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16. Abstract

This is the third technical report prepared for the Texas Department of Transportation (TxDOT) Project 0-4035 "Further Development of Post-Tensioned Prestressed Concrete Pavements in Texas." The contents of this document intend to complement the information provided in the two previous reports. The guidelines included here are applicable to the post-construction evaluation of a new prestressed concrete pavement (PCP) to be constructed in Texas. They recommend a series of tasks that need to be performed to document the evolution of the pavement, so that it could be evaluated in terms of performance. Likewise, this report suggests a methodology to determine the financial feasibility of the PCP technology and the reasons that justify its use under certain circumstances. Finally, the report includes conclusions and recommendations for the project. Special specifications (SS) were prepared for the PCP and will be ready for implementation before the pavement is constructed.

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Plan for Post-Construction Evaluation and Special Specifications for a PCP

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Research performed in cooperation with the Texas Department of Transportation.

Products

This report contains products P5 and P8. Product 5 can be found on page 3, page 9, and in Appendix A. Product 8 can be found on page 9.

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1. Introduction

1.1 Background

This report is the third and last technical document prepared for Research Project 0-4035, “Further Development of Post-Tensioned Prestressed Concrete Pavements in Texas.” This project started in Fiscal Year (FY) 2000 and was in charge of conducting the necessary tasks to design, construct, and monitor a prestressed concrete pavement (PCP) to be constructed near Hillsboro, Texas, in the Waco District. Because of budgetary and construction project priorities, the construction of the PCP was not accomplished in agreement with the original time frame. Therefore, the project focused on developing the tasks necessary to design the pavement and many other issues related to it.

The first technical report in this project, 4035-1 “Design of a Post-Tensioned Prestressed Concrete Pavement, Construction Guidelines, and Monitoring Plan,” (Ref 1) is a comprehensive document that presents a literature review of the experiences related to this type of paving technology in the United States and around the world. It summarizes the findings of various PCP applications and focuses on the experience gained in Texas, where a PCP was constructed in 1985 and has performed in an excellent manner. The report also describes the process that was followed to design a new PCP that will be completed in FY 2005. Other topics discussed in Report 4035-1 include a description of the materials that will be used in the construction of the PCP, construction guidelines, preliminary monitoring plan, and a proposed comparison of the PCP technology versus conventional continuously reinforced concrete pavement (CRCP).

Another report, 4035-2 “Application of PSCP 3.0 Program to Predict Stresses in Prestressed Concrete Pavements,” (Ref 2) describes the use of computer program PSCP 3.0, which is an improvement over a previous program developed in an earlier study at the Center for Transportation Research (CTR) of The University of Texas at Austin. The computer program predicts stresses and displacements in a specified PCP slab caused by environmental conditions and wheel loads. The updated version of this program provides a graphical interface that makes it user friendly.

1.2 Objectives

The purpose of this report is to provide complementary guidelines to those presented in the first technical report. These guidelines include instructions for post-construction evaluation of the PCP. Although the pavement section has been constructed, it was considered necessary to document how the pavement should be evaluated in terms of performance. Likewise, this report describes a methodology to assess the financial feasibility of the PCP technology and the reasons that justify its use under certain circumstances. Finally, the report includes conclusions and recommendations for the project. Special specifications (SS) were prepared for the PCP in such a way that they will be ready for implementation when the pavement is constructed.

1.3 Methodology

This is a condensed report that provides guidelines to be undertaken after the new PCP is constructed. It is anticipated that these recommendations will need minimum modifications when they are applied.

Chapter 1 provides a brief background about the Texas Department of Transportation (TxDOT) Project 0-4035 and describes the contents of the two previous technical reports. It also states the objectives of this third report and the methodology followed to accomplish them.

Chapter 2 documents the steps to be followed for a post-construction evaluation of the PCP. Because this is a proposed post-construction evaluation and the PCP has not been constructed, it is possible that some minor changes will be made to these guidelines, if TxDOT determines it.

Chapter 3 describes a methodology to perform a financial feasibility study of the PCP and states the reasons that justify the use of PCP instead of CRCP.

Chapter 4 contains the conclusions and recommendations of this study.

Appendix A contains the special specifications drafted for the PCP. These specifications are to be followed by the contractor when the pavement is constructed.

Appendix B contains a series of tables that summarize destructive and nondestructive testing methods used in concrete pavement evaluations and that could be used in the new PCP to be constructed.

2. Proposed Post-Construction Evaluation

2.1 Introduction

This chapter describes the duties that should be pursued to document the evolution of the prestressed concrete pavement (PCP) section after it is constructed. These activities will help to better understand and assess the performance of the PCP. It is vital that the tasks recommended here are followed as closely as possible because the information that will be obtained from the evaluation of the PCP will allow for conducting a more rational comparison of the PCP and continuously reinforced concrete pavement (CRCP) technologies, which is one of the major objectives of this project and is of great interest to the Texas Department of Transportation (TxDOT). The results obtained from the post-construction evaluation will define the practicality of the application of PCP and will provide a step forward on the evaluation of this paving technology that no other agency in the United States—or the world—has ever taken.

2.2 Aspects to Evaluate

The construction process of a PCP is somewhat like the process followed for construction of a CRCP. There are, however, some additional aspects that need to be handled carefully in the field. The most important features of a well-constructed PCP are related to the adequate placement of the transverse joints, correct alignment of prestressing tendons, and correct application of prestressing force. If these three aspects are handled correctly, the rest of the construction process resembles the construction of a CRCP.

There are key features of PCP construction and performance that should be evaluated during and after construction—the most important ones are described in the following subsections.

