Chapter 1
Introduction

This manual provides a ready reference and/or instruction guide for anyone involved in designing or constructing concrete pavements. The emphasis is on the concrete material itself—specifically, on optimizing concrete's performance. To optimize concrete's performance in today's pavement construction environment, everyone in concrete paving projects must understand concrete as the central component of a complex, integrated pavement system.

Readers will find some overlap and repetition of information among the chapters. This is a result of the integrated nature of the various stages and considerations involved in designing and constructing concrete pavement projects.

Purpose of This Manual

The purpose of this manual is to bridge the gap between recent research and common practice related to producing concrete for pavements. The intended audience is agency or industry personnel who are interested in optimizing concrete performance for every paving project. Readers may include

- Engineers.
- Quality control personnel.
- Specifiers.
- Contractors.
- Materials and equipment suppliers.
- Technicians.
- Construction supervisors.
- Tradespeople.

Specifically, this manual will help readers do the following:

- Understand concrete pavements as complex, integrated systems.
- Appreciate that constructing a concrete pavement project is a complex process involving several discrete practices. These practices interrelate and affect one another in various ways.
- Implement technologies, tests, and best practices to identify materials, concrete properties, and construction practices that are known to optimize concrete performance.
- Recognize factors leading to premature distress in concrete, and learn how to avoid or reduce those factors.
- Quickly access how-to and troubleshooting information.

Today's Construction Environment

In the early days of road building, a civil engineer would work on all aspects of a project. This included securing right-of-way, designing the road and selecting materials, and acting as the resident engineer to help the contractor build the project. The engineer knew everything about the project, and this centralized knowledge facilitated project quality.

As the pavement industry has grown and changed, processes previously handled by a single engineer have been split into separate specialties or departments. This is at least partly because the various processes have become more complex. More ingredients (like supplementary cementitious materials and chemical admixtures) have been introduced to the concrete mix. New testing procedures have been developed. Equipment and placement techniques have changed.

In today's complex road-building environment, dividing responsibilities among departments is effective only as long as communication is effective. Too often, however, this is not the case. The materials engineer focuses on materials, the design engineer focuses on design details, the contractor focuses on construction, and rarely do the parties think about or communicate with each other about the effects of their activities on other parties involved in the process.

For example, engineers trying to advance a new design or solve a specific problem may overlook the concrete materials and focus on other pavement details. Likewise, contractors sometimes try to overcome constructability issues associated with a poor concrete mixture by overusing their equipment rather than seeking to correct the mixture.

It is probably impossible to go back to the days when one engineer handled a concrete paving project from beginning to end. Therefore, as the number of variables and specialties continues to increase, all personnel involved in every stage of a project need to understand how their decisions and activities affect, and are affected by, every other stage of the project.

In other words, today's road-building process must be integrated to be cost-effective and reliable.

Principles of Concrete Pavement as an Integrated System

At the heart of all concrete pavement projects is the concrete itself. The concrete affects, and is affected by, every aspect of the project, from design through construction.

The concrete material itself is only one component of a specific pavement system or project. (Other components include, for example, the pavement's structural and functional design, the subgrade/base.)

- The concrete material is arguably the *central* component of the concrete pavement system.

By and large, the performance of a system is judged by the performance of the concrete.

- Concrete's performance is critically affected by many variables throughout the pavement system and throughout the process of building the system. These variables include the sources, quality, and proportions of its ingredients; construction variables like weather, paving equipment, and practices, etc.; and design parameters like design strength and climate factors (figure 1-1).
- Understanding concrete pavements as integrated systems, and pavement construction as an integrated process, will help readers optimize concrete performance.

Optimizing Concrete for Pavements

Optimizing the performance of concrete for pavements involves understanding the variables that affect concrete's performance and the properties of concrete that correspond to performance.

Variables That Affect Concrete Performance

The starting point for achieving a good-quality concrete pavement is to proportion, make, and use a good-quality concrete mixture. The definition of a good-quality concrete mix depends on the specific application. As mentioned above, how well a concrete performs for a specific application is affected by many factors, including the following:

- Structural and functional design of the pavement system. The pavement must carry the design loads without experiencing distresses. It should provide a smooth ride and adequate traction. During its design life, it may have to withstand the rigors of extreme temperature cycles.
- Quality of and variability inherent in concrete's constituent materials. Aggregates, admixtures, cement, and supplementary cementitious materials all vary in their properties to some degree based on their raw materials and manufacturing processes. These variations in materials, and variations in their proportions, affect the degree of uniformity that can be achieved when they are mixed in many separate concrete batches during a project.
- Construction factors, like weather, equipment, and personnel. Environmental variations can significantly affect the properties of plastic and hardening concrete. Pavements are built outside, where weather conditions during concrete placement can be unpredictable and can vary widely from conditions assumed during mix design and materials selection. Site conditions, equipment, and the construction and inspection teams play vital roles in the development of good-quality concrete.

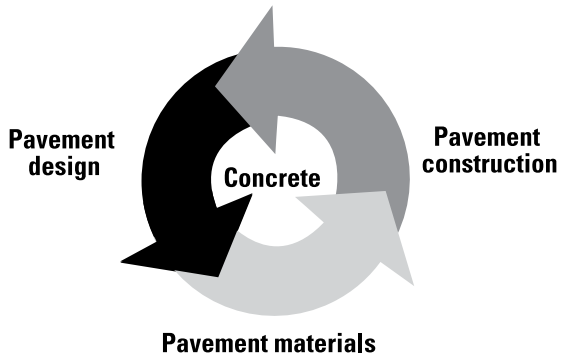

Figure 1-1. Concrete pavement construction is an integrated system, with the concrete material at the center.

