Framework for LTPP Forensic Investigations—Final

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Federal Highway Administration

Long-Term Pavement Performance
Serving your need for durable pavement

Framework for LTPP Forensic Investigations

Background

The idea of forensic investigations has been discussed within the Long-Term Pavement Performance (LTPP) program for many years. The concept is that after a test section has gone out of service or is scheduled for rehabilitation, a forensic-type investigation should be performed to examine the details surrounding the causes and mechanisms of distress. In cases where the test section is going out of study or is scheduled for rehabilitation for reasons other than pavement failure, forensic investigations can also be performed to examine what worked and why.

Accordingly, the purpose of this document is to provide a framework for forensic investigations at LTPP test sections. The framework is intended to promote consistency and uniformity within the program and to ensure that maximum benefit is derived from the investigations. The word “framework” was purposely chosen over “plan” because no two sections are alike and therefore a unique, detailed plan cannot be developed that applies to all LTPP test sections. A key element of the framework detailed in this document is the development of a forensic plan tailored to each test section. Another key element of the framework is that, as appropriate, it goes beyond the distress mechanism investigations and addresses the collection of missing or desirable test section data.

Because each test section is unique and no two investigations will be the same, the development of tables in the LTPP pavement performance database to store forensic data is not envisioned at this time. Thus, the primary mechanism for dissemination of the forensic investigation results will be technical reports. Production of a “Forensic Investigations CD–ROM” may be considered later, depending on the actual number of investigations performed. Likewise, future consideration will be given to including a new table in the database listing test sections where a forensic investigation has been performed and whether an associated report is available.

Besides the report, additional missing or desirable data will be collected as part of the investigations and, when possible, entered into the existing database tables.

Investigation Framework

The proposed LTPP forensic investigation framework consists of the following three elements:

1. Recommendation for forensic investigation.
2. Development of forensic investigation plan.
3. Implementation of forensic investigation plan.

This document provides details on the activities to be performed in each element and the assignment of responsibilities.

1. Recommendation for Forensic Investigation

The LTPP program is nearing its 16-year mark. The number of active test sections in the program, which once totaled almost 2,500, is rapidly decreasing and the number of sections being rehabilitated or going out of study is expected to accelerate in the coming years. Ideally, forensic investigations would be performed on all test sections going of out of study. However, this will not be possible using only LTPP program funding because of current and anticipated constraints. Thus, a decision on whether to proceed with forensic investigations will need to be made on a section-by-section basis.

Assessment of Data Availability

The first step in the decisionmaking process is to assess both the quantity and quality of data available in the database for the test section in question. The purpose of this assessment is twofold:

1. To compile pertinent information such as pavement structure (layer thicknesses, material types, material characteristics), traffic loads/volumes, existing pavement condition and performance history (distress, roughness, structural capacity), and climatic conditions for use, if needed, in development of a detailed forensic plan.

2. To compile a list of missing or questionable data that may be addressed as part of the forensic investigation (e.g., missing materials data or layer thickness information).

The product of this step is a test section report detailing the results of the assessment in terms of the two issues addressed above. The LTPP regional support contractors (RSCs) are responsible for completing the test section report.

Assemble Forensic Team

The next step in the process is to assemble a forensic team to help with the decision and, depending on the decision, to help develop and implement a forensic plan. The forensic team shall consist, at a minimum, of the following:

- One or more RSC representatives intimately familiar with the test section and its performance history or with forensic investigation experience.

- One or more highway agency representatives familiar with the test section who can help facilitate the forensic investigation or who have experience with forensic investigations.

- FHWA LTPP Team and other FHWA staff members who are in a position to make decisions or delegate tasks or who are experienced in forensic investigations.

- Additional personnel who, depending on test section conditions, may contribute to the forensic investigation (e.g., ground-penetrating radar (GPR), materials, and/or forensic experts).

The RSC offices, in cooperation with the FHWA LTPP Team, are responsible for assembling the forensic team. The RSC offices will nominate a team leader, subject to approval by the FHWA.

Decision Process

Once the team is finalized, each member of the forensic team will receive a copy of the test section report. The team will then be required to decide whether a forensic investigation will be conducted on the test section in question. Critical issues to consider when making this decision include the following:

- Benefit to the LTPP program (e.g., will it lead to collection of critical data currently missing in the database, will it help explain causes of pavement failure not apparent from available data, or are other supporting critical data available for the site?).

  Note: A test section will be considered for forensic investigation only if it meets the minimum data completeness requirements for monitoring categories S1, S2, or G, as specified in *LTPP Directive GO-19: LTPP Data Completeness Assessment and Monitoring Adjustment Process.* If a test section does not meet the minimum data requirements before the forensic investigation but will meet them as a result of the investigation, then the test section is considered viable.

- Willingness of the highway agency to support forensic investigations; it is expected that not all highway agencies will be willing to support forensic investigations.

- Cost impact on LTPP program (e.g., will the LTPP program have to drop or delay other priority activities to carry out the forensic investigation?).

The relative importance of the sections to the overall program should be based on the following priority listing in order from highest to lowest. This is provided to help in cases where the final decision rests in selecting one or a few test sections from a group of many.

1. Seasonal Monitoring Program (SMP) test sections.
2. Category S1 and S2 test sections: Specific Pavement Studies (SPS) –1, –2, –5, –6, and –8.
3. Category G test sections: SPS–9 and General Pavement Studies (GPS) –1, –2, –3, –4, –5, –6B/C/D/S, –7B/C/D/F/R/S, and –9.
4. Category C test sections: SPS–3, –4, and –7 and GPS–6A and –7A.

The RSCs will work with highway agency and FHWA LTPP personnel to address the above (and other) issues to arrive at "go" or "no go" decision for the test section. A face-to-face meeting with the members of the forensic team may be required but is not mandatory. The background and results of the decision process should be recorded on the "LTPP Forensic Investigation Go–No Go Record" in Appendix A and retained by the RSC and copies provided to the FHWA LTPP team and the highway agency.

If a decision is made to proceed with a forensic investigation, the steps detailed in the remainder of this framework are to be followed.

2. Development of a Forensic Investigation Plan

Once a decision to proceed with an investigation is made, the next step is to develop a detailed forensic investigation plan. Toward this end, the forensic team will first conduct a preliminary site inspection to obtain information on site-specific conditions, distresses, likely causative mechanisms, and other factors needed to formulate a final plan. It is expected that the preliminary site inspection can be completed within a working day or less.

The RSCs are responsible for coordinating activities with the highway agency and forensic team, including scheduling of site inspection (date and time), logistic arrangements (hotel, meeting place, etc.), and setup of traffic control. In addition, the RSCs are responsible for assembling and compiling observations and/or notes made during the site inspection by forensic team members. During the preliminary site inspections, meetings with appropriate State and Federal highway agency officials should be considered to discuss logistics, site access, traffic control, material handling, material tests, and other practical considerations for developing the final plan.

A detailed forensic investigation plan, tailored to each test section, will then be developed based on the results of the data assessment (contained in the test section report) and the preliminary site inspection. Responsibility for developing the plan rests on the RSCs, but it should be closely coordinated with the FHWA LTPP Team, forensic team, and highway agency. Final review of the plan by the FHWA LTPP Team is required before its implementation.

