)	Load cell
Load application speed	Linear wheel speed	8-10 km/h	0 - 13 km/h
Tire description	Explanation of tire type	Varies with experiment	Vary with experiment
Tire pressure	Tire inflation pressure	690 kPa	Variable (up to 690 kPa)
Description of load carriage suspension	Suspension type	Hydraulic suspension	Hydraulic suspension
Lateral movement and wander	Description of wander simulation and range	± 1000 mm	Varies
Load applications (One- or two-way)	Direction of load application	One-way/two-way	One-way/two-way

TABLE 2 (Continued)

Load Application Data Element	APT Facility			
	FHWA-PTF (*12*)	INDOT/Purdue (*13*)	KS-APT (*14, 15*)	LTRC-PRF (*16, 17*)
Loading device	Super single or dual tires, single wheel assembly	Single or dual tires	Standard truck tandem axle with super single or standard tire	Dual-tire, single wheel assembly
Load magnitude	44-100 kN	Up to 89 kN	Up to 178 kN	43-85 kN
Load monitoring	Static scale	Portable scales	Load airbag pressure	Four load cells mounted on the machine
Load application speed	4-18 km/h	8 km/h	11.3 km/h	17 km/h
Tire description	11R22.5 radial ply, 425/65R x 22.5 G286 super single	11 R 24.5 and 425/65 R22.5 super single	10x20, 8.25x20, 11x22, super single	11R22.5 single wheel
Tire pressure	690 kPa	620 kPa (variable)	620 kPa	724 kPa
Description of load carriage suspension	Air bag suspension	Coil springs	Air bag suspension	Air bag, steel shock absorbers
Lateral movement and wander	± 700 mm	± 200 mm	None	± 400 mm
Load applications (One- or two-way)	One-way	One-way/two-way	One-way/two-way	One-way

TABLE 2 (Continued)

Load Application Data Element	APT Facility			
	Mn/ROAD Low Volume Test Road (*10*)	NCAT-PTT (*18*)	OH-APLF (*19*)	TxMLS (*3, 4*)
Loading device	Tractor-semi-trailer	Four tractor/triple trailer	Various wheel load configurations	Six bogies (full standard truck tandem axles each)
Load magnitude	365 kN GVW (4 days/week) 454 kN GVW (1 day/week)	88.9 kN/axle	9 to 30 kips	150 kN/tandem axle
Load monitoring	Static scales	Scales	Hydraulic (automatically adjusted)	Weigh-in-motion
Load application speed	60 – 100 km/h	72 km/h	Up to 8 km/h	18 km/h
Tire description	Std. singles, duals, wide-base single (super single)	295/75R22.5, radial	Std. singles, duals, wide-base single (super single)	295x75R22.5, low profile radial
Tire pressure	700 – 880 kPa	Variable, 700 kPa	Variable	690 kPa
Description of load carriage suspension	Air bag, steel springs	Conventional highway truck springs (steel springs)	Hydraulic actuator	Conventional highway truck springs (steel springs)
Lateral movement and wander	Actual driver behavior	Actual driver behavior	Random, ± 254 mm	± 435 mm (left/right of centerline)
Load applications (One- or two-way)	One-way	One-way	One-way/two-way	One-way

TABLE 2 (Continued)

Load Application Data Element	APT Facility	
	WES-HVS	**WesTrack (*20*)**
Loading device	Super single, dual truck, or C141 aircraft tire	Four driverless tractor/triple trailer units
Load magnitude	45-445 kN	88.9 kN/axle
Load monitoring	Hydraulic pressure	Scales
Load application speed	13 km/h	64 km/h
Tire description	Vary with experiment	295/75R22.5, radial
Tire pressure	Variable (up to 2400 kPa)	700 kPa
Description of load carriage suspension	Hydraulic suspension	Conventional highway truck springs (steel springs)
Lateral movement and wander	± 900 mm (1.0 m maximum)	± 400 mm (left/right of centerline)
Load applications (One- or two-way)	One-way/two-way	One-way

- Stiffness data (for example, modulus of elasticity, resilient modulus [M_R], and shear modulus)
- Aggregate toughness/abrasion properties (for example, hardness, abrasion resistance, durability, and soundness)
- Changes in material properties with time and environmental exposure

Table 4 lists the material characterization data elements reported in the literature in examples of the tasks conducted by the different APT facilities.

Environmental Conditions Data

Generally, test pavements are constructed to represent actual pavement design and field conditions. Some APT equipment is mobile to allow on-site testing of in-service pavements. However, field environmental conditions cannot be simulated exactly in APT facilities because of the short duration of testing.

Nevertheless, environmental factors are important, and related data are collected as part of the tests. Temperature and precipitation data are usually collected. Weather stations

TABLE 3 Examples of pavement description data elements

Pavement Description Data Element	Explanation of Data Element	APT Facility	
		CAL-APT (*5, 7*)	**CRREL-HVS (*11*)**
Pavement structure designation	Commonly used name of the pavement under study	Flexible/rigid pavement tests	Flexible
Surface layer thickness	AC or portland cement concrete (PCC) thickness	Varies with experiment. Test site 500RF has a 140-mm thick AC layer	Varies with test; currently subgrade failure study
Intermediate layers	Base/subbase thickness	Varies with experiment. Test site 500RF has 80-mm asphalt-treated base (ATB), 180-mm aggregate base (AB), and 230-mm aggregate subbase (ASB)	Varies with test; currently subgrade failure study
Subgrade	Method and depth of subgrade stabilization	Varies with location; test site 500RF is clay subgrade	Varies with experiment; A-2-4, A-4, A-6, A-7-6, & A-2-4 soils being investigated
PCC slab dimensions	Slab length and width	Varies with experiment	PCC pavements not tested
Load transfer devices (PCC)	Common name	Varies with experiment	
Length/width of traffic lane	Test section dimensions	8 x 1 m	7.0 x 3.0 m
Construction related information	Construction procedure used	Standard Caltrans	Standard USACE
QC/QA, procedure, frequency	QC/QA tests used and their frequency	Standard Caltrans	Standard USACE
Test pavement design method	Structural design method	Caltrans/AASHTO	USACE Layered Elastic Design
Method, degree of compaction	Compaction method	Varies with experiment	Standard USACE
Cross-section design	Transverse slopes	2%	None
Grades and slopes	Longitudinal slopes	Minimal grades	None
Drainage provisions	Common name	Varies with experiment; drained/undrained	Varies with experiment

(*continued on next page*)

TABLE 3 (Continued)

Pavement Description Data Element	APT Facility			
	FHWA-PTF (*12*)	**INDOT/Purdue (*13*)**	**KS-APT (*14, 15*)**	**LTRC-PRF (*16, 17*)**
Pavement structure designation	Flexible/rigid	Composite	Flexible, rigid, composite	Flexible
Surface layer thickness	Varies with experiment; i.e., 102-, 203-, 204-mm thick AC layer. PCC tests: (a) 64 and (b) 89 mm thick	Varies with test; 76- to 125-mm thick AC layer	(a) AC: 76-mm; (b) PCC: 229-mm (c) 100-mm AC overlay of 229-mm PCC	Varies with experiment; e.g., a study to evaluate different bases used 9-cm thick AC layer
Intermediate layers	Varies with experiment; e.g., 559-, 457-mm thick base layer	None. Rutting of AC overlay of existing PCC	102-mm cold in-place recycled base (fly ash stabilized), 102-mm aggregate base	Varies with experiment; e.g. combinations of plant and in-situ mixed agg-cement base
Subgrade	Unmodified existing subgrade	Not applicable	1220-mm subgrade over drainage layer	Varies with experiment; existing subgrade in example
PCC slab dimensions	(a) 1.83 and 1.22 m square; (b) 1.22 and 0.91 m square	1.5 x 6.0 m	3.66 m x 6.10 m	None tested so far
Load transfer devices (PCC)	None	None	None used	
Length/width of traffic lane	14 m x 1 m	1.5 x 6.0 m	5.5 x 2.44 m	12 m x 1.2 m
Construction related information	Standard highway construction procedure	Project specific	Standard Kansas DOT	Louisiana Department of Transportation and Development (LaDOTD)
QC/QA, procedure, frequency	Virginia DOT	Indiana DOT	Standard Kansas DOT	LaDOTD
Test pavement design method	Virginia DOT	Indiana DOT	Standard Kansas DOT	LaDOTD
Method, degree of compaction	Varies with experiment	Project specific; maximum and 64 kg/m^3 lower	Standard Kansas DOT	Varies with experiment
Cross-section design	No cross slopes	None	None	LaDOTD
Grades and slopes	0.5%	None	None	None
Drainage provisions	Piped edge drains	Drained/undrained; not used to date	Pea gravel drainage layer in test pit	None

TABLE 3 (Continued)

Pavement Description Data Element	APT Facility			
	Mn/ROAD - LVTR (*10*)	**NCAT-PTT (*18*)**	**OH-APLF (*19*)**	**TxMLS (*3, 4*)**
Pavement structure designation	8 PCC, 9 AC, and 4 gravel pavement test cells	Flexible	Flexible, rigid	Flexible/Composite
Surface layer thickness	AC: 80, 100, and 130 mm PCC: 130, 160, 190 mm Gravel: 50, 60 mm Double chip seal: 30 mm	50 mm surface course	203-mm PCC slab (example study: Evaluate PCC and dowel response to environ. and traffic loadings)	Varies with test. Thickness data available for all tests; e.g., 40- to 75-mm thick AC
Intermediate layers	Various thickness of the granular base ranging from 130 to 360 mm	610 mm asphalt base, 100-mm permeable asphalt base	152-mm dense graded aggregate base	Varies with test. Thickness data available for all tests; e.g., 380 mm base
Subgrade	Varies from cell to cell	A2 subgrade	1.8-m A-6 subgrade	Varies with test
PCC slab dimensions	3.7 by 3.7 m, 3.7 by 4.6 m, 3.7 by 6.1 m	PCC pavements not tested	4.57 m x 3.66 m Dowels	PCC pavements not tested
Load transfer devices (PCC)	2.5-cm diameter dowels			
Length/width of traffic lane	Varies	60 x 3.66 m	13.71 m x 3.66 m	12 x 3 m
Construction related information	Standard MnDOT	Standard (sponsoring DOT)	Standard Ohio DOT	Standard TxDOT
QC/QA, procedure, frequency	Standard MnDOT	Standard (sponsoring DOT)	Standard 1-, 1.3-, 2-, 14-, 28-, and 391-day PCC related information	Standard TxDOT
Test pavement design method	MnDOT design procedure	Sponsoring DOT	Standard Ohio DOT	TxDOT design procedure
Method, degree of compaction	Varies with experiment; R values range from 12 to 70 for the subgrade	Standard Alabama DOT	Standard Ohio DOT	Standard TxDOT
Cross-section design	Transverse slopes	2%, 15% superelevation	None	Standard TxDOT specs
Grades and slopes	Minimal longitudinal grades	Minimal longitudinal grade	None	None
Drainage provisions	Varies with experiment	Yes	None used	Varies with test; no drainage provisions in example test

TABLE 3 (Continued)

Pavement Description Data Element	APT Facility	
	WES-HVS (*11*)	**WesTrack (*7, 20*)**
Pavement structure designation	Flexible	Flexible (34 total sections; 26 original, 8 replacement)
Surface layer thickness	100-mm thick AC	150-mm HMAC
Intermediate layers	Varies with test. 580- and 840- mm thick 100 California Bearing Ratio (CBR) base	300-mm dense stone base, 300-mm engineered fill subbase
Subgrade	1.22-m thick 6 CBR clay subgrade	150-mm scarified and mixed
PCC slab dimensions	PCC pavements not tested	PCC pavements not tested
Load transfer devices (PCC)		
Length/width of traffic lane	3.0 m x 12.0 m	70 x 3.7 m
Construction related information	Standard USACE	LTPP SPS-9 Procedure
QC/QA, procedure, frequency	Standard USACE	AC content, aggregate gradation, volumetrics, air voids (*20*)
Test pavement design method	USACE Layered Elastic Design	WesTrack design using M-E principles
Method, degree of compaction	Standard USACE	Superpave specifications
Cross-section design	None	2% pavement, 6% shoulder
Grades and slopes	None	Nearly flat (<0.1%)
Drainage provisions	None	None

have been used at Mn/ROAD, WesTrack, and NCAT-PTT to monitor rainfall, temperature, wind speed, humidity, and barometric pressure. Generally, freeze-thaw effects are not considered in APT tests unless the tests are specifically designed to include these effects, such as those conducted at CRREL (*11*). Instrumentation is commonly used to monitor temperature and moisture conditions at various locations within the pavement structure. Table 5 provides examples of environmental data collected at APT facilities.

Pavement Response Data

Measuring response parameters generally requires instrumentation within the pavement structure, making it difficult, time-consuming, and expensive. For these reasons, in-service pavement tests seldom include pavement response data collection. Typical pavement response data include strain, pressure, and multiple depth deflections, as shown in Table 6.

Pavement Performance Data

Pavement performance is measured by visible surface distresses and deformations estimated using manual or automated means. The most common measurements are cracking, loss of skid resistance, and roughness; surface rutting of flexible pavements; and faulting pumping, corner breaks, joint failure, and joint and corner spalls of rigid pavements.

Some experiments may require only limited performance data. For example, only rutting of the AC mix was measured in a study conducted at the INDOT/Purdue facility to evaluate rutting resistance of the Superpave mixtures (*13*). On the other hand, deflection data, longitudinal and transverse pavement profiles, and surface distress data were collected using manual and automated means on Mn/ROAD. On the LTRC facility, crack density and rutting data were collected after every 25,000 passes (*16*). Extensive fatigue cracking data were collected for validating the Superpave performance models at the FHWA-PTF (*12*); no other distress data were collected.

Nondestructive testing (NDT) methods are also used at APT facilities, to characterize pavement materials. For example, FWD testing was conducted on Mn/ROAD to measure pavement layer stiffness during different seasons; an FWD, a seismic pavement analyzer (SPA), and a portable SPA were used by TxDOT to evaluate pavement material properties (*33*), and the dynamic cone penetrometer (DCP) was used at the Ohio, Caltrans, Minnesota, Texas and WES APT facilities to characterize granular layer material.