Mix Properties That Correspond to Concrete Performance

Several properties of concrete mixtures correlate with concrete performance. A 16-State pooled fund study at Iowa State University, "Materials and Construction Optimization for Prevention of Premature Pavement Distress in Portland Cement Concrete Pavements" (TPF-5[066]), has identified many of these properties, including workability, strength gain, air-void system, permeability, and thermal movement (see all of chapter 5).

During the various stages of a concrete paving project—mix design, pre-construction verification,

and construction—these and other properties can be monitored and necessary adjustments can be made to mixture proportions or to construction practices to help ensure the final concrete product performs as designed. Design, verification, and field tests are critical elements of quality assurance and quality control (QA/QC).

In a departure from past practice, laboratory tests of mixture properties, using materials specific to a project, are now often needed before construction starts. Ideally, full-size trial batches should be done before paving is begun to verify laboratory findings and determine if adjustments are needed. This is especially important when using unfamiliar materials.

These tests provide data that serve as a basis for making necessary adjustments in the field. The construction team (agency and contractor) should prepare in advance for situations that may arise during construction, such as changes in materials sources or unexpectedly hot or cold weather. The team should pre-determine how these changes will likely affect the concrete mixture properties, and decide in advance how to compensate for the effects.

For example, will hot weather lead to decreases in air entrainment? How rapidly will a mixture lose workability in hot weather? The project team should have answers to these types of questions well before construction begins so that solutions are at hand if and when conditions change. Trial batching at the plant is essential to verify the laboratory findings.

Organization of This Manual

The manual is organized into 10 chapters, listed at right. Some chapters are more detailed than others. In addition, each chapter and section begin with general information and then become more detailed.

Critical Details: Chapters 3, 4, 5, 6, 9

The emphasis throughout the manual is on concrete as a material and how its quality (performance) is affected by all aspects of a pavement project. Topics covered in the chapters highlighted in blue at right—3 (Materials), 4 (Hydration), 5 (Properties), 6 (Mix), and 9 (QA/QC)—are central to this emphasis; these chapters are quite detailed.

Chapter 2. Basics of Concrete Pavement Design: how concrete pavement design interacts with materials and construction requirements.

Chapter 3. Fundamentals of Materials Used for Concrete Pavements: the ingredients that we have to work with, and how they influence concrete performance.

Chapter 4. Transformation of Concrete from Plastic to Solid: how cement chemistry and the cement's physical changes during hydration are central to good-quality concrete, and how supplementary cementitious materials and chemical admixtures affect the hydration process.

Chapter 5. Critical Properties of Concrete: fresh and hardened properties of concrete that correlate with concrete performance.

Chapter 6. Development of Concrete Mixtures: how to achieve the required performance with the materials that we have.

Chapter 7. Preparation for Concrete Placement: how the subgrade and base influence the concrete.

Chapter 8. Construction: how construction activities and workmanship influence the concrete, what tools are available, and the current best practices to ensure high-quality pavement.

Chapter 9. Quality and Testing: a brief discussion of quality systems, and descriptions of some test methods that can be used to monitor concrete performance.

Chapter 10. Troubleshooting and Prevention: identifying the problem and the fix when something goes wrong, and preventing recurrence.

Complete coverage of the topics in the remaining chapters is beyond the scope of this book. These chapters provide overviews only, but again from the perspective of optimizing concrete performance.

Quick References: Chapters 4 and 10

Some sections of the manual are presented as references:

Chapter 10 (Troubleshooting). Field personnel in particular will find chapter 10 useful on site.

Stages of Hydration charts in Chapter 4 (Hydration). Many readers will refer to the Stages of Hydration charts (pages 76–83) again and again. Understanding cement hydration is central to successfully integrating the various stages of concrete pavement projects for optimum concrete performance.

The charts provide a quick reference to help readers understand the relationships among cement chemistry, stages of hydration, the implications of hydration for the construction process, and the effects on hydration when supplementary cementitious materials and mineral admixtures are included in the mixture. In addition, the charts highlight some materials incompatibility issues that can arise.

A full-size Stages of Hydration poster. If a poster is not included with this manual and you would like one, contact the National Concrete Pavement Technology Center (contact information is inside the front cover on the Technical Report Documentation page).

Subject index. The manual ends with an abbreviated subject index. (See the sidebar below.)

Cross-References and the Subject Index

The topics addressed in this manual are complex. Concrete pavements are complex, integrated systems, and the process of designing and constructing them is a complex, integrated process. Any thorough discussion about optimizing concrete as the central component of pavement systems cannot be presented in a strictly linear manner.

Readers will therefore discover overlap, repetition, and interaction among the chapters.

Here are two examples:

- **Aggregates**. Aggregates compose the largest volume in concrete mixes. Readers will find pertinent information about aggregates in several sections of the manual.
  - Chapter 3 describes the ingredients of concrete mixtures, including aggregates—their role in concrete, and the various types and properties of aggregate that can positively or negatively affect concrete performance.
  - Chapter 6 provides guidelines for proportioning the ingredients, including aggregates, to achieve the desired concrete performance.
  - Chapter 8 describes the importance of managing aggregate stockpiles so as not to tip the moisture balance in the mix.
- **Testing**. As mentioned earlier, testing is critical to an effective QA/QC program to ensure concrete performance. Readers will find information about testing in several sections of the manual.
  - Chapter 3 includes information about testing required or recommended for the ingredients of concrete.
  - Chapter 5 covers tests of concrete properties, both fresh and hardened.
  - Chapter 9 provides suggested procedures for conducting tests identified and conducted in Iowa State's study (TPF-5[066]).

As a result of this kind of overlap of information, important topics are thoroughly cross-referenced throughout the manual.

In addition, a basic index at the back of the manual lists primary topics and the chapters and pages where each is discussed (see page 323).