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16. Abstract

Segmental, post-tensioned (PT) bridges are major structures that carry significant traffic. These bridges are designed and constructed because they are economical for spanning long distances. In Texas, there are several signature PT bridges. In the late 1990s and early 2000s, several state highway agencies identified challenges with the PT structures, mainly corrosion of the PT strands. The Texas Department of Transportation (TxDOT) performed some comprehensive inspections of their PT bridges. A consultant's report recommended that all ducts be re-grouted. However, the environment in Texas is very different than the environments in which the corrosion of the PT strands was observed in the other bridges. Report 0-4588-1 summarized the research findings from a comprehensive study on the corrosion characteristics, reliability, materials, and repair for PT bridges. This document, an inspection and repair manual, was developed from information from this research program. This document provides an efficient approach to inspect and repair PT bridges. However, it should be noted that in this manual, repair does not include filling the voids in the tendons with grout. A recent failure of a tendon in a bridge in Virginia was suspected of being caused by repair grouting of the tendon, possibly due to the formation of a galvanic couple between the new repair grout and the original grout. Although a procedure for pressure-vacuum grouting of tendons is provided in Appendix A of this manual, this method should not be used until the potential issue associated with galvanic corrosion of the strands after repair is resolved.

17. Key Words

Inspection, Repair, Post-Tensioned Bridge; Corrosion, Tendon; Voids; Grout; Durability; Strength Reliability; Service Reliability; Deterioration

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EFFECT OF VOIDS IN GROUTED POST-TENSIONED CONCRETE BRIDGE CONSTRUCTION: INSPECTION AND REPAIR MANUAL FOR EXTERNAL TENDONS IN SEGMENTAL, POST-TENSIONED BRIDGES

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The contents of this product reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the Federal Highway Administration (FHWA) or the Texas Department of Transportation (TxDOT). References to specific products are for information only and do not imply any claim of performance for that particular product. This product does not constitute a standard, specification, or regulation. This product is not intended to replace the existing inspection requirements for post-tensioned (PT) bridges but is instead a recommendation for the additional inspection and testing specifically for the external tendons on PT bridges. The repair grouting procedure presented in Appendix A of this manual should only be used after the effect of repair grouting on the strand corrosion is quantified and the moratorium or the wait-and-see approach on these repairs is lifted. The application of the content of this document to internal tendons is limited and difficult. The researcher in charge was David Trejo, P.E. #93490.

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1 INTRODUCTION

1.1 BACKGROUND INFORMATION

Post-tensioned (PT) bridges have the advantages of spanning longer distances, reducing the bridge's self-weight, and having shorter construction periods. Many PT bridges have been constructed over the last several decades. However, recent investigations of these bridges have identified voids in the ducts, and the exposed strands at these void locations can undergo corrosion. The rate of corrosion is very high when high humidity, water and/or chlorides are present inside the tendons. The corrosion of strands can lead to the failure of tendons. It is critical to be proactive in protecting tendons from corrosion because a tendon failure will adversely affect the bridge's performance, will be costly to replace, and will increase the probability of bridge failure. Therefore, an inspection program for the condition assessment of PT tendons should be developed to ensure public safety and extend the service life of PT bridges. The critical factors that should be identified in an inspection program include the identification of voids, moisture, and/or chlorides that have been or are present in the tendons at the time of inspection. This manual presents procedures for the inspection and minor repair of external tendon systems.

During the inspection, if moisture or chlorides are found infiltrating the tendons, a method is needed to prevent further infiltration of these substances. Common practice has been to repair with grout (i.e., fill the voids with repair grout) to prevent further ingress of the deleterious materials. Volume 2 of Report 0-4588-1 developed the pressure-vacuum grouting (PVG) method to perform repair grouting. However, a recent tendon failure in a bridge in Virginia indicates that repair grouting may lead to accelerated corrosion and early failure of the tendon. At the time of the development of this manual, repair grouting of tendons was not employed by TxDOT. Research is needed to determine if the corrosion activity is influenced by repair grouting. This manual will present the repair grouting procedures only in Appendix A. Should TxDOT decide to employ them in the future, it is recommended that this procedure be used only after the current moratorium or the wait-and-see approach on repair grouting is lifted. As such, the word "repair" in this manual refers to all repairs, such as repairing drain lines, ducts, grout ports, bridge joints, etc., with the exception of repair grouting.

1.2 CURRENT NEEDS

Routine safety (visual) inspections of all bridges are performed every two years. It is expensive and time consuming to perform in-depth inspections, especially in-depth inspections of PT tendons inside segmental bridges. At the same time, the consequences of having a structural failure are severe—PT bridges in Texas carry significant traffic. Therefore, bridge owners should do everything economically feasible to prevent the exposure of strands to high relative humidity levels, water, and/or chloride conditions. These actions could include repairing drain lines, sealing ducts and grout holes, repairing bridge joints, or performing other repairs.

1.3 INSPECTION, ANALYSIS, AND REPAIR STRATEGY

This manual recommends an inspection, analysis, and repair strategy for external tendons found only in segmental, PT bridges. This manual is not intended to replace the existing inspection requirements for PT bridges but instead is a recommendation for the additional inspection and testing specifically for external tendons (not for internal tendons) in segmental, PT bridges. An inspection, analysis, and repair strategy that optimizes the resource requirements is developed by dividing the overall inspection, analysis, and repair program into three major steps. These are:

- special inspection and analysis program for PT systems,
- surveying of the selected tendons for in-depth inspection, and
- in-depth inspection, analysis, and repair program for PT systems.

Figure 1-1 shows a flowchart with the overall inspection, analysis, and repair program as described above. The following sections present further details on these three steps.

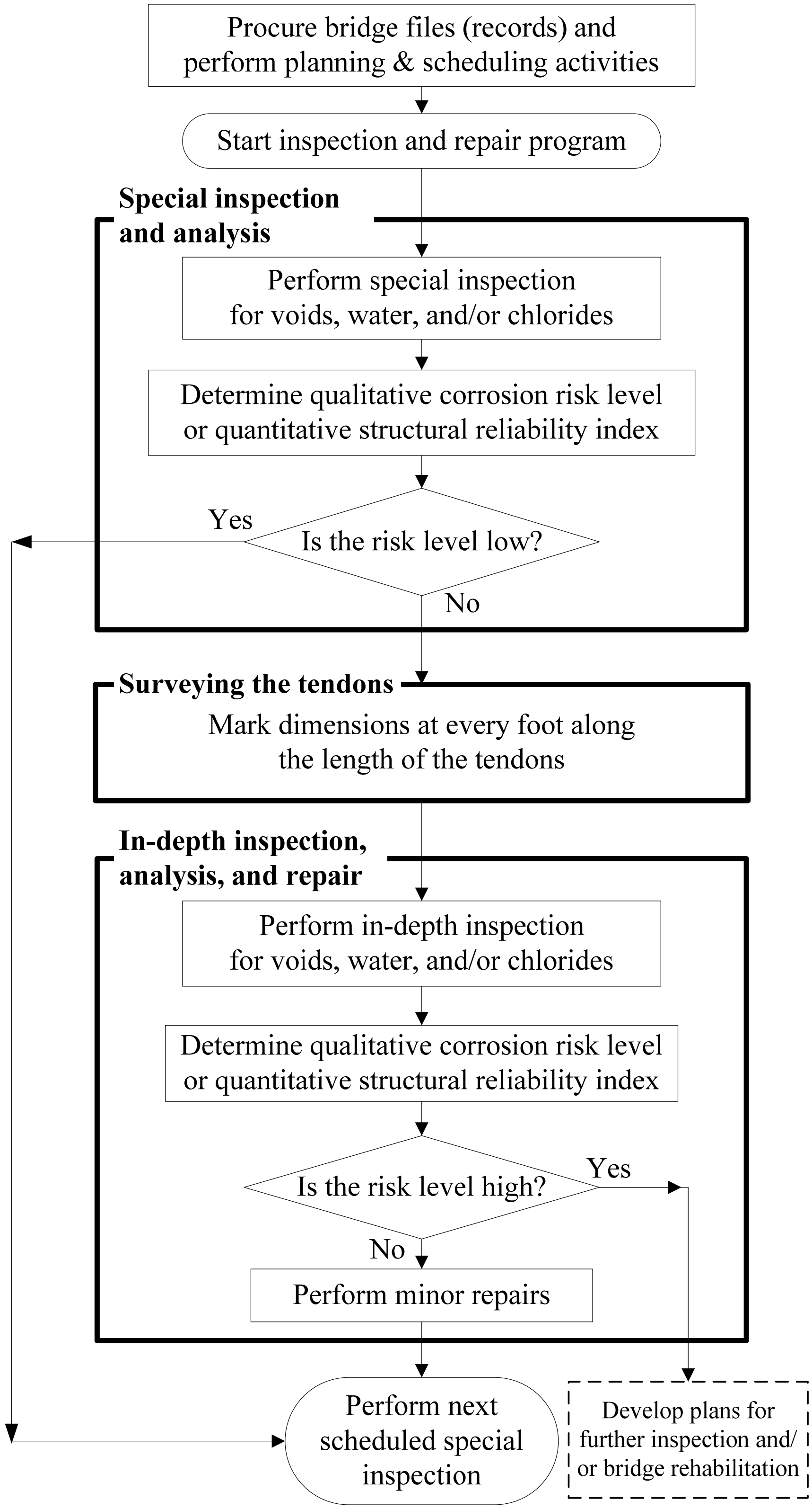


Figure 1-1. Overall Inspection, Analysis, and Repair Program for Post-Tensioned Bridges.

Special inspection and analysis program

This proposed program includes a "walk-through" inspection to identify the potential presence of voids in ducts and the presence of water and chlorides. It should be noted that the proposed special inspection procedures are not intended to replace but to augment the existing special inspection procedures for PT bridges. Based on the obtained information, the qualitative corrosion risk or quantitative structural reliability of the bridge system can then be assessed. The results from the risk or reliability analyses can be used to determine if in-depth inspections are needed.

Surveying of the tendons selected for in-depth inspection

The word "surveying" in this manual indicates the process of marking gridlines and/or markers on the tendons and inside the girder. This is done only for the in-depth inspection, analysis, and repair program.

In-depth inspection, analysis, and repair program

Past bridge inspections and Volume 1 of Report 0-4588-1 cite that the presence of voids along with moisture and chlorides can cause strand corrosion in PT bridges. Volume 1 of Report 0-4588-1 also identified that the rate of corrosion can be maximized at the interface between the void and the grouted region in the tendon. A completely exposed strand will also have very high corrosion rate when exposed to high relative humidity levels, water, and/or chloride conditions.

In-depth inspections should be performed on tendons that are identified as having medium or high risks of corrosion or capacity loss. These tendons are identified during special inspections and are typically tendons that have damage to the duct, have standing water in the tendon, have chlorides in the water, or exhibit more than surface corrosion of the strands. Random in-depth inspections can be performed if deemed necessary by the person in charge of the inspection. The following sections provide details of the in-depth bridge inspection program.

1.4 Personnel for the Inspection, Analysis, and Repair

This manual assumes that personnel associated with the inspection of PT systems have different responsibilities. This manual uses the following definitions.

- **Inspection program manager** – The person responsible for the overall management of the inspection, analysis, and repair program. He/she is also responsible for the testing of samples collected and the analysis of the inspection data.

- **Inspection team leader** – The person responsible for the field activities regarding the inspection program (including management of the inspection, surveying, and minor repair crews).

1.5 TOOLS FOR RISK ASSESSMENT AND DECISION MAKING

Based on the environmental conditions (i.e., relative humidity, moisture, and chloride conditions) inside the tendons, the qualitative corrosion risk level for the tendon and/or span can be determined. Qualitative corrosion risk levels are shown in Figure 1-2.