2.2.1 Production Rate

Current pavement and bridge contractors are familiarized with the construction of conventional CRCPs and jointed concrete pavement (JCP). In the past, JCP projects were abundant not only in Texas, but nationwide. Contractors and engineers used this type of pavement as a good, more durable, alternative to flexible pavements. It was not until the 1960s, when more concrete pavements were constructed to build the interstate highway system. It was during those years that the emerging paving technology, CRCP, started to be applied in some states. In the beginning, contractors were uncomfortable with the construction of CRCP, but when they became used to the system their products had a better quality and their production rate increased.

A very similar trend is expected with the PCP technology. Although not new in the paving industry, PCPs are not very common. The main reason for the slight application of this type of pavement is the lack of well-defined design and construction standards. Most of the applications of prestressed concrete are in bridges, buildings, and ground floors. In these areas, it has been proven that prestressing concrete allows use of the outstanding compressive strength of the concrete to build lighter structures that use less material and that technically, in many cases, overperform heavy robust equivalent ones.

It is recommended that daily production rates be recorded when the PCP is constructed in Hillsboro, Texas. It is presumed that once the contractor becomes confident with the construction process, the production of PCP will be the same as CRCP.

2.2.2 Construction Difficulties

It is a fact that the construction of the PCP will face favorable and adverse conditions. It is relevant that both circumstances are documented in the daily construction book, so that when summarizing all the tasks, the most difficult ones can be identified and design aspects changed. From the previous experience gained during the construction of the old PCP near West, Texas (Ref 1), it can be said that all difficulties were overcome and the final product surpassed the performance expectations.

2.2.3 Performance

Probably the most important feature of any engineering work or construction is defined in terms of performance. In pavements, this simple word describes a lot about the overall behavior of the structures. For the PCP section to be constructed, the performance will be measured by means of continuous evaluations conducted for at least 10 to 15 years. At times, the evaluations will be conducted by simple visual inspections; in other cases, more objective measurements will be taken to assess the structural adequacy of the pavement.

2.3 Evaluation Approach

The PCP will be evaluated during and after construction. A plan to monitor the early age of the pavement and a proposed instrumentation were provided in a previous report (Ref 1). This section focuses on describing the evaluation of the pavement once construction has ended. Although the behavior of the pavement will be observed over determined periods of time, its actual performance will be obtained after some time has passed, maybe a few years later. Therefore, it is very important to continuously evaluate the condition of the pavement. The assessment of the PCP will be conducted mostly by means of nondestructive testing (NDT). If destructive testing such as coring is to be conducted, provisions should be made to identify the exact locations where no damage is induced to the prestressing tendons. It might be appropriate to mark the pavement surface at specific locations along the PCP where cores could be extracted in the future. The following subsections present a proposed plan to evaluate the performance of the PCP. Appendix B includes a series of tables that summarize potential destructive and NDT methods that are used for concrete pavement evaluation. The tables summarize the material property to be measured, the test designation and method, a brief description of the procedure, indication on whether the test is a direct or surrogate measurement, the type of test (NDT or destructive), and the equipment used for evaluation.

2.3.1 Nondestructive Testing

The use of NDT has been of great interest to state agencies. There are multiple methods that can be used to measure key properties of the concrete and the pavement. The following are among those methods or test procedures:

- Maturity
- PSPA
- Free Resonance
- Ultra Sonic (V meter)
- Impact Echo
- Short Pulse Radar or Ground Penetrating Radar (GPR)
- Acoustic Emission
- Falling Weight Deflectometer (FWD)
- Rolling Dynamic Deflectometer (RDD)

Describing all of these methods listed above is out of the scope of this report. Nevertheless, this document focuses on describing the most important features of the PCP that will be observed to measure its performance. From the previous experience with the old PCP project built in McLennan County, Texas, it was concluded that horizontal (joint opening) and vertical (curling) movements, load transfer efficiency at the joints (and cracks if present), and deflection were among the most important characteristics to monitor in the PCP. All these characteristics can be estimated by first conducting visual condition surveys and then using the required tools and equipment. Section 2.3.3 presents a plan to conduct the testing.

2.3.2 Destructive Testing

This type of evaluation, although extremely useful, is not ordinarily performed, unless rehabilitation of the pavement is planned or forensics investigation of problem areas is conducted. Among the limitations of some destructive testing methods are the following (Ref 3):

- Tests are performed on prepared samples that may or may not reflect specific in situ conditions of the pavement (e.g., cylinders and beams).
- Surrogate properties are measured in lieu of the actual properties that really affect pavement performance.
- Statistically, sampling provides limited area coverage.

The most common destructive testing that is performed in pavements is coring. This procedure is very helpful because it provides properties of the concrete that were probably not measured when sampling cylinders or beams during construction. Among the key features that can be measured using pavement cores are concrete tensile strength and modulus of elasticity, effective slab thickness, concrete coefficient of thermal expansion (CTE), delamination, alkali-silica reaction (ASR), petrography, etc.

Although no coring program is planned for the new PCP to be constructed near Hillsboro, Texas, it is *very* important to identify spots in the pavement where this test could be performed safely in the future without jeopardizing the structural adequacy of the pavement. It is expected that before any coring is performed, previous condition surveys and deflection tests will be performed to identify a real problem in the pavement.

2.3.3 Testing Plan

The construction of the PCP is a milestone that will place the Waco District in Texas in a very distinctive position compared to other districts in Texas. It was in this same district that the old PCP section was constructed in 1985. Likewise, when the new PCP is built, an equivalent CRCP section will be constructed just south of the PCP. This conventional pavement section will serve as a control section for the PCP. As it was originally planned, one of the objectives of this project was to compare the PCP to an equivalent section.