The plan should consist of two parts:

1. Investigations aimed at examining the details surrounding the causes and mechanisms of distresses.

2. Activities aimed at addressing missing, questionable, or desirable data.

Distress Mechanism Investigations

Some types of investigations and field tests that should be considered for this type of work include the following:

Crack cores: By coring through a crack it *may* be possible to determine the location of the crack starting point and if it extends completely through the bound surface layer.

Rut trenches: If rutting is the major distress, transverse trenches at selected locations can be used to determine which layer in the pavement structure contributed to the rutting mechanism.

Drainage evaluation: Depending on the specific features of the site, drainage evaluation can provide valuable supplemental information on likely distress mechanisms. On sites with in-pavement drainage features, it could also lead to the need for further functional drainage evaluation tests, such as water injection, video inspection of edge drains, and excavations of edge drains, lateral, and other features to examine them for signs of functionality and intrusion of fines.

Joint seal evaluation: Depending on the nature of the pavement structure, if a portland cement concrete (PCC) pavement has exhibited suspected moisture-related distresses at the joints, such as pumping, the Iowa vacuum joint seal tester can be used to evaluate condition of the seals.

Voids under PCC pavements: Slab removal and the Strategic Highway Research Program (SHRP) epoxy core test can be used to examine the extent and sources of possible voids. In addition, nondestructive techniques may be used, such as GPR or slab impulse response techniques.

Joint/crack faulting and joint/crack width: Excavation and removal of concrete around joints and cracks can be performed to allow inspection of the condition of steel reinforcement, dowel bars, and tie bars.

Table 1, “Distress Mechanism Investigation Matrix,” outlines appropriate actions for the various types of distress that may be found in test sections. These are broken down by the type of structure.

Collection of Missing or Desirable Data

Missing Data

Data requirements identified in the initial data availability assessment that can be satisfied through field sampling, testing, and laboratory testing must be reflected in the forensic plan. The data elements will require particular test protocols, which in turn will require samples to be retrieved from the test section. This sampling and testing must rely on existing materials sampling and testing protocols and shall be indicated based on the scope of the missing data. Test results from these efforts are expected to be fully compatible with database protocols.

End-State Physical Properties

While forensic activities tend to be based on what failed, equally important and more difficult to address is the investigation of what worked and why. Knowing what worked requires understanding what did not work. For example, in the case of superior performing pavements, it may be deemed prudent to conduct additional exploratory tests to discover and confirm the absence of factors thought to contribute to distress formation.

Table 1. Distress Mechanism Investigation Matrix.

Structure Type	Distress	Actions	Comments
AC, AC/AC	Fatigue cracking	Core	Within and outside area
	Longitudinal WP	Core	
	Longitudinal NWP	Core	
	Rutting	Trench	Layer profile
	Transverse cracking	Core	
AC/JCP, AC/CRCP	Longitudinal WP	Core	
	Longitudinal NWP	Core	
	Rutting	Core	Within and outside to note differences
	Transverse	Mill off AC	Observe joint/crack condition
JCP	Transverse	Core	
	Corner Break	Core	
	Longitudinal Cracking	Core	
	Pumping	Test pit	Void detection using NDT
	Faulting		
CRCP	Punchout	Core	
	Pumping	Test pit	Void detection using NDT
Site specific conditions not listed above should be investigated at the discretion of the forensic team.			

Note: NDT = nondestructive testing, NWP = nonwheelpath, WP = wheelpath.

All sections identified for forensic investigation must be evaluated to capture the physical properties of the system and its components. This will require sampling and testing of materials beyond examining the distress mechanisms. LTPP policy requires closeout monitoring of sections going out of study: falling weight deflectometer (FWD), manual distress survey (MDS), and profile measurement. For forensic sections these activities should be supplemented with the following elements:

- Cross slope measurement of PCC sections with Dipstick® device.
- Cores at FWD locations.
- Cores at cracks: asphalt concrete (AC), AC/AC, jointed concrete pavement (JCP), and AC/JCP (reflection cracking, saw, and seal joints).
- Trenches cut across the full lane width on AC and AC/AC sections.
- Pachometer surveys of jointed reinforced concrete pavement (JRCP) and continuously reinforced concrete pavement (CRCP) to identify steel locations (dowels, reinforcement).
- GPR, spectral analysis of surface waves (SASW), and/or impact echo measurements to develop layering profiles (correlate results with cores and trenches).
- Drainage system investigation where underdrains are known to exist.

While extensive excavation activity may not be desirable for sections undergoing major rehabilitation short of reconstruction, the agency will decide the type of sampling (e.g., trenches and test pits) to be conducted. It must be emphasized that this is a national program and that the greater the detail and extent of data collected, the greater the eventual benefit to the stakeholders.

The following sections provide details of investigative activities according to the type of pavement structure needed to collect end-state physical properties to supplement LTPP data. These lists are not all inclusive and additional testing may be identified during development of the plan. Table 2 summarizes the field activities anticipated and table 3 presents the laboratory testing envisioned for this effort. Appendix C presents guidelines for trench excavation in AC and AC/AC pavement structures. Appendix D provides suggested locations for cores and nondestructive testing.

AC and AC/AC

1. Excavate trenches at three locations to confirm layering: stations 0, 76 meters (m), and 152 m.

   - Yields layer dimensions.
   - Identifies location of permanent deformation.
   - Allows in situ moisture and density testing.

2. Conduct bulk sampling for possible laboratory testing: AC, unbound base, subgrade materials.

AC/PCC

1. Test pits at two locations (stations 30 m and 121 m). This would allow in situ density and moisture content determination and provide bulk samples of bound and unbound pavement layer materials for missing materials tests.
2. Remove AC surface at several locations to visually assess transverse joint condition, measure width periodically during the sampling day, and observe amount of spalling, if any.
3. Take temperature gradient measurements throughout the sampling day.

AC/CRCP

1. Test pits at two locations (stations 30 m and 121 m). This would allow in situ density and moisture content determination and provide bulk samples of bound and unbound pavement layer materials for missing materials tests.
2. Remove AC surface at several locations to visually assess transverse crack condition, measure width periodically during the sampling day, and observe amount of spalling, if any.
3. Take temperature gradient measurements throughout the sampling day.

JCP

1. Test pits at two locations for in situ density and moisture.
2. Take bulk sample at test pits for missing materials tests.
3. Use Dipstick device for warp and curl measurement periodically during sampling day.
4. Take temperature gradient measurements throughout the sampling day.
5. Measure transverse joint faulting.
6. Conduct pachometer studies for sample of slabs to determine depth of steel and number of bars.
7. Conduct pachometer studies at joints to evaluate dowel orientation and depth.

Table 2. Field Testing Activities for Collecting Supplemental Data.

Field Activity	Pavement Type	Purpose
Core at crack	All	Visual determination of crack origin
Core at saw and seal locations	AC/JCP	Locate joint relative to saw cut
Core at reflection cracks	AC/JCP, AC/CRCP	Determine PCC joint versus crack
Trench	AC, AC/AC	Detailed layering study; determine location of any permanent deformation
Test pits	JCP, CRCP	Sampling and in situ density and moisture testing
GPR	All	Layer thickness, material condition
SASW	All	Layer thickness, voids under PCC
Pachometer	JCP, CRCP	Location and depth of steel, dowel, and reinforcement
Drainage evaluation	All	Excavate and assess condition of drainage elements (laterals, collectors, filter materials)
Dipstick	All	Cross slope

Table 3.Tests for End-State Physical Properties of Pavement Materials.

