Texas A&M Transportation Institute

Accelerated Pavement Construction Evaluation Procedures

Product 0-6985-P8

Cooperative Research Program

TEXAS A&M TRANSPORTATION INSTITUTE
COLLEGE STATION, TEXAS

in cooperation with the
Federal Highway Administration and the
Texas Department of Transportation
http://tti.tamu.edu/documents/0-6985-P8.pdf

Technical Report Documentation Page

1. Report No. FHWA/TX-21/0-6985-P8	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle ACCELERATED PAVEMENT CONSTRUCTION EVALUATION PROCEDURES		5. Report Date Published: November 2021 6. Performing Organization Code
7. Author(s) Darlene C. Goehl, Kunhee Choi, Thomas Scullion, Charles Gurganus, and Bryan Wilson		8. Performing Organization Report No. Report 0-6985-P8
9. Performing Organization Name and Address Texas A&M Transportation Institute The Texas A&M University System College Station, Texas 77843-3135		10. Work Unit No. (TRAIS) 11. Contract or Grant No. Project 0-6985
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Implementation Office 125 E. 11th Street Austin, Texas 78701-2483		13. Type of Report and Period Covered Technical Report: September 2018–August 2021 14. Sponsoring Agency Code

15. Supplementary Notes

Project performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration.

Project Title: Perform Feasibility Study on Use of Innovative Tools and Techniques to Accelerate Pavement Construction

URL: http://tti.tamu.edu/documents/0-6985-P8.pdf

16. Abstract

The researchers investigated innovative tools and techniques that accelerate the construction of roadway improvement projects. In coordination with local Texas Department of Transportation (TxDOT) districts, the researchers identified four major roadway improvement projects and performed case studies using innovative tools and techniques to accelerate pavement construction. The researchers tested these projects by employing advanced planning tools. A novel construction schedule–cost–traffic integration approach was implemented to help TxDOT make the most informed decisions with regard to balanced trade-offs to lessen traffic disruption to the traveling public while minimizing constructon time and road user cost. The researchers prepared and presented training materials and guidance to include methodology, testing procedures, and other tools used in the selection and design of pavement for candidate projects.

17. Key Words Accelerated construction, non-destructive pavement testing, construction scheduling	18. Distribution Statement No restrictions. This document is available to the public through NTIS: National Technical Information Service Alexandria, Virginia http://www.ntis.gov

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 42	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

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Published: November 2021

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DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of FHWA or TxDOT. This report does not constitute a standard, specification, or regulation.

This report is not intended for construction, bidding, or permit purposes. The engineer (researcher) in charge of the project was Darlene C. Goehl, P.E. #80195.

The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

ACKNOWLEDGMENTS

This project was conducted in cooperation with TxDOT and FHWA. The authors thank the following individuals: project directors—Shelley Pridgen and Chris Glancy with TxDOT Research and Technology Implementation Office; TxDOT project team; technical advisors—Boon Thian, Brenda Guerra, Paul Wong, Eduardo Acosta Jr., and Ryan Phillips; TxDOT employees—Soojun Ha, James Williams, James Robbins, Thomas Reed, and Jared Johnson; Walker county maintenance office for assisting with district testing coordination; and Texas A&M Transportation Institute employees Jason Huddleston, Lee Gustavus, Ross Taylor, and Tony Barbosa for collecting the non-destructive testing data, pavement sampling, and laboratory testing.

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CHAPTER 1. OVERVIEW

The research team developed recommendations and guidance for innovative tools and techniques used to evaluate existing pavement condition, pavement design, and traffic control strategies. Case studies were used to demonstrate the equipment, and techniques were used to evaluate an existing pavement and develop pavement design options. The optimal pavement design strategy was then evaluated for traffic control timing including delay cost and project time determination. The case studies are documented in report 0-6985-R1.

Descriptions of the methods and procedures for using non-destructive testing tools to evaluate existing pavement are discussed in Chapter 2. Chapter 3 provides a methodology for selecting rehabilitation strategies in conjunction with accelerated construction techniques. Chapter 4 contains information and recommendations for current Texas Department of Transportation (TxDOT) specifications related to accelerated pavement construction, scheduling, and traffic control.

CHAPTER 2. NON-DESTRUCTIVE TESTING TOOLS AND TECHNIQUES

Various pavement evaluation tools are available to measure a pavement’s functional and structural properties. Specifically, functional properties include roughness, rut depth, geometry, skid resistance, and noise, while structural properties contain pavement and subgrade stiffness, pavement layer thickness, pavement layer condition, and load transfer. These properties together provide information that is useful in a pavement design and evaluation process. This chapter lists specific non-destructive tools to address many of these properties and focuses on tools that specifically promote accelerated construction design.

STRUCTURAL PROPERTIES

Pavement Stiffness

Two vehicle-mounted non-destructive devices used for measuring pavement stiffness are the falling weight deflectometer (FWD) and the total pavement acceptance device (TPAD). The FWD utilizes the MODULUS software to analyze the data. This data analysis results in an estimate of the pavement structure’s remaining life and the elasticity values’ layer modulus to input into TxDOT’s flexible pavement design software, FPS-21. The TPAD utilizes the TPADana software for data analysis. This software integrates a high-definition video (HDV) image, global positioning system (GPS) location, and ground-penetrating radar (GPR) data to assist with the analysis. Also, the analysis helps with identifying the locations of poor subgrade support and load transfer.

The dynamic cone penetrometer (DCP) is also used to measure stiffness. An Excel spreadsheet is used to calculate the penetration depth per blow to assess the in-situ strength of undisturbed soil or compacted materials.

Pavement Layer Thickness and Deterioration

GPR identifies the pavement layer thickness and potential deterioration areas. Pavement forensic studies successfully use GPR as a tool to:

- Estimate the pavement layer thickness.
- Identify the base’s defects.
- Identify the hot mix’s defects (stripping, segregation, or joint density).
- Locate deterioration in asphalt-covered bridge decks.
- Locate the water-filled voids under concrete pavements.
- Define the limits of defects.

The DCP can also be used to estimate layer thickness based on changes in layer stiffness.

Load Transfer (Jointed Concrete Pavement)

FWD and TPAD systems can identify poor load transfer in jointed concrete pavements.

FUNCTIONAL PROPERTIES

Roughness

An inertial profiler measures longitudinal and transverse roughness statistics at highway speeds. The real-time measurements are quantified into two indexes: serviceability index and the international roughness index. The serviceability index is an input parameter in TxDOT's flexible pavement design software, FPS-21. Construction projects use the international roughness index to measure a new construction's ride quality. The indexes also identify the locations of localized roughness, bumps, and dips.

Geometry

The mobile light detection and ranging (LiDAR) system measures the roadway geometry. The data generated are useful for many geometric calculations. Some of the typical uses are rut mapping and cross-slope estimation. Geometric calculations can also measure the side road geometry to provide information for drainage or other design needs.

Subgrade Properties

The U.S. Department of Agriculture's web soil survey (USDA-WSS) includes the subgrade physical and engineering properties. Field testing at specific locations with moisture content concerns can use electrical resistivity tomography (ERT).

Traffic Characteristics

A portable weigh-in-motion (p-WIM) system was developed to measure the traffic characteristics for a project. Site-specific field traffic measurements include traffic volume, vehicle speed, axle spacings, vehicle classification, axle loads, and vehicle weights.

PAVEMENT TESTING SYSTEMS

One-page equipment technical summaries were developed for the pavement testing systems and are presented here. These summaries are useful reference tools designed to provide a basic introduction to the pavement testing systems and include the following topics:

- General description.
- Properties measured.
- Data analysis.
- Benefits to accelerated construction.
- System limitations and availability.

USDA Web Soil Survey

General Description

- USDA-WSS provides soil data and information produced by the National Cooperative Soil Survey.
- USDA Natural Resources Conservation Service operates USDA-WSS, which provides access to the largest natural resources information system in the world.
- https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm

You are here: Web Soil Survey Home

The simple yet powerful way to access and use soil data.