In order to get more accurate performance indicators for the two pavements it is required that different tasks and tests be conducted at the same time. The CRCP section will be monitored in the traditional way, that is, conducting visual inspection and quantifying crack spacing and distresses at regular intervals during and after construction. Additionally, deflection measurements will be conducted at regular intervals of time, preferably at the same time deflections are measured in the PCP.

It is very important that all the information is processed electronically in spreadsheets. It is also useful to take pictures of the pavements as they age. Photos of early age flaws will be essential, because if the pavement deteriorates at specific locations where initial construction had trouble, there is a greater chance that those spots will deteriorate later in time and affect the performance of the pavement.

The better way to compare both pavements will be from two standpoints: performance and cost. In other words, it is essential not only that initial costs are considered when comparing the economics of the projects, but maintenance costs also must be considered. Chapter 3 describes in detail the steps to be taken to compare the pavements from a life-cycle cost analysis (LCCA) standpoint.

As for the testing plan for the PCP, Table 2.1 presents the basic tasks and tests that should be performed to accomplish a reasonable evaluation. It is very important to follow this plan, so that an objective performance of the PCP is obtained from reliable data. The CRCP should follow a similar plan, except that vertical and horizontal movements are not measured. Crack spacing and width plus spalling might be measured and monitored instead.

Table 2.1 Work plan for post-construction evaluation of PCP

Task/Test Description	Work Plan
Condition Survey	Perform daily at early age during the first 96 hours. Survey monthly after construction for the following 6 months. Subsequently, survey once a year and alternate between summer and winter conditions.
Horizontal Movement	Measure daily during the first 96 hours after slabs are placed at both sides of joints. Then measure monthly during 6 months and once a year thereafter. Alternate between summer and winter conditions. Coordinate with condition surveys.
Vertical Movement	Measure daily during the first 96 hours after slabs are placed at both sides of joints. Then measure monthly during 6 months and once a year thereafter. Alternate between summer and winter conditions. Coordinate with condition surveys.
Falling Weight Deflectometer (FWD)	Perform right after construction is finished. Then once a year alternating between summer and winter conditions.
Rolling Dynamic Deflectometer (RDD)	Perform right after construction is finished. Then once a year or every 2 years, as possible, alternating between summer and winter conditions.
Roughness	Measure after construction has finished, this will be the early age initial roughness. Then measure once or twice a year, according to equipment availability.

2.4 Summary

This chapter proposed a plan to evaluate the PCP section that will be constructed in Fiscal Year 2005 in Hillsboro, Texas. All the tasks presented in this plan are to be conducted for at least 10 to 15 years after the construction of the pavement. The results obtained from these evaluations will allow estimating the true performance of the pavement, then that performance can be compared to the performance of the CRCP control section that will be constructed adjacent to the PCP.

3. Financial Feasibility of Prestressed Concrete Pavement

3.1 Introduction

A true comparison of the costs of a prestressed concrete pavement (PCP) and a structurally equivalent continuously reinforced concrete pavement (CRCP) is not an easy task because no current information is available for a PCP. Furthermore, a realistic comparison of the costs of the two pavements will be feasible when the PCP initial construction cost and performance data are available. This means it will be 10 to 15 years before a performance indicator is available for PCP. Nevertheless, this chapter intends to provide a plan for conducting a life-cycle cost analysis (LCCA) for the two pavements that will be constructed in Fiscal Year (FY) 2005 on IH 35 in Hillsboro, Texas.

3.2 Advantages of Prestressed Concrete Pavement over Continuously Reinforced Concrete Pavement

The main advantages of a PCP when compared to a conventional CRCP are associated with a more efficient use of the construction materials. For instance, constructing a PCP requires using thinner concrete slabs, which means using less concrete mass. If less concrete is used, fewer problems associated with concrete temperature differentials will result. Likewise, prestressing the concrete implies that one makes use of the outstanding compressive strength of the material, and by doing that, tensile effects on the concrete are reduced in the pavement, delaying its failure. Furthermore, it has been proved that if the design and construction of a PCP are successful, the overall maintenance cost of the pavement will be insignificant. These characteristics of a well-constructed PCP translate into considerable long-term money savings. Indeed, the initial cost of a PCP will be higher than the initial cost of a CRCP, but what is most relevant is the final outcome 15 years or more following the construction of the two pavements, working under the same conditions of climate and traffic.

3.3 Financial Analysis Approach

The financial feasibility of any investment is the most important step to ensure economic stability and well-being. In transportation and pavements, this statement is fully applicable. Thus, to determine the viability of a paving project, it is necessary to conduct an LCCA. This analysis should consider all aspects of pavement design, construction, maintenance, and user impacts throughout the analysis period.

Highway construction is not only associated with construction costs, but also with user costs and related external costs that sometimes are difficult, if not impossible, to assess. Hence, the best approach for analyzing the economic feasibility of the PCP is using reliability concepts and the variability of construction and cost models (Ref 4). A good LCCA allows defining a level of confidence for predicting total life-cycle costs, user costs, accidents, and other parameters.

Currently, there are some life-cycle cost methodologies that use preprogrammed maintenance and rehabilitation actions to determine the total life-cycle cost of a particular pavement. Usually, these methodologies consider different types of pavements such as asphalt concrete, portland cement concrete, and other variations. However, there is no methodology to analyze PCP because this type of pavement has no accurate performance models. Therefore, as this paving technology advances, future methodologies and LCCA programs will include the PCP.