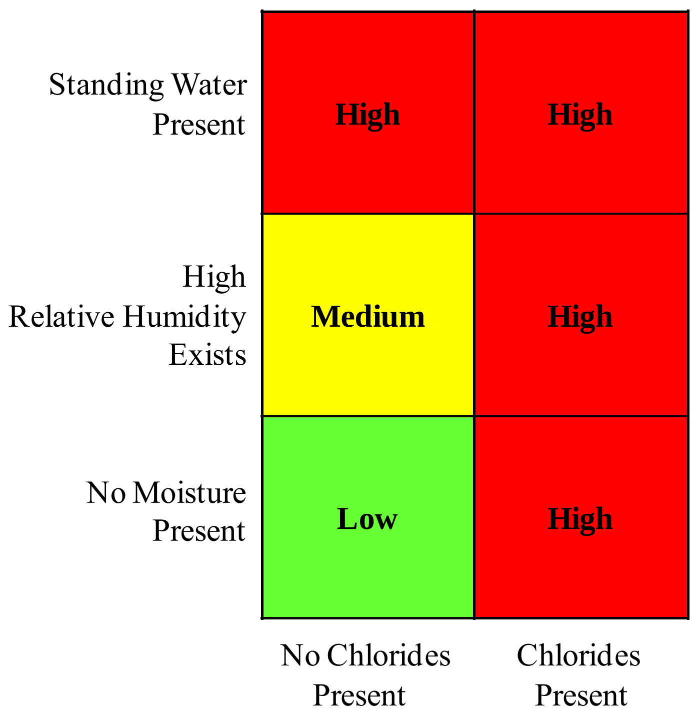


Figure 1-2. Qualitative Corrosion Risk Chart for PT Systems.

Appendix B provides examples of possible damage types that could be found on PT systems. These damage types with a particular corrosion risk level are shown in Table 1-1. Table 1-1 also summarizes the recommended actions for each damage type and/or corrosion risk level. In Table 1-1, some of the damage types are characterized by the level of corrosion on strands. Figure 1-3 provides a set of photographs of corroded strands that could assist in determining the corrosion level.

Table 1-1. Required Actions from Findings on Damage Type.

Corrosion Risk Level	Possible Damage Types*	Recommended Actions
Low (Green)	• No damage • Small void without other damage indicators • No strand corrosion*	• No repair • Continue regular inspections
Medium (Yellow)	• Cracked PT ducts, drainage pipe, spalled concrete with corrosion products (not from tendons), exposed grout cap, or opened grout port • Corrosion of anchor head plate or reinforcement at anchorage zone • Low levels of strand corrosion*	• Minor repairs required • Seal the PT system or repair/replace the leaking element to prevent water and/or chloride infiltration
High (Red)	• Water present in duct with or without chlorides • Moderate or high levels of strand corrosion* • Broken strands	• Develop and implement bridge rehabilitation program and replace the corroded tendon OR • Dry the tendon, fill the voids with repair grout, and prevent water and/or chloride infiltration (if TxDOT decides to perform repair grouting)

* Characteristics of strand corrosion are provided in Figure 1-3.

Even surface
Low uniform surface corrosion
No pitting corrosion

(a)

Slightly uneven surface
Low localized or pitting corrosion

(b)

Moderately uneven surface
Moderate localized or pitting corrosion

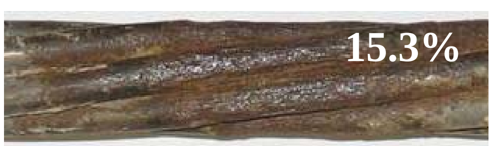
(c)

Highly uneven surface
High localized or pitting corrosion

(d)

Highly uneven surface
High localized or pitting corrosion

(e)



Highly uneven surface
High localized or pitting corrosion

(f)

Note: 1 kip = 4.45 kN

Figure 1-3. Photographs Showing the Typical Tensile Strength, Corrosion Level, and Surface Characteristics of Strands (Note: These photographs were taken after cleaning the strand surface using a synthetic cleaning pad and/or a steel wire brush).

2 SPECIAL INSPECTION AND ANALYSIS PROGRAM

2.1 OBJECTIVES

The objectives of the special inspection program are to:

1. identify the type and location of damage in PT systems;
2. identify voids and their locations in PT systems;
3. identify the presence of moisture and/or chlorides (or the indicators that water has been present) in the PT system;
4. identify the causes and locations of water and/or chloride infiltration; and
5. collect the water samples, if present, and evaluate the chloride concentrations and pH.

The special inspection team leader will submit the findings to the special inspection program manager, who will then assess the "qualitative corrosion risk of the bridge span" and make further decisions for the in-depth inspection and testing program, if needed.

2.2 SAFETY

General safety precautions must be taken. Both personnel and public safety requirements must be met by following standard TxDOT requirements. Note that a segmental, PT bridge may be considered a "confined space" and that inspectors may require appropriate training.

2.3 PLANNING, SCHEDULING, AND EQUIPMENT

Planning and scheduling

Based on bridge files, records, and other factors, the inspection program manager will develop the overall strategy for the special inspection program. It is recommended that special inspections be performed shortly after heavier rains or during the rainy season. This will allow the inspector to identify if water is present, before evaporation or drying. The inspection program manager will also identify the bridge spans for inspection and provide this information to the inspection team leader. The inspection team leader will be responsible for detailed planning and management of the field activities.

Tools and equipment for special inspection

Table 2-1 lists recommended tools and equipment required for special inspections. Note that this list may not be comprehensive.

Table 2-1. Recommended Tools and Equipment for Special Inspection.

Safety Tools	Special Inspection Tools
Hard hats	Special inspection form and pen
Head flashlights	Clipboard
Handheld flashlights	Steel tapping hammer (for inspecting voids in tendons)
Safety goggles	Mirrors (for inspecting damage underneath ducts)
Protective coveralls	Paint marker
Yellow safety vests	Spray paint that can be clearly seen (lighter colors)
Gloves	Plastic bottles (e.g., 80 ml) for collecting water samples
Respirators	Plastic pipette to collect water samples
Dust masks	Thermometer (for measuring temperature)
Ear plugs	Hygrometer (for measuring relative humidity)
First-aid kit	Tools for making holes (dremel with copper drill bit)
Extra batteries	HDPE pipe pieces and ABS cement to seal the ducts
Fire extinguisher	Digital camera
Air horn	Lift truck
Safety harness and rope	Binder with all papers (inspection manual, blue print, etc.)
Safety boots	Wet wipe to clean the duct surface
Hand-held radios (Walkie-talkie)	Wood and saw (for holding the door open) or chain and latch
Oxygen meter and CO meter	Keys and tools required to unlock and open the access door
Confined space training manual	
Drinking water	

Notes: HDPE – High density Polyethylene; ABS - acrylonitrile butadiene styrene; CO – Carbon monoxide

2.4 SPECIAL INSPECTION FORMS, TEST SAMPLES, AND REPORTS

The data from the special inspection of each span should be recorded on the "special inspection form." Each span inspected will require at least one form. Figure 2-1 and Appendix C provide examples of the special inspection forms.

Note: This only applies to segmental PT bridges

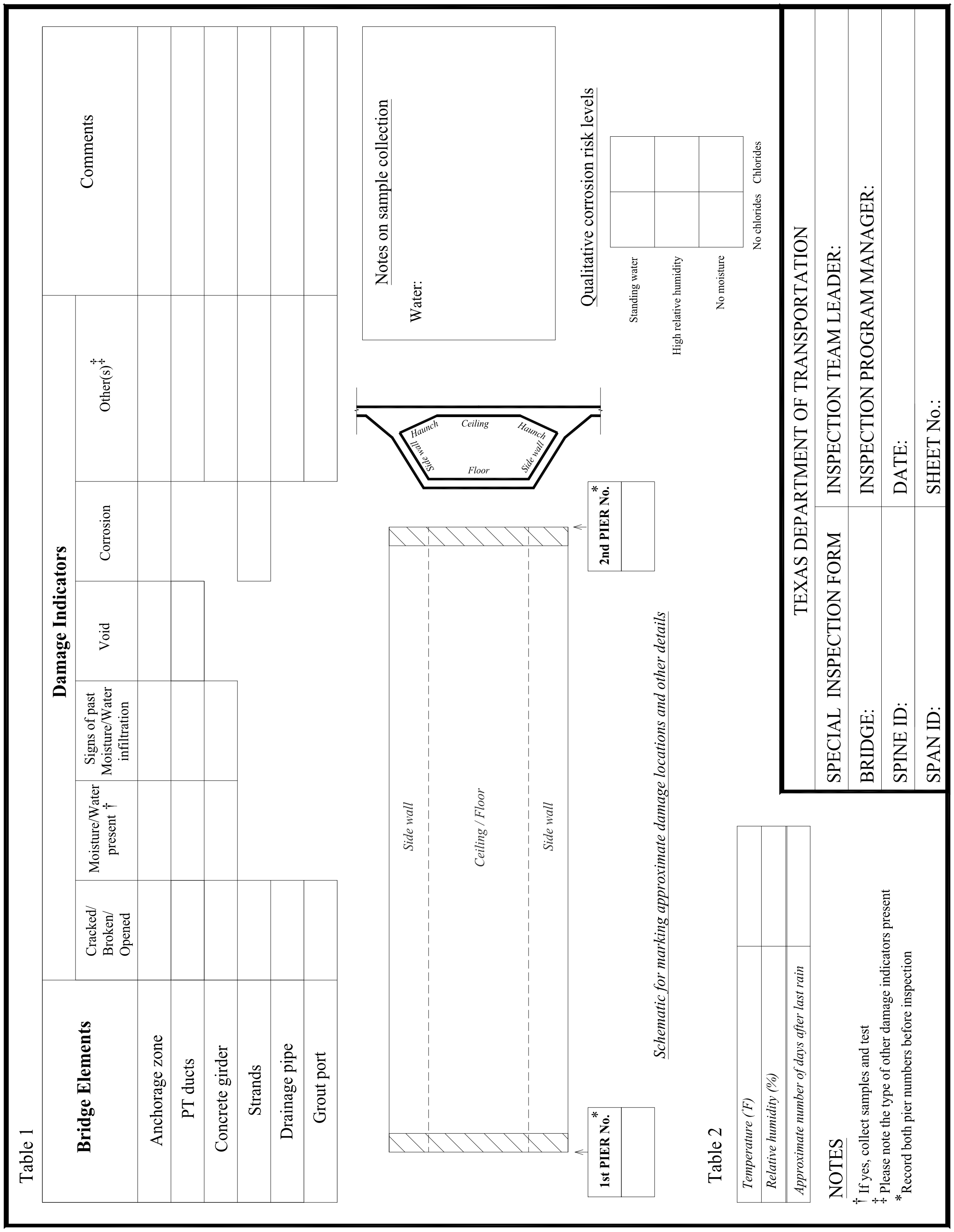


Table 1

Bridge Elements	Damage Indicators						Comments
	Cracked/ Broken/ Opened	Moisture/Water present †	Signs of past Moisture/Water infiltration	Void	Corrosion	Other(s)‡	
Anchorage zone							
PT ducts							
Concrete girder							
Strands							
Drainage pipe							
Grout port							

Notes on sample collection

Water:

Qualitative corrosion risk levels

	No chlorides	Chlorides
Standing water		
High relative humidity		
No moisture		

Table 2

Temperature (°F)	
Relative humidity (%)	
Approximate number of days after last rain	

NOTES

† If yes, collect samples and test
‡ Please note the type of other damage indicators present
* Record both pier numbers before inspection

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SPECIAL INSPECTION FORM	INSPECTION TEAM LEADER:
BRIDGE:	INSPECTION PROGRAM MANAGER:
SPINE ID:	DATE:
SPAN ID:	SHEET No.:

Figure 2-1. Special Inspection Form.

The special inspection team leader will also submit the test samples, if any, collected during the special inspection to the inspection program manager, who will then submit the test samples to the testing laboratory to obtain the test results. A "chain of command form" shall be maintained for all the samples collected.