Sites	Laboratory Test
All forensic	
From bulk of unbound base	
	Moisture-density relationship
	Resilient modulus
	Engineering properties (Atterberg limits, gradation)
	Specific gravity
From bulk of subgrade	
	Moisture-density relationship
	Resilient modulus
	Engineering properties (Atterberg limits, gradation)
AC and AC/AC	
From cores/bulk samples of AC	
	Mix properties, density, voids, AC content
	Resilient modulus
	SHRP properties from SST
	PG of extracted/recovered AC
	Core inspection for stripping
JCP and CRCP	
From cores	
	Compressive strength
	Splitting tensile strength
	Elastic modulus
	Inspect core for corrosion
	Inspect core for ASR

Note: ASR = alkali-silica reaction, PG = performance grade, SST = Superpave® Shear Tester.

CRC

1. Test pits at two locations for in situ density and moisture.
2. Take bulk sample at test pits for missing materials tests.
3. Conduct pachometer studies for a sample of pavement length (three locations each 3 m by full lane width) to determine depth of steel and number of reinforcing bars.
4. Conduct in situ corrosion and chlorides testing at same locations as steel survey.
5. Measure point location of transverse cracks (at intersection of crack and midlane).
6. Measure crack width at same spot as point location measurement periodically during the sampling day.
7. Take temperature gradient measurements throughout the sampling day.

Sites in the Seasonal Monitoring Program require effort beyond that outlined above. End-state conditions are highly desired to confirm material properties used for calibrating the instrument data. Therefore, detailed excavation, sampling, and testing at locations where instruments were installed are critically important. Appendix B is a memorandum that details a plan used in the successful forensic investigation of an SMP site in Connecticut. This plan, coupled with the activities presented above, should be the basis for forensic plans for SMP sites.

Additional Requirements

Each candidate forensic site will have a different set of data needs. As such, the activities presented are not considered all inclusive. The RSC and other members of the forensic team must examine the available information and this document and then develop a comprehensive plan to collect the needed data. The RSC is responsible for compiling the forensic plan and presenting it in a written recommendation to the FHWA LTPP Team. It is the responsibility of the FHWA LTPP Team to review the plan and make suggestions on funding sources and potential sources of assistance so the plan can be implemented successfully.

3. Implement Forensic Investigation Plan

The FHWA LTPP Team will review and work with the RSC and forensic team to finalize the forensic investigation plan before implementation. The purpose is to refine the plan details and objectives in the context of cost sensitivity and program benefits. The RSC will provide cost estimates for the plan to the FHWA LTPP Team for review and consideration. Once the plan is fully approved, implementation by the RSC in coordination with the forensic team and FHWA LTPP Team will begin.

Because each forensic plan is section specific, the scope of data collection will vary. A project manual for each plan must be developed to clearly define the data to be collected, methods and protocols to be used, and data sheets to be completed. Based on the range of possible field activities, a number of additional protocols are required to support consistent data collection. Many protocols exist from the implementation of the LTPP program, but Appendix C addresses specific procedures for trench excavations and Appendix D addresses cores taken at crack locations and nondestructive testing of PCC pavement (SASW, GPR, and pachometer).

Additional data collection protocols and supporting sheets may need to be developed based on unanticipated site-specific conditions. In these cases the RSC is responsible for identifying the needed procedure and coordinating its development with the LTPP technical support services contractor. The extent of new forms and protocols must be balanced with the need for consistency in data types collected. Reliance on existing LTPP forms and procedures is critically important to render the forensic data readily accessible to users.

Appendix A - Go-No Go Form

LTPP Forensic Investigation Go-No Go Record	
RSC:_____________________ Team Leader:_____________________________ Date: __ __ / __ __ / __ __ __ __	State Code: ________________ SHRP ID: _________________ Experiment: _______________ SMP ?: (Y/N) ______________

Site Description: (location, pavement type, reason for forensic, priority (SMP / S1 or 2 / G / C))			
Site Report Summary:			
Data Availability		Needed	Available
	Material Properties		
	Layering		
	Traffic		
	Maintenance & Rehabilitation		
	Close-out Monitoring		

Criteria:	**(Y/N)**
1. Will it lead to collection of critical data currently missing in the database?	
2. Will it help explain causes of pavement failure not apparent from available data?	
3. Are other supporting critical data elements available for the site?	
4. Does it meet the minimum data completeness requirements for monitoring categories S1, S2 or G, as specified in ***LTPP Directive GO-19: LTPP Data Completeness Assessment and Monitoring Adjustment Process?***	
5. If it does not meet the minimum data requirements prior to the forensic investigation, will it meet them as a result of the investigation?	
6. Will the highway agency support a forensic investigation?	
7. Will the LTPP program have to drop or delay other priority activities in order to carry out this forensic investigation?	
Team Decision	Go No Go

Team Member Name	Affiliation

Acknowledgement:
For the RSC_________________________________ For FHWA-LTPP_____________________________

Appendix B - Example SMP Forensic Plan

MEMORANDUM

TO:	Cheryl Richter
FROM:	Gary E. Elkins
DATE:	April 13, 2000
SUBJECT:	Supplemental Data Collection - Connecticut Test Section 091803 FHWA Contract No. DTFH61-97-C-00002 PCS/LAW Project No. 10900-7-0714-02-102
PAPER FILE:	Pavement Instrumentation/Seasonal Monitoring/SMP IMS Issues
CC:	A. Lopez, L. Rodriguez, M. Symons, H. Zhou, B. Henderson, F. Meyer

Introduction

LTPP GPS-1 test section 091803, located in Groton Connecticut, is scheduled for rehabilitation. This test section was included in the Seasonal Monitoring Program (SMP) phase 1 study. Prior to rehabilitation of the test section Connecticut DOT has offered to perform additional sampling and testing at the site to supplement the previously collected information. An overview of supplemental data collection needs and field procedures are presented in this memorandum. This data collection activity is in addition to the standard LTPP pavement performance measurements to be performed prior to the rehabilitation construction event.