A previous report in this project presented a preliminary LCCA based on a program used by the California Department of Transportation (CalTrans) (Ref 5). The program uses a set of spreadsheets that analyze the type and cost of the project and provide cycle cost, net present value, benefit/cost (B/C) ratio, internal rate of return, and payback period. Although the program is not the optimum analysis tool, it at least provided useful information that served as the starting point for the financial feasibility of the PCP.

3.4 Major Components of Analysis

This subsection provides a description of the most important aspects of the LCCA that should be considered for the analysis of the PCP. Although some of the analysis components are neither easily calculated nor valuated, an attempt to quantify and valuate each aspect should be made in developing a comprehensive approach. The following are the most relevant components to be considered in the analysis.

- Pavement Performance—the first step in the analysis is to evaluate the pavement design and the conditions under which it is expected to operate throughout the analysis period. The general inputs would include project geometry, traffic and loads characteristics, environmental conditions, distresses, and economic variables.
- Maintenance and Rehabilitation Strategies—the PCP should be evaluated at least every year so that performance models can be prepared based on distress. This distress is evaluated and the appropriate maintenance or rehabilitation strategy is determined based on preferences.
- User Costs Caused by Construction Activities—users feel the impact when a paving project takes place. This impact translates into user costs attributable to the presence of a work zone and construction activities. Examples of these costs are: 1) the time-delay costs incurred while traveling at slower speeds through work zones, and 2) vehicle-operating costs incurred while traveling at slower speeds through work zones.
- External Costs—these costs are those in which the activities of one consumer have a direct effect on the welfare of another consumer. External costs have been excluded by the LCCA in the past because they are difficult to quantify and to valuate. An example of these costs would be the increase in highway noise levels caused by the construction of a new highway; if those effects are considered, the highway agency may be required to spend more money on a pavement surface that causes less tire noise, or to construct noise barriers for nearby residents.

- Life-cycle Cost Calculations—this aspect of the analysis considers the events and their timing, as predicted by the performance and rehabilitation strategy models, and assigns a cost for each component of each event. For instance, the annual maintenance cost will be predicted for each year, and appropriate strategies will be selected based on the Texas Department of Transportation's practices. User costs, such as vehicle-operating costs, time-delay costs, accidents, and noise, will be calculated.
- Project Ranking—there are various methods that can be used to rank projects once the total costs are calculated over the analysis period. The total annual costs can be then discounted to the present time to provide a net present value (NPV). Ranking alternatives by their overall NPV is important to the engineer who uses LCCA as a tool in decision making. In a proper analysis, the alternatives should be ranked by all components discussed in the previous paragraphs.

The LCCA discussed here attempts to describe most of the costs incurred by the transportation agency, by users of the facility, or by others affected by its presence. Including the full impact of a highway project, the total life-cycle cost can be predicted and compared with other alternate pavement. As previously mentioned, when performance data are available for the PCP approximately 10 to 15 years after construction, a feasible LCCA will be conducted and a realistic comparison will be made between the PCP and CRCP control section. Hopefully, the results will reflect that PCP technology is competitive technically and economically to CRCP.

3.5 Summary

The objective of this chapter was to describe a scheme to determine the financial feasibility of the PCP technology. This methodology will allow comparing the PCP with the control CRCP to be constructed in Hillsboro, Texas, in the near future. Currently, a true comparison of the two pavement techniques cannot be accomplished fully because performance and cost data are required for the PCP. However, this methodology, in addition to the one proposed in a previous report (Ref 1), provides guidelines to perform an objective analysis of the financial aspect of the PCP.

4. Conclusions and Recommendations

4.1 Introduction

The Texas Department of Transportation (TxDOT) Project 0-4035 was in charge of developing and implementing the design and construction of a prestressed concrete pavement (PCP) in Hillsboro, Texas, in the Waco District. However, the implementation or construction of the project was not accomplished primarily because of TxDOT's budget plan and priority of construction projects. Nevertheless, the design of the PCP was accomplished successfully, recommendations for material utilization were prepared, and construction guidelines were drafted. It is hoped that with all of the results provided by this investigation the new PCP is constructed in the near future.

4.2 Project Conclusions

This project performed all the necessary tasks to design a state-of-the-art pavement structure or PCP, which unfortunately could not be constructed under this same project. However, a number of tasks were developed that will facilitate the construction of the pavement sometime during Fiscal Year 2005. Among the tasks conducted under this research project are the following:

- A comprehensive literature review related to design, construction, maintenance, and evaluation of PCPs was performed and included information of projects constructed in the United States and overseas.
- The existing PCP in Texas, built in 1985, was comprehensively evaluated and design flaws were corrected, so that the new PCP performs even better than the previously constructed PCP. Instrumentation of the previous PCP included measurement of joint movements related to concrete temperatures and evaluation of the structural adequacy of the pavement and its joints using deflection equipment such as falling weight deflectometer (FWD) and rolling dynamic deflectometer (RDD).
- Based on the previous Texas experience, the new PCP was designed using a mechanistic-empirical procedure. Likewise, Program PSCP 3.0 was compiled and updates the previous software, which was not user-friendly. It is expected that when the PCP is constructed, PSCP 3.0 will be calibrated and adjusted to provide more accurate results.
- The location of the new PCP construction was visited and the preconstruction conditions were evaluated and recorded. Condition surveys were performed and deflection measurements were taken using FWD and RDD.
- The design of the PCP considered various aspects such as placement season, aggregate type, and coefficient of thermal expansion, etc. The design was

conducted using a fatigue analysis procedure plus an elastic design for environmental stresses and wheel loads.