Measured Properties

- USDA Natural Resources Conservation Service has soil maps and data available online for more than 95 percent of the nation’s counties and anticipates having 100 percent in the near future.
- The site is updated and maintained online as the single authoritative source of soil survey information.

Data Analysis

- Online soil data explorer.
- Soil data that are relevant to pavement design and construction, such as:
    - Plasticity index.
    - Gypsum content.
    - Organic content.
    - Depth to the water table.

Benefits for Accelerated Construction

- Identification of potential problem areas as well as good areas.
- Timely decisions to assist with field sampling locations due to the data availability and ease of analysis.

Limitations and Availability

- Free-access website supported by USDA.
- Limitations in the data occur when using the website based on the identified area of interest.

Reference

USDA. (2019). *Web Soil Survey*. https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm. Accessed November 8, 2019.

High-Definition Video

General Description

- HDV is a high-definition video system that is used to document the pavement surface condition. HDV can provide data for design, performance monitoring, and construction.
- HDV collects data at highway speeds. Traffic control is typically not required.

Measured Properties

- HDV is captured and saved as images.
- The operator can adjust the image spacing before collecting the video.
- GPS location and distance from the start of the collection are recorded.

Data Analysis

- TxDOT uses the PaveView program, which was developed by the Texas A&M Transportation Institute (TTI), to view and document the pavement condition.

Benefits for Accelerated Construction

- Forensic investigations of existing pavement structures.
- Timely decisions due to the ease of data collection and analysis.
- Data used to support the following functions:
  - Forensic studies.
  - Support of pavement management activities at both project and network levels.
  - Supplementary material for other testing data.
- Information for construction.

Limitations and Availability

- PaveCheck software is needed to view as a video; otherwise, individual images can be viewed.
- TxDOT currently owns several systems in various districts.

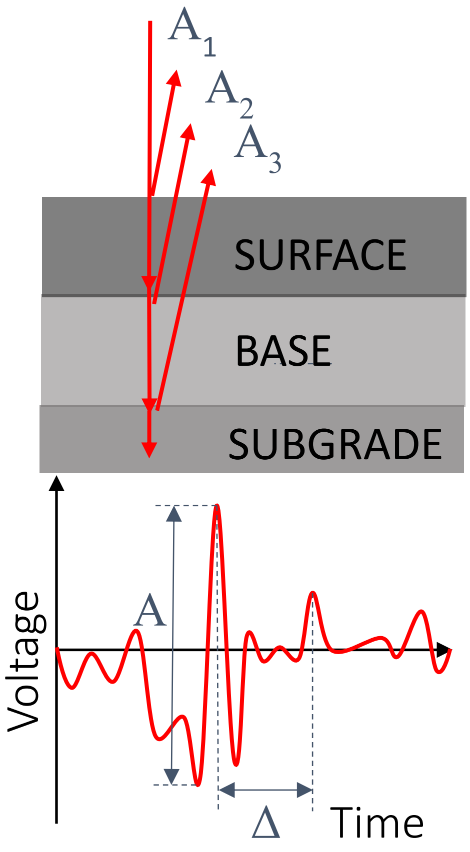
Ground-Penetrating Radar Systems (Overview)

General Description

- GPR is used for the in-situ characterization of pavement layers. GPR is widely used in pavement engineering to evaluate surface and subsurface pavement condition.

Measured Properties

- The antenna transmits electromagnetic radar waves into the pavement. These waves are reflected at significant pavement layer interfaces; the system captures and displays these reflections as a plot of return voltage versus arrival time.
- High-frequency radar will measure shallow depths at a high resolution. A 2-GHz radar has good resolution for hot-mix asphalt overlays less than 2 inches thick, while a 1-GHz radar has a suitable resolution for the full pavement structure down to 20 inches.
- Low-frequency radar can penetrate deep into the pavement and subgrade. Under ideal conditions, the 200-MHz antenna can penetrate up to 30 ft.



Data Analysis

- Estimate the locations of subsurface defects and the limits of the defects.
- Estimate variations in surface density and the presence of subsurface moisture.
- Estimate the density within the hot-mix asphalt layer.
- Use various software packages for data analysis depending on the GPR system.

Benefits for Accelerated Construction

- Forensic investigations of existing pavement structures to help determine the appropriate maintenance or rehabilitation strategy.
- Timely decisions due to the ease of data collection and analysis.

Limitations and Availability

- Some materials, such as lightweight or slag aggregate, will give false positive indications of potential problem areas.
- The test surface must be dry.
- Experienced personnel will need to collect and analyze data.
- The need for pavement coring is not eliminated; however, GPR data are helpful when developing a strategic coring plan.

Ground-Penetrating Radar, 1-GHz Antenna

General Description

- A vehicle-mounted 1-GHz antenna transmits pulses of radar energy into the pavement. The system has an integrated HDV logging system to provide images to complement the GPR data.
- The antenna collects data at highway speeds. Traffic control is typically not required.

Measured Properties

- The antenna transmits electromagnetic radar waves into the pavement at a frequency of 1 GHz. These waves are reflected at significant pavement layer interfaces; the system captures and displays these reflections as a plot of return voltage versus arrival time.
- The effective depth of penetration is 20 inches.

Data Analysis

- PaveCheck software, which was developed by TTI, assists with data analysis. The software integrates a video with a color plot of the waveforms. The software allows the user to:
    - Find anomalies visually.
    - Calculate the layer thickness.
    - Calculate the layer dielectric values.
    - Estimate locations of subsurface defects and the limits of the defects.
    - Estimate variations in surface density and the presence of subsurface moisture.

Benefits for Accelerated Construction

- Forensic investigations of existing pavement structures to help determine the appropriate maintenance or rehabilitation strategy.
- Timely decisions due to the ease of data collection and analysis.

Limitations and Availability

- Some materials, such as lightweight or slag aggregate, will give false positive indications of potential problem areas.
- The need for pavement coring is not eliminated; however, GPR data are helpful when developing a strategic coring plan.
- Experienced personnel will need to collect and analyze data.
- TxDOT currently owns five antennas.

Step-Frequency Ground-Penetrating Radar, 3D-Radar System

General Description

- Vehicles mounted with 24 step-frequency channels have the capability of scanning a 6-ft-wide strip in one pass.
- An HDV logging system can provide images to complement the GPR data.
- This system collects data at highway speeds. Traffic control is typically not required.

Measured Properties

- The antenna transmits a continuous radar wave and steps the frequencies within a range of 200 MHz to 3 GHz. These waves are reflected at significant pavement layer interfaces; the system captures and displays these reflections as a plot of return voltage versus arrival time.
- The effective depth of penetration with good resolution is 1 inch to 30 ft and along the 6-ft width of the multichannel antenna system.

Data Analysis

- Examiner software, developed by 3D-Radar, is used for data analysis. The program provides a plot of the waveforms. The program allows the user to:
  - Find anomalies visually.
  - Estimate the layer thickness based on an assumed dielectric value.
  - Estimate locations and limits of subsurface defects.

Benefits for Accelerated Construction

- Forensic investigations of existing pavement structures to help determine the appropriate maintenance or rehabilitation strategy.
- Timely decisions due to the ease of data collection and analysis.

Limitations and Availability

- Some materials, such as lightweight or slag aggregate, will give false positive indications of potential problem areas.
- Software currently does not allow dielectric value calculations. The layer thickness calculation is based on an assumed dielectric value.
- The need for pavement coring is not eliminated; however, GPR data are helpful when developing a strategic coring plan.
- Experienced personnel will need to collect and analyze data.
- TxDOT currently owns one antenna.

Ground-Coupled Ground-Penetrating Radar, Antenna Frequency Range of 200 MHz to 2.5 GHz

General Description

- A cart-mounted antenna transmits pulses of radar energy into the pavement.
- The antenna collects data while moving at walking speed. Typical traffic control is a lane closure.