DATA TYPES

A questionnaire was sent to the 15 APT facilities listed in Table 1 to gather information on the type of data collected at each facility in the following 10 categories:

- Administrative information
- Machine loading characteristics
- Pavement test programs
- Material characterization

TABLE 4 Examples of material characterization data elements and related tests

Material Characterization Data		APT Facility			
		CAL-APT	CRREL-HVS	FHWA-PTF	INDOT/Purdue
Physical description of constituent materials	AC	Gradation, sand equivalent, Superpave aggregate tests, AC & void content (*5, 21, 22, 23*)	In situ density, moisture	Superpave and Marshal volumetric tests, agg tests	Superpave and Marshall volumetrics, gradation
	PCC	Agg gradation, cement type	Not tested	Slump, air content, cement content and type	Cement type and content, air content, slump, material proportions
	GM[a]	Moisture content, Atterberg limits, density	Not applicable	Gradation	Not applicable
	SG	Moisture content, Atterberg limits, density, gradation	All classification tests	Gradation	Not applicable
Strength description	AC	Caltrans (Hveem) (*5, 22*)	Falling weight deflectometer (FWD), laboratory tests	Simple shear tester (SST), fatigue test	Strategic Highway Research Program (SHRP) shear test, Marshall flow and stability
	PCC	Flexural, compressive	Not applicable	Compressive and flexural	Flexural, compressive, and indirect tensile strength
	GM[a]	Dynamic cone penetrometer (DCP), R-value	CBR, DCP	Not tested	Not applicable
	SG[b]	DCP, R-value	FWD, CBR, DCP	Not tested	Not applicable
Changes in material properties	Due to environment	Not applicable	Variation in temperature and moisture content	None studied	Not applicable
	Due to traffic loading	Loss in modulus	Not applicable	None studied	Change in modulus
Stiffness description	AC	Resilient modulus (*5, 21, 22*)	Modulus	Resilient modulus	SST complex modulus
	PCC	Modulus	Not applicable	Modulus	Modulus
	GM	Resilient modulus	FWD	Resilient modulus	Not applicable
	SG	Resilient modulus	FWD	Resilient modulus	Not applicable
Aggregate toughness/abrasion resistance	AC	Not applicable	Not applicable	Not tested	Not applicable
	PCC	Los Angeles abrasion	Los Angeles abrasion	Not tested	Not applicable
	GM	Not applicable	Los Angeles abrasion	Not tested	Not applicable

- Environmental data
- Instrumentation
- Pavement response to loads
- Pavement performance
- Construction and postmortem testing
- Data documentation and storage

Administrative Information

Administrative data include general information about operation and ownership of the test facility (that is, facility names, owner, and location). This information is listed in Table 1 for each of the 15 facilities included in this study.

Four of the APT facilities are classified as test roads (using actual truck traffic), and 11 are classified as test machines. Ten of the test machines are mobile (that is, can be moved to different sites), the other 5 are fixed. Six of the 11 test machines were designed for indoor use, 2 for both indoor and outdoor use, and 3 for outdoor use only.

Test pavements at all facilities were generally constructed under contract, with in-house personnel being responsible for QC/QA checks. In some cases, in-house personnel constructed test pavements. Laboratory tests were conducted on samples obtained from the various pavement layers during construction.

Machine Loading Characteristics

Loads were applied on four test tracks (Mn/ROAD, NCAT-PTT, PS-PDF, WesTrack) by full-scale trucks traveling in one direction. All APT machines, except the TxMLS, FHWA-PTF, and LTRC-PRF, are capable of applying two-way traffic. All facilities allow for traffic wander, from a minimum of ±250 mm (1 in.) to a maximum of ±1,000 mm (40 in.).

The longest test section, 150 m (492 ft), is located at Mn/ROAD. Test section widths vary from 1.5 to 11.6 m (5 to 38 ft), as listed in Table 7.

The speed of load application at test roads ranges from crawl speeds to approximately 65 km/h (40 mph), while speeds on APT machine facilities range from 8 to 25 km/h (5 to 15 mph).

Table 8 identifies the wheel and axle configurations used by the various APT facilities.

Most APT facilities use the manufacturer-specified tire pressure during load application, unless the effect of tire pres-

TABLE 4 (Continued)

Material Characterization Data		Example Tests Conducted at APT Facility			
		KS-APT (*15*)	**LTRC-PRF**	**Mn/ROAD - LVTR**	**NCAT-PTT**
Physical description	AC	Marshall volumetrics, aggregate gradation, %AC	Gradation, AC content, density (*1*, *17*)	Density, bulk specific gravity (SG), viscosity, penetration, ductility, flash point, binder's performance grade (PG), voids in mineral aggregate (VMA), voids filled with asphalt (VFA) (*1*, *2*, *3*)	All Superpave tests
	PCC	Material proportions, slump, air entrainment	Not tested	Aggregate gradation, slump, cement type, etc.	Not tested
	GM	Density, Atterberg limits, moisture content, gradation	Gradation, particle shape and surface texture	Water content, gradation, % crushed	Gradation, particle shape and surface texture, density
	SG	Atterberg limits, gradation, density, classification	All classification tests	Water content, gradation, absorption, % crushed	All classification tests
Strength description	AC	Marshall stability	Gyratory shear index, indirect tensile strength, indirect creep (*17*)	Unconfined compressive strength, Marshall, tensile strength, creep (25, *26*, *27*)	All Superpave tests
	PCC	Compressive strength, flexural strength	Not applicable	Flexural, compressive	Not applicable
	GM	CBR	Unconfined compressive strength, CBR, R-value	DCP, R-value	Triaxial shear test
	SG	CBR	Not tested	DCP, R-value	Not tested
Changes in material properties	Due to environment	Not applicable	None studied	Variation in in-situ moisture content, modulus (*27*)	None studied
	Due to traffic loading	Change in modulus	At the beginning and end of load application	Loss in modulus (*5*, *27*)	Before start and after completion of traffic loading
Stiffness description	AC	Resilient modulus	Modulus (*17*, *24*)	Dynamic modulus (25, *26*, *27*)	SHRP Shear Tester, etc.
	PCC	Modulus	Not applicable	Modulus	Not applicable
	GM	Not applicable	Resilient modulus	Resilient modulus	Resilient modulus
	SG	Not applicable	Resilient modulus	Resilient modulus	Resilient modulus
Aggregate toughness/abrasion resistance	AC	Los Angeles abrasion	Los Angeles abrasion	Los Angeles abrasion (*25*, *26*)	Los Angeles abrasion
	GM		Los Angeles abrasion	Los Angeles abrasion	Los Angeles abrasion
	SG	(supplier)	Not applicable	Los Angeles abrasion	Not applicable

(*continued on next page*)

sure is being investigated. Tire pressures range from 206 kPa (30 psi) to 1,724 kPa (250 psi).

Most APT facilities have the capability of using single, dual, or supersingle tires to apply test loads. Three test roads that use actual trucks use both single and dual axles. Four existing facilities use air bag, three use steel spring, and three use hydraulic wheel suspension systems. Test roads (NCAT-PTT, WesTrack, and Mn/ROAD) use actual trucks. Eight facilities use powered axles only to apply load to the test pavement, three facilities use towed axles only, and five use both towed and powered axles (the four test roads and TxMLS).

Most APT facilities incorporate some means of load monitoring. However, only three facilities (ATREL, OH-APLF, and LTRC-PRF) have continuous load-monitoring devices mounted on the test frame. Static scales are the most common method of monitoring applied load; hydraulic and air pressure systems have also been used.

Hours of attended operation (within 24-hour time frame) of APT facilities are shown in Table 9. In addition to the hours of attended operation, several APT facilities allow unattended operation, resulting in some cases of 24-hour operation per day.

Pavement Test Programs

AC pavements are the most commonly investigated pavements. Both AC pavements and AC overlays were tested at six facilities; each of PCC pavements, PCC overlays or AC overlays were tested at one facility; and AC and PCC pavements and overlays were tested at five facilities.

Most tests have been conducted on specially constructed (that is, not in-service) pavement sections. Generally, pavements were designed and constructed using standard DOT practices. The longitudinal and transverse cross slopes usually were not incorporated in the geometric designs (slopes were zero). At all the indoor APT facilities, provisions for artificial wetting of the subgrade were incorporated into the test pavements.

Material Characterization

Information was obtained on all materials that are likely to be used in the construction and evaluation of APT test pavements.

TABLE 4 (Continued)

Material Chracterization Data Element		Example Tests Conducted at APT Facility			
		OH-APLF	**TxMLS**	**WES-HVS**	**WesTrack**
Physical description	AC	None tested.	In-situ density, AC content, specific gravity, moisture content, void ratio (*2, 28, 29*)	All Superpave tests	AC content, void ratio, aggregate. angularity, sand equivalent, QA Superpave binder test (*7, 20*)
	PCC	Cement type and content, density, mix proportions	Not tested	None tested to date	Not tested
	GM	Density, classification tests	Moisture content, Atterberg limits, density	Atterberg limits, gradation, density, classification	Moisture content, density, permeability, Atterberg limits, gradation
	SG	Density, classification tests	Moisture content, Atterberg limits, density, gradation	Atterberg limits, gradation, density, classification	Moisture, density, Atterberg limits, permeability, gradation
Strength description	AC	No applicable	Tensile and shear strength (*2, 28, 29*)	SHRP shear test	Hveem, Marshall (*20*)
	PCC	Compressive and flexural strength	Not applicable	Not applicable	Not applicable
	GM	Triaxial test	Shear strength	Triaxial tests	CBR, R-value
	SG	Triaxial test	Shear strength	CBR	CBR, R-value
Changes in material properties	Due to environment	Not applicable	Variation in in-situ moisture content (*29*)	Not applicable	Not included in the experiment design
	Due to traffic loading	Change in modulus	Loss in modulus (*2, 28, 29*)	Change in modulus	Loss in terms of modulus (*31*)
Stiffness description	AC	Not applicable	Modulus (*2, 28, 29, 30*)	SST complex modulus	Modulus (Superpave tests) (*31*)
	PCC	Modulus (FWD)	Not applicable	Not applicable	Not applicable
	GM	Resilient modulus	Modulus (*2, 28, 29, 30*)	Not tested	Resilient modulus
	SG	Resilient modulus	Modulus (*2, 28, 29, 30, 32*)	Not tested	Resilient modulus
Aggregate toughness/abrasion resistance	AC	Not applicable	Texas wet ball mill abrasion	Superpave tests	Los Angeles abrasion (*20*)
	PCC	Not applicable	Not applicable	Not applicable	Not applicable
	GM	Not applicable	Texas wet ball mill abrasion	Los Angeles abrasion	Los Angeles abrasion
	SG	Not applicable	Not applicable	Los Angeles abrasion	Not applicable

[a] GM = Granular base/subbase material
[b] SG = Subgrade material

Tests were conducted on pavements incorporating an HMA layer at ten APT facilities. All 10 recorded the asphalt content in the mix and the laboratory density; 9 facilities conducted aggregate characterization tests (for example, gradation) and abrasion resistance tests, 8 facilities conducted Marshall and fatigue-related tests on HMA, 7 facilities conducted Superpave volumetric and shear tests, 7 facilities used the M_R test to determine stiffness characteristics of HMA, and creep and triaxial strength tests were conducted at 6 and 5 facilities, respectively.

Seven APT facilities have tested PCC as a pavement layer. Six facilities determined and recorded the PCC modulus of elasticity and compressive and flexural strengths; only three facilities tested concrete to determine the indirect tensile strength. Five facilities tested for and recorded the cement content in the mix and cement type, air content, slump, and aggregate gradation; only three facilities conducted additional aggregate tests.

Table 10 lists the tests conducted for characterization of granular base, subbase, and subgrade. More tests were conducted to characterize the base material than the subbase or the subgrade material of AC pavements. Aggregate gradation, Atterberg limits, and the moisture-density relationship were the most common tests followed by resilient modulus and California bearing ratio tests.

Three facilities tested for residual cement in cement stabilized base/subbase/subgrade materials. Two facilities test for residual AC, M_R, and triaxial shear strengths of AC stabilized base/subbase/subgrade materials. Two facilities performed unconfined compressive strengths on stabilized base/subbase layers; one facility used this test to characterize stabilized subgrade material.

Environmental Data

Tests are often conducted to simulate field conditions in terms of traffic loads and environmental conditions (temperature and moisture). Some APT facilities (mainly indoor facilities) have provisions for cooling and heating the pavement structure; three facilities indicated an ability to apply high temperature, and five reported the ability to apply both freezing and high temperatures.

Most APT facilities collect data on air, pavement surface, and in-pavement temperatures; only four facilities measure temperatures in granular pavement layers and subgrade.

Rainfall is not a concern for indoor facilities but is measured at test roads and outdoor APT facilities. Climatic data for test tracks are usually collected and recorded using an automated weather station. Moisture content of granular lay-

TABLE 5 Examples of environmental data

APT Facility	Measurements in Air Above Pavement		Measurements in Pavement Structure	
	Temperature	Moisture	Temperature	Moisture
CAL-APT	Air and surface	Tipping bucket gage for rainfall	AC or PCC layer only	Hydro-Probe, Gravimetric, ground penetrating radar (GPR)
CRREL-HVS	Air	Relative humidity	One at 0.08 m, and 8 at 0.15-m increments below the surface, all 2.31 m from edge	6 at 0.6-m increments below the surface
FHWA-PTF	Air and surface	None collected	AC or PCC layer only	None collected
INDOT/Purdue	Air and surface	Not collected	AC or PCC layer only	Not collected
KS-APT	Not collected	Not collected	Top and bottom of slab and 0.4 and 0.9 m below pavement surface	3 sensors, middle and 4.9 m from each edge, middle of subbase
LTRC-PRF	Air and surface temperature, relative humidity, wind direction and speed, precipitation		AC or PCC layer only	Water table
Mn/ROAD	Temperature, barometric pressure, humidity, wind speed and direction		Flexible: AC (3 depths), base (2 depths), subgrade (5 depths) in wheel path and centerline Rigid: PCC (4 depths, temp only), base (5 depths), subgrade (3 depths) in outer wheel path	
NCAT-PTT	Air and surface temp., relative humidity, wind direction and speed, precipitation		Binder course: top and bottom, center of outer wheel path; middle and surface of wearing course, in the wheel path	At cell intersections, 1 probe 100 mm into the fill. 3 probes each at two additional locations
OH-APLF	Air and surface	Relative humidity	AC or PCC layer only	Moisture, frost depth
TxMLS	Air and surface temperature, relative humidity, wind direction, and speed, precipitation		AC or PCC layer only	Lab moisture content and time domain reflectometry (TDR) probes
WES-HVS	Air and surface	Not collected	Top, middle and bottom of AC, then every 0.25 m	Troxler moisture probes in granular material every 0.25 m, water table
WesTrack	Air temperature, relative humidity, wind direction and speed, solar radiation, precipitation		AC (3 depths), base (15 depths)	TDR (moisture) Resistivity (frost)

ers and subgrade and the ground water table level are sometimes recorded.

Instrumentation

Instrumentation is commonly installed to measure strain, stress, permanent deformations, and deflections; the type of instrumentation depends on the purpose of the test.

The most commonly installed sensors are those used to measure pavement temperature (11 facilities), strain (10 facilities), and deflection (8 facilities). Many APT facilities record environmental data (temperature: 11; moisture: 5). Data are collected mostly by automated data acquisition systems ranging from sophisticated units to simple PCs with data acquisition cards.

All APT operators make backups of data at varying frequencies to safeguard against accidental loss. Some operators make backup copies of the raw data in the field, whereas others wait until completion of the test.

Pavement Response to Loads

Pavement response to wheel loads (test loads) and FWD applied loads can be measured by APT.