- A monitoring plan was proposed for implementation during and after construction. This plan performs extensive testing of the PCP in order to accumulate historical data about the pavement.
- A postconstruction evaluation plan was prepared and a methodology for comparison of PCP versus CRCP was planned. This plan is based on a life-cycle cost analysis, the best tool available to determine the financial feasibility of any type of engineering project.
- Special specifications that will prevent failures observed in other PCP projects were prepared for the new PCP.

4.3 Report Conclusions

The items and tasks reported in this document complement the information provided in the two preceding technical reports in this project. This report provides guidelines for post-construction evaluation of the PCP. The strategy proposed will aid in evaluating the pavement after it is constructed. A testing work plan is also provided for postconstruction and for the long-term.

Similarly, this report describes a methodology to assess the financial feasibility of PCPs based on performance and final projected costs, which will be obtained some years after the pavement is constructed and operated. Finally, special specifications using TxDOT’s format were prepared for the PCP and will be ready for implementation when the project is let.

4.4 Recommendations

At this stage, it is recommended that the guidelines provided in this and previous reports are followed as closely as possible. Experience shows that when a project is constructed following a documented methodology, the results are more gratifying and contribute more to the development of new forthcoming projects.

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Appendix A

Special Specification for Prestressed Concrete Pavement (PCP)

SPECIAL SPECIFICATION

ITEM 300X

PRESTRESSED CONCRETE PAVEMENT

300X.1. Description. Construct prestressed concrete pavement (PCP) without curbs.

300X.2. Materials.

A. Hydraulic Cement Concrete. Provide hydraulic cement concrete in accordance with Item 421, "Hydraulic Cement Concrete," except that strength overdesign is not required. Provide Class P concrete designed to meet a minimum average flexural strength of 750 psi at 28 days in accordance with Tex-448-A or a compressive strength of 5,000 psi at 28 days in accordance with Tex-418-A.

B. Post-Tensioning Steel Strands. Provide 0.6 in. in diameter strands that belong to any of the following two groups:

1. Uncoated, low-relaxation wire strand, Grade 270 (1860 MPa)
2. Uncoated, stress-relieved (normal-relaxation) strand, Grade 270 (1860 MPa)

Both groups should conform to AASHTO M203 (ASTM A416), "Uncoated Seven-Wire Steel Strand for Concrete Reinforcement." Additionally, Group B strands should conform to AASHTO M204 (ASTM A421), "Uncoated Stress-Relieved Steel Wire for Prestressed Concrete." Additionally, the capability of the strand to properly develop bond should be certified from the strand supplier. A light bond coating of tight surface rust on prestressing tendons is permissible provided the strand surface shows no pits visible to the unaided eye after rust is removed with a nonmetallic pad.

C. Anchors. Provide a standard fixed-end anchorage system hardware that ensures the full prestress force is applied to the joint panel over the length or width of the slab and allows setting the wedges after the strands are inserted into the ducts. Anchor the steel strands to the end of the slabs. Provide bonded tendons that meet the following requirements:

1. An anchorage for bonded tendons tested in an unbonded state will develop 95% of the actual ultimate strength of the prestressing steel, without exceeding anticipated set at time of anchorage. An anchorage that develops less than 100% of the minimum-specified ultimate strength shall be used only where the bond length provided is equal to or greater than the bond length required to develop 100% of the minimum-specified ultimate strength of the tendon.
2. The required bond length between the anchorage and the zone where the full prestressing force is required under service and ultimate loads will be sufficient to develop the specified ultimate strength of the prestressing steel. The bond length is determined by testing a full-sized tendon.
3. If in the unbonded state the anchorage develops 100% of the minimum-specified strength, it need not be tested in the bonded state.

Provide anchorage castings that are nonporous and free of sand, blowholes, voids, and other defects. For a wedge-type anchorage, provide wedge grippers designed to prevent premature failure of the prestressing steel due to notch or pinching effects under static test-load conditions to determine yield strength, ultimate strength, and elongation of the tendon. Provide an acceptable testing program that demonstrates that these basic requirements are met.

The load from the anchorage device will be distributed to the concrete by means of approved devices that will effectively distribute the load to the concrete. These devices shall conform to the following requirements:

1. The average bearing stresses (S_b) on the unconfined concrete created by the device shall not exceed either of the following values:

   At service load:

   $$f'c \rangle \; S_b = 0.6 \times f'c \times \sqrt{\frac{A'B}{AB}}$$

   At transfer load:

   $$S_b = 0.8 \times f'c \times \sqrt{\frac{A'B}{AB} - 0.2}$$

   where

   AB = bearing area of the device
   A′B = maximum area of the device bearing surface that is similar to and concentric with the bearing area of the device
   f'c = compressive strength of the concrete at the time of initial prestress

2. Bending stresses in the plate or assembles induced by the pull of the stressing will not cause visible distortion when 85% of the ultimate load is applied as determined by the engineer. Plastic flexural strength of the plates or assembles will be adequate for 125% of the ultimate load. Design will not be based on a yield stress in the plates or assembles greater than 50 ksi.

D. Tendons, Anchors, and Tendon Couplers. Provide tendon, anchors, and couplers that develop at least 100% of the required ultimate strength of the tendon, with a minimum elongation of 2%. In addition they will withstand 500,000 cycles from 60 to 70% of the required ultimate strength of the tendon without failure or slippage. Provide tendons that are easily identified by reel number and tagged. Anchors will be identified and furnished by the contractor for testing purposes in accordance with Test Method Tex-710-I. Likewise, the contractor will furnish prestressing tendons including couplers with end fitting attached, to be tested for ultimate strength. Provide tendons that are 5 ft of net length, measured between ends of fittings. If additional testing is required, specimens will be furnished by the contractor without cost.