Measured Properties

- The antenna transmits pulses of radar energy with a central frequency based on the antenna selected. This wave is reflected at significant layer interfaces in the pavement.
- The antenna frequencies range from 200 MHz to 2.5 GHz into the pavement.

Data Analysis

- Data analysis is performed with RADAN® software by Geophysical Survey Systems Inc. The program allows the user to:
  - Find anomalies visually.
  - Locate utilities, sink holes and voids, honeycombing in concrete, depth of concrete above the reinforcement, buried fuel tanks, archeological sites, and aquatic springs.
  - Calculate the layer thickness and dielectric value of layers.
  - Estimate locations and limits of subsurface defects.
  - Estimate variations in surface density and presence of subsurface moisture.

Benefits for Accelerated Construction

- Forensic investigations of existing subsurface conditions.
- Timely decisions due to the ease of data collection and analysis.

Limitations and Availability

- The effective penetration depth is subject to the antenna frequency, soil type, and degree of saturation.
  - High-frequency antennas provide higher near-surface resolution but lower penetration depths.
  - Lower-frequency antennas can penetrate much deeper, at up to 30 ft.
- The need for pavement coring is not eliminated; however, GPR data are helpful when developing a strategic coring plan.
- Several antennas are needed at different frequencies based on the depth range that the evaluation requires.
- Experienced personnel will need to collect and analyze data.
- TxDOT currently owns one set of antennas.

Ground-Penetrating Radar, Rolling Density Meter

General Description

- A cart- or vehicle-mounted system of three 2-GHz antennas transmits pulses of radar energy into the pavement.
- The system collects data while moving at a slow speed. Typical traffic control is a lane closure.

Measured Properties

- The antenna transmits electromagnetic radar waves into the pavement at a frequency of 2 GHz. These waves are reflected at significant pavement layer interfaces; the system captures these reflections as a plot of return voltage versus arrival time.
- Continuous surface dielectric values along three profiles are measured. The surface dielectric can be correlated to layer density.
- Measurements are made every 6 inches along the path.

Data Analysis

- The PaveScan program by TTI is used to collect and present the dielectric data.
  - The software was designed specifically for measuring the density for asphalt construction; the data are presented in terms of lots, sublots, stations, etc.
- Results are shown in terms of dielectric or density/air voids.
- The result statistics are shown for the data’s mean and distribution.

Benefits for Accelerated Construction

- Only one data collection pass is needed to collect measurements in and between the wheel paths.
- The non-destructive method ensures compaction uniformity over the entire mat.
- This system has the potential to replace nuclear and nonnuclear density equipment.
- Engineers can make timely decisions due to the ease of data collection and analysis.

Limitations and Availability

- Coring is needed to develop a calibration between dielectric and density.
- Experienced personnel will need to collect data.
- TxDOT currently owns one system.

Falling Weight Deflectometer

General Description

- FWD is a load-deflection response testing system that is widely used to evaluate pavement structural condition. The system can provide data for design, performance monitoring, and remaining life estimation.
- The system collects data in a static position for approximately 1 minute before moving to the next location. A moving traffic control operation is typically used; however, a lane closure may be needed.

Measured Properties

- A series of geophone sensors (usually seven) is used to measure the pavement response (vertical deflection) at various distances from the dropped load. The applied load simulates a single heavy-moving wheel.
- The combined deflections away from the load are used to define the deflection basin.

Data Analysis

- TxDOT uses the MODULUS program, which was developed by TTI, to back-calculate the layer moduli.

Benefits for Accelerated Construction

- Forensic investigations of existing pavement structures.
- Timely decisions due to the ease of data collection and analysis.
- Data that are used to support the following functions:
  - Routine pavement design.
  - Forensic studies and rehabilitation strategies.
  - Routing of super-heavy loads and an evaluation of their effect on pavement.
  - Evaluation of the pavement for load zones.
  - Support of pavement management activities at both project and network levels.
- Information or acceptance testing for new construction.

Limitations and Availability

- The MODULUS back-calculation of thin layers should be less than 3 inches thick.
- The approximate layer thickness should be known in order to perform the back-calculation.
- Experienced personnel will need to perform the data collection and analysis.
- TxDOT currently owns 15 FWDs.

Total Pavement Acceptance Device

General Description

- TPAD is a rolling dynamic deflectometer that collects a continuous deflection profile.
- The device collects data while moving at approximately 2 mph. A moving operation is typically used; however, a lane closure may be needed.

Measured Properties

- TPAD collects the following types of data at the same time:
    - Continuous deflection.
    - GPR.
    - GPS location.
    - HDV.

Data Analysis

- TxDOT uses the TPADana program, which was developed by TTI, to analyze the combined data.

Benefits for Accelerated Construction

- Forensic investigations of existing pavement structures.
- Indication of load transfer in jointed concrete pavement.
- Identification of weak areas and potential voids underneath the concrete pavement.

Limitations and Availability

- Since TPAD is a relatively new and unique technology, the analysis procedures of the continuous deflections are still being developed.
- Experienced personnel will need to collect and analyze the data.
- TxDOT currently owns one TPAD.

Mobile Laser Scanner

General Description

- LiDAR is a laser-based imaging system for right-of-way geometric evaluation.
- The system is comprised of the following:
  - A SICK laser scanner.
  - Road Doctor® CamLink camera.
  - NovAtel GPS.
  - NovAtel inertial measurement unit.
  - 3D accelerometer.
- Finland-based Roadscanners constructed the laser scanner package.
- The system collects data at highway speeds; therefore, traffic control is typically not required.

Measured Properties

- Two primary pieces of data are generated by the laser:
  - The reflectivity of the target object.
  - The straight-line distance to the object in relation to the angle of the laser.

Data Analysis

- Programs are being developed to assist with the following:
  - Calculation of rutting depths.
  - Estimation of the cross-slope.
  - Determination of the location of patches.
  - Identification of pavement surface changes.
  - Calculation of ditch depths and grade.
  - Estimation of the surface drainage behavior.

Benefits for Accelerated Construction

- Geometric information for new construction.
- Forensic evaluation of pavement and drainage conditions within the right of way.

Limitations and Availability

- The data analysis is complex.
- Experienced personnel will need to perform the data collection and analysis.
- TxDOT currently owns one system.

Inertial Profiler

General Description

- The inertial profiler uses a laser and inertial roughness profiler to quantify ride quality.
- Ride data are collected in accordance with TxDOT test method Tex-1001-S and at highway speeds. Traffic control is typically not required.

Measured Properties

- The inertial profiler measures the surface profile for computing any number of smoothness statistics:
  - The locations of localized roughness and amplitudes.
  - The surface texture depending on the equipped laser.

Data Analysis

- Ride data are analyzed using TxDOT's Ride Quality computer program.
- Profile data can be used for a variety of analyses, such as:
  - Vehicle simulation.
  - Profilograph simulation.
  - Power spectral analysis.
  - Grinding simulation.
  - Straightedge simulation.

Benefits for Accelerated Construction

- The ride quality and localized roughness can determine the need for maintenance or rehabilitation.
- Engineers can make timely decisions due to the ease of data collection and analysis.

Limitations and Availability

- The inertial profiler is not appropriate for stop-and-go environments.
- Splash and spray on wet surfaces will adversely affect the profile data.
- The inertial profiler requires periodic verification of accelerometer and laser calibration. The profiler should be certified on at least an annual basis, particularly for profilers used for construction quality control/quality assurance and for network-level inventories of pavement smoothness.
- Experienced personnel will need to collect the data.
- TxDOT currently owns five inertial profilers.

Portable Weigh in Motion

General Description

- The p-WIM traffic data collection system is used to measure traffic loading. The system can provide traffic data for planning and design purposes.
- The system has a modem communication system that allows for remote monitoring, viewing, and downloading of traffic data in real time.

Measured Properties

- Site-specific field traffic measurements include the following:
    - Traffic volume.
    - Vehicle speed.
    - Axle spacings.
    - Vehicle classification.
    - Axle loads.
    - Vehicle weights.