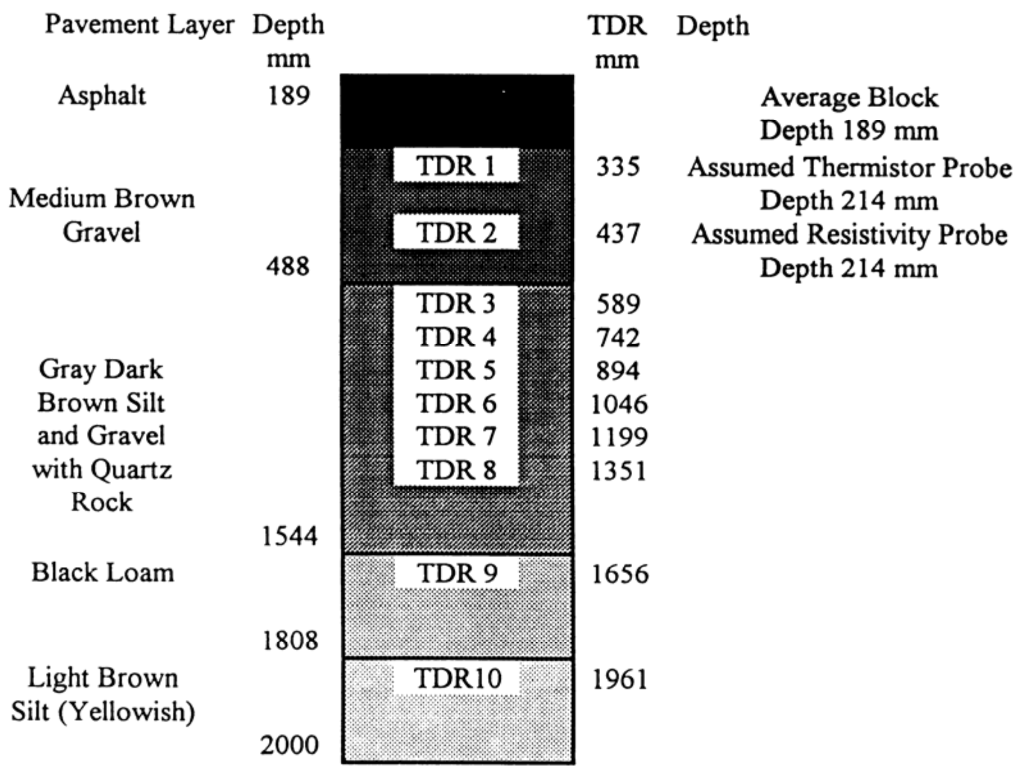
Data Needs

- Specific gravity measurements are needed on the unbound granular materials surrounding the Time Domain Reflectometry (TDR) probes. This information is useful for estimation of moisture contents from the TDR measurements.
- In-situ dry density of material adjacent to the TDR probes. Although difficult to measure, this value is used to convert volumetric moisture contents estimated from the TDR measurements to gravimetric contents that can be compared to laboratory determined values.
- "Ground truth" moisture contents at TDR probe locations coupled with TDR measurements. A matched set of TDR measurements and gravimetric moisture contents from the material surrounding the TDR probes will permit evaluation of the accuracy of the estimated moisture contents from the TDR measurements. Also during installation, a complete set of matching TDR and gravimetric moisture content measurements was not obtained.
- Materials characterization of the subgrade layer(s). During the standard GPS materials sampling and testing performed under SHRP, because of the presence of rocks and cobbles in the subbase material, material samples of the subgrade layer(s) were not obtained. The only information available on these layers is the visual classification performed during site verification and instrumentation placement. (Note there appears to be two distinct layers of material beneath the subbase in which TDR probes are located.)
- Distress mechanism investigation. As a test section go out of service, in some instances, it is useful to perform different types of measurements to investigate the distress formation mechanism. For example, if a test section has rutting, then a transverse trench could be used to identify the layers contributing to the permanent deformation.

· Within section layer thicknesses. One unknown for GPS test sections is the variation in layer thicknesses along the test section. This information can be used to refine FWD backcalculation and as a measure of construction variability.

Pavement Structure

The pavement layer structure and location of the TDR probes are shown in Figure 1, which was obtained from the SMP Instrumentation Installation Report prepared for this site.



SMP Instrumentation Measurements

Unlike many of the other supplemental data collection to be performed during this exercise, the data collected from these measurements can and should be entered into the IMS. Just prior to beginning excavation of the materials at the instrumentation hole location, we recommend that the following SMP instrumentation measurements be performed:

1, Three sets of automated TDR measurements using the LTPP mobile data acquisition unit. These measurements can be performed in sequential order at the start of the work day.

2. As part of the standard LTPP mobile data acquisition, automated resistivity measurements should also be obtained. Although it is not anticipated that the site will contain frost lenses when this work is performed, the purpose of these measurements are to provide comparative data to the first set of measurements in order to evaluate the performance of the resistivity probe. Manual electrical resistivity measurements are not proposed.

3. One set of manual TDR measurements. Since the interpretation methods between automated and manual TDR measurements differ, the interpretation of the manually collected will provide a good indicator of change and comparison of the difference between the two methods.

4. Water table depth measurement.

These measurements should be possible since, except for the water table depth, they are all performed using the mobile data acquisition unit. Since this SMP site was previously deactivated, issues concerning air, rainfall and pavement gradient temperature measurements, measured by the instrumentation previously installed on-site are not considered an issue.

Materials Sampling at SMP Instrumentation

In order to obtain the material samples and perform material tests to provide supplemental data for the TDR measurements, an excavation will be required next to the instrumentation location located at station 5+21. There are two approaches to this excavation. The first approach would be to use a backhoe to excavate a small test pit adjacent to the instrumentation hole large enough for a person to stand in order to obtain material samples from around the TDR probes and perform measurements. The second approach utilizes an auger boring adjacent to the instrumentation.

During the excavation and sampling process, efforts should be made to remove some of the TDR and other SMP probes to examine them, note their general condition and take pictures. The intent of this procedure is to provide indications of the likely longevity of these types of probes and the likely corrosion mechanisms that affect their performance. Particular attention should be given to sensors, which have failed in order to discover why they failed.

Test Pit

Constructing a small test pit directly adjacent to the instrumentation hole, following the general LTPP procedures, is the preferred option. By carefully constructing a hole larger enough for a person to stand in, is the only way to attempt a measurement of the in-situ density and moisture content using a nuclear gauge at the approximate TDR depths as the hole is deepened. By performing in-situ density measurements with a nuclear gauge, material samples from the base and subbase layer for laboratory moisture content-density relations tests would not be needed. It also permits acquisition of a larger volume of material from the subgrade layers which include the relatively thin black loam layer in which TDR 9 is located and the light brown silt layer in which TDR 10 is positioned. It will also improve the ability to extract material samples from around the TDR probes for moisture content tests.

Some concerns over using a test pit excavation include increased pavement repair size, trench safety regulations, and equipment availability as compared to the auger boring option. However, due to the presence of rocks and cobbles in the subbase, the test pit option may require less time since the back hoe can remove the larger size material and afford easier access for hand removal of problem "large" rocks.

The field work associated with the test pit option would include the following general steps:

1. Remove AC material above instrumentation hole and in test pit. It is desired that the removal of the AC layer be performed without the use of a water cooled saw cut. Depending on equipment availability and site conditions, a backhoe may be able to remove the AC material in the vicinity of the instrumentation hole. If a water-cooled saw is used, then consideration should be given to cutting a larger hole than necessary to reduce the impact of the cooling water on the moisture content of the base layer.

2. Perform nuclear gauge measurements on the base material. Since LTPP standard practice is to use the extension rod for these tests, one density test should be performed on the base layer.

3. Hand excavate material from around the TDR probes and obtain samples for laboratory moisture and specific gravity tests.

4. In the test pit, carefully remove base material to the surface of the subbase.

5. Perform nuclear gauge density measurements on the surface of the subbase.

6. Hand excavate the material from the adjacent instrumentation hole down to TDR 3. Capture moisture and specific gravity samples.