E. Transverse Joint Hardware. Provide a transverse joint assembly as shown on the plans.

Provide joint hardware that complies with specifications as follows:

1. **Armor Angles.** Provide armor angles that conform to the requirements as specified in Item 441, "Steel Structures," and Item 442, "Metal for Structures."
2. **Joint Extrusion.** Provide a joint extrusion that conforms to the requirements of ASTM A606-01, "Standard Specification for Steel, Sheet and Strip, High-Strength, Low-Alloy, Hot-Rolled and Cold-Rolled, with Improved Atmospheric Corrosion Resistance," and to the configuration shown on the plans.
3. **Neoprene Seal.** Supply a neoprene seal or diaphragm that conforms to the requirements as specified in Item 434, "Elastomeric Bridge Bearings."
4. **Dowel Bars.** Provide dowel bars that conform to the requirements as specified in Item 360, "Concrete Pavement." Provide stainless steel that conforms to the requirements of ASTM 176-99, "Standard Specification for Stainless and Heat-Resisting Chromium Steel Plate, Sheet, and Strip." Provide encasements of no less than 0.01 in. in thickness.
5. **Dowel Bar Expansion Sleeves.** Provide expansion sleeves made of stainless steel. They will be properly welded to the armor angle at the locations shown on the plans. The free end of the sleeve will be capped to prevent entry of mortar or grout.

F. Strand Ducts. Provide encasing material or ducts of sufficiently strong polyethylene, conforming to the requirements of ASTM D1248-02, "Standard Specification for Polyethylene Plastics Extrusion Materials for Wire and Cable." Provide a minimum sheathing thickness of 0.036 in. Use ducts that are strong enough to retain their shape during construction operations. The sheathing should prevent the entrance of cement paste or water from the concrete, and it should not cause harmful electrolytic action or deterioration. The inside diameter will be at least 1/4 in. larger than the nominal diameter of a single strand. The inside cross-sectional area of the sheath will be at least twice the net area of the prestressing steel. Sheaths should have vents at each end of the slab and near the central stressing pockets to allow injection of the grout.

G. Grout. Provide a grouting material that secures effective bond between steel strands and ducts. Use grout already available in the market or provide grout made of a mixture of cement, sand, and water that achieves a minimum compressive strength of 2,500 psi at 7 days and 5,000 psi at 28 days when tested in accordance with Tex-418-A. Provide a mortar that has adequate consistency and facilitates placement. Water content should be the minimum necessary for proper placement, and the water-cementitious materials ratio shall not exceed 0.45. Fly ash and pozzolanic mineral admixtures may be added at a ratio not to exceed 30% by weight of cement.

H. Friction-Reducing Membrane. Provide a friction-reducing membrane that consists of polyethylene sheeting conforming to the requirements of ASTM D2103-97, "Standard Specification for Polyethylene Film and Sheeting." Use a 6-mil-thick Type 4 membrane.

Provide sheeting that always exceeds the width or length of the concrete strip being poured by at least two feet.

I. **Reinforcing Steel.** Provide reinforcing steel that conforms to conventional pavement requirements, as specified in Item 360, "Concrete Pavement." Perform periodic tensile strength tests of the reinforcing steel in accordance with Item 440, "Reinforcing Steel."

300X.3. Equipment. Furnish equipment as per Article 360.3 except for the following. Use concrete measuring, mixing, and delivery equipment that conform to the requirements of Item 421, "Hydraulic Cement Concrete." Obtain approval for other equipment used.

A. **Coring Equipment.** Provide the same equipment as described in Item 360, "Concrete Pavement." Take preventative measures if the PCP is cored to evaluate the in situ strength of the concrete. Make provisions to eliminate the possibility of cutting the post-tensioning strands. Although the hazard associated with cutting a bonded strand is greatly reduced compared to an unbonded one, it represents a risk for the maintenance crew and for the structural soundness of the PCP. Place warning signs along the pavement section as a safety measure and identify the location of embedded strands. These measures will greatly reduce the possibility of any inadequate drilling or cutting of the concrete.

B. **Strand Stressing Equipment.** Provide hydraulic jacks or rams to stress strands. The rams will be equipped with either a pressure gauge or a load cell for determining the applied stress. Use accurate and calibrated gauges certified by an authorized entity. If a load cell is used, it will be calibrated and will be provided with an indicator showing the equivalent prestressing force applied to the strand. The range of the load cell will be such that the lower 10% of its capacity will not be used in determining the jacking stress. Extra safety measures will be taken by the contractor and TxDOT to prevent accidents due to possible breaking or slippage of the prestressing tendons during post-tensioning activities.

300.X4. Construction. These construction specifications are complementary to the applicable specifications provided in Item 360, "Concrete Pavement" and Item 421, "Hydraulic Cement Concrete." Prestressing of the PCP slabs will be made in accordance with the plans and the following specifications as closely as possible, and they will govern the furnishing, storing, and handling of prestressing materials. For any other requirements, TxDOT's "Standard Specifications for Construction of Highways, Streets and Bridges," dated June 1, 2004, should be used. Additionally, if indicated, other national standard requirements (e.g., ASTM, AASHTO, etc.) should apply.