Data Analysis

- An Excel spreadsheet has been developed to calculate and generate ready-to-use traffic data characteristics for pavement design and analysis.
- Generated outputs include average daily traffic (ADT), average daily truck traffic (ADTT), %trucks, average of the ten heaviest wheel loads daily (ATHWLDs), Truck Factor (TF), equivalent single-axle loads (ESALs), etc. for use in the Flexible Pavement System, Texas Continuously Reinforced Concrete Pavement—Mechanistic–Empirical (TxCRCP-ME) Design Program, Texas Mechanistic–Empirical (TxME) software, etc.

Benefits for Accelerated Construction

- Site-specific traffic data.
- Timely decisions due to the ease of data collection and analysis.
- p-WIM data that are used to support the following functions:
    - Planning.
    - Pavement design and rehab.
    - Forensic studies.
    - Support of pavement management activities at both project and network levels.
    - Supplementary material for other testing data.

Limitations and Availability

- This system is an emerging technology from recent and ongoing research work.
- Traffic control is required for 1.5 hours during setup and 0.5 hours during removal.
- TTI has five operational p-WIM systems.

Electrical Resistivity Tomography

General Description

- ERT is used to conduct a geophysical survey that can indicate subsurface geological conditions.
- ERT is a geophysical method that provides an image of the bulk electrical resistivity structure in a vertical plane beneath a linear array of metal electrodes planted in the ground and connected by a multicore cable.

Measured Properties

- A predefined sequence of measurements is comprised of the voltages that develop across selected pairs of electrodes:
  - For any single measurement, the pair of electrodes chosen to measure voltage acts as a receiver; the pair of electrodes chosen to inject and withdraw current acts as the transmitter.
  - The dipole–dipole measurement protocol is typically used for this type of survey.

Data Analysis

- Customized software generates a graphical display of the voltages measured in the field that are normalized by the injected current and multiplied by a geometric array factor that is appropriate for the dipole–dipole configuration:
  - An automated inversion procedure is executed in the software to generate an Earth resistivity section.
- The tomogram shows bulk resistivity that can indicate potentially saturated soils.

Benefits for Accelerated Construction

- Engineers can make timely decisions in the design phase to mitigate construction delays caused by subgrade with high moisture content.

Limitations and Availability

- Experienced personnel will need to collect and analyze the data.
- TTI can schedule the testing.

Reference

M. E. Everett. *Near-Surface Applied Geophysics*. Cambridge University Press, 2013, 24–29.

Dynamic Cone Penetrometer

General Description

- DCP uses the penetration depth per blow to assess the in-situ strength of undisturbed soil or compacted materials.
- Applications include forensic investigations, compaction uniformity checks, and layer moduli verification.

Measured Properties

- DCP measures the depth of penetration per number of hammer drops (blows):
  - A 17.6-lb hammer is dropped from a set height.
  - The number of blows and penetration depth are recorded.
- Refer to American Society for Testing and Materials test method D6951/D6951-18.

Data Analysis

- Excel spreadsheet developed to assist with data analysis.
- Identification of the layer thickness.
- Estimation of the relative strength with depth.
- Estimations:
  - Layer Moduli Verification.
    $M_r = 2.55 \times CBR^{0.64}$
    Where:
    - Mr is = ksi
  - California Bearing Ratio (CBR).
    $CBR = 292 \div P_r^{1.12}$
    Where:
    - CBR = %
    - Penetration Rate and P_r = depth/blow (recorded depth in inches, inches*25.4 ÷ no. blows)

Benefits for Accelerated Construction

- Check the uniformity of the layer compaction.
- Estimate the layer moduli.

Limitations and Availability

- This cost-effective tool is commercially available for purchase.
- Several TxDOT districts own DCPs; DCPs are available by contacting the district laboratory.

CHAPTER 3. ACCELERATED CONTRACTING STRATEGIES

Transportation infrastructure projects often cause inconveniences to the traveling public. Construction increases traffic delays, detours, safety risks, and disruptions to adjacent businesses and communities. There is an urgent need to accelerate construction in order to ameliorate its negative impact on the public, especially for projects located in urban areas where the traffic volume is high and the affected population is large [1-4].

The latest U.S. Census reports indicate that 81 percent of the population lives in urban areas [5] and the trend of this population increasing is expected to continue [6]. According to the Federal Highway Administration (FHWA), about 35 percent of U.S. highway construction projects are undertaken in urban areas [7]. These urban projects seriously disrupt traffic in communities that use affected roadways, resulting in major inconveniences to the traveling public and commercial enterprises. Thus, many state departments of transportation are under increased pressure to reduce project duration [8]. To mitigate this traffic disruption, state transportation agencies (STAs), including receiving agencies and their local districts, have adopted alternative contracting strategies that offer the potential to accelerate construction and thus reduce traffic disruption.

ACCELERATED CONSTRUCTION PROCEDURE

One innovative way to reduce construction duration is to offer an early completion incentive bonus to contractors procured through the cost-plus-time bidding process, commonly referred to as A+B. This bidding process is common within receiving agencies, especially in local urban districts. The system of incentive/disincentive (I/D) rewards contractors with bonuses for early completion of projects and levies fines for delays. In theory, to encourage competitive contractors to bid on projects, an agency must offer I/D amounts greater than the contractor's additional cost of acceleration; this estimate must fall within the agency's budget and still be sufficient to motivate the contractor to complete the project ahead of schedule. The maximum time allowed for the project must be estimated by the contracting agency to serve as the baseline for the I/D rates. In the conventional contracting arrangement, the general contractor and subcontractors have no input until they are selected; agency engineers who lack experience in identifying long lead items and project constraints may be responsible for determining contract completion times. The use of A+B bidding takes advantage of contractors' ingenuity by utilizing their realistic estimates of the construction schedule and cost. It is also generally acknowledged that this bidding process eliminates unqualified contractors.

Urban districts have used I/D contracting strategies either as a stand-alone method or in combination with alternative contracting methods. The use of A+B combined with I/D provisions is common, especially on urban highway 3R projects (i.e., resurfacing, reconstruction, and rehabilitation). This A+B+I/D contracting can help agencies balance the cost of road user delay and project delivery expenses while also reducing construction time. This alternative contracting method has been used to accelerate construction in both the design-bid-build and the design-build delivery methods. Indeed, it has become a favored alternative strategy for satisfying the public's expectation of early project completion and is applied widely in numerous high-impact transportation infrastructure improvement projects in more than 36 states.

A+B Bidding Mechanism

Basic A+B Bidding Concept

The use of A+B is a desirable alternative contracting strategy for early project completion [9]. The A+B bidding strategy has become one of the most widely used alternative contracting techniques for shortening construction time, especially in time-critical projects, and often is accompanied by I/D provisions for meeting the accelerated project delivery requirement and minimizing traffic delays [10].

In A+B contracting, the winning bidder is the group that turns in the lowest total combined bid for the cost (A) and time (B) required to complete the project. This equation can be written as:

$$TCB = A + B \tag{1}$$

$$B = CT \times DRUC \tag{2}$$

Where:

TCB = the project's total combined bid price in U.S. dollars.
A = the project bid price for the construction cost in U.S. dollars.
B = the project bid price for time-dependent costs in U.S. dollars.
CT = the contract time in the number of working (or calendar) days.
DRUC = the daily road user delay cost in U.S. dollars per day.