2.5 GENERAL PROCEDURES IN SPECIAL INSPECTION AND ANALYSIS

This subsection provides the procedures to perform the special inspection program. Figure 2-2 shows the detailed flowchart for the special inspection and analysis. Note that the inspection program manager is responsible for the procurement of the bridge files and records and development of the special inspection and analysis strategy. The following steps provide the special inspection procedures. The bulleted steps in the following list start with a code (e.g., R-1) that represents the corresponding box in the flowchart. In the flowchart, the boxes inside the larger box with a thick border indicate the steps in the special inspection. The boxes outside the larger box indicate the procedures before and after the special inspection.

- **R-1**: Identify the starting and ending spans to be inspected.
- **R-2**: Select bridge files associated with the select bridge spans to be inspected and other relevant information. Collect files showing tendon profiles (indicating anchorage locations).
- **R-3**: Procure necessary tools and equipment before entering the starting span. Refer to Subsection 2.3 for the recommended list of tools and equipment.
- **R-4**: Take copy of the special inspection form for each span under inspection. Then record the following:
  - all information (except engineer's name) in the title box,
  - both pier numbers of the span in the appropriate boxes in the schematic shown, and
  - the environmental data (in Table 2).
- **R-5**: Table 1 on the special inspection form (Figure 2-1) shows different bridge elements and damage indicators or types. Typical photographs of these damage indicators are shown in Appendix B. Identify the presence of these damage indicators on the PT systems. If found, record the presence of these damage indicators in Table 1 of the special inspection form.
  - Damage types other than the types shown in Appendix B may also be observed. In such instances, photographs should be taken and information recorded as directed in the special inspection form.
  - If damage (such as cracked ducts, opened grout holes) is identified, then:

– mark the damage and its location and type in the special inspection form, and

– mark the damaged area on the PT system, if any, with spray paint.

▪ If exposed strands are found, take photographs.

- **R-6**: Inspect for voids using sounding tests[1] at random locations along the sides of the tendons. If voids are found, then record the information in the table in the special inspection form.

- **R-7**: Inspect for the presence of water in the girder.
  ▪ Check for the presence of standing water on the floor of the girder. If water is found, then mark the location on the drawing in the special inspection form. Also, look for possible sources of water ingress and mark them on the special inspection form.

- **R-8**: Inspect for the presence of water inside the tendons.
  ▪ Identify the tendons that do not extend through the expansion joints (such as T1, T2, and T3 tendons shown in Figure 2-3 [a]). Select tendons and perform the following steps.

  ▪ Identify a location to drill a 1/8-inch diameter hole on the horizontal portion of the duct between the deviator blocks (details are provided in Figure 2-3 [a] and [b]). Special drill bits made of copper are required to avoid strand damage.

  ▪ Place a plastic container such that the draining water, if any, can be collected.

  ▪ If water drains out of this hole, then:

  – collect the draining water into a small plastic bottle and fill out the chain of command form;

  – locate and check whether or not the grout hole at the anchorage of this tendon is opened or damaged; and

  – record all the information regarding the presence of water, possible sources and locations of water ingress, and sample collection on the special inspection form.

  ▪ Seal the 1/8-inch diameter hole using an HDPE pipe piece and cement (see Figure 2-3 [c] for details).

- **R-9**: Submit all the completed special inspection forms and test samples, if any, to the inspection program manager.

[1] The sounding test is a procedure used to identify the presence of voids based on the noise produced by tapping of the duct surface using a metallic impact tool (typically a small hammer). A dull or low-pitch sound indicates the presence of voids. A high-pitch sound indicates a fully grouted tendon (i.e., no voids). This research found that the small void or "bleed line" along the top part of the tendon was not detrimental to the corrosion of strands, so this area, if small, does not need to be drawn on the special inspection form. It is recommended that sounding be performed along the sides of PT ducts to identify large voids.

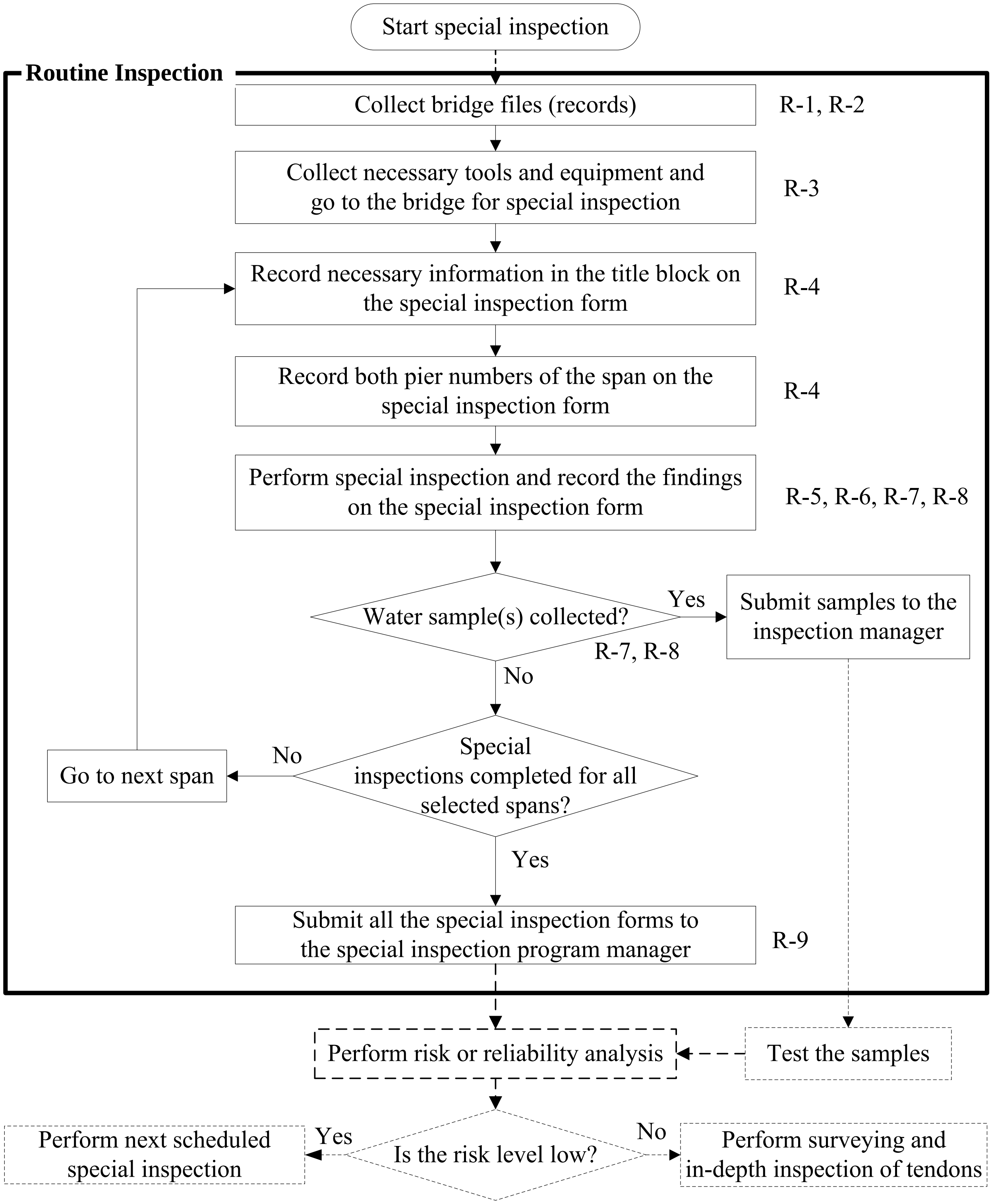
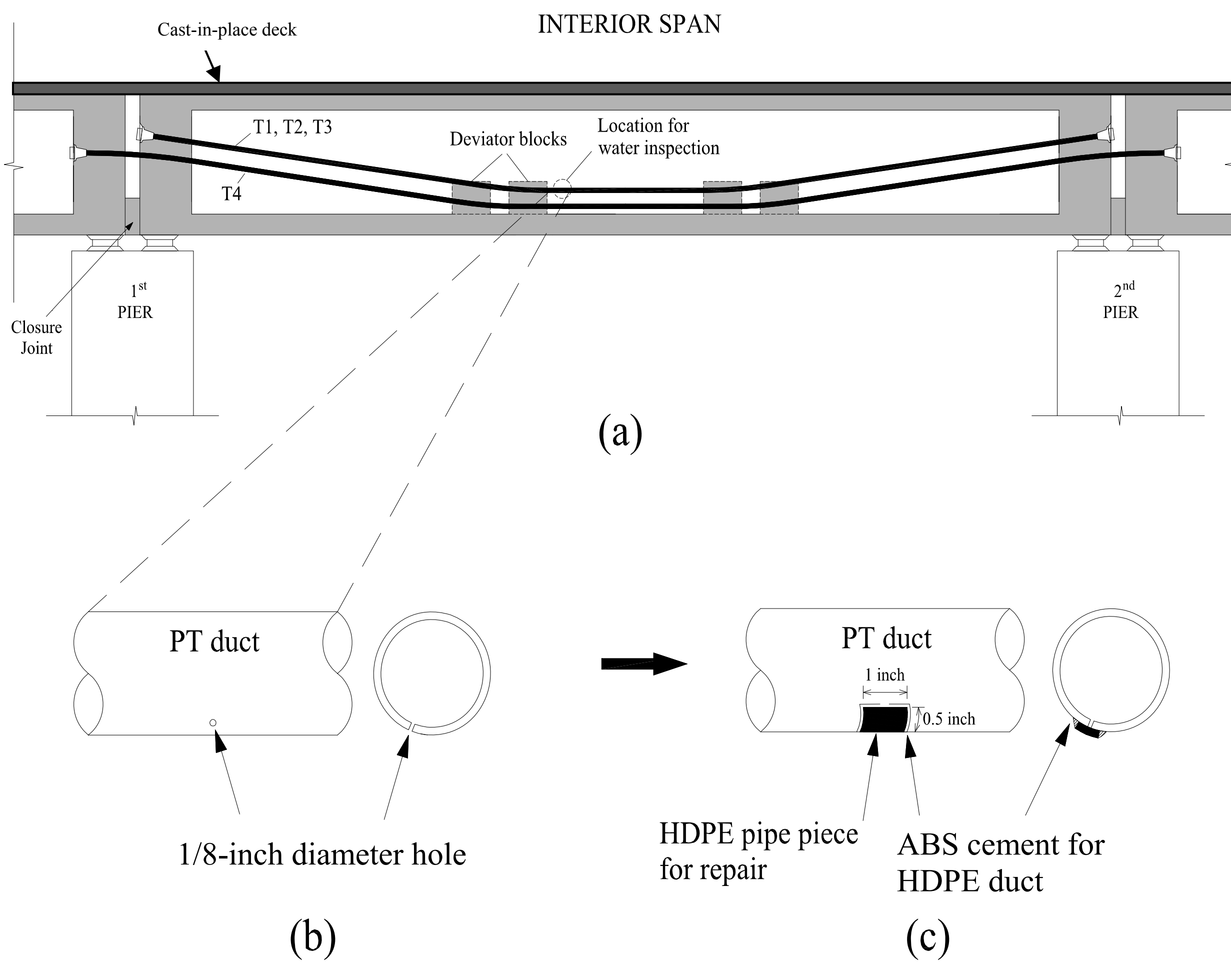


Figure 2-2. Flowchart of Special Inspection and Analysis.



Note: 1 inch = 25.4 mm

Figure 2-3. Tendon System Showing (a) the Location for Water Inspection, (b) a Close-up of the Location for Water Inspection, and (c) the Sealed Duct after Water Inspection.

3 SURVEYING THE TENDONS

3.1 OBJECTIVES

The tendons selected for in-depth inspection need to be surveyed such that inspectors can quickly determine location of voids or other damaged areas. This section provides general procedures to survey the tendons.

3.2 GENERAL PROCEDURES IN TENDON SURVEY

The two main tasks for surveying include performing a survey along tendon profiles and documenting the location of anchorage zones (diaphragms) and deviator blocks on the in-depth inspection form. Figure 3-1 shows a flowchart of the tendon surveying process.