A. **Placement of Friction-Reducing Membrane.** Once the subbase and leveling layers of the PCP are placed and compacted to specifications, place a polyethylene membrane on the ground and extend it longitudinally across the entire length of the PCP slab or slabs to be poured. Provide longitudinal and transverse overlaps of at least 2 ft. Provide sheeting at least 2 ft wider at each side of the concrete strip being poured. Tack and secure the sheeting before continuing with other activities.

B. Placement of Transverse Joints. Place transverse joints at predefined locations. Provide a completely fabricated joint assembled at the provider's facilities, including the insertion of the neoprene seal, dowels, deformed Nelson bars, and all the necessary hardware for the anchors. Weld small steel jumper plates across the top of the joint to keep the assembly closed with the neoprene seal inside. Carry the joint to the site ready for installation, set it in place, and secure it to the ground to avoid being displaced when performing other tasks.

C. Prestressing Strand Placement. Place longitudinal and transverse post-tensioning strands at the locations defined by the design. Use quality approved chairs to support strands. Place chairs carefully so as not to damage the strand ducts or the friction-reducing polyethylene sheet. Place tendons accurately; a tolerance of ±1 in. with respect to the specified tendon spacing is accepted. The tolerance for vertical positioning of strands is ±¼ in. Use appropriate chairs at intersections of longitudinal and transverse tendons.

D. Central Stressing Pocket Form Placement. Use material that does not react with the concrete; it should be a nonabsorptive, strong material that withstands the imposed forces of placement, vibration, buoyancy, and weight of the plastic concrete during placement. Anchor the forms properly to prevent movement or misalignment during concrete placement. Apply oil or other bond-breaking coating to the sides of the form before concrete reaches it. Avoid materials that might stain or react with the concrete. Fill the pockets with the same type of concrete mixture used in the pavement after removing the forms and once post-tensioning activities are finished. Apply texture to the concrete surface accordingly.

E. Concrete Placement. Perform paving activities after transverse joints, prestressing strands, and central stressing pocket forms are in place for a number of slabs. The paving process is similar to conventional CRCP paving. Exercise special attention during placing, vibrating, and finishing of the concrete near transverse joints and forms. Check the correct positions of chairs and tendons continuously as the paver passes through. Remove concrete or aggregate trapped in transverse joints.

Place the concrete pavement in an organized predefined sequence to minimize traffic disruptions. TxDOT will provide a detailed plan for paving activities, and the PCP slabs will be paved as indicated. Once the first pavement strip is poured, construct consecutive strips using one of the edges of the previously poured strip as side form. Prepare those edges of hardened pavement strips that will serve as side forms to prevent bonding between strips; use asphalt as a bond-breaking interface between concrete slabs. Finish the concrete using the carpet drag method or similar to provide an adequate final texture to the pavement.

F. Concrete Curing. Cure concrete in accordance with Section 360.4.I, "Curing."

G. Post-Tensioning. Longitudinal strands are stressed first. Perform post-tensioning of the concrete pavement in at least two stages. Apply the first post-tensioning operation after the concrete gains sufficient compressive strength. For instance, if the slabs are placed early in the morning, initiate post-tensioning no more than 8 hours later. Apply a force of 10 kips and check the conditions at anchor zones. If the slabs are placed late in the afternoon, apply initial post-tension no earlier than 8 and no later than 12 hours after placement. Perform compressive tests of concrete cylinders at the job site to determine the actual allowable post-tensioning force. Be cautious to not exceed this force to more than 15 kips to minimize the level of creep taking place after initial prestressing.

Apply final post-tensioning when concrete has gained sufficient strength, usually after 48 hours for a concrete mixture prepared with Type I portland cement. Apply the maximum tendon prestress force of 46.6 kips. Stress each strand by jacking it at the central stressing pockets. Start loading at the center strands of each pavement strip and continue toward the edges by alternatively loading strands on each side of the center strands. Request that spare jacking equipment is available at the job site in case of malfunction of the equipment. If equipment breaks down and paving operations are stopped, the contractor may be required to set a temporary header and to temporarily post-tension the portion of the slab being poured.
Stress transverse strands similarly to longitudinal strands. Apply the post-tension once the concrete has gained sufficient strength and apply a prestressing force of no less than 25 kips and no more than 30 kips, if additional pavement strips are to be constructed to the sides. Apply the final prestressing force of 46.6 kips once all the strips are placed together.

H. **Miscellaneous Construction Tasks.** Perform additional activities required to instrument the PCP for monitoring purposes. Conduct concrete testing, measurement of paved concrete, and payment issues as for conventional pavements.

300X.5. Measurement. Construction progress will be measured by the completed square yardage of pavement, based upon the dimension stipulated on the plans.

300X.6. Payment. The work performed and the materials furnished in accordance with this Item and measured as specified under “Measurement” will be paid for at the unit price bid for “Prestressed Concrete Pavement.” This price is full compensation for: furnishing, loading and unloading, storing, hauling, and handling all concrete materials needed, including the freight involved; placing and adjusting forms; placing expansion joints and their hardware; mixing, placing, finishing, and curing concrete; furnishing and installing all materials, including reinforcing steel, prestressing strands, strand ducts, dowels, anchors, couplers, and friction-reducing polyethylene; providing all post-tensioning operations; furnishing and installing all devices for placing and supporting the reinforcement steel, prestressing strands and dowels; and providing all the handling, labor, equipment, appliances, tools, and incidentals necessary to complete the work.