7. Within the subbase layer, excavate the hole in 1 foot increments. For each excavation increment, perform a nuclear density measurement on the bottom of the pit and hand excavate and capture material samples from around the TDR probes. (Although some of the probes in this portion of the hole are spaced at 6" intervals, the 1' interval is suggested

to increase speed of the excavation. The density profile is also not expected to change dramatically.

8. Once the black loam layer is reached, perform nuclear gauge measurements on its surface.

9. Obtain a bulk sample of material from the black loam layer. Approximately 200 lbs is required for all standard LTPP subgrade material tests.

10. Hand excavate material from the instrumentation hole and obtain moisture and specific gravity samples from around TDR 9.

11. When the light brown silt layer is reached, repeat steps 8-10.

12. After completion of sampling and testing, fill test pit in lifts and compact.

Since this test section is scheduled for overlay, the destructive nature of some of these procedures are not judged to be as critical as if the test section had to be put back into service with a surface patch for a long period of time.

Auger Boring

The auger option is less intrusive since a smaller volume of material is removed and thus requires less pavement repair material. However, it does not afford the ability to attempt in-situ density measurements, makes large rock and cobble removal more difficult, limits the amount of material that can be obtained from the subgrade, and increases the difficulty in obtaining "good" samples of materials from around the TDR probes. In spite of these difficulties, this method is considered viable.

For the auger option, the largest size auger available is desired. A 10" diameter, hollow stem auger was used to excavate the instrumentation hole. Of primary concern is the amount of material that can be obtained from the black loam subgrade layer. Obviously a smaller auger will produce less material. For LTPP standard testing, three auger borings were used to obtain adequate amounts of materials, however, in the general situation, the base layered tended to be the controlling factor in the need for three borings.

The field work associated with the auger option includes the following general steps:

1. Remove AC material above instrumentation hole and in test pit. It is desired that the removal of the AC layer be performed **without** the use of a water cooled saw cut. Depending on the equipment availability and site conditions, a backhoe may be able to remove the AC material in the vicinity of the instrumentation hole. If a water-cooled saw is used, then consideration should be given to cutting a larger hole than necessary to reduce the impact of the cooling water on the moisture content of the base layer.

2. Obtain an uncontaminated sample of the base material from the auger hole for the moisture-density relation test.

3. Auger into the subbase layer. Obtain one sample from the top of the layer and one near the bottom of the layer for moisture-density relation test.

4. Auger into the black loam layer, and if possible, capture 200 lbs of material for the standard battery of LTPP subgrade tests.

5. Auger into the light brown silt layer, and if possible, capture 200 lbs of material for the standard battery of LTPP subgrade tests.

6. Using a fabricated side hole material sampling device, starting with TDR 10 and progressing upward to TDR 7, obtain samples of material from the instrumentation hole in the general location of each TDR probe.

7. Starting from the surface of the base layer, hand excavate material from the instrumentation hole and obtain material samples for moisture content and specific gravity at each TDR location. Excess material from the instrumentation hole can be deposited into the auger hole.

8. Once the maximum practical extent of hand excavation is reached, use the side-hole material sampling device to obtain moisture and specific gravity samples from the remaining TDR probe locations.

9. After completion of sampling and testing, fill the auger hole lifts and compact.

Subgrade Material Characterization

It is proposed that the material characterization of the subgrade layers be performed on samples obtained only at the SMP instrumentation location. The standard LTPP practice is to obtain samples from each end of the test section. The concern over not sampling the section approach is the amount of time required to complete the excavation at the SMP instrumentation hole, and the difficulty imposed by the presence of rocks and cobbles in the subbase layer. If all of the field material sampling operations were to be performed within a single day, an additional drill rig might be required.

If the auger option is selected for the excavation at the instrumentation hole, then sample size is a concern for the black loam layer. One way to reduce the needed size of this sample is to omit the resilient modulus test. (We are not sure if Connecticut DOT has the necessary equipment to perform the LTPP P-46 test.) From the perspective of what is needed for SMP instrumentation interpretations, although preferred, the resilient modulus test of this relatively thin subsurface layer could be omitted.

The following are the standard battery of material characterization tests on GPS subgrade materials:

Material Type, SHRP Test Designation, and Properties	Test Method	SHRP Protocol
SS01. Sieve Analysis	AASHTO T27-88I	P-51
SS02. Hydrometer to .001mm	AASHTO T88-86	P-42
SS03. Atterberg Limits	AASHTO T89-87I T90-87I	P-43
SS04. Classification/Type of Subgrade Soils	AASHTO M145-82 ASTM D2488-84	P-52
SS05. Moisture-Density Relations	AASHTO T99-86 T180-86	P-44
SS07. Resilient Modulus	AASHTO 274-82	P-46
SS09. Natural Moisture Content	AASHTO T265-86	P-49

Distress Mechanism Investigation

One of the ideas that have been discussed within the LTPP program for many years is the investigation of distress mechanisms. The concept is that after a test section has gone out of service, or is scheduled of rehabilitation, a "forensic" type of investigation should be performed to examine the details surrounding the causes and mechanisms of distress. Due to funding constraints, LTPP has not developed a formal program for these types of investigations.

To perform this type of investigation, we recommend that as a first step a site inspection be performed by LTPP and highway agency representatives. The purpose of this inspection is to note site specific distresses and likely causative factors. The result of this activity is an investigation plan. Some of the types of investigations and field tests that have been suggested for this type of work include:

- Crack cores. By coring through a crack it **may** be possible to determine the location of the crack starting point and if it extends completely through the bound surface layer.
- Rut trenches. If rutting is the major distress, transverse trenches at selected locations can be used to determine which layer in the pavement structure contributed to the rutting mechanism.
- Drainage evaluation. Depending on the specific features of the site, drainage evaluation can provide very valuable supplemental information on likely distress mechanisms. On sites with in-pavement drainage features, it could also lead to the need for further functional drainage evaluation tests, such as video inspection of edge drains.
- Joint seal evaluation. If a PCC pavement has exhibited suspected moisture related distresses at the joints, such as pumping, depending on nature of the pavement structure, use of the Iowa PCC joint vacuum device might be indicated to evaluate condition of the seals.

While this approach is based on "what failed", equally important and more difficult to addressed is the investigation of "what worked" and why. Similar to diagnosing problems with a car from a manufacturer's viewpoint, knowing what worked requires understanding of what didn't work. Hence, in the case of superior performing pavements, it may be deemed prudent to conduct addition exploratory tests to discover an unknown factor.

Thickness Variation

If a test section is scheduled to go out of service, that is, no longer be monitored as part of the LTPP program, then measurements of the variation in the thickness of the bound surface layers is important. The concept is to obtain cores at the FWD test points within the test section. This reduces coring costs and provides significant information that can be used to improve the results from the backcalculation of FWD basin tests (i.e. non load transfer, corner, and edge tests on rigid pavements) and to quantify construction variability. First priority is to obtain thicknesses in the wheel path locations. Second priority is at the middle lane, basin test locations.