Most facilities use FWDs to measure deflections and for backcalculating pavement parameters. FWDs are also operated over in-pavement strain gages to aid in calibration checks and to collect load response data.

A linear variable differential transformer (LVDT) displacement transducer is used to measure the deflection due to test loads at a particular location in the pavement structure. A multi-depth deflectometer (MDD) consisting of several LVDTs is used for measuring deflections at various depths within the pavement.

About half of the 15 APT facilities measure strains. For AC pavements, horizontal strain is measured in the wheel paths, generally at the bottom of the AC layer, and, in some cases, at all the layer interfaces. For PCC pavements, horizontal strains are measured in the center and edge of the slabs and sometimes at the joints (top, middle, and bottom of PCC

TABLE 6 Examples of pavement response data

APT Facility	Pavement Response			
	Strain Gages	Pressure Cells	MDDs	LVDTs
CAL-APT	Top and bottom of the surface layer	None installed	Deflection of the top and bottom of AC, asphalt-treated permeable base (ATPB), AB, ASB, and subgrade (1 m)	Pavement surface deflection
CRREL-HVS	At the bottom of the surface layer	At three depths in the top half of the subgrade	Five levels, at the interface of each layer	Not installed
FHWA-PTF	Strains at the top and bottom of AC and PCC. PCC strains at corners, mid-slab, and along joints	Not installed	Not installed	Installed to measure surface deflections
INDOT/Purdue	Strains in the surface layer (top/bottom)	Not installed	Not installed	Only for ultra-thin whitetopping (UTW), surface deflection
KS-APT	At the bottom of AC in the wheel path	In the subgrade and at the interface of the granular layer and subgrade (in the wheel path)	Not installed	Dial gages to measure surface deflection (one test only)
LTRC-PRF	Layer interface under the wheels	Layer interface under the wheels	Installed at layer interfaces	Not installed
Mn/ROAD	Bottom of AC in the wheel path. Near bottom and surface of PCC. Also on dowels.	Large diameter for bases, small for subgrade	Bottom of granular material and 2.4 m into the subgrade	Surface deflections in the wheel path
NCAT-PTT	No pavement response instrumentation			
OH-APLF	25 mm from the surface and bottom of PCC slabs at mid-slab and along slab edges. Dowel bars along the middle edge	Not installed	Not installed	At slab corners and along the longitudinal edge to measure surface deflections
TxMLS	Only on specially constructed test sections (evaluated at Victoria shakedown tests)	Only on specially constructed test sections (evaluated at Victoria shakedown tests)	Deflection at layer interfaces (three depths)	Not installed
WES-HVS	3 locations; AC, AC/base interface	Installed on top of the subgrade	3 locations; 5 depths (layer interfaces) down to 2.1 m	2 locations; surface deflections
WesTrack	10 strain gages were installed in each of the 26 sections, at the bottom of the AC.			

slabs). Some APT facilities measure vertical strains in the pavement structure, mainly at the top of the subgrade.

Three APT facilities reported the use of pressure sensors to measure pressure (interpreted as stress) under the applied wheel loads at various depths, mainly at the interface between layers.

Pavement Performance

All APT facilities investigating AC pavements measure rut depths, and all facilities investigating PCC pavements measure joint faulting. Eleven facilities map crack patterns. Transverse and longitudinal profiles are measured at 11 and 10 facilities, respectively. Surface friction, pavement roughness, and joint pumping are measured at four facilities each.

Besides individual performance measures, manual distress surveys are conducted at 12 facilities following American Society for Testing and Materials (ASTM) (*34*) or Strategic Highway Research Program (SHRP) protocols. Mn/ROAD and NCAT-PTT use automated video distress data collection.

The frequency of pavement performance measurements ranged from daily to about every 25,000 load cycles and continued until little change was measured.

Construction and Postmortem Testing

Ten APT facilities have conducted laboratory tests on laboratory- and field-prepared samples for construction monitoring. Eleven facilities used the nuclear gage to measure density and moisture content during construction. Field cores were used at 10 facilities to determine thickness variation, at 9 facilities to determine density, and at 6 facilities for strength testing. DCP was used at six facilities during construction to obtain an estimate of granular layer strength. GPR was used at four facilities to obtain a thickness profile; rod and level was used for thickness determinations at six facilities.

TABLE 7 Test section dimensions

APT Facility	Test section dimensions (m)	
	Length	Width
ATREL	19.8	n/a
CAL-APT	7.9	1.5
CRREL-HVS	36.6	6.4
FHWA-PTF	45.7	4.0
FL-APTRF	6.1	1.5
INDOT/Purdue	6.1	1.5
KS-APT	6.1	3.7
LTRC-PRF	12.2	4.0
Mn/ROAD	152.4	3.7
NCAT-PTT	61.0	3.7
OH-APLF	13.7	11.6
PS-PDF	30.5	3.7
TxMLS	12.2	3.1
WES-HVS	12.2	3.1
WesTrack	70.1	3.7

TABLE 8 Wheel and axle configurations

APT Facility	Wheel configurations			Axle type	
	Single	Dual	Super	Single	Dual
ATREL	×	×	—	—	—
CAL-APT	×	×	×	—	—
CRREL-HVS	×	×	×	×	—
FHWA-PTF	—	×	×	—	—
FL-APTRF	×	×	×	×	—
INDOT/Purdue	×	×	×	×	—
KS-APT	×	×	×	×	×
LTRC-PRF	—	×	—	—	—
Mn/ROAD (LVTR)	×	×	—	×	×
NCAT-PTT	×	×	—	×	×
OH-APLF	×	×	×	×	×
PS-PDF	×	×	×	×	×
TxMLS	—	×	—	—	×
WES-HVS	×	×	×	×	×
WesTrack	×	×	—	×	×

TABLE 9 Attended and unattended operating hours of APT facilities

APT Facility	Attended	Unattended
ATREL	8 to 10 hours	12 to 14 hours
CAL-APT	24 hours	Never
CRREL-HVS	10 hours	14 hours
FHWA-PTF	9 hours	15 hours
FL-APTRF	24 hours	Never
INDOT/Purdue	8 to 10 hours	8 to 10 hours
KS-APT	24 hours	Never
LTRC-PRF	10 hours	14 hours
Mn/ROAD (LVTR)	8 hours	Never
NCAT-PTT	19 hours	Never
OH-APLF	9 hours	Never
PS-PDF	24 hours	Never
TxMLS	12 hours	Never
WES-HVS	4 hours	5 hours
WesTrack	22 hours	Never

TABLE 10 Granular base and subbase tests

Characterization Test	Number of APT facilities conducting tests		
	Granular base	Granular subbase	Granular subgrade
Gradation	8	5	7
Moisture-density relationship	7	5	7
Atterberg limits	6	4	6
Resilient modulus	5	5	7
California bearing ratio	5	3	5
Los Angeles abrasion	4	3	—
Triaxial shear	4	2	2
Soundness	2	2	—
Angularity	2	2	—
Crushed particles	2	1	—
Durability	1	1	—
Hardness	1	1	—

Nine APT facilities excavated trenches as part of post-mortem testing. Tests included visual inspections and layer thickness measurement to determine subsurface rutting. Strength tests were made using DCP and California bearing ratio (CBR) test methods. Granular layer density and moisture content were also determined at most facilities.

Data Documentation and Storage

For small studies, spreadsheets have commonly been used for data recording; the principal investigator kept track of the data. For large studies, special databases have been developed and a specific person has been assigned to data tracking and storage.

Depending on the quantity of data, APT facilities use a combination of logbooks, file cabinets, spreadsheets, and dedicated databases to store data.

Most facilities used photographs to document testing and changes in pavement condition; half of the facilities kept a video record of activities. All facilities record, document, and store test reports and test data; many prepare technical reports for submittal to sponsors and papers for presentation at technical conferences.

SELECTED FEATURES OF APT FACILITIES

Some of the features of APT facilities obtained from visits and other information are summarized.

Advanced Transportation Research and Engineering Laboratory

ATREL is located in Rantoul, Illinois, and is owned and operated by the University of Illinois at Urbana-Champaign. The facility became operational in April 2002 and has the following characteristics:

- It uses a powered crawler track system to move longitudinally and transversely from one test pavement to another.
- It is designed for outdoor use, but a movable shelter provides shielding from rain, snow, and direct sunlight.
- The test bed is 26 m (85 ft) long (constant speed is provided in the middle 20 m [65 ft]).
- The maximum wheel wander is ±760 mm (±30 in.).
- Load wheel options include dual and super-single truck wheels, single aircraft (up to 777 size), and railcar wheel.

CAL-APT HVS Program

The CAL-APT was installed in 1994. Caltrans owns two HVSs that have been renovated and updated. One of the two HVSs is located at the Richmond Field Station near University of California, Berkeley and has been used for testing AC- and PCC-surfaced pavements with different sections. The other HVS is now used as a mobile device to test highway sections within the state, the first of which was a PCC pavement near Palmdale, north of Los Angeles.

Cold Regions Research and Engineering Laboratory

CRREL operates an HVS at its Frost Effects Research Facility (FERF) in Hanover, New Hampshire. The FERF was constructed in 1985 in a 2,700-m^2 environmentally controlled building. The facility contains eight cells 6.5 m (21.3 ft) wide, 7.6 m (25 ft) long, and 2.5 m (8.2 ft) deep; and it has four cells 6.5 m (21.3 ft) wide, 11.3 m (37 ft) long, and 3.7 m (12.1 ft) deep. The ambient air temperature can be varied from –3.9 ºC to 24 ºC (25 ºF to 75 ºF), and the test temperature in each cell can be varied from –37 ºC to 49 ºC (–34.6 ºF to 120 ºF) (*11*).

Federal Highway Administration Pavement Test Facility

FHWA PTF uses two ALFs located on the grounds of Turner Fairbank Highway Research Center in McLean, Virginia. Twenty-four test lanes, each 25.1 m (82 ft) long and 4 m (13.1 ft) wide, can be constructed at the test site, but more typically, paving is done on 12 test lanes, each 50.3 m (165 ft) long and 4 m (13.1 ft) wide. Each of the 12 test lanes would provide four ALF test sites. The facility has been used to study the effect of pavement construction methods, construction materials, and axle loads on pavement performance.

Florida Accelerated Pavement Testing and Research Facility

The Florida DOT operates the FL-APTRF, which consists of an HVS Mark IV, at the State Materials Research Park in Gainesville, Florida. The FL-APTRF has eight 45 m (147.6 ft) long and 3.7 m (12.1 ft) wide linear test tracks. Two smaller test tracks have provisions for varying the moisture content of the underlying base and subgrade layers. The facility is located outdoors with no cover.

INDOT/Purdue Accelerated Pavement Testing Facility

The INDOT/Purdue APT is located adjacent to the Research Division facilities in the Purdue University Research Park. The facility has been used for testing UTW and HMA pavements.

Kansas Accelerated Pavement Testing Facility

The KS-APT facility located in Manhattan, Kansas, is operated by the Kansas State University, in cooperation with the Kansas DOT, and is part of the Kansas Testing Laboratory for Civil Infrastructure and Highway Research. The facility is housed in a 650-m^2 (7,000-ft^2) building with separate test and office spaces, 536 m^2 (5,775 ft^2) and 114 m^2 (1,225 ft^2), respectively. The test space accommodates 418-m^2 (4,500-ft^2) test pits, a 93-m^2 (1,000-ft^2) FWD calibration area, and 25-m^2 (275-ft^2) electrical and mechanical rooms. The facility also has a pulse load system to test rigid pavement joints and faulted pavement conditions.

LTRC Pavement Research Facility

The LTRC Pavement Research Facility is located in a newly developed industrial area in Port Allen, near Baton Rouge, Louisiana, in a fenced area that contains the test area and an office building.

Experiments have been completed on different structural sections to determine which of several pavement structures performs best. Though data from tests have been stored in databases, no formal database has been developed for permanent storage or for transmittal to other parties.

Low-Volume Test Road at Mn/ROAD Test Facility

Mn/ROAD is located in Monticello, Minnesota, and includes 20 low-volume road test sections. The LVTR incorporates 2,499 electronic sensors for collecting detailed temperature and pavement response-related data. The project objectives include investigating the effects of pavement materials, commercial truck traffic, and annual freeze/thaw cycles on pavement performance.

NCAT Pavement Test Track

The main objective of the NCAT-PTT is to study the rutting performance of different HMA mixes. Secondary objectives include monitoring the fuel consumption of trucks and pavement smoothness and friction over time. The facility also includes a 436.6-m^2 (4,700-ft^2) testing laboratory, a 241.5-m^2 (2,600-ft^2) truck maintenance facility, and an asphalt plant. The track consists of 46 cooperatively funded 61-m (200-ft)-long test sections. Of these, 36 sections have the same HMA surface and binder course thickness and 10 sections have different thicknesses for the binder and the surface courses. All test sections have the same support structure consisting of a 305-mm (12-in.) improved roadbed, a 152-mm (6-in.) crushed granite stone base, and a 127-mm (5-in.) asphalt-treated drainage layer. The binder and surface courses vary according to the experiment requirements. A database that will contain test road data will be developed and posted on the Internet.

Ohio Accelerated Pavement Loading Facility

The OH-APLF is located in Lancaster, Ohio, and is owned jointly by Ohio University and Ohio State University. The OH-APLF allows testing of different pavement, base, and subgrade materials under known conditions of various tire configurations and load levels. The facility is climate-controlled and can be used to study the effects of temperature gradients in flexible pavement, and the effect of temperature and humidity gradients, curling and warping, joint load transfer, and dowel bar on performance of rigid pavements. The facility has been used to evaluate the performance of ultra-thin concrete, verify three-dimensional pavement models, and investigate other aspects of flexible and rigid pavement structures.

Pennsylvania State University Pavement Durability Facility

No pavement performance tests have been conducted at PS-PDF for many years; the facility is now being used for other purposes.

Texas Mobile Load Simulator

TxDOT developed the TxMLS to represent actual truck traffic; the TxMLS design incorporates six truck boogies with tandem axles, dual wheel configuration. The boogies are linked by a chain-type mechanism and are propelled by electric motors on two of the boogies. Traffic wander can be simulated by allowing each boogie to wander 250 mm on each side of the centerline independent of other boogies. Tests have been conducted to address a variety of topics related to materials, design, construction, and life-cycle costs of pavements.

Waterways Experiment Station HVS

The WES HVS is located at the USACE ERDC on Halls Ferry Road in Vicksburg, Mississippi. It is part of a research program to develop improved numerical models for pavement response and performance. The HVS will be used to load test sections with extensive instrumentation to gather data for model validation.