Contract Time Determination for A+B Bidding

Generally, A+B combined with I/D provisions is known to increase costs for both agencies and contractors, but agencies benefit from the construction time saved and contractors benefit from incentive bonuses. Contract time determination for this A+B+I/D best-value procurement contracting method relies greatly on the experience and judgment of the contracting agency engineers tasked with estimating the project's duration, road user cost, and realistic I/D rates [8, 11]. Overestimation of contract time can lead to contractors receiving incentive fees with little effort. As a result, 99 percent of the contractors in 35 states who contracted with I/D provisions received incentive bonuses [12], supporting the assertion that overestimation of contract time is prevalent. For this reason, appropriately determining contract times for A+B+I/D bidding is crucial. Following are general recommended guidelines for determining contract time for A+B+I/D bidding:

- Accurate estimation of contract time during the project scoping phase is of the utmost importance.
- Contract times should be determined after considering accelerated production rate assumptions that account for any additional resource commitments necessary to achieving early completion of the contract work.
- Use of historical production rates and innovative scheduling tools (e.g., Construction Analysis for Pavement Rehabilitation Strategies [CA4PRS]) should be considered when conducting time-cost trade-off analyses to determine the most feasible and efficiently balanced construction and traffic control options.
- The value of the daily road user cost (DRUC) should be established by TxDOT and the estimated DRUC incorporated into the B value in the A+B bidding.
- It is important to adjust the calculated DRUC downward to establish a realistic DRUC, typically ranging from 50 percent to 100 percent of the original estimate, with some variation in cases where the estimated DRUC is fairly high.
- The DRUC should not exceed the liquidated damages; otherwise, it may be more economical to pay the liquidated damages rather than finish within the project duration bid.
- The contract time should be determined by the receiving agency because it serves as the maximum allowable time for the project. It establishes a baseline for monetary incentives.
- When A+B is used in conjunction with I/D provisions, the intent is for the contractor to bid a reasonably shorter B duration to win the project. District engineers should determine a reliable B contract time in order to ensure that contractors receive the appropriate amount of compensation for their additional effort.
- The maximum number of allowable working (or calendar) days should be specified in the plans, specifications, and estimate (PS&E) packages in order to lessen the impact that the B value has on competitive bidding.
- Use of A+B bidding as a stand-alone method to achieve interim milestones should be avoided, since there are more effective methods for achieving this goal, such as establishing I/D.
- When the contract time is defined in calendar days, the project duration estimate should also consider typical weather conditions during the time the project is executed.
- When coupled with I/D provisions, determination of the maximum time allowed for the project during the advanced planning stages should be based on critical path methods (CPMs), with the researchers assuming an accelerated production rate as suggested later in this chapter.

In sum, the B value of the contract time determined by the receiving agency serves as the maximum allowable contract time and must be specified in the PS&E packages. The contractor’s bid for the B value establishes the contract time in calendar days, after accounting for weather, holidays, and other non-workdays. The three primary reasons for using calendar days instead of workdays in A+B bids are:

- It reduces disagreements regarding when a day should not be counted due to inclement weather since all calendar days are counted.

- It encourages the contractor to find ways to make up for days lost due to weather.
- It allows for the contractor to innovate in order to complete work during the winter months.

In A+B bidding, fixed completion date contracts are discouraged because the number of actual days the contractor bids and the completion date are likely to conflict.

Pros and Cons of A+B+I/D Bidding

To date, A+B implementation experiences indicate that the effectiveness of A+B contracting is debatable, largely due to inherent inaccuracies in contractors' specifications of project duration during bidding.

Following is a list of the pros and cons of the A+B+I/D contracting method compared to the conventional contracting process:

- Pros of the A+B+I/D contracting method:
    - Reduces contract time and construction-induced delays with almost no additional cost.
    - Encourages contractors to leverage innovative means of reducing contract time to achieve accelerated production rates.
    - Enables contractors to involve careful front-end planning; contract time is more realistic than contract times set by the contracting agency.
    - Lowers agency risk by transferring that risk to the contractor through disincentive clauses.
    - Eliminates the selection of inefficient contractors.
    - Results in higher number of project bids because contractors expect to receive incentive bonuses, an advantage for agencies trying to reduce cost to the public.

- Cons of the A+B+I/D contracting method:
    - Increases the frequency and magnitude of contract change orders, which can result in substantial delays in contract time; therefore, it is crucial to identify any potential risks associated with third-party conflicts (e.g., design uncertainties, right of way, utilities) before the procurement stage, and the project must be relatively free of third-party conflicts.
    - Increases contract time and cost to the contracting agency if it is not effectively implemented.

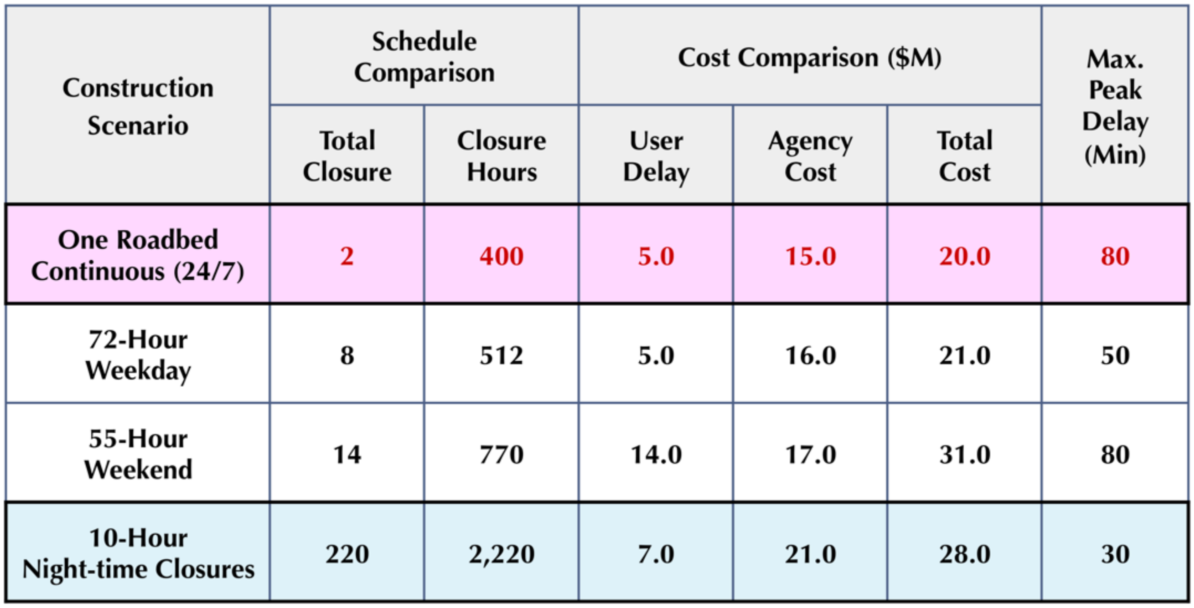
STATE-OF-THE-ART TOOL FOR DETERMINING THE BEST ACCELERATED STRATEGIES

This section discusses the best use cases of a state-of-the-art tool for determining the most effective and economical accelerated construction strategies. This tool, called the CA4PRS, allows the research team to develop a schedule–cost–traffic integrated seven-step analytical procedure for determining the most feasible and realistic accelerated construction and traffic control options for a given project. This integrated analysis also enables the agency to determine contract times and daily I/D rates for A+B contracting projects. More specifically, when determining contract times for A+B projects involving incentive provisions, choices regarding lane closure schemes (e.g., single-lane closure, double-lane closure, full-lane closure with counterflow traffic) and construction windows (e.g., nighttime, weekdays, weekends, around the clock) play an instrumental role. Some pioneering states like California have already attempted to implement a similar schedule–traffic–cost integration analysis approach to making better-informed contract time determination decisions.

Construction Analysis of Pavement Rehabilitation Strategies

There are processes and tools that can help STAs perform comprehensive analyses of construction options and cost and time trade-off investigations. One state-of-the-art tool is CA4PRS, which has become popular due to its ability to simultaneously analyze schedules, road user costs, construction costs, and work zone traffic impact. The CA4PRS tool was developed under the FHWA pooled fund research program by a multistate consortium (California, Texas, Minnesota, and Washington).