It is our present understanding that this site is proposed for monitoring continuation after rehabilitation. If the site is accepted for monitoring continuation, then this type of destructive sampling within the test section should not be performed. An on-site inspection maybe useful in evaluating the impact of the pipeline buried, in circa 1997, along the edge of the shoulder on the performance of this section. It is also noted that the agency has collected significant WIM traffic data on this site and has committed to reinstall the WIM scale after rehabilitation.

Appendix C - Guidelines for Trench Excavations

Guidelines for Trench Excavations

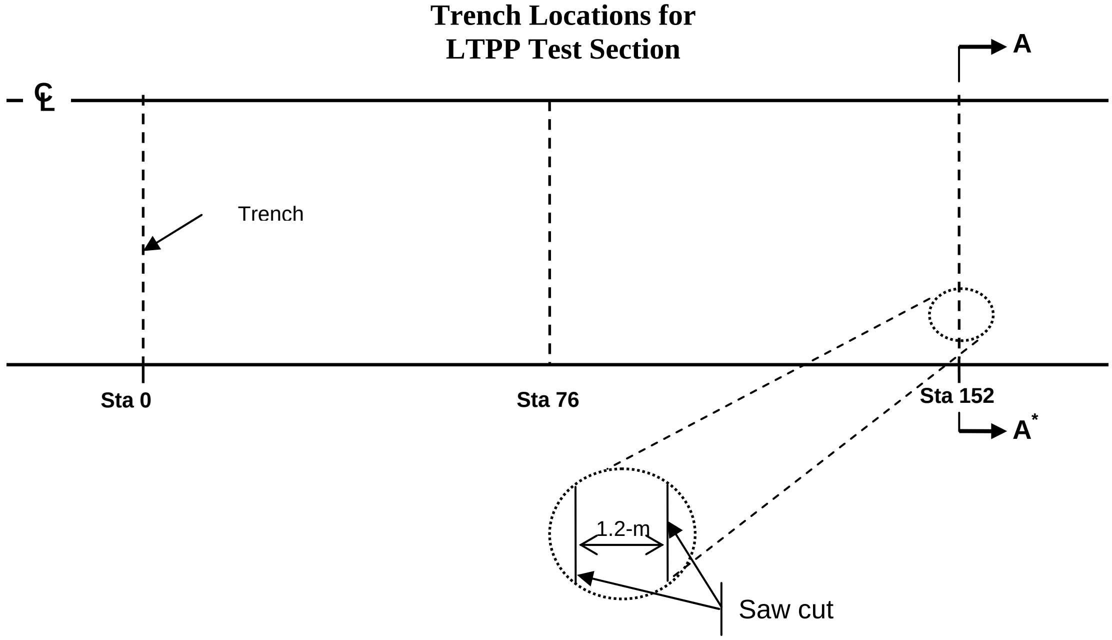
Trenches are suggested for all AC and AC/AC sections. Locations for trench excavation should be at station 0, 76m and 152 m. Dipstick measurements of transverse profile should be conducted prior to excavating the trench. Once completed, the surface bound layers should be sawed using care to prevent excess water from draining into the underlying materials. Dimensions of the excavation should include the edge of pavement to the centerline (or as close as safety allows) and approximately 1.2 m in width. In no case shall the trench be less than 1 meter in width.

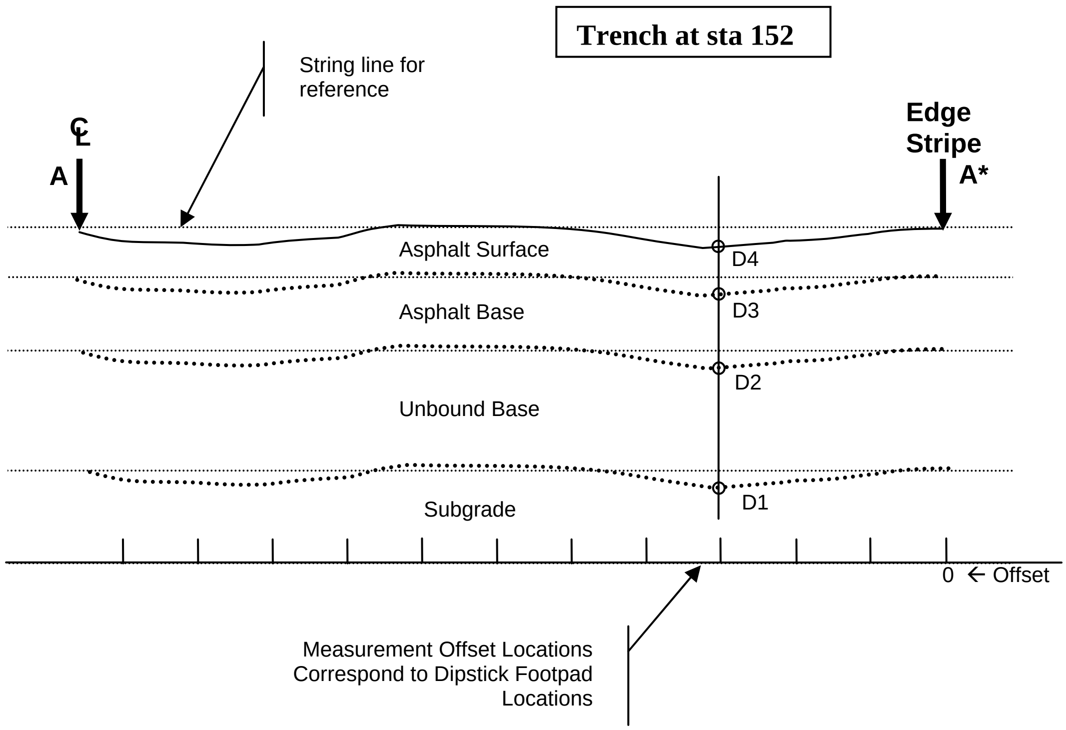
On completion of saw cuts, portions of the AC layers should be carefully removed to expose the underlying base materials. Successive excavation, layer by layer is needed to allow for density and moisture testing of the unbound materials followed by bulk sampling. Once the excavation is advanced to subgrade an additional 0.3m of excavation is desired to provide samples and to expose the base/subgrade interface.

On completion of excavation the downstream trench face should be brushed clean to make possible identification of layer/lift interfaces. PK nails should be driven into the pavement at either end of the trench excavation on the downstream face. A string should be tied to the PK nails and pulled tight and level (no sag) to provide a reference line for measurements. Using the dipstick footpad spacing as a reference, measurements of the distances from the reference line to the interface of each layer/lift shall be recorded to the nearest 1 mm.

The following figures illustrate the trench location and concept of the measurement of layer thicknesses as described.