- **S-1 to S-2**: Prepare the information and equipment for surveying.
  - Check all tools and equipment required before entering the surveying span.
  - Go to the span.
  - Record all the information in the title block on the in-depth inspection sheet.
- **S-3 to S-4**: Record the starting point.
  - The start point in each span is designated by the order of numbering spans. Thus, the diaphragm located toward the lower numbered span is the start point in spans. (See Figure 3-2—Section A-A is the starting point on this span.)
  - Record the pier number under the starting point.
- **S-5 to S-9**: Mark the dimensions along the length of the tendons.
  - Mark segment numbers using marking spray and stencil (if needed) (see Subsection 3.3).
  - Mark tendon numbers using marking spray and stencil (see Subsection 3.3).
  - Measure the thickness of both diaphragms. This is to estimate the length of the portion of the tendon embedded inside the concrete diaphragm (see Figure 3-4).
  - Mark survey stations at every foot from the inside diaphragm at the start point (as shown in Figure 3-4 and Figure 3-5) until a deviator block is reached.
  - See Figure 3-4 and Figure 3-5 to see an example showing how the deviator blocks are marked on the in-depth inspection form. Document locations of deviator block on the in-depth inspection form. Continue marking the dimensions until entire tendon length is marked.
  - Perform marking with a paint marking pen.
- **S-10 to S-12:** After completing the survey, submit all the in-depth inspection forms to the inspection program manager.

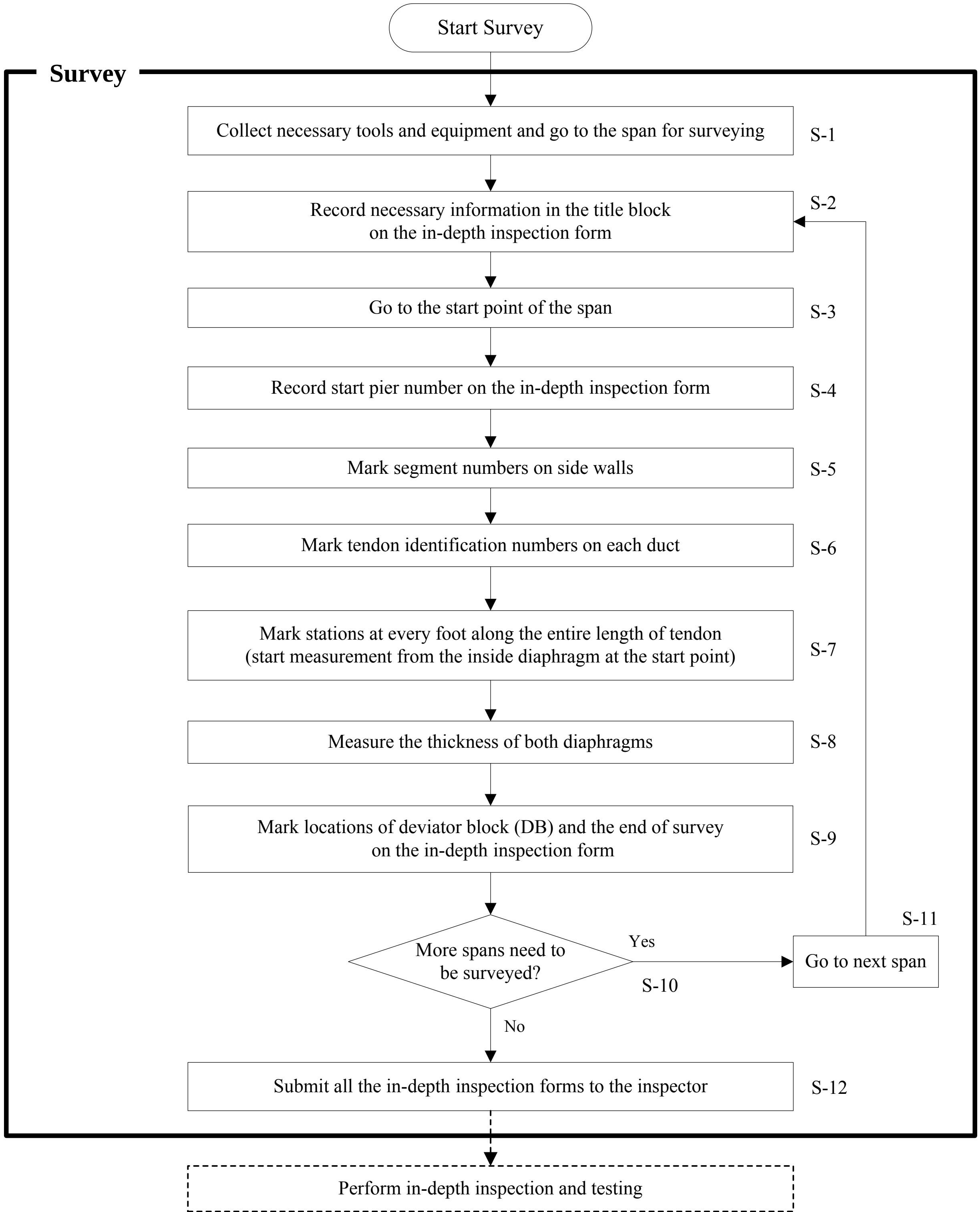


Figure 3-1. Flowchart for Surveying the Tendons and Segments.

3.3 NUMBERING THE TENDONS AND SEGMENTS

Standardization of numbering the tendons and segments is critical in the management of bridge tendon conditions. Inspectors must mark the PT ducts and segments in a clear and readable manner.

Figure 3-2 provides a general idea on the numbering of spans and piers on a typical PT bridge. Figure 3-3 shows the schematic of a typical tendon identification system. The two sectional views shown correspond to the first and second piers in Figure 3-2. The cross-section of a girder is divided into left (L) and right (R) sides. However, the left side and right side can be reversed if the surveying direction is reversed. Figure 3-2 and Figure 3-3 show that the survey and inspection are in the same direction as the increasing span numbers. Hence, "Left" means the left side when looking down the span into the direction of increasing span numbers (the direction of inspection).

The numbering of segments begins at the start point of the surveying and inspection in each span. Thus, the numbering of segments increases in the same direction as the span number increases and follows standard procedures. Numbering segments can be performed using permanent markers or paint and stencil. This should be done for every segment in a girder.

3.4 MARKING THE CONCRETE DIAPHRAGMS AND DEVIATOR BLOCKS

First, inspectors measure the thickness of both diaphragms. The portion of the tendon outside the diaphragm is then surveyed. The "start point" in the in-depth inspection form is defined as the point at which the tendon comes out of the diaphragm. Then location of the deviator blocks from this "start point" is measured. The deviator blocks are marked on the in-depth inspection form. The total length of the tendon will be estimated by the inspection manager. The "end of survey" point is defined as the point which the far tendon enters into the concrete diaphragm. This is also marked in the in-depth inspection form. These are shown in Figure 3-4 and Figure 3-5. Considering the smooth duct surface and the lack of daylight, a yellow paint marker is recommended as the marking tool. Figure 3-6 shows the interior view of a span, after surveying.

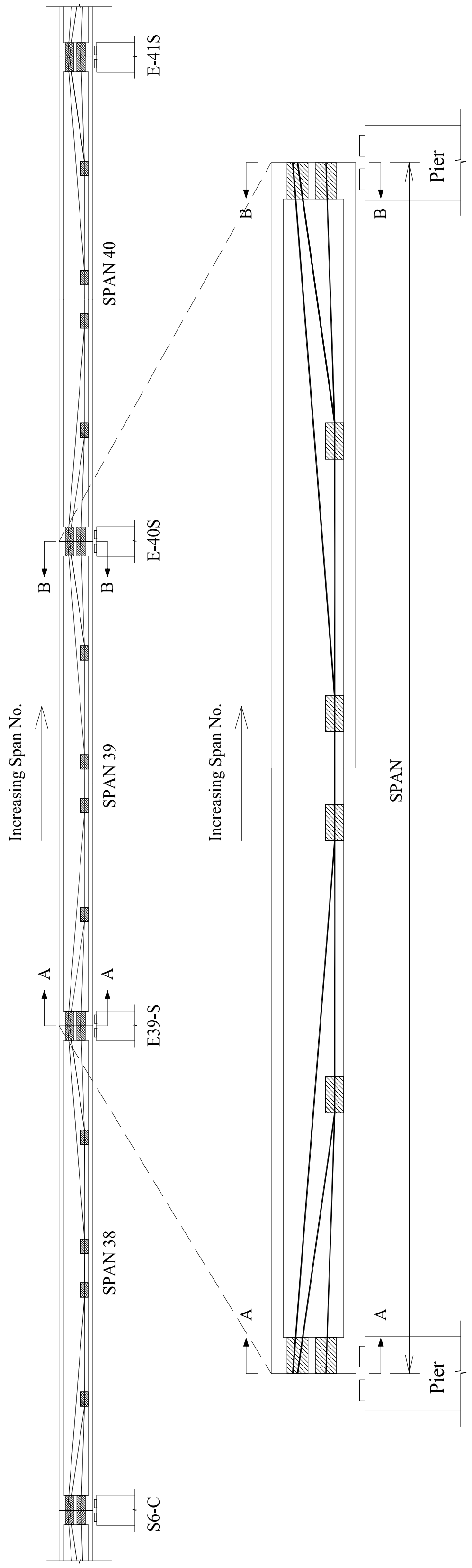


Figure 3-2. Typical View of an External Tendon System Showing the Span and Pier Identification Systems.

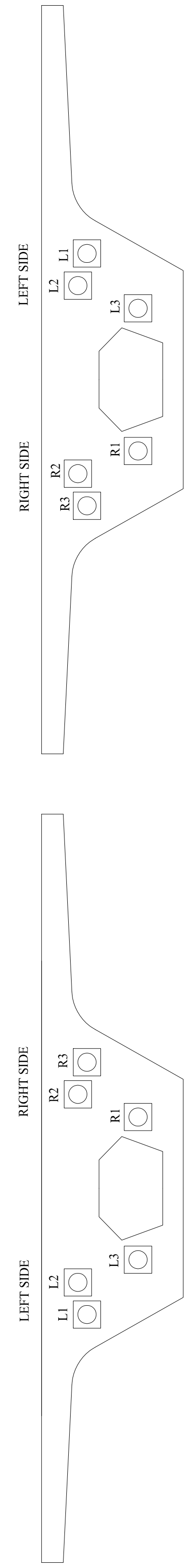


Figure 3-3. Typical Numbering System for Tendons of a PT Girder.

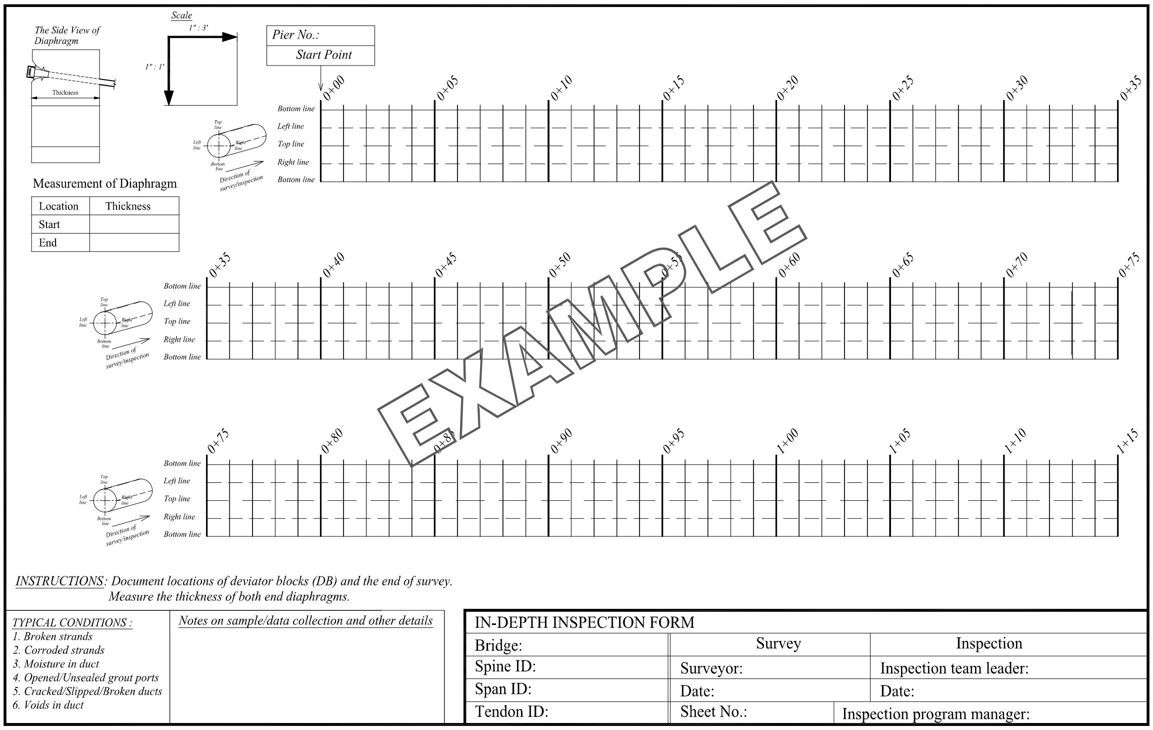


Figure 3-4. In-Depth Inspection Sheet before Marking Location of Deviator Block.