The CA4PRS tool is effective at evaluating the effects of different traffic control options on contract time, road user cost, and level of traffic inconvenience. More specifically, since 1999, the capabilities of CA4PRS have been confirmed through several major highway rehabilitation projects in California, Washington, Minnesota, and Texas. As an example, CA4PRS was used to select the most economical rehabilitation scenario for the I-15 Devore Project in Southern California, optimally balancing contract time, road user cost, and level of traffic inconvenience (see Figure 1). The 4.5-km concrete reconstruction project, which would have taken 10 months using traditional nighttime closures, was completed over two 9-day periods using one-roadbed continuous closures and around-the-clock construction. Implementing continuous closures rather than repeated nighttime closures resulted in significant savings: $6 million in agency costs and $2 million in road user costs. Alternative strategies enabled by the use of CA4PRS led to an accelerated project process dubbed Rapid Rehab that has been roundly praised by professionals [1].



Construction Scenario	Schedule Comparison		Cost Comparison ($M)			Max. Peak Delay (Min)
	Total Closure	Closure Hours	User Delay	Agency Cost	Total Cost	
One Roadbed Continuous (24/7)	2	400	5.0	15.0	20.0	80
72-Hour Weekday	8	512	5.0	16.0	21.0	50
55-Hour Weekend	14	770	14.0	17.0	31.0	80
10-Hour Night-time Closures	220	2,220	7.0	21.0	28.0	30

Figure 1. CA4PRS Results for the I-15 Devore Project near Los Angeles by the California Department of Transportation[1].

Validation studies using several major highway rehabilitation projects in California, Washington, and Minnesota proved the scheduling reliability and accuracy of the software, and as a result, there has been growing acceptance of the program on a national level, including recent arrangements by FHWA to distribute free group licenses to all 50 U.S. states [13]. To boost nationwide deployment, FHWA and the American Association of State Highway and Transportation Officials have arranged free group licenses for all STAs. FHWA also encourages the use of CA4PRS for highway rehabilitation projects by conducting workshops and training sessions through the National Highway Institute [14].

Systematic Procedures for Determining the Most Feasible Accelerated Construction Options

The integrative seven-step procedure begins with the exploration and determination of potential what-if construction and traffic control options. Then, the effects of individual what-if scenarios on project duration are estimated. In the subsequent step, the mobility impact of each of the perceived alternatives is assessed based on the estimated number of workdays; namely, the DRUC and work zone delay estimates in minutes are produced in this step. Finally, the most economical option is selected based on three important decision-making datapoints for each construction/traffic control option: duration, road user cost, and traffic delay in minutes. For the final alternative selected, the estimated initial duration is then reevaluated and adjusted.

The adjusted number of workdays is then converted into calendar days, accounting for weather, holidays, and weekends. Through this process, the agency arrives at the maximum time allowable for completing the entire contract. Coupled with the estimated DRUC value, this number of maximum allowable days is incorporated into the B value in the A+B bidding.

This B contract time then serves as the baseline for the I/D rates (i.e., the daily I/D, closure I/D, and incentive cap rates), with the expectation that the contractor will bid a reasonably shorter B duration while also ensuring it receives the appropriate amount of compensation in exchange for committing the additional resources necessary to accelerate construction.

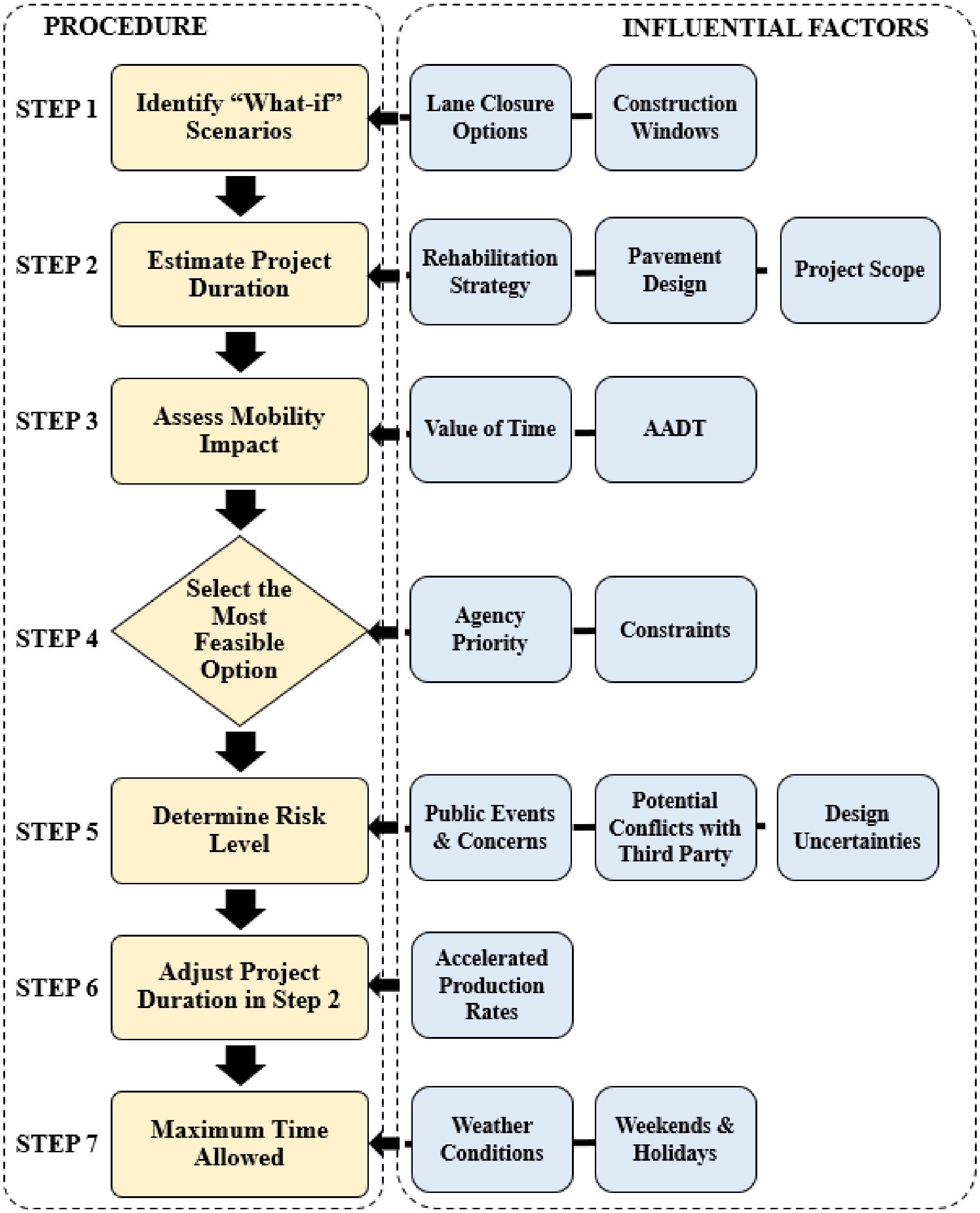


Figure 2. Flowchart of the Best Accelerated Contracting for the Contract Time Duration Procedure.