Trench Locations for
LTPP Test Section





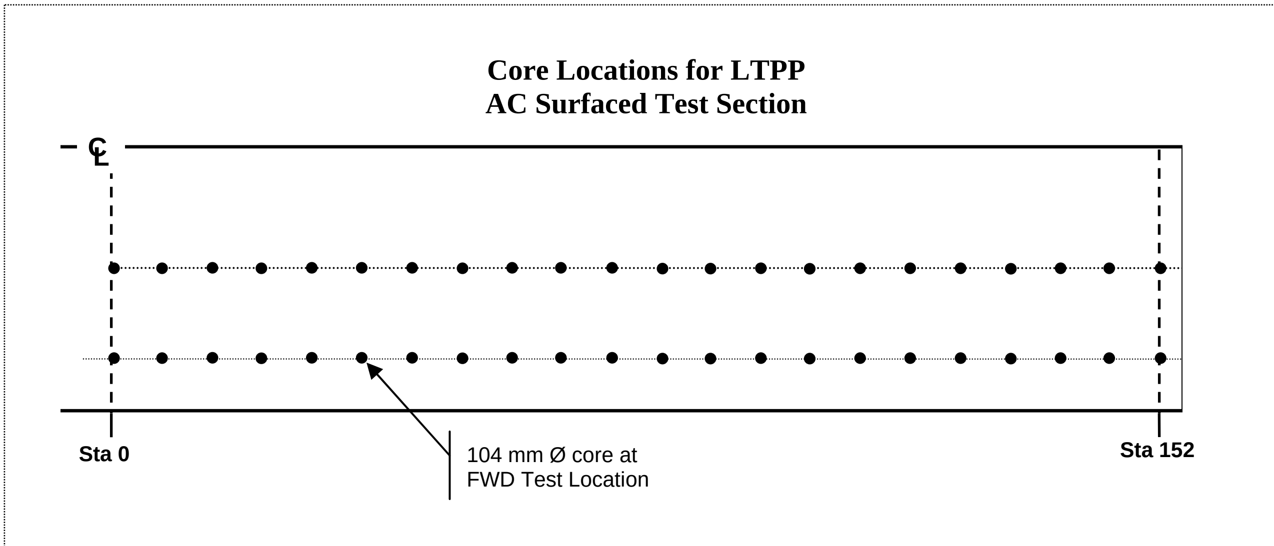
Distances (e.g. D1) are measured from the string line to the top of the layer. Layer numbers should correspond to the IMS layer number unless field conditions deviate from information contained in the database. Regardless, careful documentation of the layer description and measurements shall be made.

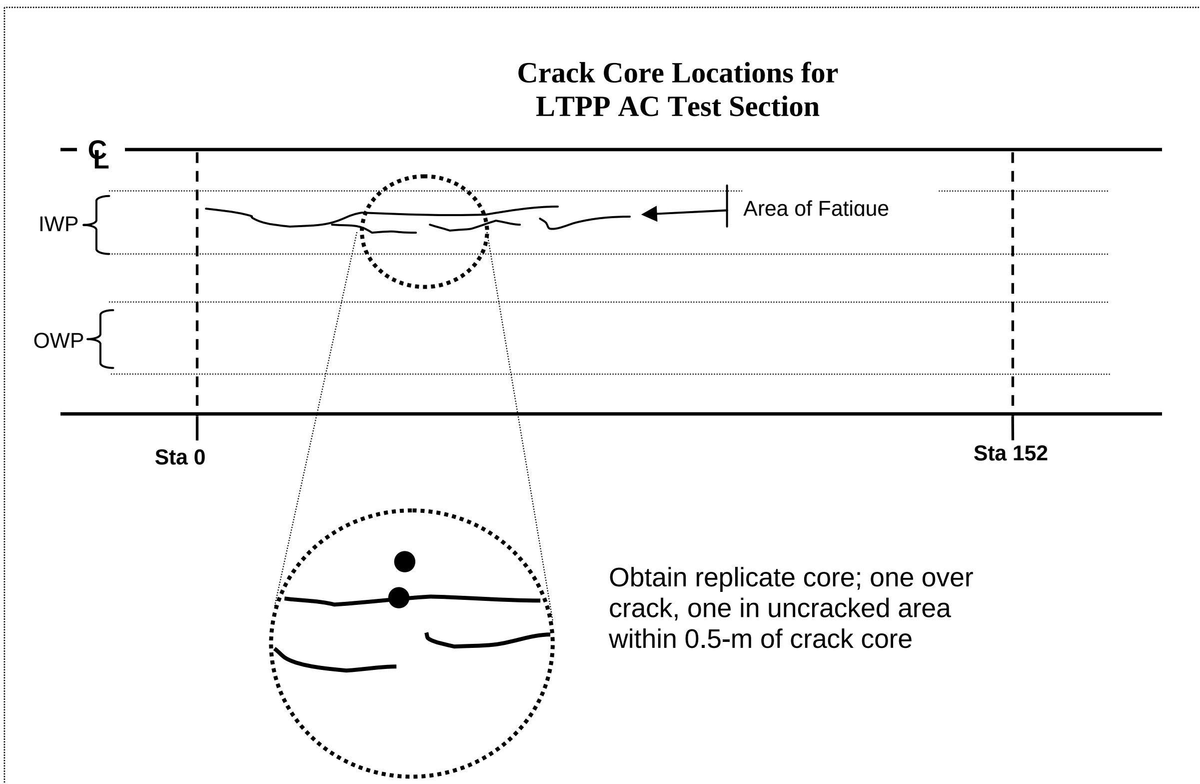
Example of Measurement Data Table

Layer Number	1	2	3	4	5	6	7	8
Offset, m								
0	D1	D2	D3	D4				
.305								
.610								
.915								
…								
End (Centerline)								

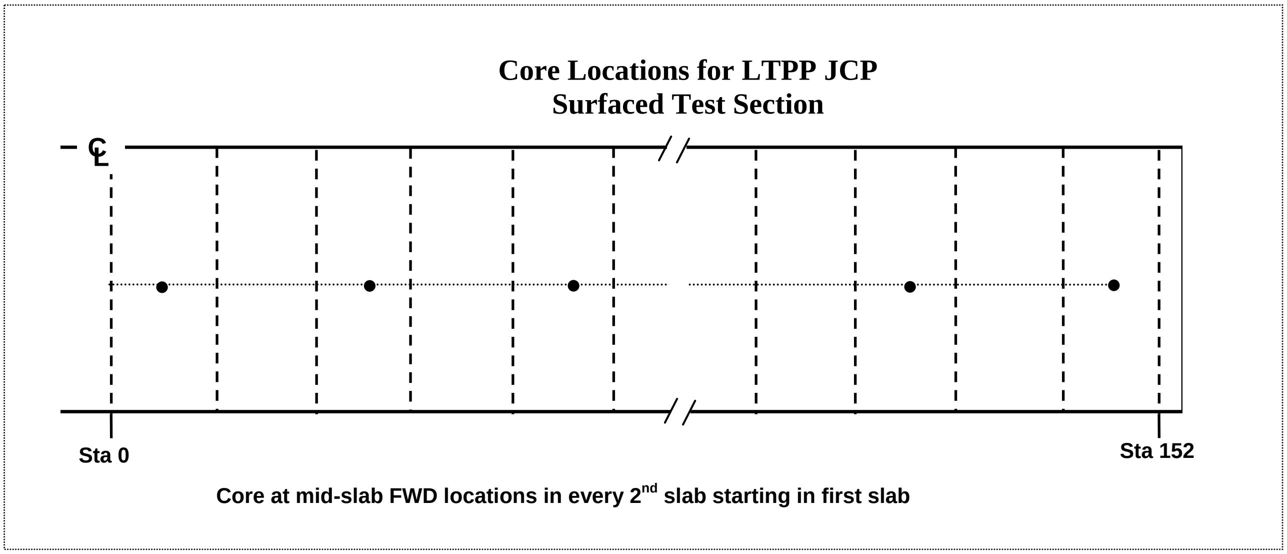
Appendix D - Coring Layout and NDT Location Suggestions