WesTrack Nevada Automotive Test Center

WesTrack was constructed in 1995 at the National Automotive Test Center near Carson City, Nevada, to further develop HMA PRS by evaluating the impact of deviations in materials and construction properties (for example, asphalt content, air void content, and aggregate gradation) on performance using a large-scale, accelerated field test. WesTrack also provided early field verification of the SHRP Superpave Level III mix design procedures. The track is no longer in use. The following information is available about tests conducted at the site:

- A database was developed in Microsoft Access; the raw data are stored in Excel files.
- Wheel loads were stored in the database in terms of ESALs.
- Driverless tandem trucks were used because they were safer, more controllable, and more cost-effective.
- Each tandem axle was equivalent to 10.46 ESALs per pass.
- QC during construction was considered much better than that commonly achieved in pavement construction.
- Little to no rutting occurred in the base, subbase, or subgrade during tests.
- FWDs were used to monitor pavement deflections, both during construction and during testing (at the surface).
- Wheel wander was set manually on the loading trucks, changing the “channel” from time to time, or alternatively by control program with a shift of 127 mm (5 in.) every 256 passes.
- Destructive measurements were taken in test pits both before and after the load test.
- Data gathered in SI units were left as such; all other nonspecific data were stored in English units.

CHAPTER 3

DATA ELEMENTS

INTRODUCTION

A literature review, analysis of the survey response data, and personal contacts with APT operator agencies were used to identity terms and data elements that pertain to APT. Definitions for these terms and data elements were made consistent with the current and predominant usage in APT operations. A format appropriate to all APT facilities was followed, recognizing that some APT facilities and test programs may have unique requirements and may require data elements and terminology of special design. The data elements were categorized as follows:

- Administrative
- Load application
- Pavement description
- Material characterization
- Environmental conditions
- Pavement response
- Pavement performance

Chapter 4 discusses these categories in relation to data storage and retrieval. Definitions of related data elements and guidelines for their collection and storage are presented in Chapter 5.

COMBINING OF DATA FROM DIFFERENT SOURCES

One of the objectives of standardized data reporting is the facilitation of exchange of information between APT users. Only three projects were found where there had been attempts to combine databases from different APT tests. Two of these projects are briefly described below.

Investigation of Rutting

NCHRP Project 1-34A, "Contributions of Pavement Structural Layers to Rutting of Flexible Pavements," studied the contribution of various pavement layers to rutting (*35*). Data from forensic investigations of in-service pavements (*36*), test tracks, and APT facilities were used to evaluate proposed criteria for determining the failed layer in AC pavements. The NCHRP study found it difficult to compare rut data from the various data sources. Some issues noted were the following:

- Differences in total width and spacing of measurements of transverse profiles.
- Variation in reference for the surface elevation measurements.

For surface transverse profile, certain information is required to ensure maximum usefulness of results. For example, profiles should extend the full lane width in all cases and onto paved shoulders in all cases because partial-width transverse profiles do not include the full range of surface distortions needed to identify the source of rutting clearly. Transverse surface profile data are defined by spacing of test points; if the spacing is too great, the detail of the surface profile may not correctly identify the failed layer.

Measurements should be made in trenches from an adequate reference to the pavement surface and layer interfaces to properly identify rutting location. Measurements from a horizontal reference line offer flexibility in determining the surface profile and associated rutting and cross slope.

Equipment Evaluation

The objectives of NCHRP Project 9-17, "Accelerated Laboratory Rutting Tests: Asphalt Pavement Analyzer," were to evaluate the suitability of the Asphalt Pavement Analyzer (APA) for predicting rutting potential and for its use in QC/QA testing and to compare the effectiveness of the APA with that of other loaded wheel testers (LWTs) and with the results of a simple strength test (*37*). For LWT devices to be used with confidence, an acceptable correlation between laboratory measurements and actual field rutting was needed. This project used data from different studies.

Ten HMA mixes selected from three full-scale pavement research projects that covered different climatic regions, project characteristics, and materials (WesTrack, Mn/ROAD, and the FHWA-PTF) were tested with the APA. These included three mixes used on WesTrack, three mixes from the Mn/ROAD full-scale pavement study, and four mixes from the FHWA ALF. The results were compared with the known field rutting data to determine the combination of testing conditions for the APA that can best predict field rutting.

Issues Related to Use of Data from Different Sources

Factors contributing to difficulties in combining data sets from different APT facilities include differences in pavement construction and materials, types of instrumentation installed, environmental and climatic factors, and load application method.

The capabilities of local contractors and availability of construction materials vary from state to state and affect the local pavement construction preferences. Even though the required type and quantity of data may be available and pavement construction practices and material properties are well documented, the differences may still be large enough to cause concern as to the value of combining data from different sources.

Differences in working principles sometimes dictate that data from a specific instrumentation cannot be readily combined with data from a similar instrumentation design or for obtaining the same measurement. For example, strain data from two different types of strain gages can rarely be combined before analysis.

The method in which load is applied to the pavement affects pavement performance. Generally, the study objectives determine the method of load application, suspension type, and tire type used during an APT test. In almost all experiments, one truck suspension type and tire type are selected to represent the traffic mix on actual pavements. Although performance data are recorded during all APT tests, differences in the method of load application make it difficult to combine data from different studies in a systematic analysis. Also, because many APT test programs have been conducted to evaluate local or specific materials and/or local design factors, the results do not readily lend themselves to comparison with results from other studies involving different materials and design features.

CHAPTER 4

METHODS FOR DATA STORAGE AND RETRIEVAL

INTRODUCTION

The method used for data storage depends on the type of data being collected. For example, administrative data usually are collected manually. Monitoring data from old facilities were collected manually, whereas automated data collection systems are used by newer facilities. Future facilities are likely to use either automated or semi-automated data collection systems.

Administrative Data Elements

In general, most administrative information is readily available to facility operators. For facilities that are owned and operated by state agencies, principal investigators are often responsible for the projects being carried out. Information regarding specific test programs may be contained in research contracts, correspondence, or other documents, whereas information pertaining to the APT facility itself and its objectives is available from facility owners/operators. However, the principal investigator often maintains data on a particular test or project, including information on sponsors and key research personnel.

Load Application Data Elements

To control the magnitudes of loads applied to the test pavement, some APT devices employ gravity loads with various types of wheel suspension systems; others use a hydraulic counterweight mechanism to stabilize the load magnitude. None of the existing APT facilities duplicate actual truck suspension characteristics.

Some APT loadings are applied in a channelized fashion (that is, with no wander), while others are applied using a wander pattern that simulates the lateral distribution of highway traffic. Various tire pressures have been used, and often the tire pressure is monitored and recorded regularly using remote pressure sensors. In some APTs, loads are applied in either a unidirectional or bidirectional mode, while in others unidirectional loadings are applied.

Although loads are generally recorded using automated equipment and data storage, the magnitude or position of each and every applied APT load is not recorded. Instead, the loads are monitored on a regular basis for verification (for example, check of longitudinal or lateral position and load magnitude). The number of wheel passes corresponding to a specific loading pattern are generally recorded using automated equipment on a continuous basis.

When using gravity loads, it is important to check and record the actual loading because the roughness of the test section can result in loads that are alternately larger and smaller in magnitude than the nominal gravity load.

Pavement Description Data Elements

Project- or test-specific information relating to pavement description (for example, structural and geometric details) is recorded under this category of data. The principal investigator is generally familiar with this information. However, project design and bid documents and reports, as-constructed records, technical reports, and historical archives may also contain such information. Occasionally, limited field tests are conducted to determine some of this information.

Test objectives define the test pavement origin and design, pavement type, and special construction requirements. For specially constructed pavements, all the data pertaining to the type of pavement, subgrade, and intermediate layers, as-designed and as-built cross section, test bed and traffic lane dimensions, and other test-specific information (for example, PCC slab dimensions, reinforcement, and load transfer information, if applicable) should be recorded.

For tests conducted on existing pavements, a search of the historical archives may be required to obtain information on pavement type, age, and traffic history. Pavement history (construction and maintenance) data are found in the as-constructed and annual maintenance record files. However, if such data are unavailable, exploratory field testing by DCP, GPR, or coring may be required to determine the type of the existing pavement structure and other structural details. Project contract documents should provide information about the pavement contractor.

Material Characterization Data Elements

Typically, material characterization data are obtained from laboratory tests or field investigations. These should include the source of the material, date and method of sampling, and type and method of testing. Laboratory tests may use manual or automated procedures. Automated test methods may produce large amounts of data, which may necessitate a multi-stage data collection and electronic storage medium. Permanent deformation tests—such as AASHTO TP7, "Test Method for Determining the Permanent Deformation and Fatigue Cracking Characteristics of Hot Mix Asphalt (HMA) Using the Simple Shear Test (SST) Device"—produce large data files. The data are generally postprocessed, and only specific sample data are used for calculations; the original data files may be archived as "off-line" data. The data used to calculate specific material characteristics (that is, strain or resilient modulus), might be part of the "on-line" data in the overall database design. The collection of the "on-line" data may also be automated or semi-automated.

Many material characterization methods are conducted manually. The data relevant to collection and handling are the same as those for materials tested with automated test methods. Measurements and observations are typically recorded on worksheets. Calculations are then made, and the results are transferred to a final test report sheet. Often, the worksheets are only kept until the test is completed and measurements and calculations are checked. Only a small subset of the data collected during the test process may be transferred into a database. For example, while a standard moisture-density test would produce a moisture-density curve, only values for maximum dry density and optimum moisture content are extracted and entered into the database.

Environmental Conditions Data Elements

Automated methods are well suited for collecting environmental data. Although the intent of APT is to apply loads to a pavement over a short period of time, the test may continue for months; the ambient conditions are best collected with automated methods. On-line weather stations and instrumentation will produce data streams that will likely be processed by automated means and placed into a database. Although indoor facilities may be maintained at constant temperature and moisture conditions during the conduct of a test, monitoring the conditions is normally integral to the overall facility. Outdoor test tracks will be exposed to normal transient conditions and are best monitored by automated means.

However, some environmental or climatic data elements, (for example, surface temperature during special load tests) may best be measured and recorded manually.

Pavement Response Data Elements

Pavement responses (for example, deflection, stress, and strain) are monitored to establish relationships between response, traffic or axle loads, and pavement performance for use in predicting field performance of pavements. However, these relationships should consider effects of climate and aging.

It is also important to differentiate between pavement surface responses and pavement responses at depth. Deflection tests at the surface of the pavement using an FWD or other deflection-based devices do not disturb the pavement structure and therefore do not affect pavement materials. However, the installation of response gages within pavement depth may affect the properties of the materials.

Although pavement response data are almost exclusively recorded and stored using automated equipment, it is generally not necessary to record these values under each and every applied load. Instead, pavement responses are measured on an intermittent basis to monitor both their magnitude and periodic changes.

Pavement Performance Data Elements

Pavement performance data are measured manually most often and semi-automatically on occasion. These data are usually entered and stored in the database on a periodic basis.

Crack surveys usually consist of a manual measurement of cracks along the wheel track and characterization of their extent and severity; the direction of the cracks is also noted. Usually, a photographic record of each "milestone" (for example, every 25,000 load repetitions) is made to document the development of cracking or other types of surface distress.

Transverse cross sections (to measure rutting) or the longitudinal profile (to calculate roughness) of the pavement surface may be measured using rod and level or with laser sensors. Measurements are usually made at more than one line in each test section. For example, transverse profile may be measured every meter in an 8-m test section, that is, nine measurements for each measuring sequence. One or more longitudinal profiles may be measured depending on wheel load wander and other factors that may influence the longitudinal profile, such as environmental effects outside the wheel path.

For jointed plain concrete pavement (JPCP), pumping may be monitored visually or through photographs. Joint faulting is measured in conjunction with the profile survey or manually with the surface distress survey at each measuring sequence.

DATA STORAGE AND RETRIEVAL

Recent improvements in computer technology and automated data collection make it easy to collect and store large amounts of data. It is impractical to maintain such data using either paper filing systems or custom software programs manipulating standard sequential files. Database systems have become the most viable means of maintaining and utilizing the large quantities of data collected by APT devices.

The storage and retrieval of data encompasses both hardware and software. With regard to the hardware, data have been stored on devices ranging in simplicity from paper to complex optical disks and flash memory cards. With regard to software, data storage has ranged from written information (for example, tables) filed in folders and stored in cabinets to electronic text files and spreadsheets for small data amounts to dedicated databases for large data amounts.

Hardware

The most familiar form of data storage and retrieval is paper; observations are recorded on paper and stored for later use and analysis. These data are most likely transferred to an electronic form before analyses are conducted. The main advantage of paper storage is ease of use, but such data are hard to work with. Paper storage is appropriate for very simple data sets that do not involve a large number of repetitive calculations.

Much of the data are collected in some electronic form on electronic storage media. Storage media range in simplicity from floppy disks for small databases to flash cards to hard drives and optical disks for larger databases.

The current floppy disk (89-mm micro floppy) operates on the principles of magnetic recording using magnetic heads for data storage and retrieval on a single rotating magnetic disk. Because of their limited capacity 1.44 megabytes MB and extremely low data transfer rate (0.06 MB/sec), floppy disks are useful only for storing small data files. However, they do offer universal compatibility and low cost.

Hard disk drives contain several spinning disks that are read from, and written to, using separate read and write heads that float above the disks with a separation in the order of 10 to 20 microns. These drives are sealed permanently to protect the disks and heads from dust particles. Over the past few years, the fixed hard disk drive technology has improved; drives with larger storage capacity are becoming less expensive. There are a number of other removable magnetic storage media devices with different sizes [for example, 40 MB Iomega Click! Drive, 100 MB and 250 MB Zip drives, and 1 gigabyte (GB) and 2 GB Jaz drives].

Flash memory cards are electronically programmable and non-reprogrammable solid-state data storage devices that use flash memory chips to store data. Entire sections of the microchip are erased (or flashed) at once. These cards lose power when they are disconnected, but the data are retained for long periods of time or until the microchip is rewritten; these are normally used in laptop PCs and digital cameras. Many types and configurations of these cards are available with memory ranging from 1 MB to 1 GB.

Compact disk–read only memory (CD-ROM) technology was introduced as CD-digital/audio (CD-DA). CD-ROM features include standard design and physical structure of the disk, data format, and error correction code schemes. A CD-ROM is 12 cm in diameter with a 1.5-cm hole and is 1.2 mm thick. CD-ROMs can store up to 650 MB of data (74 minutes of play time for CD-DA); they are a highly reliable means of data storage with good data protection from damage, both inside and outside the CD-ROM drive.

An advancement in CD-ROM technology is the inexpensive CD-ROM/CD-RW combination drive for personal computers, which can easily copy data to recordable CDs (CD-R) or a rewriteable CDs (CD-RW) that look almost like a CD-ROM. These CDs are inexpensive and mobile writeable storage media.

The DVD (digital versatile disk) is an optical storage system that, like a CD, has read-only, recordable, and rewriteable versions. DVDs are likely to replace CDs in the future; current DVD drives are compatible with CD media. DVDs can store up to 17 GB of data, compared with the 650-MB capacity of CD-ROMs.

Software

Data that are recorded on paper and stored in file cabinets can be retrieved manually. Depending on the importance and amount of data collected, electronic storage in text files, spreadsheets, or dedicated databases may be warranted.