The best-practice systematic procedure for determining contract times is presented in Figure 2 and is comprised of the following steps:

- **Step 1: Identify what-if construction and traffic control options**. Alternatives should be defined with respect to the duration and occurrence (e.g., nighttime, weekday, weekend, 24/7). Each alternative can be executed through one of three standard lane closure scenarios (i.e., single-, double-, and full-lane closure), with some variations.
- **Step 2: Estimate the number of workdays needed for all alternatives being considered**. In the advanced planning stage (from the schematic to design document scoping phases), traffic assessments for each alternative should begin with an estimate of the number of workdays needed for the traffic control options being considered. This process should be followed because the estimated number of workdays is needed to serve as the baseline for conducting mobility impact assessments.
- **Step 3: Assess the mobility impacts of all alternatives being considered**. These assessments should include estimates of road user cost and mobility impacts (i.e., delayed minutes due to lane closure options). Since such assessments are directly affected by project duration estimates, mobility impact assessments should be performed in close relation to the project duration estimates.
- **Step 4: Select the most economical option out of all the options being considered**. After accounting for prioritized values and/or trade-offs with regard to project duration, cost, and amount of traffic disruption for each of the alternatives considered, the agency should then select the most feasible and economical option for the given project.
- **Step 5: Determine the risk (or level of uncertainty) for the selected option**. The A+B process for bidding is known to increase the frequency and magnitude of contract change orders, resulting in substantial delays in contract time. Therefore, it is crucial to identify any potential risks associated with third-party conflicts such as the scope of the project, design uncertainties, right of way, utilities, etc.
- **Step 6: Adjust the initially estimated duration by applying accelerated production rates**. With regard to the final alternative selected, an accelerated production rate should be applied, with the expectation that the I/D project will use 15 percent to 20 percent more resources than a conventional schedule. The initially estimated project duration should then be adjusted accordingly to be incorporated into the B value in the A+B bid.
- **Step 7: Convert the adjusted workdays into calendar days**. It is recommended that A+B+I/D projects define workdays as calendar days and account for weather, holidays/weekends, and other non-workdays during the time construction is executed. Adjustments should also be made for weather.

The research team has developed a comprehensive stepwise framework that can concurrently link a time–cost–traffic trade-off analysis with accelerated project rates. This framework can be used to establish the most effective contract time for an A+B+I/D project. The contract time determined through these seven steps can then serve as the basis for establishing an effective daily I/D rate that falls within an agency’s budget while also being sufficient to motivate a contractor to complete the project ahead of schedule.

CHAPTER 4. CONSTRUCTION SPECIFICATIONS

A review of TxDOT's current specifications was performed. There is flexibility to set up various scenarios for I/D, milestones, and working days for the construction time schedules. Special specifications can be used to describe new strategies. Plan details can be developed for proven accelerated construction techniques.

ITEM 8, "PROSECUTION AND PROGRESS"

This item provides the project schedule requirements. Working days for the contract, including how those working days are defined and measured, are described. The contractor's project schedule development, submission, and updates are shown and allow the designer the choice of requiring, in the plans, the contractor's schedule format as either a bar chart or CPM.

This item is very flexible, and no changes are recommended.

ITEM 502, "BARRICADES, SIGNS, AND TRAFFIC HANDLING"

This item provides traffic control based on the plan details and is set based on the number of months that the work is expected to take. No changes are recommended.

ITEM 508, "CONSTRUCTING DETOURS"

This item provides information for constructing and maintaining detours. No changes are recommended.

SPECIAL SPECIFICATIONS

Special Specification 3013, "Thin Whitetopping (Concrete Overlay)"

Thin whitetopping is defined as a 4- to 7-inch concrete overlay that is placed and bonded to a milled and distressed asphalt pavement surface, as shown in Figure 3, with minimal disruption to traffic, which is normally constructed at intersections where rutting and shoving in asphalt pavement are major concerns. The completed overlay is cured for 36 hours to achieve enough compressive strength before opening to traffic.

No changes are recommended; however, consideration should be given to developing a formal design procedure.

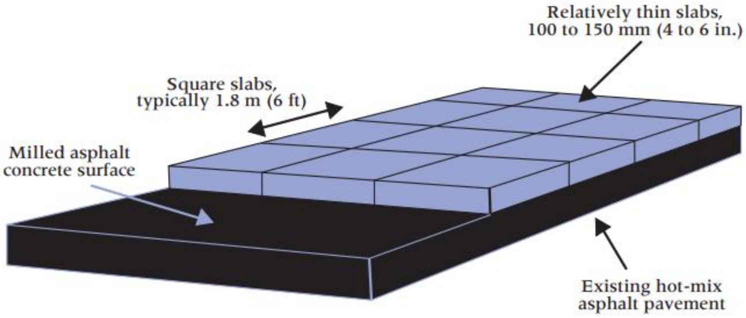


Figure 3. Thin Whitetopping.

Special Specification 3018, "Two-Lift Concrete Pavement"

Two-lift concrete pavement involves the placement of two wet-on-wet layers of concrete instead of one homogenous layer, as illustrated in Figure 4. Less material cost with extensive use of recycled aggregates from reclaimed concrete or hot-mix asphalt and durable surface layer performance are the primary benefits provided by the two-lift concrete pavement. Generally, recycled or locally available aggregates that are not suitable for use in the thin surface layer are utilized in the thick bottom layer with a thickness of typically 80 to 90 percent of total pavement thickness. The dense and wear-resistant aggregates that are durable and friction resistant with low noise are used for the thin surface layer.

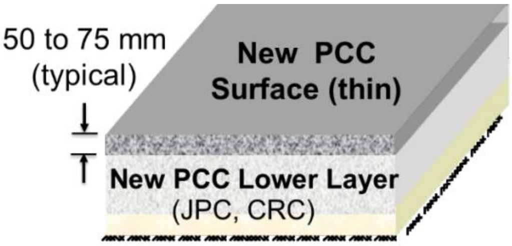


Figure 4. Two-Lift Concrete Pavement.

Coarse aggregates with coefficients of thermal expansion greater than 5.5 microstrain/°F and less than 5.5 microstrain/°F are used to produce the bottom-lift concrete and top-lift concrete, respectively. The bottom-lift concrete layer is placed first and is capable of supporting top-lift concrete with minimal intermingling of the two layers at the time of placement, and then the top-lift concrete is placed within 60 minutes after the placement of bottom-lift concrete to ensure a wet-on-wet placement. Sawing and sealing of longitudinal contraction joints are required to be shown on the plans.

No changes are recommended.

Special Specification 3072 and 3038, "Rubblizing Existing Concrete Pavement"

Removing the old deteriorated concrete pavement and replacing it with a new concrete pavement is expensive and time consuming. Placing an asphalt overlay on an old concrete pavement is less expensive. However, reflection cracking in asphalt overlays could be initiated from concrete joints and becomes a major concern. To mitigate reflection cracking, rubblization of an existing concrete layer is considered a practical and economically doable option. Fracturing the worn-out concrete layer into 2- to 6-inch small pieces and breaking the concrete/steel bond, as presented in Figure 5, is an in-place process. The fractured concrete pieces are compacted and solidified before resurfacing with asphalt overlays. In the rubblization process, removing pavement, drilling and placing dowels, and curing Portland cement concrete patches are all unnecessary, which can result in significant cost and time savings.

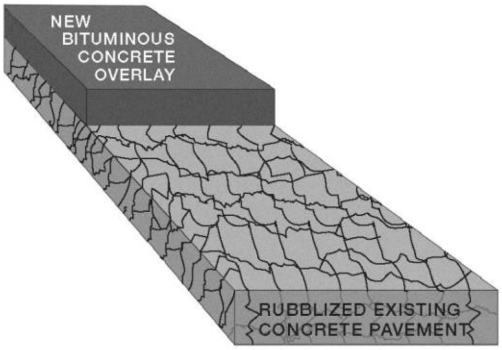


Figure 5. Rubblization with New Asphalt Overlay.

Traffic opening is not allowed on the rubblized pavement except at the engineer-approved points. When the next layer is hot-mix asphalt, it is constructed within 48 hours after completion of rubblization.

No changes are recommended, but development of a formal design procedure based on the recommendations in TxDOT research report 5-4687-03-R1, *Implementing Rubblization and Drainage Improvement Techniques on Severely Distressed Concrete Pavements: Technical Report*, should be considered.

FULL-DEPTH RECLAMATION SPECIAL SPECIFICATIONS

Full-depth reclamation (FDR) is an in-place recycling process, as shown in Figure 6, used to pulverize a distressed asphalt surface layer and base layer, and then utilize them as a durable, stabilized base layer. Using the FDR process, natural resources such as aggregates are saved and the structural capacity is increased. In addition, since minimal materials need to be transported in or out, the construction schedule is shortened. The FDR process is also convenient for residents since a traffic detour is not needed for lower-volume roadways. Several special specifications are related to FDR and are based on the type of stabilizer or combination of stabilizers used in the process. There are also several standard specifications (Items 260, 265, and 275) for similar processes.