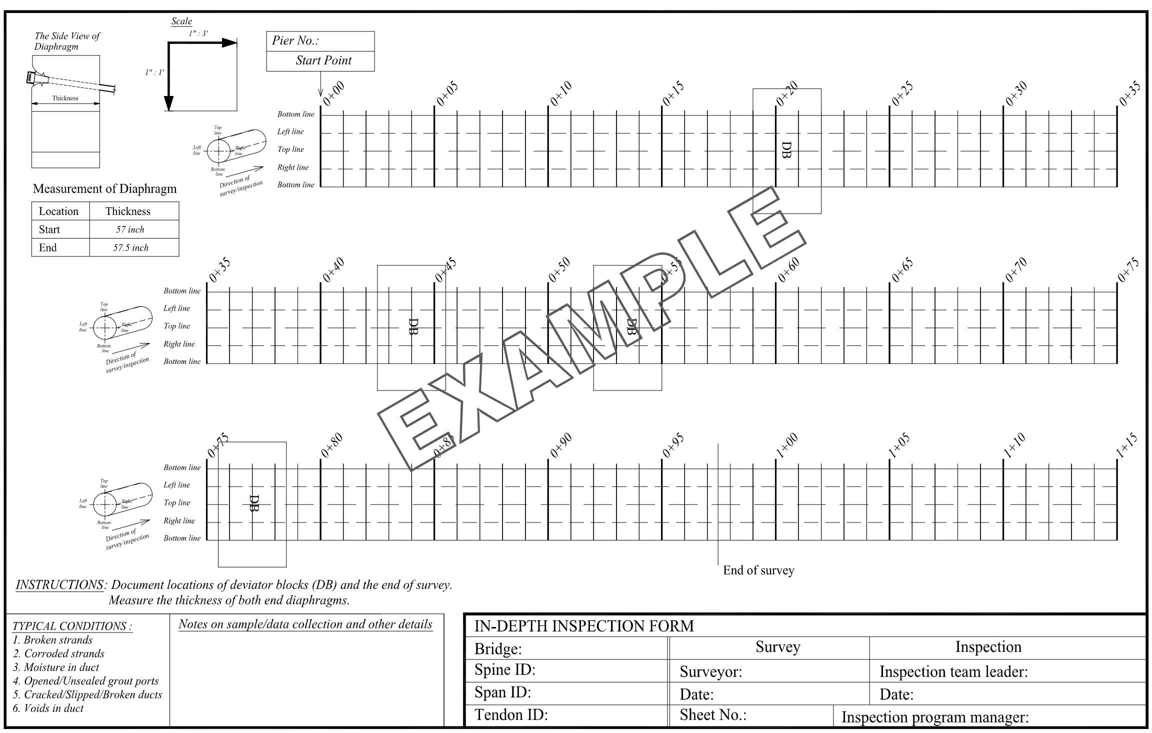


Figure 3-5. In-Depth Inspection Sheet after Marking Location of Deviator Block.

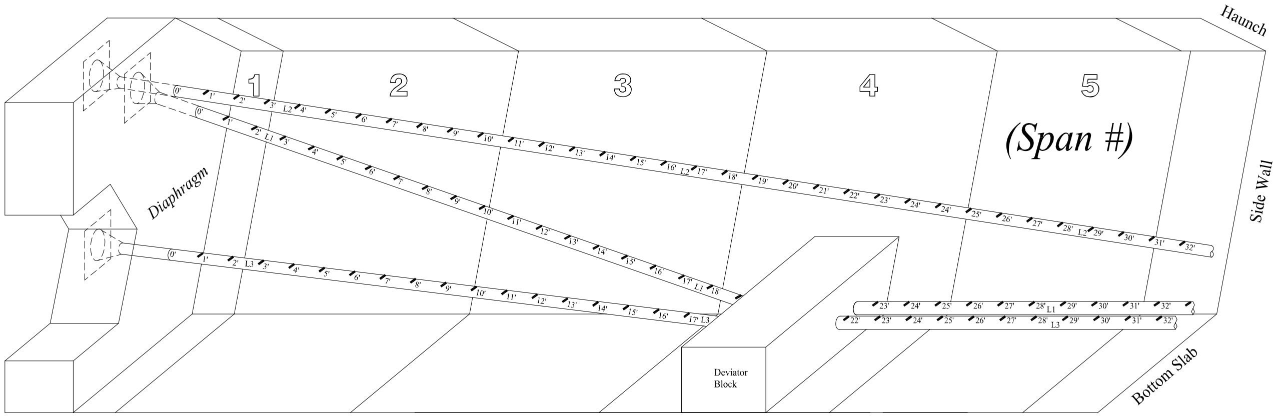


Figure 3-6. An Isometric Interior View of a Bridge Girder (after Surveying).

4 IN-DEPTH INSPECTION, ANALYSIS, AND REPAIR PROGRAM

4.1 INTRODUCTION AND OBJECTIVES

This in-depth inspection is intended to be performed if the special inspection program has indicated that further inspections are needed. The in-depth inspection will require more time, will be more costly, and will require larger opening holes in the ducts of PT tendons. However, this inspection will also provide qualitative information on the condition of the strands, providing relevant information on the condition of the bridge.

The objectives of the in-depth inspection program are to:

1. identify the type and location of damage in PT systems;
2. identify the size and location of voids in PT systems;
3. identify the presence of moisture and/or chlorides (or the indicators that water has been present) in the PT system, especially at the interface between the void and grout;
4. identify and confirm the causes and locations of water and/or chloride infiltration;
5. collect the water samples, if present, and evaluate the chloride concentrations; and
6. collect photographs of strands and identify the level of corrosion of strands.

The in-depth inspection team leader will submit the findings to the in-depth inspection program manager, who will then assess the “qualitative corrosion risk of the bridge span” and make further decisions for the in-depth inspection and testing program, if needed.

4.2 SAFETY

General safety precautions must be taken. Both personnel and public safety requirements must be met by following standard TxDOT requirements. Note that a PT bridge may be considered a “confined space” and that inspectors require appropriate training.

4.3 PLANNING, SCHEDULING, AND EQUIPMENT

Planning and scheduling

Based on the data from special inspections, bridge files, records, and other factors, the in-depth inspection program manager will develop the overall strategy for the in-depth inspection program. The in-depth inspection program manager will also identify the bridge spans for inspection and provide this information to the inspection team leader. The inspection team leader will be responsible for detailed planning and management of the field activities.

It is recommended that in-depth inspections, if needed, be performed by the same inspection crew. It is also recommended that in-depth inspections be performed immediately after the special inspections (during the same season) to prevent further deterioration.

Tools and equipment for in-depth inspection

Table 4-1 provides a list of recommended tools and equipment required for in-depth inspections. Note that this list may not be comprehensive.

Table 4-1. Tools and Equipment for In-Depth Inspection.

Safety Tools	In-depth Inspection Tools
Hard hats	Inspection form, clipboard, and pen
Head flashlights	Steel tapping hammer (for identifying voids in ducts)
Handheld flashlights	Mirror (for inspecting damages underneath ducts)
Safety goggles	Borescope
Protective coveralls	Generator (with gas and oil) for borescope
Yellow safety vests	Extension cord
Gloves	Tools for making holes (dremel with copper drill bit)
Respirators	Sealing tools (e.g., HDPE pipe piece, ABS cement, etc.)
Dust masks	Paint marker
Ear plugs	Spray paint (light color)
First-aid kit	Plastic vials for water samples
Extra batteries	Plastic pipette to collect water samples
Fire extinguisher	Plastic bags for grout samples
Air horn	Tweezers (for picking grouts in ducts)
Safety harness and rope	Digital camera
Safety boots	Binder with all papers (inspection manual, blue print, etc.)
Hand-held radios (Walkie-talkie)	Lift truck
Oxygen meter and CO meter	Keys and tools required to unlock and open the access door
Confined space training manual	Wet wipe to clean the duct surface
Drinking water	Wood and saw (for holding the door open) or chain and latch
Oxygen meter and CO meter	

4.4 IN-DEPTH INSPECTION FORMS, TEST SAMPLES, AND REPORTS

The data from the in-depth inspection of each span should be recorded on the "in-depth inspection form." Each span inspected will require at least one form. Figure 4-1 shows a sample copy of the in-depth inspection form.

The in-depth inspection team leader will submit test samples, if any, collected during the in-depth inspection to the in-depth inspection program manager, who will then submit the test samples to the testing laboratory to obtain test results. A chain of command form shall be maintained for all the samples collected.

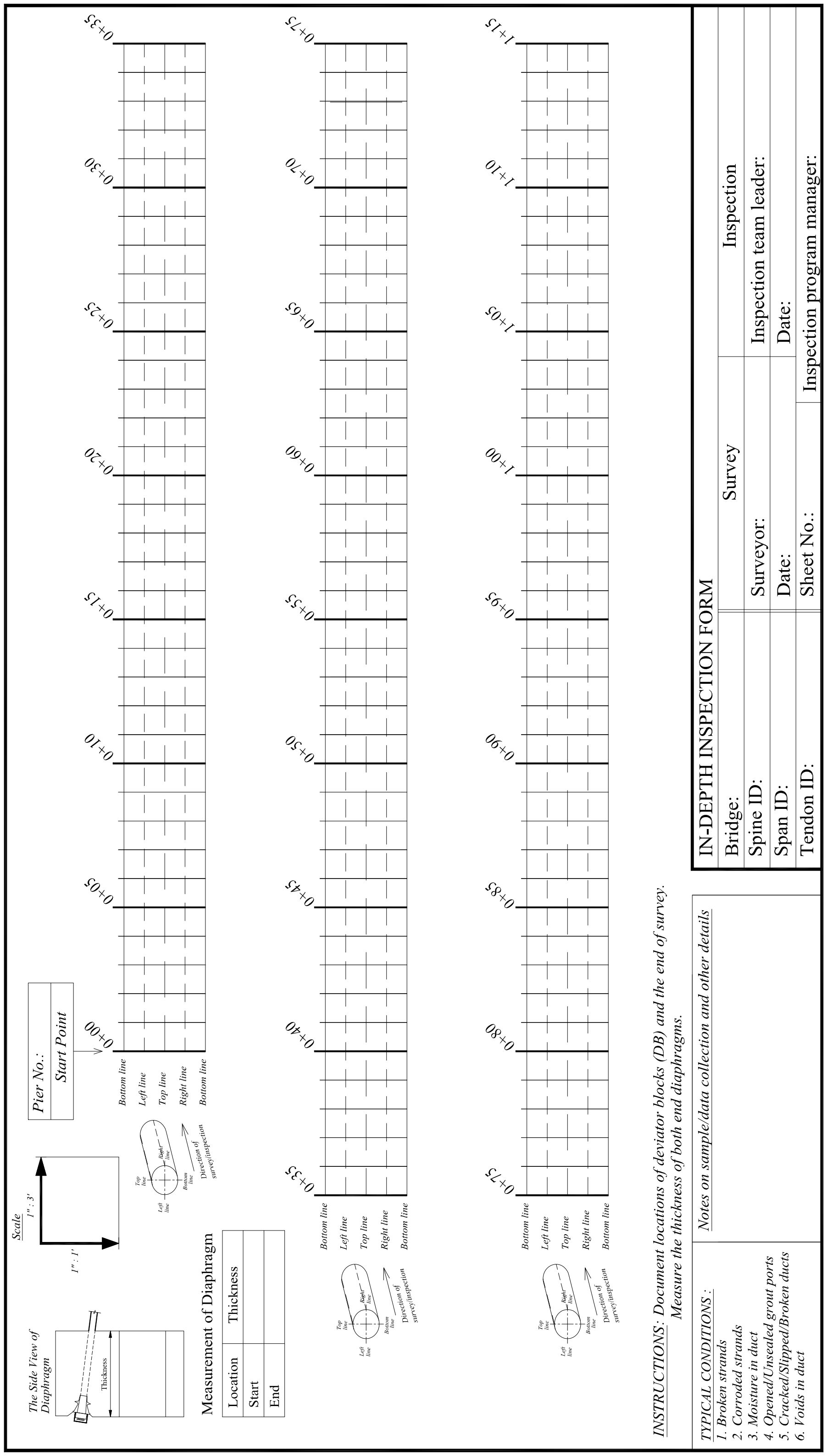


Figure 4-1. In-Depth Inspection Form.