Electronic text (*.txt) files are simple ASCII files that can be read by most word processing, spreadsheet, and database software programs. They are platform independent and can be read on IBM compatible PCs, Apple PCs, and mainframes. A shortcoming of text files is that they cannot incorporate text attributes, such as bold and underlined characters. Rich text format (*.rtf) files can retain formatting and can be opened by major word processors in both IBM and Apple environments.

Data stored in text files can have data fields that are separated, or *delimited*, by a comma, a tab, or a space. Each row represents a data record. Such data-delimited text files can be read into a word processor, spreadsheet, database, or specialized statistical package for further manipulation and analysis.

Spreadsheet programs can be used to store and manipulate fairly large data sets, constrained only by available memory and PC processor speed. A spreadsheet allows the user to organize information into both columns and rows. Each cell of the spreadsheet, defined as the unique intersection point of a column and a row, can contain a label, a value, or a formula. A label provides descriptive information, a value is a number, and a formula manipulates values and labels. Though spreadsheets have been used as databases for small amounts of data, they are generally difficult to verify and audit and do not provide good tools for managing data, whether in terms of consolidation or searching for specific details. When used as databases, spreadsheets are unable to display one record (row) at a time and do not allow a multiple-report format. Relational links to other tables and data are also not supported.

Dedicated databases that arrange information in tables and records are best suited for large-scale data storage, manipulation, and retrieval. Traditional databases are organized as fields, records, and files. A field is a single piece of information; a record is a complete set of fields; and a file is a collection of records. A “database” or a database management system (DBMS)—consisting of a collection of programs that enable entering, selecting, and organizing data in a database—is used to access information from a database.

State-of-the-Art in Databases

The purpose of recording and storing data is to make them available at a later date for use in analyses. The data types, data terms, units of recording, and format may vary greatly from project to project. An electronic database is a collection of information optimized for quick selection of desired data using a DBMS. The relational database, or *automatic navigation system,* is the state-of-the-art system for data storage and retrieval; it does not require the user to specify *how* to retrieve the data but merely what should be retrieved. Hierarchical and network models, on the other hand, require that the user understand how the data are structured within the database.

Data stored in a standard relational database system can be used by more than one application. It can be loaded, analyzed, manipulated, and stored in a way that suits the format of each user. Data stored in a standard relational database system are retrieved and manipulated using standard database manipulation language, Structured Query Language (SQL).

SQL Server is a relational DBMS that provides centralized security, data integrity and control, rich user interfaces, and a variety of off-the-shelf productivity tools. SQL Server is known for high performance and scalability and provides support for very large databases. SQL Server employs a dynamic locking architecture that keeps concurrent users from interfering with each other during queries and updates. It implements comprehensive user-level permissions on tables, views, stored procedures, and SQL commands. It also supports field-level database security features; permissions can also be applied to groups.

The popularity of the relational model is due in part to its use by most microcomputer DBMS (for example, Microsoft Access) and its ease of use and understanding of the relational model. In particular, it is a simple matter to train end users to retrieve data from relational databases through the use of SQL, a fundamental standardized component of any relational DBMS. Because it is a common, standardized system, a person learning to use SQL for a microcomputer database would find little difference in retrieving data from a relational database implemented on a different hardware platform, such as a client-server workstation or a mainframe computer.

The Jet database engine is a generalized piece of software that provides the ability to store data in, and retrieve data from, a range of DBMSs (for example, Microsoft Access). In other words, when Microsoft Access is used to manipulate a database, Jet is behind the scenes performing all of the real work. While it is optimized for accessing Access database files directly, Jet can attach to *any* database that supports the Open Database Connectivity (ODBC) interface. This means that an end user can manipulate a database in any format as long as the user's computer has the appropriate ODBC driver. Databases that Jet can manipulate include Microsoft Access, Oracle, dBase 5, Btrieve 6.0, and FoxPro.

Data Access Objects (DAOs) are the clearly defined pieces of code that provide an interface to the functionality of Jet. DAOs allow a programmer to manipulate databases within his or her working environment (for example, COBOL, C, C++). In other words, DAOs allow a programmer to design and write his or her own DBMS software programs

The main purpose of a data storage system is to store and retrieve data. Factors to be considered in the selection of a data storage system include data safety, ease of use, storage capacity, cost, performance, reliability, and manageability.

PROTOCOLS FOR COLLECTION OF DATA ASSOCIATED WITH APT

A list of data collection protocols was prepared for data categories and data elements. When materials are characterized using a nonstandard test (for example, in research situations), the test procedure should be documented in the database. Some data elements, especially those belonging to the administrative data elements, will not require a standard protocol for data collection. Some of the standard protocols, where sampling or testing is conducted as a function of stationing along the test section, may need to be modified to accommodate ATP devices that operate over very short sections of pavement. The use of standard data definitions and adequate documentation of test methods will ensure proper interpretation of data by users.

CHAPTER 5

ACCELERATED PAVEMENT TESTING: DATA GUIDELINES

INTRODUCTION

Accelerated Pavement Testing

This chapter presents recommended guidelines for the collection, retrieval and storage of data associated with APT programs. Use of these guidelines will ensure proper interpretation of the data and facilitate their use by other agencies. APT facilities have become widely used for determining pavement response and performance and for evaluating potential pavement materials, designs, and features. The primary concern in APT is the application of a sufficient traffic volume to produce measurable deterioration in a reasonable length of time for an acceptable cost. Application of traffic loads at an increased rate is the most desirable means of inducing pavement damage because alteration of other factors (for example, load magnitude and pavement structure) results in behavior that may not reflect the behavior of in-service pavements.

Scope of the Guidelines

These guidelines identify data collection and storage requirements for an APT and provide definitions for data elements. These definitions pertain to APT facilities where full-scale wheel loads are applied to full pavement structures by machines or vehicles in a test facility, at a test track, or on an in-service pavement to determine pavement response and performance under a controlled and accelerated accumulation of damage.

Organization of the Guidelines

Data elements to be collected for APT projects have been divided into the following seven categories:

- Administrative
- Load application
- Pavement description
- Material characterization
- Environmental conditions
- Pavement response
- Pavement performance

Figure 1 shows these main data categories with examples of related data subelements.

DATA ELEMENTS AND DEFINITIONS

Organizing data elements into many data sets reduces the potential for repeated data recording; information need only be entered once. Use of multiple data sets also makes it easy to retrieve specific information (for example, produce a list of every material or load configuration used in a research project).

Project objectives and conditions unique to a facility determine the specific information to be collected. Tolerances are shown in SI units; however, researchers may use any consistent set of units if each measurement is labeled with the appropriate unit.

Administrative Data

Administrative data, which can be facility related (unique to the APT facility) or project related (unique to each project at the facility), are concerned with personnel running the facility, the facility location, who owns and operates the facility, and how to contact the facility personnel. There should only be one set of facility data at each facility, and these data should be maintained by the facility administrator. Facility administration data generally remain unchanged, but may be updated if needed. These data should be provided by the facility to researchers for inclusion in the researcher's files. Table 11 defines the data elements that should be recorded in the facility administration data file.

Project administration data are concerned with the personnel running each project at an APT facility. Project information should be gathered at the beginning of the project and updated on an as-needed basis thereafter. The principal investigator generally is responsible for maintaining this information. Table 12 defines the data elements for project-level administration data.

Load Application Data

Load application data elements pertain to the characteristics of the loads applied to a test pavement. Loading conditions must be recorded for each test. Since APT is a method of quickly applying large numbers and/or magnitudes of load repetitions to a pavement to accelerate its degradation, it is

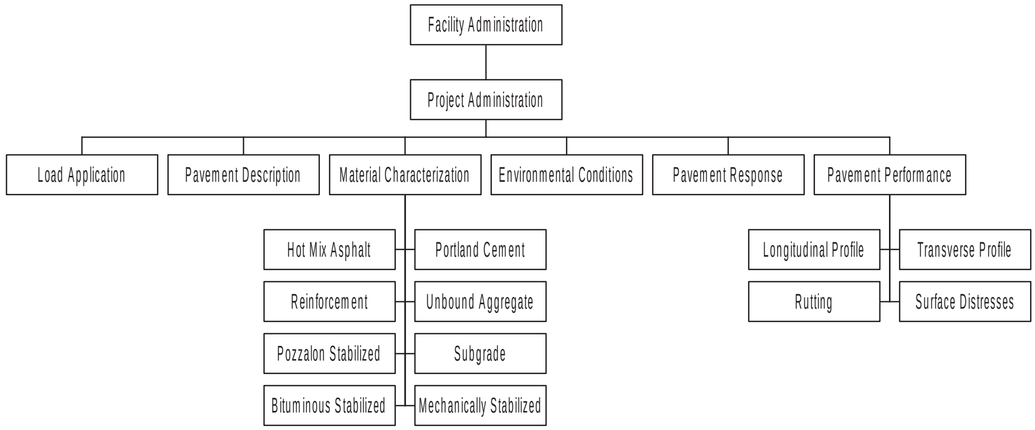

Figure 1. APT data categories.

TABLE 11 Facility administration data elements

Data Element	Definition
Name	Name of the APT facility; should be unique
Location	Physical location of the APT facility; address of fixed facilities or the home office of a mobile facility
Objectives	Set of goals to be achieved
Owner agency	Agency (agencies) that own(s) the facility
Operator	Agency (agencies) that operate(s) the facility
Key personnel	Name and phone number, fax number, address, email address, and any other contact information for key personnel at the facility, including the director, administrator, owner point of contact, and operator point of contact

TABLE 12 Project administration data elements

Data Element	Definition
Name and identification	Project name and identification information
Objectives	Research goals and scope of work or the abstract of a completed project
Status	Completeness of a project: proposed, % complete, or complete; specify if percent complete is in terms of time, effort, or money
Location	If the project is at a fixed facility, the name and address of that facility; if the project is mobile, the area where testing occurs, identified by highway number, mile marker or Global Positioning System (GPS) coordinates
Time frame	Anticipated or actual start and finish dates; also any planned or unplanned breaks in the testing schedule
Funding agency	Agency (agencies) providing funding for the project
Key personnel	Name and phone number, fax number, address, email address, and any other contact information for key personnel on the project, including the principal investigator, key researchers, key technicians, the funding agency point of contact, and the APT facility point of contact

vital that the loads are measured, characterized, and counted properly. Data elements must describe how the loads are applied, the magnitude of the loads, and the load patterns and spacing. Table 13 defines the suggested load application data elements.

Load application data are specific to each test performed during the course of a project; therefore, these data should be collected for each test. All measurements should be reported to at least 1-percent accuracy, with units specified. Some data, such as wheel spacing and position or contact area shape, are best described using drawings.

Pavement Description Data

Pavement description data elements record the gross physical characteristics of test pavement sections. Table 14 defines the suggested minimum data elements necessary to record the design and construction of a test pavement section. The objectives of a particular project may dictate the collection of more, fewer, or different data elements than the ones suggested. Drawings may be used to record or display one or more data elements if the data are better conveyed by graphical means.

TABLE 13 Load application data elements

Data Element	Definition	Tolerances and Units
APT machine	The APT equipment used to load the pavement	N/A
Loading method	Source of the load (hydraulic, gravity, etc.)	N/A
Load type	Type of loading device (aircraft wheel, truck tire, etc.)	N/A
Load monitoring	Type and placement of sensors to detect load on the pavement; also manufacturer, model numbers, and calibration dates of the load monitoring equipment, e.g., portable scales, weigh-in-motion system, in-pavement sensors	N/A
Load magnitude	Load imparted to pavement; list both total load and contact pressures at each wheel	±1%, report in kN
Tire pressure	Inflation or actual pressure of the tire on the pavement	±5 kPa
Contact shape/area	Area of the footprint of each tire on the pavement surface, and the shape of the contact area	±500 mm
Load configuration	Number of contact areas, wheel position (spacing) of each load; a drawing is the best format to present this information	Position: ±10 mm
Load frequency	How often a load pulse is applied to the pavement	±0.1%
Load test duration	Time period that load pulses are continuously applied to the pavement, e.g., an APT machine runs 8 AM to 5 PM every day for 6 days a week and imparts 1,000 cycles/shift	N/A
Test duration	Test start and stop dates and times, and interruptions	N/A
Pulse duration	Length of time load is applied during each load cycle	±1 %
Cycles	Total number of load cycles imparted over duration of test	N/A
Load application speed	Load travel speed over the test pavement; includes any variations in speed; method of measurement (radar, speedometer, etc.)	±1 kph
Load wander distribution and measurement	Load wander width and distribution patterns and datum (wheel-to-wheel, centerline-to-wheel, etc.), and method of load wander measurement (radar, GPS, etc.)	±10 mm
Loading direction	Load direction (unidirectional, bidirectional, static, impulse)	N/A

Knowledge of age, construction, traffic history, and design details of a pavement are essential to the use of that pavement in an APT program. Details about each layer of the pavement should be recorded individually. Thickness and construction methods are of particular interest.

The QC/QA program should include results for all tests, such as in-situ moisture, density, modulus, and strength tests, that were conducted to ensure the quality of the pavements that were constructed. The reported data for each test procedure should include frequency of sampling and testing, location of samples, description of test equipment and facilities, test procedure standards and details, number of tests per sample, and any statistical analysis of the data.

Material Characterization Data

Material characterization data elements are information about the properties of the materials used in constructing the pavement layers. These data elements vary depending on the purpose of the project and the type of material being tested. The materials used in pavement construction have been divided into the following categories:

- Hot mix asphalt (including hot mix permeable asphalt-treated base)
- Portland cement concrete (including lean concrete and Econocrete)
- Reinforcement and load transfer devices
- Bituminous stabilized base/subbase
- Cement, lime, and fly ash stabilized base/subbase
- Unbound aggregate materials
- Subgrade
- Stabilized subgrade

Material characterization data are obtained at various stages during the design, construction, and testing of the pavements and after test completion. Tables 15 through 22 define the specific data elements for the different material categories.

There are three components to each material characterization data element: the test method, the test results, and the variability of the results. The procedure used to perform the test and the results of the test should be recorded, along with an indication of whether the reported value is a mean, a weighted mean, a median, or some other form of average. The number of samples and the variability among samples should be reported using a confidence interval, standard estimate of error, standard deviation, or other statistical measure.

A list of selected material characterization data element protocols is provided in Appendix A. Users should review the list to identify the test suited for use in specific APT studies.