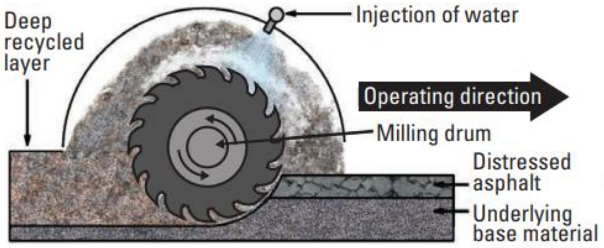


Figure 6. Full-Depth Reclamation Process.

Special Specification 3088, "Full Depth Reclamation Using Foamed Asphalt (Road-Mixed)"

Foamed asphalt is used for stabilization and may include another additive (e.g., lime, cement, and fly ash, when applicable).

Special Specification 3089, "Full Depth Reclamation Using Asphalt Emulsion (Road-Mixed)"

Asphalt emulsion is used for stabilization and may include another additive (e.g., lime, cement, and fly ash, when applicable).

Special Specification 3095, "Full Depth Reclamation Using Fiber (Road-Mixed)"

This FDR process utilizes a polypropylene fiber and may include another additive (e.g., lime, cement, and fly ash, when applicable).

FULL-DEPTH RECLAMATION STANDARD SPECIFICATIONS

The standard specifications are based on the stabilizer:

- Item 260, "Lime Treatment (Road-Mixed)."
- Item 265, "Fly Ash or Lime-Fly Ash Treatment (Road-Mixed)."
- Item 275, "Cement Treatment (Road-Mixed)."

The researchers recommend the following:

- Consider implementing and continuing the research being conducted in TxDOT project 0-7027, Accelerating Mix Designs for Base Materials, to develop a laboratory testing procedure that can be used to evaluate different types and combinations of stabilizers.
- Continue to use lessons learned during construction projects to update the special specifications.
- Consider incorporating the foamed asphalt and asphalt emulsion special specifications into the standard specification books' 10-year update (2024 version).

CHAPTER 5. RECOMMENDATIONS

TxDOT's *Accelerated Construction Guidelines* states, "Accelerated construction entails all the aspects of getting a project built rapidly including project selection, planning, contracting, design, traffic control, construction methods, publicity, and contingencies" [15]. These guidelines also have information about project selection for accelerated construction.

The goal of accelerated construction should be to minimize construction zone impacts to the driving public. Pavement evaluation, design, and construction strategies, including traffic control, can lead to getting the project built rapidly.

NON-DESTRUCTIVE TESTING TOOLS AND TECHNIQUES

The innovative tools and techniques described in this study can be used for all pavement projects. A workshop was developed in this study to provide a basic introduction to developing a testing plan and the methods and equipment used to perform the testing. Additional training is needed to help designers develop a testing and sampling program. Holding additional workshops as an introductory training for designers should be considered.

The TxDOT Maintenance Division is the contact point to request help with testing and pavement design. The division is an excellent internal resource and should be utilized by the designers to provide guidance and help with pavement design and testing.

TxDOT should continue to improve current practices and develop new innovative tools and technologies to assist with pavement evaluation and design.

TRAFFIC CONTROL STRATEGIES

It can be inferred from the survey that not a lot of time, effort, or importance is placed on the development of the construction schedule by the designers. A formal method for development of construction schedules that includes following the procedure laid out in Figure 2 to evaluate and select the optimal traffic control timing strategy should be created. The schedule should be developed to complement the construction phases. Additional training is needed to help designers evaluate the traffic control timing strategies and develop realistic schedules.

TxDOT should continue to improve current practices and develop new innovative methods to assist with scheduling.

SPECIFICATIONS

Special specifications allow the designer the flexibility to try new methods and procedures. TxDOT should consider updating the standard specification book during the 10-year update (2024 update) with the statewide special specifications, especially for FDR projects.

Item 8, “Prosecution and Progress,” is a flexible specification. The flexibility associated with monitoring and charging the time on a project can lead to extended time impacts to the traveling public without impacts on construction time schedule. These extended time impacts to the traveling public lead to a false sense that the project is on time. In coordination with developing the traffic control strategies and working day determination, TxDOT should establish time requirements that reflect actual impacts to the traveling public.

One of the ways to establish these time requirements is by designating a calendar day project. This avoids disagreements over charge days with the contractor. However, for this strategy to work, more training and time devoted to schedule determination are needed. The designers should develop reasonable working day estimates that account for schedule impacts such as climate, holidays, curing times, performance periods, and controlling items of work. Incentives and disincentives are needed to ensure that time has value to both TxDOT and the contractor.

TxDOT should continue to develop practices and new innovative methods to assist with accelerating pavement construction.

REFERENCES

1. Lee, E.B., K. Choi, and S. Lim, *Streamlined strategies for faster, less traffic-disruptive highway rehabilitation in urban networks.* Transportation Research Record: Journal of the Transportation Research Board, 2008. **2081**(1): p. 38-45.
2. Napolitan, F. and P.C. Zegras, *Shifting urban priorities? Removal of inner city freeways in the United States.* Transportation research record, 2008. **2046**(1): p. 68-75.
3. Choi, K., Y.H. Kwak, and B. Yu, *Quantitative model for determining incentive/disincentive amounts through schedule simulations*, in *2010 Winter Simulation Conference (WSC)*. 2010, IEEE: Baltimore, MD, December 5-8. p. 3295-3306.
4. Napolitan, F. and P.C. Zegras, *Shifting urban priorities?: Removal of inner city freeways in the United States.* Transportation Research Record: Journal of the Transportation Research Board, 2008. **2046**(1): p. 68-75.
5. Bureau, U.S.C., *Growth in Urban Population Outpaces Rest of Nation, Census Bureau Reports*. 2012, United States Census Bureau.
6. Foxx, A.R., *Beyond Traffic: 2045 Final Report.* 2017.
7. Choi, K., Y.H. Kim, J. Bae, and H.W. Lee., *Determining future maintenance costs of low-volume highway rehabilitation projects for incorporation into life-cycle cost analysis.* Journal of computing in civil engineering, 2016. **30**(4): p. 04015055.
8. Choi, K., H.W. Lee, J. Bae, and D Bilbo., *Time-cost performance effect of change orders from accelerated contract provisions.* Journal of Construction Engineering and Management, 2016. **142**(3): p. 04015085.
9. Actis, C., D. Unkefer, and J. Lewis, *Alternative Contracting Methods: Alternative Technical Concepts*. 2014, FHWA, US Department of Transportation. http://www.fhwa.dot.gov/everydaycounts/edctwo/2012/pdfs/edc_atc.pdf Accessed April.
10. Choi, K., Y.H. Kwak, J. Pyeon, and K. Son, *Schedule effectiveness of alternative contracting strategies for transportation infrastructure improvement projects.* Journal of Construction Engineering and Management, 2011. **138**(3): p. 323-330.
11. Sun, C., P. Edara, and A. Mackley, *Refocusing on liquidated damages in incentive/disincentive contracts.* Journal of Legal Affairs and Dispute Resolution in Engineering and Construction, 2013. **5**(3): p. 136-141.
12. Pyeon, J.-H. and E.-B. Lee, *Systematic Procedures to Determine Incentive/Disincentive Dollar Amounts for Highway Transportation Construction Projects, Research Report 11-22.* 2012.
13. Choi, K., E.S. Park, and J. Bae, *Decision-Support Framework for Quantifying the Most Economical Incentive/Disincentive Dollar Amounts for Critical Highway Pavement Rehabilitation Projects.* 2013.
14. Kim, C.,E. Lee, J. Pyeon, R. Ellis Jr., and A. ShakerNia, *A Cost-Estimate Model for Transportation Management Plan (TMP) Strategies for Highway Construction Projects*. 2013.
15. TxDOT, *Accelerated Construction Guidelines*. 2018.