4.5 General Procedures in In-Depth Inspection

The in-depth inspection consists of more detailed evaluation techniques than the special inspections. These evaluation techniques include more detailed visual inspections, some with a borescope. Note that the inspection program manager is responsible for the procurement of the bridge files and records and development of the in-depth inspection strategy. It is also required that the tendons for inspection be surveyed before beginning the in-depth inspection program. The following steps provide the in-depth inspection procedures. The bulleted steps in the following discussion start with a code (e.g., I-1) that represents the corresponding box in the flowchart. The procedures for performing such an in-depth inspection follow. Figure 4-2 shows the flowchart of the process. In the flowchart, the activities inside the larger box with a thick border indicate the steps in the in-depth inspection. The activities shown outside the larger box are procedures required before and after the in-depth inspection.

- **I-1 to I-3**: Perform initial preparation.
  - Identify the spans to be inspected.
  - Select the bridge drawings associated with the select bridge span.
  - Procure necessary tools and equipment before entering the bridge (refer to Table 4-1).
  - Record the inspector name and inspection date on the in-depth inspection form. (This form should have the information from the tendon survey.)
  - Go to the starting span.
  - Identify tendons that need further assessment.
- **I-4**: Perform in-depth inspection at the anchorage zone.
  - If access through the grout hole is possible, then inspect for potential voids and strand corrosion using a borescope. If possible, take photographs of the exposed strand showing the level of corrosion.
  - Record the strand condition in the bottom left box on the in-depth inspection form. Figure 1-3 shows the photographs of strands with different levels of corrosion.
  - If the presence of water is found, then collect the water into a small plastic bottle (using a hand-held vacuum and tubing) and record the information on the in-depth inspection form.

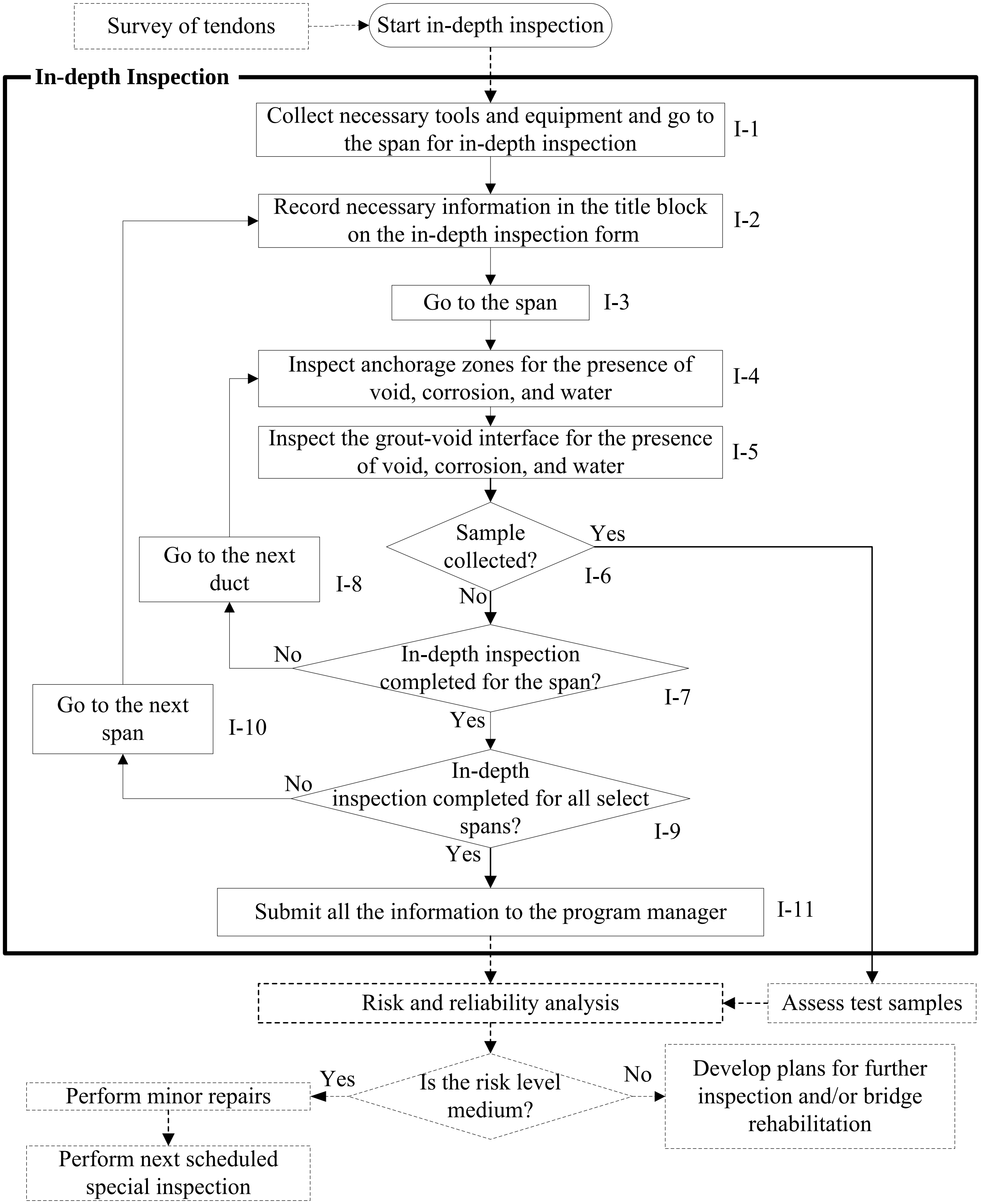


Figure 4-2. Flowchart of the In-Depth Inspection and Analysis.

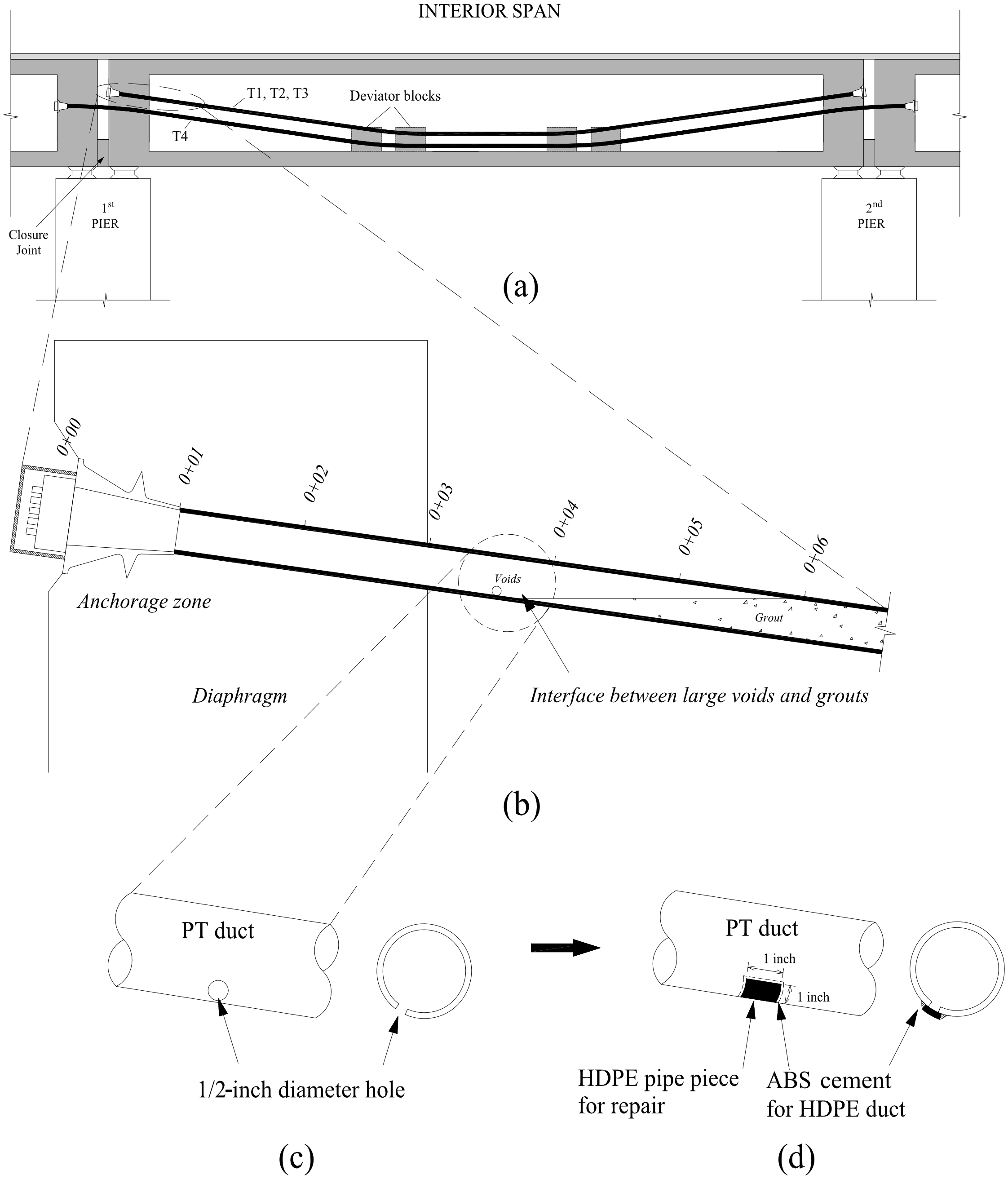
- **I-5**: Perform detailed inspection inside the tendons, especially at the grout-void interface.
  - Using the sounding procedures given in Section 4.6, draw the void profile on the in-depth inspection form.
  - Identify a location to drill a 1/2-inch diameter hole[2] at the grout-void interface, as shown in Figure 4-3 (a), (b), and (c).
  - Place a plastic container such that the draining water, if any, can be collected.
  - If water drains out of this hole, then:
    - Collect the draining water into a small plastic bottle.
    - Record all the information regarding the presence of water onto the in-depth inspection form.
    - Insert the insertion tube of the borescope through the 1/2-inch diameter hole and inspect the level of corrosion of strands at the grout-void interface. Take photographs of the strands.
  - After the inspection using the borescope is completed, seal the 1/2-inch diameter hole as shown in Figure 4-3 (d) such that strands are protected from the outside environment.