TABLE 14 Pavement physical description data elements

Data Element	Definition	Tolerances and Units
Pavement Type	Flexible, rigid, composite, etc.	N/A
Surface	AC, PCC, etc.	N/A
Shoulder	If present, type and method of tying to the pavement	N/A
Design x-section	Thickness and type of each pavement layer as designed	Thickness: ± 1 mm
As-built cross section	Thickness and type of each pavement layer as constructed and method used to measure thickness, variability of measurements	±1mm
Traffic lane dimensions	Size and location of the area where load is applied to the pavement and measurements are recorded	±1mm
Test bed dimensions	Length and width of the test pavement	±1mm
Slab size	Spacing between joints in rigid pavements	±1mm
Joint details	Typical joint construction method; may be shown in a drawing	Distance: ±1mm
Load transfer mechanism	Device(s) for transferring longitudinal and transverse loads between rigid pavement slabs; size and location of the devices	Distance: ±1mm
Reinforcement	Size, location and type of tensile pavement reinforcement	Distance: ±1mm
Grade	Elevation change along the centerline of the test pavement	±1%
Cross slope	Elevation change from edge to edge of the test pavement	±1%
Pavement origin	Special construction for this APT program, existing pavement from another APT program, or existing in-service pavement	N/A
Design method	Method used to calculate the layer thickness attributes of the pavement and the input values for the calculations (traffic volumes, design wheel loads, design subgrade conditions, layer shear strengths and moduli, life span, etc.)	N/A
Drainage provisions	Type and location of drainage structure(s) in pavement, e.g., free-draining aggregate, collector pipes, sump pumps, etc.	N/A
Designer	Name of the person who designed the pavement	N/A
Construction method	Equipment and methods (temperature, compaction method/pattern, curing time/conditions, etc.)	N/A
Construction agency	Name, address, and phone number of the contractor or organization that constructed each element of the pavement	N/A
QA/QC information	QA/QC plan, procedures, and test schedule for each pavement element (each QA/QC test result should be recorded as a material property)	N/A
Construction time frame	Commencement and completion dates of construction for each layer; including any breaks in the construction schedule	N/A
Weather	Complete environmental and climate data as defined in Table A.13 for the duration of construction	N/A

Environmental Conditions Data

APT facilities should maintain a weather station (outdoor facilities/tests) or a recording climate control system (indoor facilities/tests). Conditions should be recorded at least every 15 minutes. The conditions of environmental chambers (for example, cold rooms, humidity rooms, and curing tanks) should be recorded continuously. Table 23 defines the suggested environmental data elements that should be collected by the APT facility. In some cases, the researchers may opt to record environmental data for a project and not use the facility data. Recording environmental data at the project level may be warranted for mobile projects and projects focused on environmental conditions.

When sensors are used to maintain environmental conditions and associated pavement responses, specific information related to each sensor (for example, model number, placement information, and calibration dates) should be recorded.

Pavement Response Data

Pavement response is the reaction of a pavement to wheel load placed on the pavement or to other factors, such as a change in moisture content or temperature. Pavement response and the associated parameters are often related to the development of pavement distress and can be used to calculate material properties.

Generally, the pavement response data collection schedule is set during the project planning phase, but it may be altered during the course of the project. Pavement response is typically recorded intermittently throughout the APT project. Often, pavement response is measured at intervals (for example, every 25,000 load repetitions or every 3 months). Postmortem and baseline pavement response testing is also common. Loads used to produce pavement responses may be applied by the APT, wheel loads, FWD, or other loading means.

Pavement response is generally recorded in terms of deflection, strain, or pressure (stress). Recorded data elements

TABLE 15 Hot mix asphalt characterization data elements

Data Element	Definition
Mix design method	Mix design specification references (e.g., Hveem, Marshall, Superpave), project modifications and provisions
Mix design parameters	Gradation limits; volumetric limits; rutting, stiffness and strength criteria; may include a reference to established parameters
Mix design and resulting job mix formula	Final job mix formula (JMF), gradation, volumetrics, bulk and Rice gravities, moisture sensitivity, etc.
Binder and modifier characteristics	Varies by project, but should include Superpave, viscosity, or penetration graded asphalt binder parameters
Aggregate characteristics	Source, gradation, particle shape, surface texture, mineralogy, specific gravity, porosity, toughness, hardness, etc. for each aggregate
Filler characteristics	Gradation, source, specific gravity, and chemical composition
Anti-strip agents	Manufacturer and supplier, description, certification, quantity, blend method
Additive characteristics	Purpose (emulsifier, tensile reinforcement, etc.), type (liquid, powder, fiber, etc.), manufacturer, description, certification, quantity, blend method
Recycled AC pavement (RAP) characteristics	RAP gradation, extracted aggregate gradation, residual binder characteristics, source (milled surface, etc.), source characteristics, if known (age, JMF, etc.)
Other salvaged or recycled materials	Type (crumb rubber, crushed glass, shingles, etc.), quantity, description
Mix stiffness	Resilient modulus, creep modulus, shear modulus, etc. of lab compacted and in-place material
Strength	Compressive, shear, or triaxial strength characteristics, etc. of lab compacted and in-place material
Rutting data	Results of an asphalt pavement analyzer, Hamburg wheel tester, etc. of lab compacted and in-place material

TABLE 16 Portland cement concrete characterization data elements

Data Element	Definition
Mix design method	American Concrete Institute, Portland Cement Association, AASHTO, or other method
Mix design parameters	Workability, strength, and durability criteria
Job mix formula	Material proportions (cement, aggregate, sand, additives, other)
Cement characteristics	Manufacturer, source, type, chemical composition
Course aggregate characteristics	Source, mineralogy, gradation, specific gravity, absorption
Fine aggregate characteristics	Source, mineralogy, gradation, specific gravity, absorption
Other pozzalon/fly ash characteristics	Material (lime, fly ash), source, type, chemical composition
Mineral additives	Type, source, chemical composition, purpose
Admixtures	Type (air-entraining, water reducing, modulus enhancing, shrinkage reducing, etc.), source, composition, manufacturer certification
Air content	Entrained and entrapped air, both design (lab) and QC/QA (field) tests
Workability	Slump, etc., both design (lab) and QC/QA (field) tests
Maturity testing	Maturity test results
Strength	Compressive and flexural strength, both design (lab) and QC/QA (field) tests

TABLE 17 Reinforcement and load transfer device characterization data elements

Data Element	Definition
Type	Tie bars, mesh, rebar, dowels, etc.
Size	Material size (e.g., #8 rebar, ¼ in. braided polymer)
Material and grade	Material type (stainless steel, fiber glass, etc.) and material strength
Coating	Surface characteristics and treatments of the material
Capacity	Capacity of a nonstandard load transfer device (shear capacity, etc.)
Manufacturer's certification information	Standard manufacturer certification/warranty

TABLE 18 Bituminous stabilized base/subbase characterization data elements

Data Element	Definition
Stabilizer type	Type of stabilized material (aggregate, soil, etc.), stabilizer (asphalt, liquid asphalt, etc.), and properties of each (aggregate gradation, asphalt grade, etc.)
Mix parameters	Job mix formula and target mix properties (strength, stiffness, etc.)
Strength	Shear and/or compression strength, before and after stabilization, lab and in-situ samples
Stiffness	Resilient or other modulus, before and after stabilization, lab and in-situ samples
Density	Lab and in-situ densities, compaction methods
Aggregate	Source, gradation, particle shape, surface texture, mineralogy, specific gravity, porosity, toughness, hardness, etc. for each aggregate

TABLE 19 Cement, lime, and fly ash stabilized base/subgrade characterization data elements

Data Element	Definition
Stabilizer type	Type of stabilized material (aggregate, soil, etc.), stabilizer (lime, fly ash, etc.), source, type, chemical composition
Mix parameters	Job mix formula and target mix properties (strength, stiffness, etc.), recommended curing procedures
Strength	Shear and/or compression strength, before and after stabilization, lab and in-situ samples
Stiffness	Resilient or other modulus, before and after stabilization, lab and in-situ samples
Aggregate	Source, mineralogy, gradation, specific gravity, absorption

TABLE 20 Unbound aggregate materials characterization data elements

Data Element	Definition
Material origin	Source (quarried, natural, slag, bottom ash, etc.), and degree of crushing
Gradation	Particle size distribution
Fines	Percent fines, clay fraction, Atterberg limits
Moisture-density	Proctor or Modified Proctor results
Toughness	Abrasion loss tests
Soundness	Environmental loss tests
Shear strength	Shear properties or other strength parameters
Stiffness	Resilient or other modulus
Other index tests	Hveem Stabilometer, CBR, etc.

TABLE 21 Subgrade characterization data elements

Data Element	Definition
Classification	Unified Soil Classification System (USCS) or AASHTO soil classification
Gradation	Particle size distribution from sieve, hydrometer, or other test
Fines	Clay fraction, percent fines, Atterberg limits
Stiffness	Resilient or other modulus
Shear properties	Cohesion and friction angle
Other strength properties	Unconfined compression tests, DCP, Hveem Stabilometer, etc.
Moisture-density	Proctor or Modified Proctor results
Placement	Undisturbed soil or engineered fill

TABLE 22 Stabilized subgrade characterization data elements

Data Element	Definition
Soil properties	See subgrade characterization data elements
Aggregate properties	See unbound aggregate characterization data elements
Mix parameters	Job mix formula and target mix properties
Strength	Shear and/or compression strength, before and after stabilization, lab and in-situ samples
Stiffness	Resilient or other modulus, before and after stabilization, lab and in-situ samples
Density	Lab and in-situ densities, compaction methods
Moisture-density	Proctor, Modified Proctor, or other moisture-density relationship test

include the type of load applied, the type of sensor used, and the actual data. Table 24 defines the suggested pavement response data elements.

Pavement deflections due to applied loads are measured by a variety of means. The most common methods for measuring pavement deflection are geophones on FWD devices, geophones, accelerometers, or LVDT sensors in or on the pavement, and Benkelman beam or similar devices. An FWD provides its own load to create a pavement response and uses its own geophones to record deflection. LVDT sensors and Benkelman beam-type devices measure the deflection caused by a wheel load from the APT equipment or a calibrated truck. Other nondestructive types of equipment include the Dynaflect, the Road Rater, and the Seismic Pavement Analyzer (SPA). Deflection data are often used to determine the modulus of each pavement layer and for assessing pavement structural capacity and change over time.

Strain is typically measured at the bottom of the bound layer(s) of pavement. The strain sensors are often located proximate to LVDT sensors measuring deflection. Recorded strains are usually induced by APT equipment loads, FWD loads, or some other calibrated wheel load. Other relevant strain measurements include strain at rigid pavement joints and vertical strains in unbound materials, particularly at the top of the subgrade.

Pressure (or stress) is most often measured in the vertical direction in unbound materials. Typically, the pressure gage is located in the base or subgrade soil, and the stress is induced by APT equipment or other calibrated wheel load.

Pavement Performance Data

Pavement performance is the "serviceability" of pavement over time; as such, it is invariably linked to the presence of various surface distresses, such as rutting, cracking, or roughness. Performance data are generally measured on a periodic basis (for example, every 25,000 load repetitions or 3 months). For in-service pavements, performance data should also be measured before the start of load applications. An estimate of accumulated traffic at the time of measurement is also essential.

The type and amount of performance data depends on the purpose of the project for which the data are collected. Some projects may focus on a particular distress, such as rutting. Other projects may address the overall pavement performance, but may record a range of distresses including rutting, various types of cracking, and other distress that may develop during the test program.

Pavement surface elevation deviations are generally measured in the longitudinal and transverse directions. Surface

TABLE 23 Environmental and climate data elements

Data Element	Definition	Tolerances and Units
Air temperature	Ambient air temperature	±1°C
Temperature	Temperature at the pavement surface and various depths	Temperature: ±1°C Depth: ±1cm
Temperature sensor	Type of temperature sensor (thermocouple, IR, etc.)	N/A
Humidity	Relative humidity	±1%
Precipitation	Daily amount of precipitation	±1mm water, form (e.g., 5mm as 27mm snow)
Wind speed	Average wind speed, gusts	±1knot
UV Index	Measure of solar energy	Absolute
Water table	Depth to water table and datum	±0.01m
Instruments	Weather instruments and data acquisition equipment used	N/A
Calibration	Last calibration of weather instruments, calibration factors	DD-MM-YYYY

TABLE 24 Pavement response data elements

Data Element	Definition	Tolerances and Units
Load source	Source of the load, e.g., static, rolling (APT machine), impact (FWD), vibratory; list specific device used to load pavement, including model numbers, etc.	N/A
Load magnitude	Load imparted to pavement; list both total load and contact pressures at each wheel	±1%, report in kN
Configuration	Number of contact areas, wheel position (spacing) of each load; a drawing is the best format to present this information	Distance: ±1cm
Contact area	Area of the footprint of each tire on the pavement surface and the shape of the contact area	±5cm
Loading rate	Frequency, speed, time, or other measure of how "fast" the load is applied to the pavement	Frequency: Hz Speed: kph
Response type	Deflection, strain, pressure (stress), pore pressure, etc.	N/A
Sensor type	Sensor mechanism (LVDT, MDD, etc.), type, model number, etc.	N/A
Sensor location	Location of the sensor in/on the pavement; a drawing may be the best method to display this information; include longitudinal, transverse, and depth data	±1mm
Calibration factor	Number used to convert raw sensor readings into useable engineering units; e.g., 1.2mV from the sensor corresponds to 0.01m deflection.	Absolute; report as $\frac{\textit{engineering units}}{\textit{sensor unit}}$
Calibration data	Date and place of last sensor calibration, technician that calibrated the sensor	N/A
Raw sensor data	Data as recorded by the sensor	Record sensor precision and units
Processed data	Data in appropriate engineering units	Record precision and units
Time stamp	Date and time of each sensor reading	Record the storage format of the timestamp
Repetitions	Number of APT loading cycles the pavement has experienced at time of data collection	Absolute
Test type	QC/QA, in-service, postmortem, etc.	N/A

deviations in the direction of traffic determine pavement "roughness," and surface deviations perpendicular to the direction of traffic determine pavement "rutting." Raw data typically consist of a set of elevation measurements, which give absolute elevations relative to some defined datum, or a set of deviations from a straightedge of a particular length. The method of measuring and referencing elevations should always be included in the data set. The data set should be referenced by either the time and date of the measurement or the number of repetitions the pavement has experienced. These data should be stored in raw form, but may also be processed to calculate and store an indicator of performance, such as the International Roughness Index.

There are many well-documented protocols for quantifying the type and amount of distresses present on a pavement, such as those published by AASHTO, SHRP, and ASTM. The protocols used to monitor pavement performance should be identified and documented. If a new procedure is used, the distress definitions and performed calculations should be thoroughly documented, including any "deduct" or empirical curves, equations, and assumptions. As with roughness, the data should be referenced by either time and date, or repetitions on the test pavement. If multiple surveys are performed, the variability among results or the confidence interval should be recorded. Table 25 shows data standards for four of the common pavement performance measurements.

DATA STORAGE AND RETRIEVAL

Relational Database Management Systems

These guidelines recommend storage of all data in a computerized relational database management system (RDBMS). These data should be kept in a paper form *in addition to the electronic format* with the exceptions of facility administrative data and project administrative data, which can be kept as a cover sheet or handout for distribution.

Each APT facility should maintain a master database for all files. An administrator should be assigned the responsibility of keeping files up to date; researchers should provide the administrator with the latest data. The RDBMS must have table-level data locking and password protection to ensure data security and integrity.