Appendix B

Destructive and Nondestructive (NDT) Methods Used for Concrete Pavement Evaluation

Table 1: Potential Test Methods for Measuring the Significant Basic Property of Concrete Tensile Strength

Basic Property	Test Designation	Test Method	Description	Direct/Surrogate Measurement	Nature of Test	Equipment
Concrete Tensile Strength	Splitting Tensile Strength	ASTM C496	Measures average tensile strength in splitting	Direct	Destructive testing in field cores or lab cylinders	Compression testing equipment and core drill or molds
	Maturity	ASTM C1074	Measures temperature and time relation correlated with cement hydration	Surrogate	Nondestructive testing in field or lab	Maturity meter and test correlations with field mix
	Flexural Strength	Tex 420A	Measures tensile stress in extreme fiber at fracture	Direct	Destructive testing in field or lab beams	Flexural beam tester and molds
	SPA, PSPA		Measures travel time of induced stress wave to compute E and correlate strength	Surrogate	Nondestructive testing in field or lab	Transmitter, receiver spectral analyzer, and correlation for field mix

Table 2: Potential Test Methods for Measuring the Significant Basic Property of Slab Thickness

Basic Property	Test Designation	Test Method	Description	Direct/Surrogate Measurement	Nature of Test	Equipment
Slab Thickness	Ultrasonic Pulse Velocity	ASTM C597	Measures and detects cracks and defects. Evaluates the quality of the concrete and determines thickness	Direct	Nondestructive testing in field or lab	Pulse velocity test device (V-Meter)
	Short Pulse Radar (GPR)		Reflected radar signals allow determination of slab thickness. It detects delaminations and other defects of the pavement.	Direct	Nondestructive testing on in situ pavement	Control unit, antenna, oscillographic recorder
	Impact Echo and Spectral Analysis of Surface Waves (SASW)		Based on the use of impact-generated stress waves, this technique is used to determine thickness, location and extent of cracks, delaminations, voids, and other defects.	Direct	Nondestructive testing on in situ pavement	Hammer, accelerometer, dynamic analyzer, and receiver
	FWD Testing		Obtained deflection values from the FWD and theoretical approach allow determination of thicknesses	Direct	Nondestructive testing on in situ pavement	FWD equipment and Boussinesq-Hossain equations (Delmat method)

Table 3: Potential Test Methods for Measuring the Basic Property of Concrete Modulus of Elasticity

Basic Property	Test Designation	Test Method	Description	Direct/Surrogate Measurement	Nature of Test	Equipment
Modulus of Elasticity (E)	Compression Test	ASTM C39	Measures E in compression. Load and deflection of concrete are recorded. E is determined from the stress-stress data.	Direct	Destructive testing in field cores or lab cylinders	Compressive strength testing machine
	Modulus of Elasticity and Poisson's Ratio of Concrete in Compression	ASTM C469	Extensometers are attached to a concrete cylinder and deformations are measured for applied load. E and Poisson's Ratio are calculated.	Direct	Destructive testing in field cores or lab cylinders	Compressive strength testing machine, compressometer, and extensometer
	SPA and PSPA		Measures travel time for induced stress wave to compute E	Direct	Nondestructive testing on in situ pavement	Transmitter, receiver, spectral analyzer
	RDD or FWD		Measures slab deflections for small discrete distances and allows back calculation of E for known thicknesses	Direct	Nondestructive testing on in situ pavement	RDD or FWD equipment and computer with back calculation software

Table 4: Potential Test Methods for Measuring the Significant Basic Property of Concrete Coefficient of Thermal Expansion (CTE)

Basic Property	Test Designation	Test Method	Description	Direct/Surrogate Measurement	Nature of Test	Equipment
Coefficient of Thermal Expansion	COTE	AASHTO TP60	The change in length of concrete specimens subjected to changes in temperatures is measured	Direct	Nondestructive testing in lab specimens	Thermometer and caliper, for conventional approach. Also concrete sample can be instrumented using i-Buttons and concrete strain measuring devices.
	Volumetric Dilatometer		Measurement if the volumetric expansion of concrete and aggregates due to temperature change	Direct	Nondestructive	Dilatometer consisting of steel container, lid, tower, and float. LVDTs are installed to the float to measure displacements.
	Suhometer	Tex “YYY”	During construction a concrete strain gage with a self-contained temperature gage is placed in an in situ sliver of concrete that is free to move. Thus, with the strain and temperature values, the COTE may be computed.	Direct	Nondestructive	Concrete strain gage with self contained temperature gage plus a recording gage.

Table 5: Potential Test Methods for Measuring the Basic Property of Concrete Shrinkage

Basic Property	Test Designation	Test Method	Description	Direct/Surrogate Measurement	Nature of Test	Equipment
Concrete Shrinkage	Linear Shrinkage	Tex 422A	Measures linear shrinkage	Direct	Destructive testing in field cores or lab cylinders	Compressive strength testing machine
	Restrained Shrinkage	AASHTO PP34	A concrete ring is placed around a steel ring. Strain gages on the inside of the steel ring monitor the strain in the steel ring caused by the shrinkage of the concrete.	Direct	Nondestructive testing in specially prepared samples in lab	Steel ring form, sonotube, strain gages, thermometer, and caliper
	Unrestrained Shrinkage	ASTM C 157	The length change in concrete prisms is monitored. After 24 hours of wet curing, specimens are removed from the molds. Length change measurements are conducted for various periods of time.	Direct	Nondestructive testing in specially prepared samples in lab	Steel forms, thermometer, caliper, and strain gages
	Suhometer	Tex “XXX”	The shrinkage is estimated from the cumulative residual strain over time captured during the COTE measurement.	Direct	NDT	Concrete strain gages with self-contained temperature measuring gages and recording instruments.