- **I-6**: Perform sample collection and testing.
  - Collect test samples (solution or grout samples), if deemed necessary. Water samples can be collected from standing water in the box girder or from inside tendons. Samples must be identified with the location of collection (i.e., from girder or from a tendon).
  - Label the samples and record additional information, such as sample ID, sample location, etc. Use "notes on sample/data collection and other details" on the in-depth inspection form for recording this information, and also document this information on the chain of command form.
  - Submit the collected samples to the inspection program manager, who will then transport samples to the laboratory for assessment.
  - The laboratory will test the chloride concentration and pH in the samples.
  - The laboratory will then return results to the in-depth inspection program manager for assessment or to provide better information for the reliability analysis.

- **I-7 to I-10**: Perform in-depth inspections on all tendons identified as having potential voids or durability issues. After completing the in-depth inspection on the span, transfer the tools and materials to the next span.

- **I-11**: After completing the in-depth inspection, inspectors should submit in-depth inspection forms to the program manager for further analysis and decision making regarding performing minor repairs or developing rehabilitation programs.

[2] The 1/8-inch copper drill bit (used in the special inspection) can be used for this purpose. First, draw a 1/2-inch diameter circle on the duct surface. Then, drill several 1/8-inch diameter holes along the circumference of the marked circle until a 1/2-inch diameter hole is formed.



Note: 1 inch = 25.4 mm

Figure 4-3. Tendon System Showing (a) the Location of Water Inspection for In-Depth Inspection, (b) a Close-up View of Area for the Water Inspection, (c) a Close-up of Location for Water Inspection, and (d) the Sealed Duct after Water Inspection.

4.6 VOID PROFILING OF TENDONS USING SOUNDING TESTS

The objective of the in-depth sounding technique is to detect voids to identify grout-void interface locations. This information should be recorded on the in-depth inspection form (Figure 4-1). Note that the grids on the in-depth inspection form indicate the unrolled duct surface by cutting the bottom line of ducts, as shown in Figure 4-4. Inspectors should tap all around the PT ducts with a tapping hammer and perform this inspection for each PT duct separately. Figure 4-5 shows the marking for the voids in PT ducts. This void profile assists in identifying the grout-void interface in tendons.

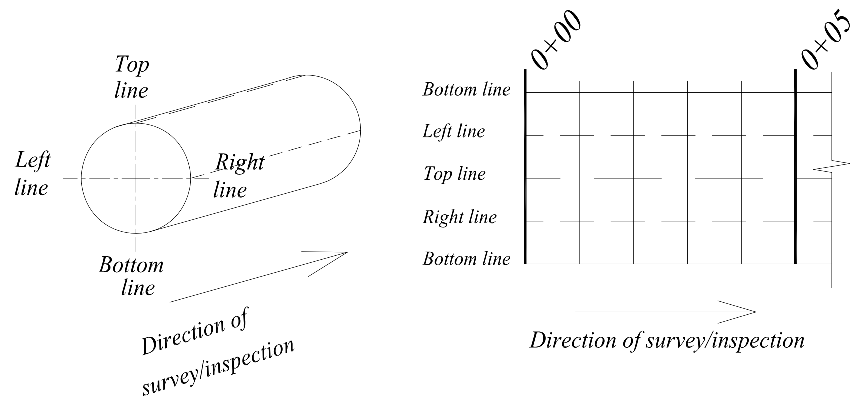


Figure 4-4. Unrolled Duct Surface in the Grids on In-Depth Inspection Form.

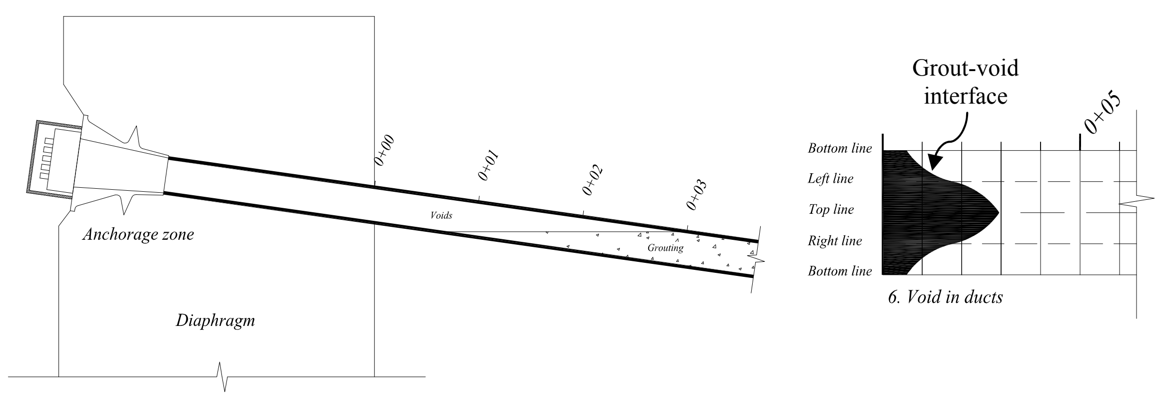


Figure 4-5. Marking Voids on the In-Depth Inspection Form.

APPENDIX A. REPAIR GROUTING PROCEDURE

INTRODUCTION

Repair grouting is defined as the process of filling the voids in a tendon with a repair grout. Currently, the vacuum grouting (VG) method is the recommended repair grouting method. This method is capable of adequately filling voids in ducts but is very expensive and time-consuming. This is because the VG method requires an air-tight tendon, which is hard to achieve in the field. By taking these difficulties into account, Research Project 0-4588 developed and recommended a feasible repair grouting method, the pressure-vacuum grouting (PVG) method. Further details of the methodology and evaluation of this method are given in Volume 2 of Research Report 0-4588-1.

The PVG method utilizes the beneficial characteristics of both pressure grouting (PG) and VG methods. The PVG method has the same filling capability and filling performance as the VG method and better economic feasibility than the VG method. This manual provides general procedures for the PVG method. Based on the recommendations from the in-depth inspection program manager, the repair program manager identifies the tendons to be repair grouted.

SAFETY

General safety precautions must be taken. Both personnel and public safety requirements must be met by following standard TxDOT requirements. Note that a PT bridge may be considered a “confined space” and that inspectors may require appropriate training.

PLANNING, SCHEDULING, EQUIPMENT, AND FORMS

Planning and scheduling

Based on the data from in-depth inspections, bridge files, records, and other factors, the repair program manager will develop the overall strategy for the repair program. The repair program manager will also identify the bridge tendons and/or spans for repair and provide this information to the repair team leader. The repair team leader will be responsible for detailed planning and management of the field activities. It is recommended that repair, if needed, be performed immediately after the special inspections (during the same season) to prevent further deterioration of the PT systems.

Tools and equipment for repair grouting

A list of recommended tools and equipment required for repair grouting is provided below. Note that this list may not be comprehensive.

- electrical power source,
- grout materials,
- mixing water,
- water for cleaning tools,
- measuring scale (to weigh water and grout materials),
- hand grout pump,
- vacuum pump,
- grout hose and connections,
- 10-gallon buckets (3 pieces),
- Nalgene drop-dispensing bottle (for protecting vacuum pump from grout in-flow),
- pipe saddle tap with ball valve (for connecting to air outlet),
- 2500 rpm drill with paddle (2 pieces),
- material testing devices (flow cone, 3-cube molds, 3 1000 ml cylinders with strand), and
- provision to dump or pour extra grout.

Repair grouting report form

A repair grouting report form has been developed to record all the data associated with the repair grouting and is shown in Figure A-1.

REPAIR GROUTING REPORT

BRIDGE:	SPINE ID:
SPAN ID:	SHEET No.:

1. Measurement of void volume and determination of the amount of repair grouts

- Person in charge: ____________________

Tendon ID	Void volume by volumeter (A)	Required volume (B)	w/p of repair grouts (C)	Wet density of repair grouts (D)	Weight of repair grouts (E)	Weight of water (F)

Note: document C and D from manufacture's specification; B = 1.1 * A + 0.6 ft^3 (0.017 m^3); E = B / D; F = C * E

2. Material testing

Person in charge		Date	
Temperature (˚F)		Humidity (%)	
Mixing time (min.)		Grout temperature (˚F)	
Start time of mixing		End time of mixing	

- Flow cone test (Tex-437-A Method 2)

Fresh Test	30 Min Flow Cone
Test start time:	Test start time:
Efflux time (s):	Efflux time (s):

Note: wet cone 1 min before each test; re-mix grout for 30 s before 30 min test

- Compression test (Tex-442-A)

Cube	7 days (date:)	28 days (date:)
1	ksi	ksi
2	ksi	ksi
3	ksi	ksi

- Wick-induced bleed test (Tex-441-A)

Note: $V_b = V_w - V_g$

Time	Interval	Cylinder A (ml)			Cylinder B (ml)			Cylinder A (ml)		
		V_w	V_g	V_b	V_w	V_g	V_b	V_w	V_g	V_b
	0 min									
	15 min									
	30 min									
	45 min									
	1 hr									
	2 hr									
	3 hr									
Final Measure										

3. Repair grouting

Repair Grouting Actions				Examination		
Date	Tendon ID	Person in charge	Note	Date	Repaired condition	Person in charge

Figure A-1. Repair Grouting Report Form.

GENERAL PROCEDURES FOR PVG METHOD

- **R-1 to R-2**: Perform general preparation.
  - Identify the span and tendon for repair.
  - Collect necessary tools and equipment and go to the span for repair.
  - Record all the information in the title block and Item 1 on the repair grouting report form.
- **R-3**: Perform preparation for repair grouting.
  - Document the tendon ID for repair grouting on the repair grouting report form (see Figure A-1).
  - If possible, determine (or approximate) the void volume and record on the repair grouting report form.
  - Compute the required volume of repair grouts (B) using the equation provided in the repair grouting report form. Compute the weight of the repair grout and water (E, F) required for mixing.
- **R-4:** Based on the completed in-depth inspection forms, mark the end of voids, as shown in Figure A-2.
  - If the voids on the in-depth inspection forms are continuously connected all along the PT ducts, mark the location at the middle of the PT ducts (in between deviator blocks).
  - If cracked/broken PT ducts are shown on the in-depth inspection forms, seal the damaged part with a 5-minute epoxy or cover with a neoprene sheet (the neoprene sheets should be secured with hose clamps).
  - Drill a 1-inch diameter air outlet hole using a copper drill bit at the marked locations and connect the vacuum safety device with the vacuum pump (see Figures A-3 and A-4).
  - Connect the hand grout pump to the grout port at the top of the anchorage.
  - Apply the vacuum pump until the pressure inside the tendon reduces by approximately 80 percent of atmospheric pressure (23.9 inHg). If the vacuum pump cannot reduce the pressure by 80 percent of atmospheric pressure, try to inspect the entire tendon again and seal the damaged parts with 5-minute epoxy.
- **R-5:** Prepare the repair grout mixture per manufacturer's recommendations. Perform the required material testing per specifications.
- **R-6:** Perform repair grouting by the PVG method and finishing.
  - Apply the vacuum pump to reduce pressure by 80 percent of atmospheric pressure (23.9 inHg).
  - Open the grout inlet at the top anchorage and inject repair grout using a hand grout pump.

  - Close the valve of the vacuum safety device until the hand grout pump cannot pump more grout. If the repair grout flows out of the air outlet, close the ball valve at the pipe saddle tap and apply the hand grout pump until it cannot pump more grout.
  - Turn off the vacuum pump.
  - Close the valve of the grout inlet.

- **R-7:** Disconnect the vacuum safety device and pipe saddle tap, and seal the air outlet.

- **R-8 to R-11**: Evaluate the repair grouting.
  - On the following day after repair grouting, perform sounding tests on the repaired tendons to identify voids, if remaining. Record the observed void conditions in the repaired tendon on the repair grouting report form.
  - Submit the report to the repair program manager.