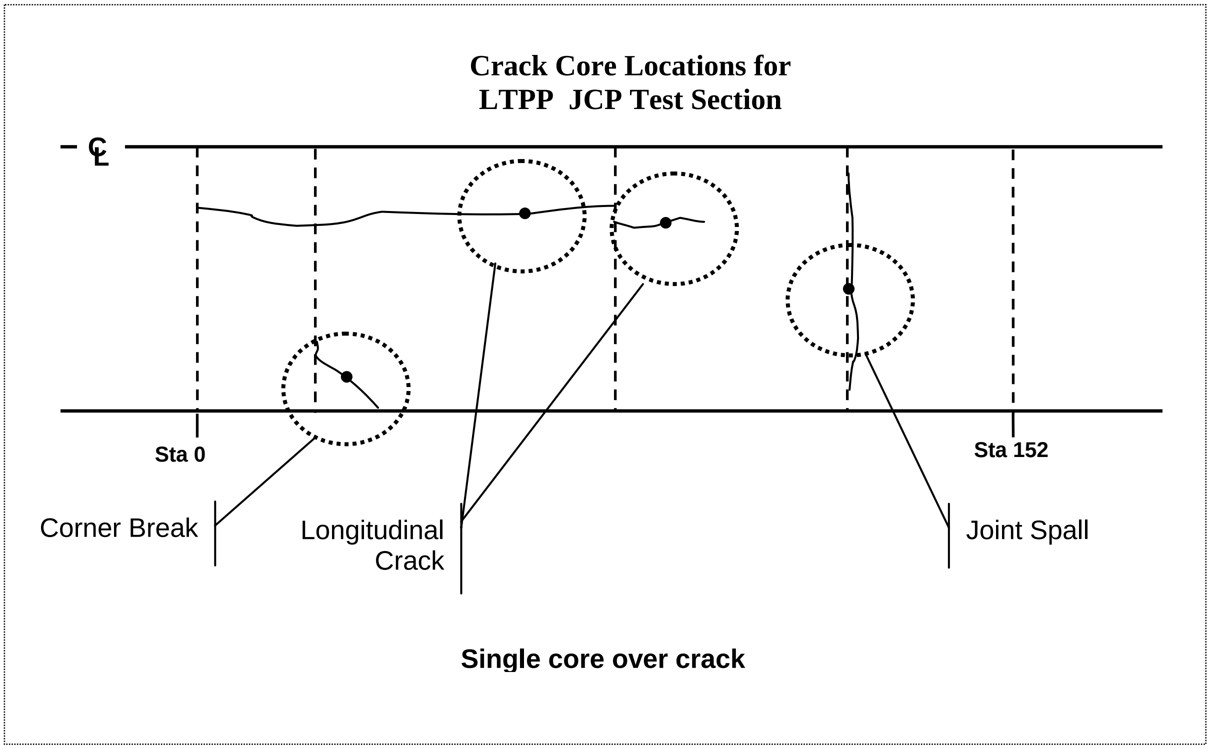
AC and AC/AC


Core Locations for LTPP
AC Surfaced Test Section
℄
Sta 0
Sta 152
104 mm Ø core at
FWD Test Location

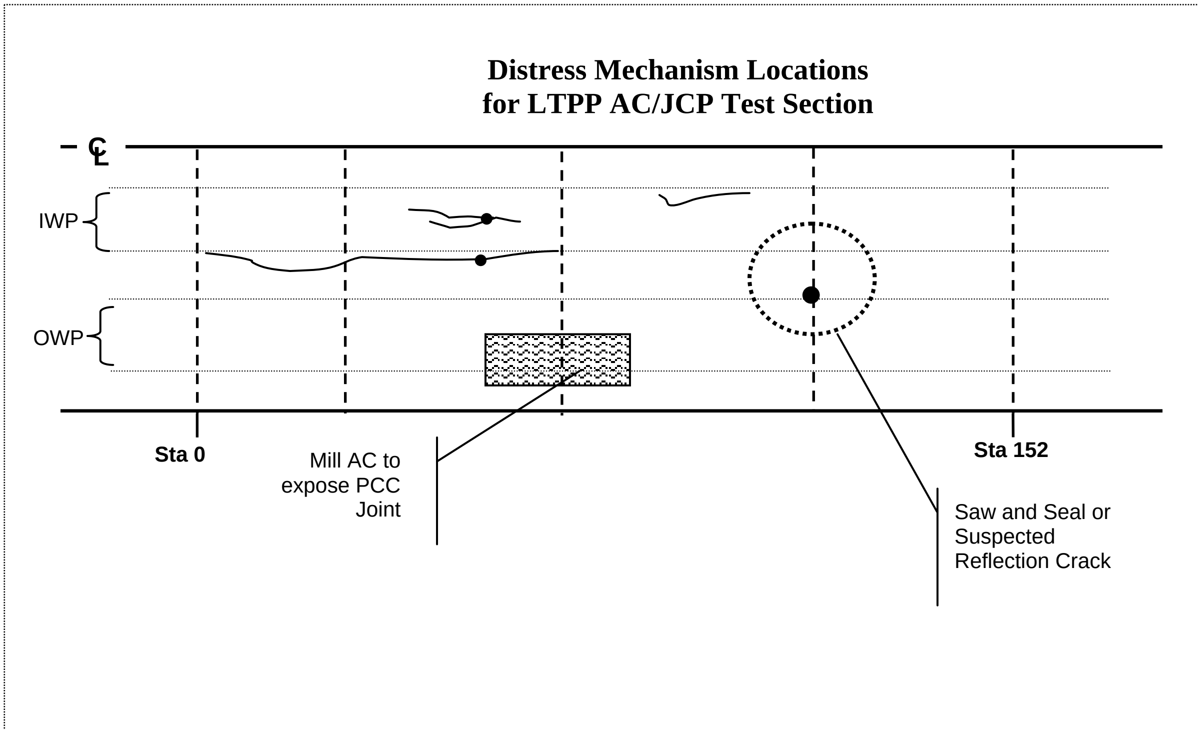

Crack Core Locations for
LTPP AC Test Section
℄
IWP
OWP
Area of Fatigue
Sta 0
Sta 152
Obtain replicate core; one over
crack, one in uncracked area
within 0.5-m of crack core

JCP and CRCP


Core Locations for LTPP JCP
Surfaced Test Section
CL
Sta 0
Sta 152
Core at mid-slab FWD locations in every 2nd slab starting in first slab


Crack Core Locations for
LTPP JCP Test Section
CL
Sta 0
Sta 152
Corner Break
Longitudinal Crack
Joint Spall
Single core over crack

AC/JCP


Distress Mechanism Locations
for LTPP AC/JCP Test Section
CL
IWP
OWP
Sta 0
Sta 152
Mill AC to
expose PCC
Joint
Saw and Seal or
Suspected
Reflection Crack

Suggested Non-Destructive Testing of PCC Pavement