An RDBMS used for APT data storage should be SQL compliant. SQL is the standard language for RDBMSs, a protocol for data manipulation in RDBMSs. The RDBMS should be able to create an SQL dump (that is, the complete

TABLE 25 Pavement performance data elements

Type of Information	Data Element	Definition
General	Survey date	Date(s) of survey
	Pretest condition	For in-service pavements, condition before APT load application and an estimate of traffic.
	Number of repetitions	Number of load pulses applied to pavement
	Survey purpose	Property being measured (smoothness, rutting, Pavement Condition Index, etc).
	Survey method	Standard used to perform survey (ASTM D5340, etc.), or the complete documentation for the survey protocol
	Survey results	Results of the survey after the data have been reduced
	Variability	Standard deviation, range, confidence interval, standard error of estimate, etc.
	Raw data	Raw performance data should be stored and the storage format defined; e.g., distress data from a visual survey or elevation data from a roughness survey should be stored
Performance Measurement	Longitudinal profile	Elevation of the pavement surface in the longitudinal direction in relation to a datum or beam; data should be reduced to a strip chart of elevation vs. station or to an index number reflecting the condition of the pavement, such as the International Roughness Index
	Transverse cross sections	Elevation of the pavement surface in the transverse direction in relation to a datum or beam; data should be reduced to a strip chart of elevation vs. transverse location, or to an index number reflecting the condition of the pavement
	Rutting	Rutting is a special case of the transverse cross section
	Surface distresses	Surface distresses are recorded and reduced to an index number reflecting the condition of the pavement

set of SQL instructions necessary to recreate the data from one SQL-compliant RDBMS in another RDBMS). Data should be exported by creating an SQL dump of the desired data and then copying the SQL dump to a CD-ROM or other media.

The RDBMS must have a simple interface for entering data. Many medium-scale Windows-based RDBMSs come with an easy-to-use front end. Large-scale Windows- and UNIX-based RDBMSs often come with a programmable user interface. Often, a large-scale RDBMS will be accessible from the Internet or an intranet using a web browser; while desirable, web accessibility is not a mandatory feature. The RDBMS must be scalable, with the ability to handle at least 1 terabyte of data. The database should also support binary storage objects, allowing documents such as Word files or Excel spreadsheets to be stored in the database. Table 26 lists the recommended file format for storing various data types.

Data Storage Media

Data storage media should be chosen based on the intended use of the media. The following three classes of use have been identified:

- Working copy: the database that is accessed and updated on a regular basis
- Archival/backup: the database is periodically copied and placed into long-term storage

TABLE 26 Recommended data file formats

Data	Recommended Format (filename extension)
Text	Database text fields
Formatted documents	PDF, MS-Word (*.doc)
Calculations	MS-Excel (*.xls)
Drawings	DXF (*dxf)
Photos	JPEG (*.jpg)
High resolution photos	TIFF (*.tif)
Video	MPEG (*.mpg)
Charts	MS-Excel (*.xls), PNG (*.png)
Raw data	Database fields, MS-Excel (*.xls), specialized formats

- Transport: the database (or a portion thereof) is being copied and transferred to another facility or researcher

Table 27 summarizes the pros and cons of currently available media and suggests uses for them.

Media used to maintain the master working copy of the database at an APT facility should be high-capacity, high-speed, and rewritable. Data archives and backups should be placed on high-capacity media that have a long life span. The database should be backed up daily to protect against data loss. The same media should not be used to maintain the working database and archive data. Data for older projects (for example, those ended more than 5 years ago) may be placed in an archive and removed from the working database to conserve space and increase performance. Media used for transport must be small and rugged. CD-ROM media are suggested for transport purposes, even though the medium is not particularly rugged. The lack of ruggedness is overcome by the ubiquity of the medium; most people can safely transport and handle a CD-ROM without causing damage. An alternative to using physical media to transport data is to use a high-speed network to transfer files directly from the APT facility computer to the researcher's computer.

SAMPLING FREQUENCY OF DATA MEASUREMENTS

The number of times a particular data element is collected depends upon the type of data element and the objectives of the study. Some data elements, especially those belonging to the administrative and pavement description categories, generally need to be collected only once, at the beginning of an APT program or test series. Others, such as material characterization and pavement performance data, are generally collected at the beginning of the test program and at regular intervals throughout the program. Still others, such as climate and environmental data, should be collected continuously throughout the test program.

A brief description of sampling frequency is provided Table 28.

TABLE 27 Data storage media characteristics

Media	Capacity	Advantages	Disadvantages	Suggested Use
CD-ROM	640MB	Common, relatively long life span, small, cheap	Delicate, non-reusable	Transport archive
CD-RW	640MB	Common, small, cheap	Delicate, relatively short life span	—
ZIP	100MB	Common, rugged media	Expensive	—
JAZ	1GB	High capacity, rugged media	Not common, expensive	—
Hard disks (single)	60GB	High capacity, long life span, rugged media	Not portable	Working copy
Hard disks (RAID)	500TB*	Extremely high capacity, extremely rugged media, extremely long life span	Not portable, very expensive	Working copy archive
Floppy disks	1.44MB	Extremely common, small, cheap	Small capacity, short life span, delicate media, slow	—
Tape	20GB	High capacity, long life span	Not common, slow	Archive
Flash/other solid state media	256MB	Small, rugged media, fast	Not common	—
Network	—	Fast, common	Not really storage	Transport

*1TB=1024GB

TABLE 28 Sampling frequency of data measurements

Data Category	Type of Information	Frequency
Administrative information	General information	Collect once at the beginning of the APT test or project
Load application	Load type and configuration	Collect once at the beginning of the APT test or project
	Load magnitude	Record once every 4 hours; record variations in load along section length
	Tire pressure	Record once every 8 hours (start and end of load application day)
	Load direction(s) and speeds	Record load direction at the beginning of the test; collect speed data every hour during load application
	Load movement or wander	Collect continuously
Pavement description	Pavement features	Collect once at the beginning of the test or project and confirm at test completion
Material characterization	Material properties	Collect once at the beginning of the test, forensic-type tests may be conducted at the end of the test series and incrementally during testing if study is to look at changes in material properties
Environment and climate	Above pavement data elements	Collect once every 15 to 30 minutes during load application; collect hourly otherwise
	Within pavement data elements	Collect once every 15 minutes during load application
Pavement response	Load-deflection	At the beginning, end, and after a predetermined number of load applications
	Pavement strain	At the beginning, end, and after a predetermined number of load applications
	Soil pressure	At the beginning, end, and after a predetermined number of load applications
	Surface distresses	At the beginning, end, and after a predetermined number of load applications
Pavement performance	PCC associated distresses	At the beginning, end, and after a predetermined number of load applications

CHAPTER **6**

FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

FINDINGS

In 2002, 15 APT facilities were in operation in the United States. The following findings are based on a survey and visits to these facilities:

1. State DOTs owned and operated 40 percent of the facilities, and 33 percent were owned and operated by educational institutions.
2. Nearly half the facilities were mobile machines.
3. Pavement test sections were constructed predominantly by contract; in-house personnel perform QC/QA tasks.
4. Generally, loads on test roads were applied at higher speeds with highway trucks than with machines.
5. Most machines were designed to accommodate dual or supersingle tires.
6. Flexible pavements were the predominant pavement type under investigation at APT facilities.
7. Different material characterization tests were conducted depending on study objectives; more tests were conducted on surface pavement layer materials (AC and PCC) than on other layers.
8. Temperature data (air temperature and pavement temperature at surface and various depths) were considered important for data analysis.
9. The quantity of collected data depended on the study objectives. Pavement deflections and strains were the most frequently collected response data; rutting and cracking data were often collected to characterize pavement performance.
10. Except for test tracks where dedicated databases are employed, data were stored and archived as spreadsheets on floppy disks and CD-ROMs.

APT operators indicated a willingness to distribute data generated at their facility to other APT operators and pavement researchers. Nonuniformity in climatic conditions, pavement materials, and construction practices were considered a hindrance to usability of data.

GENERAL CONCLUSIONS

Data collected at APT facilities were divided into seven categories:

- Administrative
- Load application
- Pavement description
- Material characterization
- Environmental conditions
- Pavement response
- Pavement performance

Data elements considered essential for appropriate use of data are related to the following items:

- Project-related information
- Load application (for example, wheel configuration, tire pressure, load magnitude and wander)
- Pavement description (that is, pavement structure-related data elements)
- Material characterization
- Environment and climate (for example, air and pavement temperature and moisture in the subgrade and unbound layers)
- Pavement response (for example, deflection, and deformation)
- Pavement performance (for example, rutting and cracking pattern)

Study objectives and the amount of data generated dictate the need for software and hardware. Large amounts of data can be stored on large-capacity drives that run dedicated databases incorporating SQL, and small amounts of data can be stored using spreadsheets. Data are usually distributed using floppy disks or CD-ROMs and also on the Internet.

RECOMMENDATIONS

During the course of this project, the applicability of the guidelines was demonstrated by comparing data obtained from NCAT-PTT, LTRC-PLF, TxMLS, and OH-APLF. The comparison revealed consistency among the different sources. To facilitate use of data among APT facilities, researchers, and other interested parties, existing facilities should make their databases more compatible with the proposed guidelines; new facilities should adopt these guidelines. In this manner, maximum benefits can be achieved from APT studies. To further demonstrate the utility of the guidelines for data collection and storage, it is suggested that APT facilities begin to implement the guidelines for selected test programs.

CHAPTER **7**

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APPENDIX A

PROTOCOLS FOR MATERIAL CHARACTERIZATION DATA ELEMENTS

- Material Characterization Data Elements

  - Soils Characterization Tests

AASHTO T88	ASTM D422	Particle Size Analysis of Soils
AASHTO T89	ASTM D4318	Determining the Liquid Limit of Soils
AASHTO T90	ASTM D4318	Determining the Plastic Limit and Plasticity Index of Soils
AASHTO T92	ASTM D427	Determining the Shrinkage Factors of Soils
AASHTO T99	ASTM D698	Moisture-Density Relations of Soils Using a 5.5-lb. Rammer
AASHTO T100	ASTM D854	Specific Gravity of Soils
AASHTO T190	ASTM D2844	Resistance R-Value & Expansion Pressure of Compacted Soils
AASHTO T193	ASTM D1883	The California Bearing Ratio
	ASTM D1241	Materials for Soil-Agg. Subbase, Base and Surface Courses
	ASTM D2216	Laboratory Determination of Water Content of Soil and Rock by Mass
	ASTM D3282	Standard Classification of Soils and Soil-Agg. Mixtures for Highway Construction Purposes
	ASTM D6519	Standard Practice for Sampling of Soil Using the Hydraulically Operated Stationary Piston Sampler
	ASTM D5298	Standard Test Method for Measurement of Soil Potential (Suction) Using Filter Paper
	ASTM D4253	Standard Test Methods for Maximum Index Density and Unit Weight of Soils Using a Vibratory Table
	ASTM D2487	Standard Classification of Soils for Engineering Purposes (Unified Soil Classification System)
	ASTM D854	Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer
	ASTM D5311	Standard Test Method for Load Controlled Cyclic Triaxial Strength of Soil
	ASTM D2488	Standard Practice for Description and Identification of Soils (Visual-Manual Procedure)
	ASTM D4959	Standard Test Method for Determination of Water (Moisture) Content of Soil by Direct Heating
	ASTM D4643	Standard Test Method for Determination of Water (Moisture) Content of Soil by the Microwave Oven Method
	ASTM D421	Standard Practice for Dry Preparation of Soil Samples for Particle-Size Analysis and Determination of Soil Constants
	ASTM D422	Standard Test Method for Particle-Size Analysis of Soils
AASHTO T208	ASTM D2166	Standard Test Method for Unconfined Compressive Strength of Cohesive Soil

  - Coarse Aggregate Characterization Tests

AASHTO T11	ASTM C117	Materials Finer than 0.075mm (No. 200) Sieve in Mineral Aggregates by Washing
AASHTO T27	ASTM C136	Sieve Analysis of Fine and Coarse Aggregates
AASHTO T85	ASTM C127	Specific Gravity and Absorption of Coarse Aggregate
AASHTO T96	ASTM C131	Resistance to Degradation of Aggregate by Abrasion and Impact in the Los Angeles Machine

- AASHTO T104 | ASTM C88 | Soundness of Aggregate by Use of $NaSO_4$ or $MgSO_4$
- ASTM C33 | Standard Specification for Concrete Aggregates
- AASHTO T19/T19M | ASTM C29/C29M | Standard Test Method for Bulk Density ("Unit Weight") and Voids in Aggregate
- ASTM D6155 | Standard Specification for Nontraditional Coarse Aggregates for Bituminous Paving Mixtures
- ASTM D5444 | Standard Test Method for Mechanical Size Analysis of Extracted Aggregate
- AASHTO T210 | ASTM D3744 | Standard Test Method for Aggregate Durability Index
- ASTM D3398 | Standard Test Method for Index of Aggregate Particle Shape and Texture
- AASHTO T248 | ASTM C702 | Standard Practice for Reducing Samples of Aggregate to Testing Size
- ASTM D75 | Standard Practice for Sampling Aggregates
- ASTM D692 | Standard Specification for Coarse Aggregate for Bituminous Paving Mixtures

Fine Aggregate Characterization Tests

AASHTO T11	ASTM C117	Materials Finer than 0.075mm (No. 200) Sieve in Mineral Aggregates by Washing
AASHTO T27	ASTM C136	Sieve Analysis of Fine and Coarse Aggregates
AASHTO T84	ASTM C128	Specific Gravity and Absorption of Fine Aggregate
AASHTO T176	ASTM D2419	Plastic Fines in Graded Aggregates and Soils by Use of the Sand Equipment Test
AASHTO T104	ASTM C88	Soundness of Aggregate by Use of Sodium Sulfate or Magnesium Sulfate
	ASTM C1252	Standard Test Methods for Uncompacted Void Content of Fine Aggregate (as Influenced by Particle Shape, Surface Texture, and Grading)
	ASTM C1137	Standard Test Method for Degradation of Fine Aggregate Due to Attrition
	ASTM C70	Standard Test Method for Surface Moisture in Fine Aggregate
AASHTO T21	ASTM C40	Standard Test Method for Organic Impurities in Fine Aggregate for Concrete

HMA and Related Tests

AASHTO T30	ASTM D5444	Mechanical Analysis of Extracted Aggregate
AASHTO T110	ASTM D1461	Moisture or Volatile Distillates in Bituminous Paving Mixtures
AASHTO T164	ASTM D2172	Quantitative Extraction of Bitumen from Bituminous Paving Mixtures
AASHTO T170	ASTM D1856	Recovery of Asphalt from Solution by Abson Method
AASHTO T308	ASTM D6307	Determining the Asphalt Content of Hot Mix Asphalt (HMA) by the Ignition Method
	ASTM D5404	Recovery of Asphalt from Solution Using the Rotavapor Apparatus
AASHTO T49	ASTM D5	Penetration of the Residue
AASHTO T201	ASTM D2170	Kinematic Viscosity of the Residue
AASHTO T202	ASTM D2171	Viscosity of the Residue at 60°C
AASHTO T166	ASTM D2726	Bulk Specific Gravity of Compacted Bituminous Mixtures Using Saturated Surface-Dry Specimens
AASHTO T209	ASTM D2041	Maximum Specific Gravity of Bituminous Paving Mixtures

■	AASHTO T245	ASTM D1559	Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus
■	AASHTO T246	ASTM D1560	Resistance to Deformation and Cohesion of Bituminous Mixtures by Means of Hveem Apparatus
■	AASHTO T269	ASTM D3203	Percent Air Voids in Compacted Dense and Open Bituminous Paving Mixtures
■	AASHTO TP4		Preparing and Determining the Density of HMA Specimens by Means of the SHRP Gyratory Compactor
■		ASTM D6307	Standard Test Method for Asphalt Content of Hot-Mix Asphalt by Ignition Method
■		ASTM D5841	Standard Specification for Type III Polymer Modified Asphalt Cement for Use in Pavement Construction
■		ASTM D4469	Standard Test Method for Calculating Percent Asphalt Absorption by the Aggregate in an Asphalt Pavement Mixture
■		ASTM D3497	Standard Test Method for Dynamic Modulus of Asphalt Mixtures
■		ASTM D3461	Standard Test Method for Softening Point of Asphalt and Pitch (Mettler Cup-and-Ball Method)
■		ASTM D946	Standard Specification for Penetration-Graded Asphalt Cement for Use in Pavement Construction
■		ASTM D5801	Standard Test Method for Toughness and Tenacity of Bituminous Materials
■		ASTM D6154	Standard Specification for Chemically Modified Asphalt Cement for Use in Pavement Construction
■		ASTM D4867 & D4867M	Standard Test Method for Effect of Moisture on Asphalt Concrete Paving Mixtures
■		ASTM D3791	Standard Practice for Evaluating the Effects of Heat on Asphalts
■	AASHTO T179	ASTM D1754	Standard Test Method for Effect of Heat and Air on Asphaltic Materials (Thin-Film Oven Test)
■	AASHTO T40	ASTM D140	Standard Practice for Sampling Bituminous Materials
■		ASTM D56	Standard Test Method for Flash Point by Tag Closed Tester
■		ASTM D3515	Standard Specification for Hot-Mixed, Hot-Laid Bituminous Paving Mixtures
■		ASTM D4123	Standard Test Method for Indirect Tension Test for Resilient Modulus of Bituminous Mixtures

- Asphalt Binder Tests

■	AASHTO T44	ASTM D2042	Solubility of Bituminous Materials
■	AASHTO T48	ASTM D92	Flash and Fire Points by Cleveland Open Cup
■	AASHTO T49	ASTM D5	Penetration of Bituminous Materials
■	AASHTO T201	ASTM D2170	Kinematic Viscosity of Asphalts
■	AASHTO T202	ASTM D2171	Viscosity of Asphalts by Vacuum Capillary Viscometer
■	AASHTO T228	ASTM D70	Specific Gravity of Semi-Solid Bituminous Materials
■	AASHTO T179	ASTM D1754	Effect of Heat and Air on Asphalt Materials (Thin-Film Oven Test)
■	AASHTO T240	ASTM D2872	Effect of Heat and Air on a Moving Film of Asphalt (Rolling Thin-Film Oven Test)
■	AASHTO T49	ASTM D5	Penetration of the Residue
■	AASHTO T201	ASTM D2170	Kinematic Viscosity of Asphalts (Bitumen)
■	AASHTO T202	ASTM D2171	Viscosity of Asphalts by Vacuum Capillary Viscometer
■	AASHTO T316	ASTM D4402	Viscosity Determinations of Unfilled Asphalts Using the Brookfield Thermosel Apparatus

AASHTO T28	ASTM D6521	Accelerated Aging of Asphalt Binder Using a Pressurized Aging Vessel (PAV)
AASHTO T313	ASTM D6648	Determining the Flexural Creep Stiffness of Asphalt Binder Using the Bending Beam Rheometer (BBR)
AASHTO T314		Determining the Fracture Properties of Asphalt Binder in Direct Tension (DT)
AASHTO TP5		Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer (DSR)
AASHTO M320	ASTM D6373	Standard Specification for Performance Graded Asphalt Binder
	ASTM D6114	Standard Specification for Asphalt-Rubber Binder
	ASTM D2196	Standard Test Methods for Rheological Properties of Non-Newtonian Materials by Rotational (Brookfield type) Viscometer

- Asphalt Emulsion Tests

AASHTO T59	ASTM D244	Saybolt Viscosity, Residue by Distillation, Residue by Evaporation, Demulsibility
AASHTO T49	ASTM D5	Penetration of the Residue
AASHTO T44	ASTM D2042	Solubility of the Residue
	ASTM D4957	Standard Test Method for Apparent Viscosity of Asphalt Emulsion Residues and Non-Newtonian Bitumens by Vacuum Capillary Viscometer
AASHTO R5	ASTM D3628	Standard Practice for Selection and Use of Emulsified Asphalts
	ASTM D3387	Standard Test Method for Compaction and Shear Properties of Bituminous Mixtures by Means of the U.S. Corps of Engineers Gyratory Testing Machine (GTM)
AASHTO M208	ASTM D2397	Standard Specification for Cationic Emulsified Asphalt
AASHTO M140	ASTM D977	Standard Specification for Emulsified Asphalt

- Portland Cement Concrete Tests

AASHTO T309	ASTM C1064 & C1064M	Standard Test Method for Temperature of Freshly Mixed Portland Cement Concrete
	ASTM C1084	Standard Test Method for Portland Cement Content of Hardened Hydraulic-Cement Concrete
	ASTM C33	Standard Specification for Concrete Aggregates
	ASTM C512	Standard Test Method for Creep of Concrete in Compression
AASHTO T126	ASTM C192 & C192M	Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory
AASHTO T196	ASTM C173 & C173M	Standard Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method
AASHTO T271	ASTM C1040	Standard Test Methods for Density of Unhardened and Hardened Concrete in Place by Nuclear Methods
AASHTO T119	ASTM C143 & C143M	Standard Test Method for Slump of Hydraulic Cement Concrete

- Reinforcing Steel Tests

	ASTM C876	Standard Test Method for Half-Cell Potentials of Uncoated Reinforcing Steel in Concrete
AASHTO M264	ASTM A775	Standard Specification for Epoxy-Coated Reinforcing Steel Bars

AASHTO M32	ASTM A82	Standard Specification for Steel Wire, Plain, for Concrete Reinforcement
	ASTM G109	Standard Test Method for Determining the Effects of Chemical Admixtures on the Corrosion of Embedded Steel Reinforcement in Concrete Exposed to Chloride Environments

- Load Transfer Device Tests

	ASTM A955 & A955M	Standard Specification for Deformed and Plain Stainless Steel Bars for Concrete Reinforcement
AASHTO M31M	ASTM A615 & A615M	Standard Specification for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement

- Portland Cement Tests

AASHTO M86	ASTM C150	Standard Specification for Portland Cement
AASHTO M185	ASTM C359	Standard Test Method for Early Stiffening of Portland Cement (Mortar Method)
AASHTO T98	ASTM C115	Standard Test Method for Fineness of Portland Cement by the Turbidimeter Lime and Fly Ash Tests

- Lime and Fly Ash Tests

	ASTM C593	Standard Specification for Fly Ash and Other Pozzolans for Use With Lime
	ASTM E1266	Standard Practice for Processing Mixtures of Lime, Fly Ash, and Heavy Metal Wastes in Structural Fills and Other Construction Applications
	ASTM D3155	Standard Test Method for Lime Content of Uncured Soil-Lime Mixtures
	ASTM D5102	Standard Test Method for Unconfined Compressive Strength of Compacted Soil-Lime Mixtures
	ASTM D3668	Standard Test Method for Bearing Ratio of Laboratory Compacted Soil-Lime Mixtures
	ASTM D3551	Standard Practice for Laboratory Preparation of Soil-Lime Mixtures Using a Mechanical Mixer
	ASTM C1097	Standard Specification for Hydrated Lime for Use in Asphaltic-Concrete Mixtures
AASHTO M216	ASTM C977	Standard Specification for Quicklime and Hydrated Lime for Soil Stabilization
	ASTM C110	Standard Test Methods for Physical Testing of Quicklime, Hydrated Lime, and Limestone
	ASTM D5239	Standard Practice for Characterizing Fly Ash for Use in Soil Stabilization
	ASTM C618	Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Concrete
	ASTM C311	Standard Test Methods for Sampling and Testing Fly Ash or Natural Pozzolans for Use as a Mineral Admixture in Portland-Cement Concrete

- Pavement Condition & Environmental Survey Data Elements
  - Pavement Condition Standard Guides and Tests

	ASTM E1777	Standard Guide for Prioritization of Data Needs for Pavement Management

▪		STANAG-4370	Environmental Testing (Department of Defense)
▪		ASTM D5858	Standard Guide for Calculating Insitu Equivalent Elastic Moduli of Pavement Materials Using Layered Elastic Theory
▪		ASTM D1196	Standard Test Method for Nonrepetitive Static Plate Load Tests of Soils and Flexible Pavement Components, for Use in Evaluation and Design of Airport and Highway Pavements

- Other Environment-Related Data Elements
  - No Standards Available
- Pavement Response Data Elements
  - Load-Deflection Tests

▪	AASHTO T256	ASTM D4695	Standard Guide for General Pavement Deflection Measurement
▪		ASTM D4694	Standard Test Method for Deflections with a Falling-Weight-Type Impulse Load Device

  - Pavement Strain Tests
  - Soil Pressure Tests
- Pavement Performance Data Elements
  - Smoothness and Profile Tests

▪		ASTM E1170	Standard Practices for Simulating Vehicular Response to Longitudinal Profiles of Traveled Surfaces
▪		ASTM E1364	Standard Test Method for Measuring Road Roughness by Static Level Method
▪		ASTM E950	Standard Test Method for Measuring the Longitudinal Profile of Traveled Surfaces with an Accelerometer Established Inertial Profiling Reference
▪		ASTM E1926	Standard Practice for Computing International Roughness Index of Roads from Longitudinal Profile Measurements
▪		ASTM E1703	Standard Test Method for Measuring Rut-Depth of Pavement Surfaces Using a Straightedge

  - Surface Distress Tests

▪		ASTM D5340	Standard Test Method for Airport Pavement Condition Index Surveys
▪		ASTM D6433	Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys
▪	AASHTO T286	ASTM E1082	Standard Test Method for Measurement of Vehicular Response to Traveled Surface Roughness
▪		ASTM E660	Standard Practice for Accelerated Polishing of Aggregates or Pavement Surfaces Using a Small-Wheel, Circular Track Polishing Machine
▪		ASTM D5329	Standard Test Methods for Sealants and Fillers, Hot-Applied, for Joints and Cracks in Asphaltic and Portland Cement Concrete Pavements
▪		ASTM C672	Standard Test Method for Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals

- PCC-Associated Distress Tests
  - AASHTO T155 | ASTM C156 | Standard Test Method for Water Retention by Concrete Curing Materials
  - AASHTO T158 | ASTM C232 | Standard Test Methods for Bleeding of Concrete
  - ASTM C1137 | Standard Test Method for Degradation of Fine Aggregate Due to Attrition

APPENDIX B

GLOSSARY

AB	Aggregate base
AC	Asphalt concrete
APA	Asphalt Pavement Analyzer
APT	Accelerated pavement testing
ASB	Aggregate subbase
ATB	Asphalt-treated base
ATPB	Asphalt-treated permeable base
ATREL	Advanced Transportation Research and Engineering Laboratory (in Rantoul, IL)
CAL-APT	Caltrans Accelerated Pavement Testing
CAL-APT HVS	Caltrans Accelerated Pavement Testing Heavy-Vehicle-Simulator
CBR	California bearing ratio
CD	Compact disk
CD-DA	CD-digital/audio
CD-R	Recordable compact disk
CD-ROM	Compact disk–read only memory
CD-RW	Rewriteable compact disk
cpd	Cycles per day
CRREL	U.S. Army Cold Regions Research and Engineering Laboratory
CRREL-HVS	U.S. Army Cold Regions Research and Engineering Laboratory Heavy-Vehicle-Simulator
DAO	Data access object
DBMS	Database management system
DCP	Dynamic cone penetrometer
DOT	Department of transportation
DVD	Digital versatile disk
ERDC	U.S. Army Engineer Research and Development Center
FERF	Frost Effects Research Facility (operated by CRREL)
FHWA-PTF	FHWA Pavement Test Facility
FL-APTRF	Florida–Accelerated Pavement Testing and Research Facility
FWD	Falling weight deflectometer
GB	Gigabytes
GM	Granular base/subbase material
GPR	Ground-penetrating radar
GPS	Global positioning system
GVW	Gross vehicle weight
HMA	Hot-mix asphalt
HVS	Heavy-vehicle-simulator
INDOT/Purdue	Indiana DOT/Purdue APT Facility
JMF	Job mix formula
JPCP	Jointed plain concrete pavement
KS-APT	Kansas–Accelerated Pavement Testing
LaDOTD	Louisiana Department of Transportation and Development
LTRC-PRF	Louisiana Transportation Research Center–Pavement Research Facility
LVDT	Linear variable differential transformer
LVTR	Low-volume test road
LWT	Loaded wheel tester
MB	Megabytes
MDD	Multi-depth deflectometer
ME	Mechanistic-empirical
Mn/ROAD	Minnesota Road Research Project
Mn/ROAD-LVTR	Minnesota Road Research Project Low-Volume Test Road
NCAT-PTT	National Center for Asphalt Technology Pavement Test Track
NDT	Nondestructive testing
NTIS	National Technical Information Service

ODBC	Open database connectivity
OH-APLF	Ohio Accelerated Pavement Loading Facility
PCC	Portland cement concrete
PG	Performance grade
PRS	Performance-related specification
PS-PDF	Pennsylvania State University Pavement Durability Facility
PTF	Pavement Testing Facility
QC/QA	Quality control/quality assurance
RAP	Recycled asphalt concrete pavement
RDBMS	Relational database management system
SG	Subgrade material
SHRP	Strategic Highway Research Program
SPA	Seismic Pavement Analyzer
SQL	Structured Query Language
SST	Simple shear tester
TDR	Time domain reflectometry
TRIS	Transportation Research Information Services
TxMLS	Texas Mobile Load Simulator
USACE	U.S. Army Corps of Engineers
USCS	Unified Soil Classification System
UTW	Ultra-thin whitetopping
VFA	Voids filled with asphalt
VMA	Voids in mineral aggregate
WES-HVS	U.S. Army Corps of Engineers Waterways Experiment Station Heavy-Vehicle-Simulator
WesTrack	Experimental road test facility of the Nevada Automotive test Center, Reno, Nevada

Abbreviations used without definitions in TRB publications:

AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ITE	Institute of Transportation Engineers
NCHRP	National Cooperative Highway Research Program
NCTRP	National Cooperative Transit Research and Development Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
SAE	Society of Automotive Engineers
TCRP	Transit Cooperative Research Program
TRB	Transportation Research Board
U.S.DOT	United States Department of Transportation