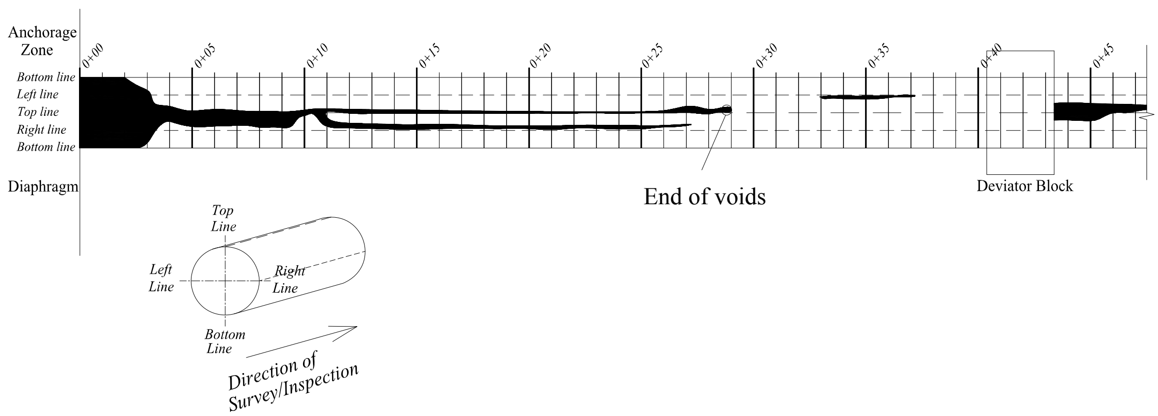


Figure A-2. Location of the End of Voids on the Detailed Inspection Sheets.

(a) (b)

Figure A-3. (a) Air Outlet Hole for PVG Method, and (b) Pipe Saddle Tap and Ball Valve for Connecting Vacuum Safety Device and Vacuum Pump.

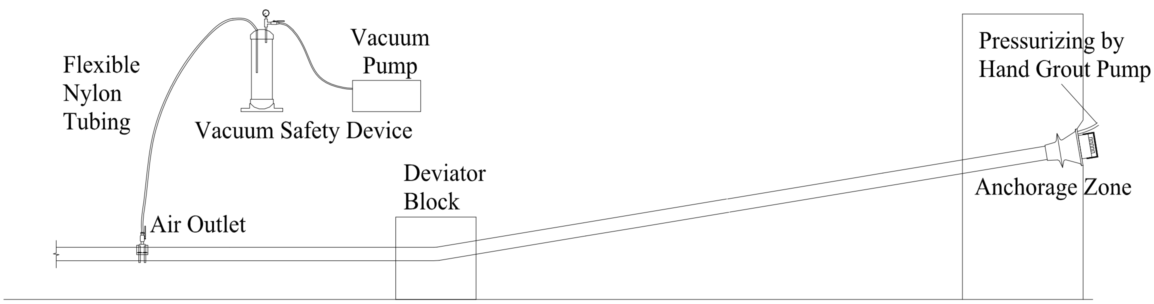


Figure A-4. Typical View for the Application of PVG Method in the Field.

APPENDIX B. DAMAGES IN POST-TENSIONED SYSTEMS

Figure A. Broken strands and broken ducts.

Figure B. Corroded and broken strands and broken ducts.

Figure C. Cracked ducts.

Figure D. Cracked ducts.

Figure E. Broken ducts and exposed strands.

Figure F. Broken ducts and exposed strands.

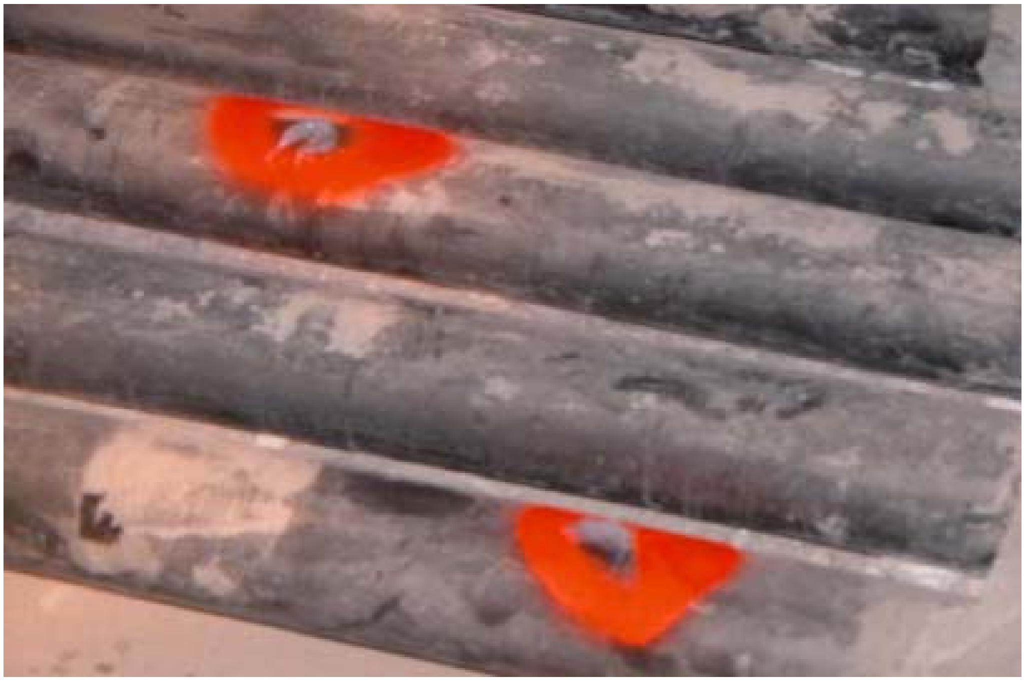


Figure G. Ducts with holes.

Figure H. Voids in tendons and corroded strands.

Figure I. Missing anchorage cap, exposed anchor head, and corroded strands.

Figure J. Loose anchorage (indicating broken strands).

Figure K. Opened grout port.

Figure L. Opened grout port, broken anchorage cap, and exposed anchorage zone.

Figure M. Standing water in the concrete box girder.

Figure N. Standing water in the concrete box girder.

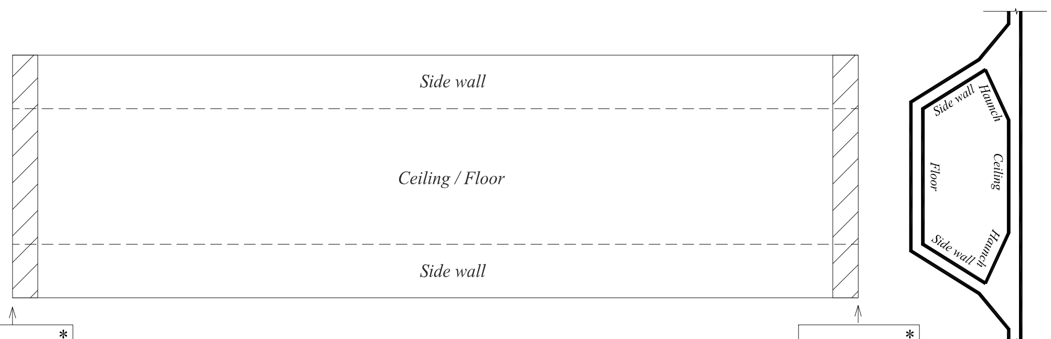
Figure O. Sign of past moisture infiltration in the concrete girder, broken drainage pipe.

Figure P. Sign of past moisture infiltration in the concrete girder, broken drainage pipe.

APPENDIX C. INSPECTION FORMS

Table 1

Bridge Elements	**Damage Indicators**						Comments
	Cracked/ Broken/ Opened	Moisture/Water present †	Signs of past Moisture/Water infiltration	Void	Corrosion	Other(s)‡	
Anchorage zone							
PT ducts							
Concrete girder							
Strands							
Drainage pipe							
Grout port							



1st PIER No.*

2nd PIER No.*

Schematic for marking approximate damage locations and other details

Notes on sample collection

Water:

Qualitative corrosion risk levels

	No chlorides	Chlorides
Standing water		
High relative humidity		
No moisture		

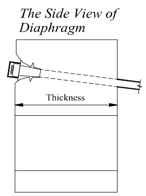
Table 2

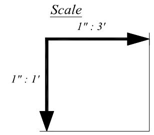
Temperature (˚F)	
Relative humidity (%)	
Approximate number of days after last rain	

NOTES

† If yes, collect samples and test
‡ Please note the type of other damage indicators present
* Record both pier numbers before inspection

TEXAS DEPARTMENT OF TRANSPORTATION	
ROUTINE INSPECTION FORM	INSPECTION TEAM LEADER:
BRIDGE:	INSPECTION PROGRAM MANAGER:
SPINE ID:	DATE:
SPAN ID:	SHEET No.:

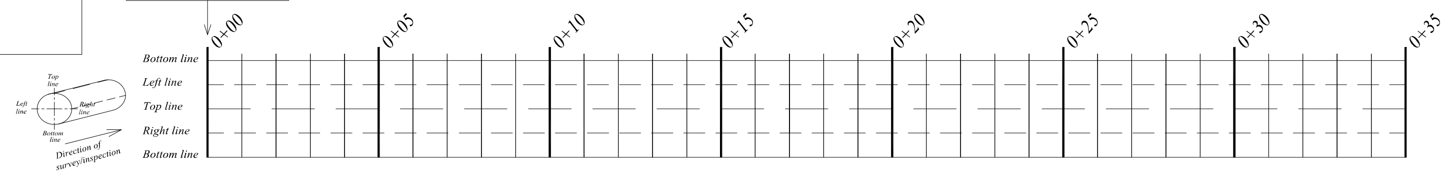


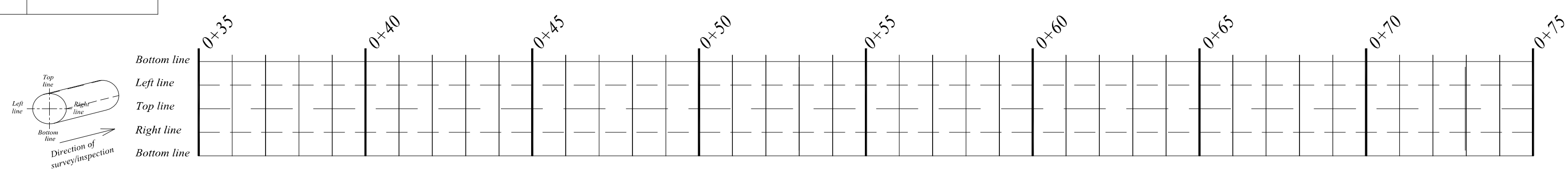


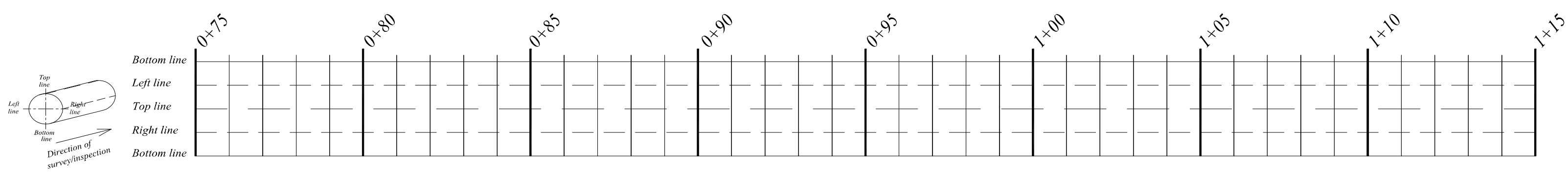
Pier No.:
Start Point

Measurement of Diaphragm

Location	Thickness
Start	
End	







INSTRUCTIONS: Document locations of deviator blocks (DB) and the end of survey.
Measure the thickness of both end diaphragms.

TYPICAL CONDITIONS :
1. Broken strands
2. Corroded strands
3. Moisture in duct
4. Opened/Unsealed grout ports
5. Cracked/Slipped/Broken ducts
6. Voids in duct

Notes on sample/data collection and other details

IN-DEPTH INSPECTION FORM		
Bridge:	Survey	Inspection
Spine ID:	Surveyor:	Inspection team leader:
Span ID:	Date:	Date:
Tendon ID:	Sheet No.:	Inspection program manager: