Considerations for Development of Inspection and Remedial Grouting Contracts for Post-tensioned Bridges

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Grout materials and grouting practices used in post-tensioned (PT) bridge construction prior to 2003 frequently resulted in the formation of air- or water-filled pockets, termed grout voids, inside PT tendons. Grout voids have been identified as conditions that can promote a corrosive environment within PT tendons. This report details the second phase of a two-phase project that was commissioned by MnDOT to identify best practices for the investigation of PT tendon conditions in bridge structures constructed prior to 2003. This report presents information and recommendations that will assist MnDOT in selecting and developing a project approach, work plan, and budget for future inspection and repair contracts for their pre-2003 era PT bridge inventory.
CONSIDERATIONS FOR DEVELOPMENT OF INSPECTION AND REMEDIAL GROUTING CONTRACTS FOR POST-TENSIONED BRIDGES

FINAL REPORT

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EXECUTIVE SUMMARY

Many post-tensioned (PT) concrete structures have been constructed in the United States over the last 50 years, and they have generally exhibited very good overall durability and performance characteristics. Typical PT systems in bridge structures consist of high-strength prestressing steel strands that are contained within ducts filled with cementitious grout. The combination of strands, duct and grout is referred to as a PT tendon. Grout materials used in PT bridge construction prior to 2003, and poor grouting practices, frequently resulted in the formation of air- or water-filled pockets, termed grout voids, inside PT tendons. Grout voids have been identified as conditions that can promote a corrosive environment within PT tendons. Many states across the country, including Minnesota, have performed investigations of PT tendon conditions in certain PT bridge structures. Grout voids and corrosion problems have been discovered in the PT tendons of multiple bridges. These two issues primarily relate to PT bridges constructed prior to 2003, before improvements in grouting materials and construction practices emerged in the industry. However, no established protocol exists for investigation of conditions within PT tendons as a component of routine bridge inspections. The presence of grout voids or the initial corrosion of prestressing strands inside a PT tendon are instead often latent conditions.

Like many states, the Minnesota Department of Transportation (MnDOT) has identified a need to proactively investigate PT tendon conditions in additional pre-2003 era PT bridge structures to determine if grout voids or corrosion conditions are present and, if so, implement repairs when necessary. To begin this process, MnDOT commissioned a two-phase project to evaluate and prioritize its bridge inventory, identify the most effective investigation and repair techniques, and to apply these techniques on a few representative structures. The first phase of the project, entitled “Development of Best Practices for Inspection of PT Bridges in Minnesota,” was completed in 2012 and resulted in the development of information and a general inspection protocol that will provide guidance for the execution of future investigation work. This report summarizes the results of the second phase of the project and is intended to supplement the report generated through the first phase.

This report is specifically intended to present information, recommendations, and general guidance that will assist MnDOT in the development of prudent and cost-effective strategies that can be implemented in future PT tendon investigation and repair contracts for the pre-2003 era PT bridge inventory in Minnesota. Typical work plans for investigation and repair work are discussed including considerations for access and maintenance of traffic, general tasks such as document review, visual survey and PT tendon location, and suggested procedures for invasive inspection and remedial grouting repair. Various contract and project approaches are presented, with their respective advantages and disadvantages identified, and experiences of performing similar work in other states are discussed. Lastly, ballpark cost information is presented for eight exemplar pre-2003 PT bridges that were identified by MnDOT to assist in future budget calculations. Recommendations are presented at the end of the report, which can be referenced in the programming of future PT tendon investigation and repair projects by MnDOT.
CHAPTER 1: BACKGROUND

1.1 BACKGROUND

1.1.1 Post-tensioned Bridge Construction

Many post-tensioned (PT) concrete structures have been constructed in the United States over the last 50 years, and they have generally exhibited very good overall durability and performance characteristics. Typical PT systems in bridge structures consist of high strength prestressing steel strands that are contained within metal or plastic ducts. The ducts are typically filled with cementitious grout. The combination of strands, duct and grout is referred to as a PT tendon. In some bridges, high strength bars are used in lieu of strands but the predominant PT systems use strands. PT tendons may be installed with vertical, straight, inclined or draped profiles along their length, and may be internal or external to the reinforced concrete elements of the structure, depending on design considerations. The ends of the PT tendons are terminated at anchorages.

PT tendons for bridges are either internal tendons, where the duct is fully encased in the concrete section, or external tendons, where the tendon is exterior to the concrete section. Both types of tendons are comprised of prestressing steel strands in plastic or metal ducts filled with a cementitious grout. For internal tendons, the cementitious grout is a key structural component of the tendon as it facilitates the development of structural bond between the concrete, duct and steel strands. Internal PT tendons are also often termed bonded PT tendons, for this reason. For both internal and external tendons, the grout also represents the last line of defense in the multi-layer corrosion protection system for the steel strands, as shown in Figure 1.1 below.

![Figure 1.1. Levels of corrosion protection for typical internal PT tendons in bridges [1].](image)

Achieving the maximum level of corrosion protection requires use of a high quality grout material with a high pH and sound grout installation practices that completely fill the duct cross-section, fully encapsulating the steel strands, along the entire tendon length. The high pH grout material creates a passive film on the surface of the strands which provides protection against corrosion. However, areas
of incomplete grout filling, or incomplete coverage, can leave strands vulnerable to corrosion at grout void locations should moisture, air, or chlorides enter the duct. Segregated or poor quality grout can also increase the risk for corrosion because it does not create the same level of passivation for the strand surfaces.

1.1.2 Grout

Grout materials used in PT bridge construction prior to 2003 were primarily composed of cement and water, with very fine aggregates or gas-forming expansive admixtures also incorporated on occasion. These early grouts flowed through the duct differently than modern grouts, filling the duct from bottom to top, like a true liquid. Even with grout vents at the tendon high points, and drains at low points, the early grout materials would often trap air and water inside the duct at high points and anchorages, particularly inside long PT tendons with an inclined, draped or vertical profile [2]. This phenomenon was caused by poor grouting practices, with respect to venting of the duct during grouting operations, and was exacerbated by segregation and bleed of the grout material, which resulted in water separating from the mix before it fully hardened. The presence of the multi-wire prestressing steel strands contribute to bleed, by wicking water from the grout mixture [3]. Once separated, the water accumulates on the top surface of the grout body as a result of hydrostatic pressure. Later reabsorption of the bleed water back into the grout creates a void space. Air or water filled voids inside the duct or anchorage of a PT tendon are termed grout voids. Figure 1.2 below shows a typical grout void inside a PT tendon.

![Figure 1.2. Typical grout void inside an internal PT tendon in a box girder bridge.](image)

The extent of bleeding that occurs with the typical cement-water grout material used prior to 2003 has been estimated at approximately 4 percent, or roughly 4 ft (1.22 m) of grout void for every 100 ft (30.48 m) of PT tendon length [4]. Modern thixotropic grouts used since 2003 fill the entire cross section of the duct at one location prior to advancing through the duct, and are much less susceptible to bleeding. As a result of this material change, and simultaneous improvements in personnel training and grouting specifications within the industry, the risk of grout voids within the PT tendons of bridges constructed
after 2003 is much lower than for the PT tendons of bridges constructed prior to 2003. PT bridges constructed after 2003 are, therefore, not a focus of this document.

As noted, grout materials used in PT bridge construction prior to 2003 occasionally included expansive admixtures. The use of expanding admixtures was an attempt to cause the grout to expand and fill any voids that might form. However, the expansion produced by the admixtures was highly variable and rarely sufficient to offset large grout voids. For external tendons, in some cases, the expansive pressures resulted in splitting of the ducts after setting of the grout.

Grout installation procedures used prior to 2003 also contributed to grout void formation. Early grouting specifications did not define the rate in which grout was to be pumped inside the tendon. At higher injection rates, turbulence sometimes formed within the duct, entrapping air and water. Flushing of the ducts with water prior to grouting operations, or excessive water addition to the grout mixture during grouting operations, were also frequent occurrences that would contribute to the formation of grout voids inside tendons. These issues acted in concert with the grout material characteristics described above, increasing the likelihood of grout voids within PT tendons of pre-2003 era bridge structures.

1.1.3 Corrosion

In numerous studies, grout voids and moist grout have been identified as conditions that can promote a corrosive environment within PT tendons. Grout voids allow oxygen, moisture (i.e., recharge), and other contaminants to come into contact with the prestressing steel strands or the metal ducts during service, resulting in corrosion. In addition, if the strands are exposed within a grout void, there is a difference in the passivation of the strands at the interface between the solid grout and the void which can also increase the potential for corrosion. Recharge can also occur at PT tendon anchorages during service, due to the propensity for water leakage through the bridge deck expansion joints that are often located above anchorages. The combination of inadequate end protection details and grout voids can promote corrosion at PT tendon anchorages.

Over time, corrosion in a PT tendon can lead to wire or strand failure resulting in a local loss of post-tensioning force, and potentially, reduced serviceability or member capacity. Additional factors have also been identified as significant contributors to PT tendon corrosion issues including poor detailing, breaches in the post-tensioning system (e.g., open vents, duct splices, duct damage etc.), and poor interior drainage conditions. More recent research suggests that rapid strand corrosion can also occur in regions of soft and segregated grout, even if no grout void exists. This phenomenon was cited as the likely cause of strand corrosion failures on newly constructed bridges in Florida and Europe [5].

Investigations of multiple PT bridges across the country, including Minnesota, have identified grout voids and corrosion problems in grouted PT tendons. The severity and extent of corrosion and has varied widely depending on the climate, construction practices, structure type and other variables. The corrosion problems have most commonly been associated with voided areas in the grouted PT tendons and poor detailing. These two issues primarily relate to PT bridges constructed prior to 2003, before
improvements in grouting materials and construction practices emerged in the industry and significantly reduced the likelihood of grout voids.

1.1.4 Inspection

The extent, location, and impact of any grout void conditions that exist inside PT tendons in bridges constructed prior to 2003 are largely unknown. Inspections of PT bridge structures that are performed in accordance with National Bridge Inspection Standards (NBIS) are essentially limited to routine observations for flexural or shear cracking and obvious corrosion staining on the exterior of the PT elements [6]. However, the presence of grout voids or the initial corrosion of prestressing strands inside a PT tendon is often a latent condition that is not accompanied by any obvious visible evidence of distress (e.g., cracking, delaminations, spalls or staining) on or around the concrete elements in which they are cast. Most of the noted corrosion damage has been found in external PT tendons where it is relatively easy to detect a broken tendon inside the cavity of a box girder. Corrosion damage to internal tendons is virtually impossible to detect without use of invasive inspection methods.

In addition, non-destructive evaluation techniques are generally limited in their ability to identify the presence of a strand corrosion within an internal PT tendon. The best and most reliable method to investigate the conditions within PT tendons is to make discrete invasive openings and perform visual observations of the internal conditions once they are exposed. This method requires hands on access to the tendons, from the exterior and/or interior of the bridge, as well as specialized equipment and expertise.

1.1.5 Summary

Poor performance of the grout materials used in PT bridge construction and inadequacies in grouting specifications and installation practices, prior to 2003, increased the potential for the formation of grout voids in PT tendons, particularly near high points and anchorages. Grout voids can leave the metal duct and prestressing steel strands vulnerable to corrosion. While significant corrosion problems have only been identified in a small fraction of the national PT bridge inventory, the presence of grout voids creates a risk for future corrosion problems to develop. Specialized inspections are required to determine if grout voids and/or corrosion exist within PT tendons. Many states have investigated the condition of i PT tendons in bridges built prior to 2003 including Alaska, Florida, Hawaii, Indiana, Minnesota, Oklahoma, Oregon, Texas and Virginia. Most have found that voided areas are fairly common, and varying levels of corrosion of ducts and prestressing strands have been observed.

1.2 UMD STUDY OF PRE-2003 PT BRIDGES IN MINNESOTA

Approximately 40 of the post-tensioned bridges in Minnesota were constructed prior to 2003. Most of the bridges in this inventory were constructed after 1992, although several structures date to the 1970’s. The vast majority of these bridges are box girder type structures, with total lengths ranging from 74 ft (22.55 m) to over 2,700 ft (822.96 m). Multiple post-tensioned slab span and spliced girder bridges also exist in the state, all with total lengths under 100 ft (30.48 m). One bridge in the inventory is a steel
multi-girder bridge with PT pier caps. Almost all of these pre-2003 era PT bridges possess only internal PT tendons with metal ducts [7]. Prior to 2010, no specialized inspections had been performed or commissioned by the Minnesota Department of Transportation (MnDOT) to investigate tendon conditions and determine if grout voids, or possibly corrosion, were present in any of these bridges.

The University of Minnesota - Duluth (UMD) was engaged by MnDOT in 2010 to begin investigating the condition of PT tendons within the inventory of pre-2003 era PT bridges in Minnesota [7]. The work performed by UMD had four primary objectives: (1) review available bridge information and identify the structures that were most likely to have potential grout voids and corrosion problems; (2) assign an inspection priority rating to all of the bridges based on those estimated risk levels; (3) perform targeted initial inspections of multiple bridges of varying construction types that were assigned high priority inspection ratings; and (4) recommend general inspection procedures to identify any potential problems with the PT tendons.

Inspection ratings were assigned by UMD based on available information for the bridges, including plans, construction records and inspection reports, and geometric factors such as the configuration, length, and vertical rise of the PT tendons. Ten (10) bridges with high inspection ratings, representing the variety of bridge types, were then selected for inspection by UMD to preliminarily evaluate a cross-section of the MnDOT inventory. The field inspections primarily consisted of external visual inspection of the selected structures, although initial limited invasive inspections were also performed in accessible portions of three (3) of the bridges. The invasive inspections were performed by personnel from VStructural LLC (VSL) and included the creation of drilled and large inspection openings. These openings were intended to allow for observation of the tendon interior conditions. No grout voids or corrosion problems were found within the sampled PT tendons on Bridge 69818N/S in Duluth, Minnesota, significant grout voids and moderate duct corrosion were found in some PT tendons on Bridge 02037E/W in Coon Rapids, Minnesota, and no grout voids but major corrosion problems were found in the PT tendons of Bridge 27611, the Plymouth Avenue Bridge, located in Minneapolis, Minnesota, as shown in Figure 1.3 below [7]. The third bridge was a twin box girder structure constructed in 1983.

![Figure 1.3. Corrosion damage in bottom slab tendons of the Plymouth Avenue Bridge [7].](image)
The complete findings of the UMD work were published in April 2012, as part of the first phase of this project, in a report titled “Development of Best Practices for Inspection of PT Bridges in Minnesota” [7]. This report includes background information on the history of post-tensioned construction, and additional information related to the concerns and corrosion problems that have been identified with earlier generations of PT bridges. The report also presented the inspection priority ratings that were assigned to the MnDOT inventory of pre-2003 era PT bridges, and presented a general inspection guide for these structures. UMD made specific recommendations for additional investigation of the three (3) bridges where invasive inspections were performed. Their recommendations included that a full investigation be performed to identify and repair all grout void conditions at Bridge 02037E/W, shown in Figure 1.4, before corrosion problems developed. This recommendation was adopted by MnDOT as a follow-up implementation project, as discussed in Section 1.3. UMD also made general recommendations that invasive inspection be performed on all other pre-2003 era bridges in the MnDOT bridge inventory and presented a general procedure for such work.

Figure 1.4. Bridge 02037W in Coon Rapids, Minnesota.

1.3 INVASIVE INSPECTION AND REMEDIAL GROUTING OF BRIDGES 02037W AND 02037E

Following completion of the UMD study, MnDOT solicited proposals to perform investigation and repair of all PT tendons in Bridges 02037W and 02037E, as well as one other bridge structure that had been assigned a high priority inspection rating by UMD. For all three bridges, the primary objectives of the work were to: (1) identify and document any grout voids that existed near all high points and anchorages of all PT tendons; (2) observe and document any evidence of strand or duct corrosion therein; and (3) repair all identified grout voids using vacuum, vacuum-assisted, or pressure grouting repair techniques. In addition, MnDOT specified that several corrosion monitoring sensors be installed within PT tendons where grout voids had been discovered to monitor for future corrosion activity following re-grouting. However, following receipt of cost proposals and in light of project budget constraints, MnDOT scaled back the scope of work to focus on only Spans 3 and 4 of Bridge 02037W and Span 2 of Bridge 02037E where known problems had been identified by UMD. The third bridge was
removed from the work scope. The team of Wiss, Janney, Elstner Associates, Inc. (WJE) and VSL were contracted by MnDOT to perform the required work in 2013. The full results of the work were published in an October 2013 summary report, a copy of which is included in Appendix A.

Grout voids were discovered at approximately one-third of all inspection locations within the three selected spans of Bridges 02037W and 02037E. The typical grout void encompassed approximately one-half of the duct diameter and measured at least 10 ft (3.048 m) long, as shown in Figure 1.5 on the next page. Prestressing steel strands were exposed at approximately half of the grout voids. No significant corrosion of the strands was observed at any location; the strands typically exhibited no corrosion or light surface corrosion, consistent with Class 1 or 2 conditions [8]. However, light to moderate corrosion was typically observed on inside surfaces of the galvanized metal ducts at the grout voids.

Following the inspection work, approximately one-third of the discovered grout voids were filled using vacuum-assisted or pressure grouting repair techniques, as shown in Figure 1.6 on the next page. The re-grouting work included all voids in Span 4 and some voids in Span 3 of Bridge 02037W. The remaining two-thirds of the discovered grout voids were not regrouted because the grout material that had been procured as a part of the work contract was exhausted. This quantity had been estimated based on the grout void frequency and size that had been documented by UMD as a part of their limited invasive inspection of PT tendon conditions at these bridges. Unfortunately, the frequency and volume of the actual grout void conditions greatly exceeded those projections and no mechanisms were available to MnDOT under the work contract to procure additional grout material to complete the re-grouting work in the selected spans. Polyvinyl chloride (PVC) ports were installed and sealed at all grout voids which were unrepaired to facilitate future remedial grouting work.

Figure 1.5. Typical grout void discovered in the internal PT tendons of Bridge 02037W.
1.4 FUTURE WORK

Like many states, MnDOT has identified a need to proactively investigate PT tendon conditions in pre-2003 era PT bridge structures to determine if grout voids and/or corrosion conditions are present and, if so, implement repairs when necessary. The repair of grout voids attempts to mitigate the risk of future corrosion problems within the PT tendons, maintaining the design service life of the bridge structures and avoiding potentially costly and unforeseen repairs. To begin this process, MnDOT commissioned a two-phase project to evaluate and prioritize their bridge inventory, identify the most effective investigation and repair techniques, and to apply these techniques on a few representative structures. The project has resulted in the development of information and a general inspection protocol that will provide guidance to MnDOT for the execution of future contracts for similar investigation work.

As noted, UMD recommended that invasive inspections be performed on all PT bridges built prior to 2003 in Minnesota to determine if grout voids are present in PT tendons. Despite the work completed to date, the proper scoping and accurate budgeting of each of these future projects presents a challenge for MnDOT. This is particularly true for bridges with only internal PT tendons, as is the case for almost all of the pre-2003 PT bridge inventory in Minnesota. The challenge arises from a combination of factors including the specialized nature of the inspection and remedial grouting work, the variability of the bridge types and their access parameters, and the unknowns associated with the grout void conditions prior to project commencement. The latter condition is the most problematic for MnDOT with respect to the development of contracts, as will be discussed herein.

This document was requested by MnDOT to provide additional guidance for contracting future inspection and repair of PT tendons. It is specifically intended to present information, recommendations, and general guidance that will assist MnDOT in the development of prudent and cost-effective strategies that can be implemented in future PT tendon investigation and repair contracts. This document focuses on only the pre-2003 era PT bridge inventory in Minnesota, which primarily
include only internal PT tendons, and is intended to serve as a companion document to the report previously prepared by UMD.

The content presented herein was developed through the author’s experiences with work of this type performed in Minnesota and several other states. Chapter 2 discusses the general tasks and procedures that should be incorporated into a typical project work plan for invasive inspection and remedial grouting of PT tendons. Chapter 3 presents information related to the solicitation and phasing of investigation and repair contracts, including identification, discussion, and analysis of the different options we believe are available to MnDOT depending on the desired outcomes and available resources. Lastly, Chapter 4 presents general information and ballpark unit costs to assist MnDOT with the development of project budgets, depending on the bridge type and selected investigation and repair approach outlined in the contract.
CHAPTER 2: PROJECT WORK PLAN - PROCEDURES AND TASKS

No established protocol exists for investigation of conditions within PT tendons as a component of routine bridge inspections. Inspections are instead limited to observing externally visible symptoms of a problem, including concrete distress and corrosion staining [9]. Unfortunately, these symptoms will not typically appear until the extent of the problem within a tendon is well advanced.

The use of non-destructive testing (NDT) equipment alone has also not yet proved to be a sufficiently reliable and robust method to investigate conditions within internal PT tendons [10] [11]. NDT methods like ultrasonic tomography or impact echo (IE) have proven to be capable of locating grout voids, however, the reliability of these methods may vary depending on the type of duct, the depth of the PT tendons, and the skill of the technician. In addition, and perhaps more importantly, these methods are not effective for determining the size of the grout voids or whether corrosion is present within the tendon, and some level of destructive investigation is still required to calibrate and confirm results [11]. In short, for internal tendons, no current NDT methods allow the presence and size of grout voids to be accurately identified, and the extent of any corrosion to the metal ducts or prestressing strands to be accurately evaluated or measured, without direct physical access to the embedded PT tendons.

The creation of discrete invasive openings is instead regarded as the best and most reliable method to investigate the presence and extent of grout voids, corrosion, and other environmental conditions within internal PT tendons. Drilled hole openings can be created to determine if a PT tendon is fully grouted. A flexible borescope/videoscope device can be inserted into the drilled hole to determine if grout voids are present and to allow for visual observations and documentation of internal PT tendon conditions. The hole can also be used to facilitate remedial grouting operations, if necessary. Larger inspection openings can be created, where warranted, to permit direct visual examination of conditions, to allow sample material to be extracted, or to facilitate additional testing or inspection. Whether or not grout voids are present, all invasive openings must be repaired to restore the corrosion protection to the PT tendon.

This chapter presents and discusses the factors, tasks, and general procedures recommended for consideration by MnDOT when developing work plans for the investigation and remedial grouting repair of internal PT tendons. This information is intended to supplement the invasive inspection procedures recommended by UMD in their 2012 report [7].

2.1 GENERAL TASKS

2.1.1 Document Review

A detailed review of the design drawings and in particular the post-tensioning shop drawings, if available, for the targeted bridge structure(s) should be performed during the project development phase and prior to the performance of field work. Both reviews will be intended to collect similar information. These drawings will illustrate the number of PT tendons, and the number of high points and anchorages along the length of each tendon. The drawings will also help illustrate the means of access.
that may be required for the various work areas. These factors will define the total number of inspection locations and, essentially, the scope and cost of the project. This is discussed further in Chapter 4. Drawing review is also valuable to identify the depth, profile, and length of the PT tendons. The depth of the tendons should be considered when selecting the best NDT methods to locate the tendons during the performance of field work. The length and profile of the tendons are important variables that should be considered when developing an inspection strategy. Construction records, if available, and bridge inspection reports should also be located and reviewed prior to the performance of field work. These documents can assist in the understanding of the current condition of the bridge, and may indicate whether any problems were recorded during the original grouting operations. Grouting problems may contribute to the presence of grout voids within the PT tendons. Note that drawings and construction records, where available, were reviewed by UMD and that information was considered in their assignment of inspection priority ratings for the pre-2003 era PT bridge inventory in Minnesota [7].

2.1.2 Access and Maintenance of Traffic

Inspection and remedial grouting repair of PT tendons requires up-close access to the concrete elements in which the tendons are embedded or contained. This typically consists of access to the interior of PT box girder bridges, or access to the exterior surfaces of PT slab span or spliced girder bridges, and PT pier cap or straddle bent bridge elements. Note that the interior of a box girder should be considered a confined space. Different access equipment may be required in different spans of the same bridge. The type(s) of access equipment required for each bridge will be primarily dictated by the position of the access hatches or work locations and their vertical distance above grade. Traffic, safety considerations, and site topography also require consideration and may eliminate certain options. Typical access equipment includes ladders, scissor lifts (35 or 60 ft / 10.668 or 18.288 m), aerial boom lifts (60 to 120 ft / 18.288 to 36.576 m), or under-bridge inspection vehicles (i.e., snoopers), as shown in Figure 2.1.

Figure 2.1. Access to the interior of box girders may require ladders, lifts or snoopers.
For most PT bridges, maintenance of traffic (MOT) considerations will be required in and around the work zone to ensure the safety of the work crews and travelling public are maintained as best as possible. Minimum MOT measures will typically include road cones and signs. See Figure 2.2. However, arrow boards and crash trucks will be necessary if shoulder or lane closures are required to allow the access equipment to be properly positioned. Examples include bridges where all work is required to be performed from a snooper, or bridges that require the access vehicles to be positioned in a shoulder or roadway adjacent to open traffic. Flaggers may also be required for certain situations and bridges. Heavily trafficked river crossings may warrant alternative access approaches that do not require any MOT to avoid the associated complications. This may include the use of aerial lifts positioned on river barges. Conversely, no access or MOT equipment may be required for some projects. No access equipment will be required for most PT slab span bridges because all work would likely be performed from the deck surface at tendon high points. MOT will not be required if all access can be achieved from areas that are protected or a safe distance from the roadway. Examples may include certain box girder bridges or simple span, spliced girder bridges where all access hatches or work areas can be reached from a ladder placed in a protected area (e.g., slope paving, embankment, wide median).

![Figure 2.2. MOT considerations will be required for most inspection work.](image)

Access and MOT equipment can be provided by MnDOT or by the specialty contractor who is performing the inspection and repair work. This equipment can be costly for certain bridges, particularly where a snooper is required to perform all work. While cost savings can be achieved should MnDOT elect to provide these services, the efficiency of the field work is entirely dependent on their complete and timely implementation. These considerations are discussed further in Chapter 4.

**2.2 VISUAL SURVEY**

A limited visual survey of the bridge, including the interior of box sections, should be performed in conjunction with the inspection or repair of PT tendon conditions. The visual survey should include general observations of the exterior from grade level and the bridge deck surface, close range...
observations of the concrete elements in which the PT tendons are embedded, and the interior of box sections. The objective of the survey is to identify any areas of concern, including any conditions that may indicate the PT system is not performing as anticipated. These conditions may include any concrete distress (e.g., cracks, delaminations, spalls, etc.), moisture staining, corrosion staining that is located at or adjacent to the PT tendons, their couplers or anchorages, and evidence of grouting issues during construction (e.g., grout leakage inside a box girder).

Shear cracking at supports, or flexural cracking at mid-span or over piers, may be indicative of excessive loading, a design deficiency, or a loss of pre-compression (i.e., prestressing strand or tendon deterioration). Longitudinal cracking that is parallel to and aligned with the PT tendons may be indicative of corrosion damage to the prestressing strands, excessive post-tensioning forces, excessive grouting pressures, or a design deficiency. See Figure 2.3. While not common, any of these conditions warrant concern and prompt evaluation.

![Figure 2.3. Longitudinal cracking along PT tendon.](image)

Evidence of uncontrolled water infiltration should also be noted because of the obvious risk it creates for future corrosion of the PT elements. This may include water leakage through expansion joints, ineffective or misdirected drainage, or general moisture staining. Where exposed or accessible, tendon anchorage areas should also be observed. These areas can be particularly vulnerable to moisture exposure because they are often positioned below bridge deck expansion joints. Any displacement or deterioration of pourbacks is often indicative of corrosion of the embedded post-tensioning system components. Evidence of grout leaks may also be present at duct splices or vent connections. While grout leaks do not necessarily mean that grout voids are present, they provide general information about the original injection of the grout and the integrity of the duct system.
Because the scope of the visual survey will typically include essentially the entire bridge structure, it is often most efficient and economical to specify that a routine bridge inspection be performed in conjunction with invasive inspection of internal PT tendon conditions.

### 2.3 INVASIVE INSPECTION

#### 2.3.1 Tendon Location and Mapping

Ground penetrating radar (GPR) should be utilized to accurately locate the internal PT tendons at the desired inspection locations. The frequency of the GPR antenna should be coordinated with the anticipated depth of the PT tendons, as determined through design and shop drawing review. While other NDT techniques, such as ultrasonic shear wave tomography or impact echo, can also accurately locate PT tendons, the authors have found that GPR will typically provide the optimal blend of ease of use, accuracy, efficiency, economy and portability. One exception may be certain PT bridges where plastic ducts were used for the tendons, and the plastic ducts are located at a depth of greater than 6 in (152.4 mm) below the concrete surface. Plastic ducts at relatively deep embedment can still be accurately located using GPR, however, a highly skilled and experienced technician would typically be required. Field calibration, including trial iterations of locating and drilling, may also be prudent. Plastic ducts for internal tendons would not be expected to be a common situation on PT bridges constructed in Minnesota prior to 2003.

Once the PT tendon is located using GPR, the centerline of the internal tendon profile should be mapped on the surface of the concrete element in which the tendon is embedded using chalk or crayon, as shown below in Figure 2.4.

![Figure 2.4. Tendon profile mapped on surface of concrete element.](image)

The length of the tendon profile that should be mapped at each inspection location will vary depending on the project parameters but approximately 3 ft (0.9145 m) is typical. Mild steel reinforcement proximate to the tendon should also be located and mapped on the concrete surface, typically using a
different marking color. The accurate locating and mapping of both the tendon and the neighboring reinforcement is recommended because it will minimize the potential damage to the structure that may otherwise be caused by trial and error hole drilling efforts.

The inspection locations will typically consist of the end anchorages and high points along the length of each PT tendon. Grout voids, if present, would typically form at these locations, as discussed in Chapter 1. Depending on the bridge type and the shape of the PT tendon, the actual high points and end anchorages may be obscured by other concrete elements or by congestion of mild reinforcement such that they are not easily accessible. Invasive inspection of these locations will likely be impractical in such situations. It is instead generally more prudent, and sufficiently informative, to perform the inspection work as close as possible to the actual high point or end anchorage. Tendon location and marking operations should align with this approach.

If present, grout voids at intermediate PT tendon high points are most likely to have formed at the apex of the tendon profile and/or just beyond the apex on whichever side is opposite the direction grout was pumped into the tendon. However, the direction of grouting will generally not be known to MnDOT or investigators prior to or during inspection work. The apex of the tendon may also not be accessible. For these reasons, particularly with box girder bridges, inspections of intermediate PT tendon high points should generally be performed on both sides of the apex (e.g., on each side of a pier wall).

### 2.3.2 Openings

#### 2.3.2.1 Drilled Hole Openings

After the PT tendons and mild reinforcement have been located and mapped, drilled hole openings can be created at each identified inspection location to investigate the conditions within the tendon. Each opening will typically consist of a single hole drilled into the concrete to the depth of the duct using a hammer drill equipped with a concrete drill bit, as shown in Figure 2.5. The recommended opening diameter is 1 in. (25.4 mm). Each opening should be positioned and drilled such that it intersects the top of the duct, where the grout void would be expected, and not the center or bottom of the duct. Caution should be exercised during drilling to avoid puncturing the duct and plunging into, or otherwise damaging, the PT tendon. Concrete coring equipment, as well as hammer drill bits that are designed to cut steel, should not be used due to the potential of damaging the strands inside the duct.
Once drilling is complete, the hole should be blown free of dust and debris using oil-free compressed air. The wall of the duct should be opened using a long flat head screwdriver. Typically, the screwdriver is pushed through the duct and then twisted to peel a portion of the duct wall back. When the PT tendon is fully grouted, this process may be somewhat difficult due to the presence of the grout in contact with the duct wall. When a grout void is present, or if the grout material is of poor quality, the duct will typically indent and then open easily. Note that care is needed when puncturing the duct wall to avoid damaging the steel strands.

Once the duct has been opened, a rugged and high-quality flexible video borescope (videoscope) should be inserted into the drilled hole to facilitate observations of the tendon conditions. A videoscope is a portable fiber-optic inspection device that consists of a handheld control with a video display monitor that is attached to a flexible hose with an optical lens at the tip. Video images captured at the lens are relayed to the display in real time so conditions can be observed by the operator. The position of the lens can typically be manipulated by the operator using the handheld control and still photographs or video footage can be recorded as desired. The length of the flexible hose can range up to 100 ft (30.48 m) for certain devices, although a length of 15 to 20 ft (4.57 to 6.10 m) is typically sufficient. The videoscope is preferred over traditional borescopes because it offers superior image quality, greater documentation capabilities and advanced control functionality (measurement and tip articulation capabilities).

If the PT tendon is fully grouted at the inspection location, grout material that is generally medium to dark gray in color and hard in composition will be visible immediately behind the duct wall, such as shown in Figure 2.6. The composition of the grout can be evaluated by probing with the screwdriver tip.
When a grout void is present at the inspection location, the videoscope should be inserted into the hole and then into the PT tendon to allow for observation and documentation of the interior conditions, as shown in Figure 2.7 on the next page. The percentage of the duct cross-sectional area that is filled or, conversely, voided should be estimated and the approximate length of the grout void should be determined. The grout void length can be determined by feeding the videoscope hose, or a long metal wire, into the void as far as possible. These two pieces of information can be used to calculate the approximate volume of the grout void. Although not common, nor often successful, the volume of the grout void can also potentially be measured using remedial grouting equipment, including a vacuum pump, if such equipment is available at the time of inspection. The grout void volume will define the necessary quantity of grout material that will be required to fill the void during remedial grouting repairs. The general quality of the grout material should also be evaluated; grout material that appears soft or white and chalky should be noted. The videoscope should also be utilized to observe the condition of any exposed prestressing strands (for corrosion or failure). The interior surfaces of the duct should also be reviewed for evidence of corrosion. If present, the extent of any corrosion should be estimated [8].
Regardless of the conditions observed, detailed documentation should be completed at each inspection location. Documentation should include field notes and photographs. Procedures should be employed to ensure both forms of documentation are accurately keyed to each inspection location. This will typically include the development of a nomenclature system that uniquely identifies each inspection location. The nomenclature should include, at a minimum, identification of the bridge, span, element, tendon, and the position of the inspection location. An example would be Bridge 02037W_Span2_Girder 1_Tendon3_High point on east side of pier 1. The documentation collected should include, at a minimum, the following information:

- The date inspection work was performed
- The position of the drilled hole (e.g., 3 ft (.914 m) east of pier wall, 6 ft (1.83 m) above bottom slab)
- If the PT tendon is fully grouted or if a grout void exists. If a grout void is present:
  - the approximate length and percentage of the duct cross section that is voided should be estimated
  - the number of prestressing strands that are exposed, if any, should be noted
  - the extent of any duct or strand corrosion that is present should be judged.
  - the number of prestressing strands that are failed, if any, should be determined
- The color and quality of the grout material

Photographs should be taken of the PT tendon conditions observed within the drilled hole, or inside the tendon if a grout void is present, at each inspection location. The nomenclature information discussed above should be marked on the surface of the concrete element using chalk or crayon, including the
date that inspection work was performed at that location. It can be advantageous for the initial photograph taken at each inspection location to capture this information. This procedure will allow all captured images to be properly sorted. Similarly, the photograph file names can be changed to include the inspection location and date. These measures will help ensure all documentation is properly cataloged.

After documentation is completed, repairs should be immediately performed to seal the drilled holes. If no grout void exists, no remedial grouting is needed and permanent repairs can be installed. The repairs should consist of completely filling the hole with high-quality cementitious repair material or epoxy mortar, as desired by MnDOT. If a grout void exists, remedial grouting should be performed as the permanent repair. However, depending on the scope and approach of the contract, the grouting work may not be performed immediately. Whether immediate or delayed, an air-tight port should be inserted and completely sealed into the drilled hole using epoxy adhesive. The diameter of the port should match the diameter of the drilled hole, typically 1 inch, to facilitate the future remedial grouting work. The most common ports are composed of polyvinyl chloride (PVC) and include valves, as shown below in Figure 2.8. Valves should be closed.

![Figure 2.8. Typical PVC ports installed at drilled hole openings.](image)

The port is required to perform remedial grouting repair and will allow grout material to be injected into the grout void. The port can also facilitate interim inspections or monitoring of the PT tendon conditions if remedial grouting is delayed. Properly repaired drilled holes, including properly sealed PVC ports, will prevent air and moisture from migrating into the PT tendon, ensuring the risk of future corrosion is not increased as a result of performing inspection work.

### 2.3.2.2 Large Openings

Large openings should be created when and where the visual survey identifies a potential problem proximate to a PT tendon. Visual indications of a potential problem would include corrosion staining,
cracking, moisture leeching from cracks. Large openings should also be considered if the inspection work performed at a drilled hole opening indicates that corrosion of the duct or prestressing strands is present, or the grout is soft, white, chalky, or generally of questionable integrity and quality. Large openings consist of approximately 8 in (203.2 mm) by 16 in (406.4 mm) areas, or larger if necessary, where concrete is removed to expose a length of a PT tendon, as shown below in Figure 2.9.

![Figure 2.9. Typical large opening.](image)

In general, the opening should be centered about the PT tendon location. The removal work will typically be performed with small hand tools excavating to the depth of the tendon. A concrete saw or grinder should be used to saw-cut the perimeter of the opening area, and concrete inboard of the saw cut can then be removed with a small chipping hammer. Concrete should be removed to the depth of the duct, such that approximately 50 percent of the circumference is exposed. Once exposed, a portion of the duct should be opened with a small grinder equipped with a rotary cut-off wheel. The size of the opening cut into the duct will vary depending on the conditions but may measure approximately 3 in (76.2 mm) high by 6 in (152.4 mm) long. Ideally, the duct section should be cut and removed in one piece so that it can be re-installed at the time of repairs. Caution should be exercised during saw-cutting, chipping and grinding work to avoid excessive damage to the concrete element or its mild reinforcement and, more importantly, to prevent damage to the PT tendon and strands.

Large openings can allow for direct visual examination, and improved documentation, of the conditions that exist inside the PT tendon at the inspection location. Large openings can also facilitate material sampling of the grout inside the tendon. Grout samples can be extracted using a small chisel and collected in sealed plastic bags for laboratory testing. Testing can identify the general quality and constituent materials of the grout, as well as the pH, chloride content, sulfate content, estimated water-cement ratio, and whether any deleterious materials exist. The test results will provide information on the general quality of the grout, and the risk of any potential future problems. The results can also assist with the selection of a compatible grout material to be used during remedial grouting repairs.
If corrosion of the prestressing strands or duct are observed, large openings can allow NDT procedures to be performed. This may include collecting immediate measurements of corrosion rate or corrosion potential of the prestressing strands, or installing corrosion monitoring sensors or similar instrumentation packages that will allow for long-term monitoring. Corrosion monitoring sensors were selected and installed in Bridge 02037W, as shown below in Figure 2.10 and as discussed in Appendix A. These sensors appeared to provide reliable data for temperature, corrosion potential and corrosion rate, but resistivity data was erratic. The data collection equipment and software that were selected for that project were also somewhat challenging to work with. While the system exhibited promise, we believe further evaluation and calibration of this system, and all other corrosion monitoring instrumentation systems that may be available, is warranted before any products are considered for specific PT bridge applications. Such research would be intended to identify the respective capabilities, limitations, and reliability of the sensors for use in grouted PT tendons.

![Corrosion monitoring sensor installed inside a grout void in a PT tendon.](image)

Figure 2.10. Corrosion monitoring sensor installed inside a grout void in a PT tendon.

Documentation of the conditions at large openings should be similar to drilled hole openings and should include photographs and field notes. The documentation should include the date and specific location of the opening, including the particular tendon being investigated, the reason for creating the opening, and all relevant findings or work performed. The latter would include whether any material samples were collected, or if NDT was performed. After documentation is completed, the duct and concrete should be repaired using materials approved by MnDOT. This may include using epoxy to seal the cut section of the duct back into place and installing a MnDOT approved concrete repair material to replace and protect the area of concrete that was removed.

### 2.4 REMEDIAL GROUTING

Remedial grouting repairs should be performed to completely fill grout voids that exist in the PT tendons, whether or not corrosion is present, as a permanent repair. A zero-bleed, prepackaged,
thixotropic grout material that is compatible with the composition of the existing grout material, and is approved by MnDOT, should be used for the repairs. The remedial grouting procedure should be selected depending on the void conditions and may consist of vacuum grouting, vacuum-assisted grouting, or pressure grouting. The difference between these procedures is discussed below. All grouting work should be performed by a grouting technician certified by the American Segmental Bridge Institute (ASBI). All repair grout material should be mixed and field tested in accordance with the recommendations in the *Specification for Grouting of Post-Tensioned Structures* published in 2012 by the Post-Tensioning Institute (PTI) [12]. Field mixing of grout should be performed as recommended by the grout manufacturer and field testing should include measurements of grout fluidity (flow cone test), grout density (mud balance), and grout temperature, or other test methods mentioned in the PTI Specification as desired by MnDOT. Material samples can be collected during grouting work for chloride testing or material compatibility testing, if desired by MnDOT.

Remedial grouting operations can be staged from a number of different locations depending on the site topography and the type and geometry of the bridge. Staging locations may include the ground, pipe scaffolding, the interior of box girder bridges, or the surface of bridge decks. Ground staging will typically be limited to certain applications, such as low straddle bents, where the grout injection locations are less than 30 feet (9.14 m) in height above the grout pump due to the limitations of the typical pumping equipment. Remedial grouting cannot typically be performed from an aerial or scissor lift due to load restrictions of the man basket.

At each repair location, vacuum testing should first be performed to attempt to verify the approximate size of the void and determine the most appropriate remedial grouting technique. It may be possible to approximate the void size by measuring the volume of air removed by a vacuum pump. At locations where the grout void can sustain a vacuum pressure of approximately 20 in (508 mm)-Hg or higher, the vacuum or vacuum assisted grouting methods should be selected for the remedial grouting repair technique. See Figure 2.11 on the next page. This method allows grouting operations to be performed at the one drilled inspection hole. Vacuum grouting equipment will include a volumeter (for measurement of void volume) and a vacuum pump. The vacuum pump draws air out of the PT tendon, creating a negative pressure which allows grout to be pulled back into the grout void. Some pressure assistance may be required to finish the filling of the grout void as the vacuum pressure drops.
However, at most repair locations, a vacuum pressure of 20 in (508 mm)-Hg is not attainable. The inability of the grout void to sustain the required vacuum pressure may be due to the size of the grout void, air leakage from the ducts or the installed port, or a combination of these factors. Pressure grouting may be the most appropriate remedial grouting repair approach at these locations. Pressure grouting requires the drilling of multiple additional holes, also typically 1 inch (25.4 mm), and the installation of additional grout ports at each hole, along the length of the grout void. Grout is then pushed into the grout void from the lowest access hole toward the upper holes. See Figure 2.12 below.
Grout ports are sequentially closed off up the length of the grout void once a steady outflow of grout is observed at the port. Grout pressure is then locked off for a predetermined time period following the closing of all ports. Depending on MnDOT grouting requirements, burping of the ducts/ports may or may not be permitted.

Vacuum-assisted grouting may be a preferred remedial grouting approach at any locations where sufficient vacuum pressure cannot be sustained, but it can also be used where good vacuum pressures are achieved. This approach is a hybrid of vacuum grouting and pressure grouting. The vacuum pump is used to draw air out of the grout void at a grout port installed at the high end of the grout void, while grout is simultaneously injected into a second grout port at the low end of the grout void. The vacuum pressure should be kept relatively high as grout flows up and through the PT tendon.

The volume of grout injected into each void can be measured during the grouting operation and compared to the air volume that was measured, or estimated, prior to the grouting procedure for quality control evaluation. The ratio of the grout used to the air volume of the grout void should ideally be greater than 90 percent. In addition, at the completion of the grouting operations, all PVC valves should be cut flush with the face of the concrete, and the grout tubes inspected to verify that they are full of grout (after the grout has hardened), as shown in Figure 2.13.

![Figure 2.13. Grout tubes should be inspected for verification of regrouting work.](image)

Verification drill holes can also be created at the high end of selected grout voids. The holes should be drilled no sooner than 24 hours after grouting is completed. The holes should be examined like a drilled hole inspection opening, with the conditions observed using a videoscope. These holes are intended to verify that the PT tendon is full of grout and a grout void no longer exists. Grouting operations should be performed again if this is not the case. The number of verification holes to be examined can be specified by MnDOT. Once re-grouting work is complete, all verification holes, inspection ports and grouting ports
should be sealed with a repair material approved by MnDOT. This will typically consist of a cementitious repair mortar, epoxy adhesive, or elastomeric waterproofing membrane. For verification holes that extend to the deck surface, a 2” thick layer of Premixed Polymer Concrete wearing course may be applied to an over-sized area so the construction joint around the repair material does not extend directly to the surface.

### 2.5 ADDITIONAL COMMENTS

If moderate to severe corrosion of the prestressing steel strands is observed at any inspection locations, additional work may be necessary prior to remedial grouting. This work would typically include creating large inspection openings to better quantify the full extent of the damage. Condition information can then be used to perform structural analysis and load rating calculations. Depending on the severity of the corrosion and the scale of the problems, it is possible that lane closures, load posting or potentially a bridge closure will be warranted unless supplemental PT is provided to offset the loss of capacity caused by corrosion.

For box girder bridges, it is likely that all drilled hole or large inspection openings will be created in the webs on the interior of the structure. The openings will not be directly exposed to traffic or weather following the completion of the work. The risk of future corrosion of the PT tendons will not be increased if proper inspection and repair procedures are utilized. However, the performance of inspection and remedial grouting repair work at PT tendons in slab span bridges or in bridge decks can at least marginally, if not appreciably, increase the risk of future corrosion. Because grout voids, if present, would form on the top side of the PT tendons, inspection of high points and anchorages must be performed by creating holes in the bridge deck surface. The repairs installed at these holes will be subjected to traffic and weather, requiring periodic maintenance to ensure continued performance. Deficiencies with the repair, or with maintenance of the repair, can create direct pathways for rain, run-off, or de-icing chemicals to migrate directly into the PT tendon. For these reasons, it is recommended that NDT methods such as tomography or IE be utilized first to determine if any grout voids are present in the PT tendons before any invasive inspections are performed to evaluate the conditions at those grout voids.
CHAPTER 3: PROJECT APPROACH AND CONTRACT CONSIDERATIONS

3.1 PROJECT TEAM

As discussed in Chapter 2, the creation and repair of invasive openings in internal PT tendons requires specialized equipment and expertise and hands on access. These requirements may exceed the available resources and capabilities of the city, county or state bridge teams that may perform the routine annual inspection or maintenance of these structures. Hand-on access to the tendons will require access equipment that can be costly and may not be readily or sufficiently available to the routine inspection teams. In addition, the necessary inspection equipment will include, at a minimum, GPR and a durable and high-quality flexible videoscope. This equipment is costly and requires training for accurate operation. Entry to the interior of a box girder bridge will also typically be necessary, and will usually require confined space training and protocols. Additional materials will be required that may not be readily available to MnDOT maintenance teams including hammer drills, epoxy, PVC ports with valves, and potentially chipping hammers. Specialized expertise helps to ensure the tendons are accurately located and invasive openings are carefully created and properly sized, positioned, and sealed or repaired. Specialized expertise also ensures all PT tendon conditions are accurately and sufficiently investigated and documented. These factors are critical to ensure that the investigation work is successful, the PT tendons are not damaged, and the risk of future corrosion is not increased as a result of creating openings into the bridge.

Because of these factors, and regardless of the selected contracting or project approach, inspection and/or remedial grouting repair work on PT bridge structures will typically be performed by a project team comprised of an engineering or testing consultant and a specialty contractor (TEAM). This format was used during both phases of this MnDOT project, performed by UMD/VSL and then WJE/VSL, and has been used by most other states that have performed similar investigation and repair work. The consultant is typically responsible for overall project management and coordination, locating the PT tendons, documenting site conditions, preparing deliverables, and providing quality control inspections during the work. Quality control inspections typically include general verification of the work performed and the procedures and material quantities used. The specialty contractor is responsible for performing the inspection and repair work, including the creation and repair of inspection openings and the execution of remedial grouting. If desired, the TEAM may be responsible for providing the necessary bridge access equipment and satisfying the applicable MOT requirements. MnDOT can achieve significant cost savings on certain PT bridge structures by providing these services.

3.2 SOLICITATION APPROACH

Similar to other bridge design and inspection projects where consultants may be engaged to perform work, several options are available to MnDOT for the solicitation of PT tendon investigation and/or repair projects depending on the scope and cost of the desired work. These options may include direct selection of pre-qualified firms experienced with this type of work, or competitive bid approaches. The
competitive bid approaches can be structured to allow responders to be ranked and selections to be made based solely on qualifications, or on best value criteria that includes qualifications and pricing. These approaches may include requests for proposals (RFP) or requests for qualifications (RFQ).

Following the work by UMD, MnDOT issued an RFP for the investigation, repair, and corrosion monitoring work that was ultimately performed by WJE/VSL at Bridge 02037E/W in 2013. Proposals were evaluated on a best value scoring basis, with 70 percent qualifications and 30 percent cost considerations. While the project approach and the associated scope of work was well defined in the RFP, the extent of the grout void problems at the structure were mostly unknown. As a result, significant assumptions needed to be made to develop cost information. The assumptions included estimating the time and materials required to complete the necessary remedial grouting repairs. The assumptions that were made by WJE proved to be inaccurate and repair work was not completed due to insufficient funding. We understand other states have successfully pursued a similar RFP approach for inspection and repair work, inclusive of cost proposals, and with incomplete information regarding the extent of grout voids. This approach and these experiences are discussed further in Sections 3.3 and 3.4 of this chapter.

Several other states have elected to use RFP solicitations that resemble an RFQ. The solicitation generally describes and defines the project approach and desired scope of the investigation work, and may or may not identify specific PT bridge structures where work is to be performed. Responders are evaluated based on their understanding of the project, proposed work plan, firm qualifications, and proposed personnel. Pricing agreements are then negotiated with the highest ranked respondent(s). The Oregon Department of Transportation (ODOT) recently employed this approach. ODOT issued an RFP in January 2016 for investigation and testing of PT tendons to understand current conditions and, if warranted, implement repairs before corrosion reached critical levels. The scope of the investigations was anticipated to include visual inspection, inspection openings, corrosion measurements, and materials testing. No specific PT bridges from their inventory were identified. Pricing agreements were to be negotiated with the highest ranked respondent(s). Contract agreements executed with the highest ranked responder(s) were to be for a period of four (4) years, and the total maximum contract value was set at $5,000,000. During the contract, ODOT will request work orders from the selected responders. The work orders will clearly define the necessary tasks, deliverables, and level of compensation.

Although the authors are not aware of their use for PT tendon investigation work, indefinite delivery/indefinite quantity (IDIQ) and construction manager/general contractor (CMGC) contracting approaches may also warrant consideration. IDIQ contracts would likely be limited in application to only PT tendon inspection work on bridge structures of a similar type (i.e., box girders), with similar access and MOT requirements. Unit price agreements could be negotiated for inspection work on a per PT tendon high point or anchorage basis. Task orders could then be developed for specific bridges based on the total number of desired inspection locations. There are challenges in using IDIQ contracting methods for remedial grouting repairs given the lack of uniformity in the size and volume of the grout voids to be repaired. However, it may be accomplished if adequate pay items are provided for mobilization, access, MOT, and grout volumes. The main benefit of IDIQ for this application would be to provide contract flexibility to add or subtract bridges based on bid prices and available budget. The CMGC delivery
method may also be beneficial for certain projects and would allow MnDOT to engage a contractor whom could provide input on costs and constructability issues, such as work plan and schedule, prior to contract letting to reduce risks and allow appropriate pay items to be established.

### 3.3 PROJECT APPROACH AND SCOPE

Relative to newer structures, post-tensioned bridges that were constructed prior to 2003 possess a greater risk that grout voids exist at high points and anchorages of PT tendons. The increased risk primarily arises from limitations of the materials that were used for grouting. Inadequacies or unforeseen consequences associated with the procedures, workmanship, and quality control measures employed during grouting operations also increased the likelihood that grout voids formed. A review of construction records and an analysis of the structure type and tendon geometry can help to define the risk level for each particular bridge structure. All of these factors, and others, were considered by UMD when developing and assigning inspection priority ratings for the pre-2003 PT bridges in the MnDOT inventory [7]. However, and although the risk of grout voids may be increased, it is not a certainty that any grout voids exist within any of the PT tendons of any particular bridge regardless of its structure type, tendon geometry or date of construction. Specialized inspections of pre-2003 PT bridges have been performed in several states. While grout voids and corrosion problems have been commonly found in at least some PT tendons, no significant grout voids have existed in many other bridges that have been inspected.

It will typically not be known to MnDOT if any grout voids exist in PT tendons prior to contract solicitation for investigation work. As such, a scope of work to perform 100 percent inspection of all PT tendon high points may not be prudent from a technical or financial standpoint. While an initial limited inspection will help to determine if grout void and corrosion conditions exist, it may not accurately define the scope of the problem. Estimates of the time and materials that may be required to perform comprehensive grouting repairs, but are derived from the results of a limited inspection, will involve guesswork. Unless the full extent of the grout void conditions are known with confidence prior to contracting for repair, the results of a limited inspection may under- or over-estimate the actual conditions.

In summary, the unknowns associated with the PT tendon conditions may create a risk of overpayment or an inability to complete the necessary work depending on the contract approach and payment mechanisms. While the use of multiple phases of work, and thus multiple contracts, can control these risks, the full identification and remediation of any potential problems will be delayed and overall projects costs may be increased as additional mobilizations are needed.

In general, four (4) project approaches are available to MnDOT for the development of future specialized inspection and remedial grouting repair contracts for the pre-2003 era PT bridge inventory. These approaches are as follows:

- A single contract for comprehensive inspection and repair of all PT tendon high points and anchorages
- Separate contracts for comprehensive inspection and then repair of all identified grout voids
- Multiple contracts for graduated levels of inspection and then full repair of all identified grout voids, or
- A “hybrid” approach that combines aspects of the separate and multiple contract approaches.

Each approach manages the unknowns associated with the potential scope of work differently. Because of these differences, each approach includes distinct advantages and disadvantages that warrant consideration by MnDOT on a per project basis depending on many factors including the size of the bridge, the number of bridges where investigation is desired, the priority rating of the bridge prescribed by UMD, and the available resources.

### 3.3.1 Single Contract for Full Inspection and Repair

For this approach option, the base scope of the contracted work would include both 100 percent inspection of all PT tendon high points and anchorages, and 100 percent remedial grouting repair of all grout voids that are discovered. Additional work that may be warranted depending on the conditions discovered could be handled through unit price agreements or contract amendments.

#### 3.3.1.1 Advantages

The specialized nature of PT tendon inspection and remedial grouting repair work limits the pool of available firms who meet the desired qualifications. Most, if not all, such firms are currently based outside of the state of Minnesota. These firms mobilize crews and equipment and travel to the bridge site(s), typically utilizing the same personnel and much of the same equipment regardless of whether inspection work or remedial grouting work is contracted to be performed. The crews and equipment are typically billed on a lump daily or weekly rate basis, in addition to global mobilization and demobilization charges. While the latter charges may be similar regardless of work duration, higher daily or weekly rates may be incurred for projects with short work durations (e.g. one week or less). The same access equipment and maintenance of traffic operations are required to facilitate inspection or remedial grouting work at the PT bridge structure, as discussed in Chapter 2. In addition, once a grout void has been identified, repairs need not be delayed. Injection ports can be installed and the void can be prepared for immediate remedial grouting repair. This is an important consideration for post-tensioned slabs, since the inspection ports will extend to the deck surface and need to be filled prior to a rain event or re-opening to traffic.

Because of all of these factors, there are potential cost benefits in combining the inspection and remedial grouting of all PT tendon high points and anchorages of a particular bridge into a single contract. This approach requires only one mobilization, and allows the inspection and repair processes to be streamlined and completed at one time, and by the same crew. If maintenance of traffic considerations are significant, or bridge access parameters are particularly costly or challenging, this approach ensures they are dealt with for only one period of time.
3.3.1.2 Disadvantages

Bridge access and MOT conditions, and the number of PT tendon high points and anchorages, can be determined through review of the available information, design drawings, and post-tensioning shop drawings of the particular bridge(s) where work is desired. This information can be used to identify the necessary equipment, and to reasonably estimate the duration of the work, that will be required to perform inspection of 100 percent of the PT tendon high point and anchorage locations. The estimates of total man hours can be developed by specialty contractors considering their experience, projected crew size and typical production rates for similar structure types with similar access parameters. The required equipment and total man hours will dictate the cost of the inspection work.

While the quantity of inspection locations can be determined, the quantity of repair locations cannot. It will typically not be known if any grout voids are present within the PT tendons of the selected bridge(s) at the time of contract solicitation. It is possible that no grout voids exist. It is also possible that grout voids are present, but only at a few discrete locations. Alternatively, a more significant quantity of grout voids may be present but the voids may not be of a significant size, or strands may not be exposed, such that the voids may not appreciably increase the risk of future corrosion within the PT tendons. Small voids can also be difficult to repair.

It is not unreasonable to pursue inspection of 100 percent of high points and anchorages, regardless of the findings. In our experience, however, a more modest sample size of randomly selected and representative locations can provide a reasonably accurate picture of the condition of the PT tendons and whether or not any significant problems or risks are present. The cost of comprehensive inspection of all PT tendon high points and anchorages may be significantly greater than necessary, and may not yield a significantly greater confidence level, if no significant grout void problems exist.

Similarly, and even if grout voids are known or strongly suspected to be present with the PT tendons of a particular bridge, the total quantity and volume of the grout void conditions will not be known to the responder when they are developing cost proposals. The extent of the problems can only be estimated, and may vary significantly within each span or PT tendon of each individual bridge. These unknowns are problematic and will significantly affect pricing for the repair phase of the work under this approach.

The duration of the project work to perform repairs, and the quantity of grout material needed for repair (if any), cannot be reliably estimated if the number of repair locations and the size of the grout voids are largely or completely undefined. This creates complexities for the development of project budgets by both MnDOT and prospective responders. It is reasonable to assume that respondents will assume widespread grout void conditions exist, and that the grout voids are generally large, to ensure that the contract includes sufficient time and materials to complete the necessary work. While these conditions may in fact exist, it is more likely that the scope of required repair work will be less. It is also possible that no remedial grouting repair work will be necessary or warranted. Depending on the compensation mechanism in the contract, the contract value could exceed, potentially significantly, the total value of the actual work in such cases.
3.3.2 Separate Contracts for Full Inspection and Repair

Contracting for grouting repairs before the need or scope of such repairs has been established is generally not advisable. Financial risk will likely be borne by the responder or MnDOT in some fashion. This potential risk can be reduced with a project approach that splits the inspection and repair work into separate phases with two distinct contracts. The base scope of work in the first contract would be to perform comprehensive inspection of all PT tendon high points and anchorages to determine whether grout voids exist and, if so, to thoroughly document the conditions present. Documentation should include collecting sufficient information to allow for accurate repair phase bidding, such as the locations and size or volume of the grout voids, location and size of ports installed for inspection that may be used for grouting, and the methods used for MOT and to access the work areas.

3.3.2.1 Advantages

The primary advantage of the two-phase project approach is that it is generally consistent with the traditional structure for typical bridge repair projects performed by transportation agencies. The inspection phase is intended to identify, document and quantify the deficient conditions and determine appropriate repairs, with a separate repair contract subsequently executed with a qualified contractor to correct the identified deficiencies. Depending on the conditions observed during the inspection phase contract, any additional work that may be warranted or desired could be incorporated into the work scope of the second contract.

Reliable estimates of the time and materials required for the repair phase can be generated following completion of the first phase; the quantity, volume and location of all grout voids will have been established. This information will allow more accurate project budgets to be developed by MnDOT for repairs. It will also allow more accurate cost proposals to be developed by specialty contractors, minimizing the assumptions that may otherwise inflate pricing or complicate bid comparison. Further, for certain bridges, the first phase may establish that no significant grout void conditions exist and, thus, a second phase is not needed.

3.3.2.2 Disadvantages

The primary disadvantages of the separate contract approach relate to time and financial considerations. The development and execution of two separate contracts will likely spread out the total project work at each bridge, or targeted bridge group, to a period of years. This approach also dictates that accurate project budgets and complete work scopes cannot be developed by MnDOT for the repair phase until the first contract is substantially complete. This may delay the implementation of the repair phase if additional time is needed to secure appropriate project funding, solicit bids and procure contracts. Two separate mobilizations will also likely be required to complete the necessary work at each bridge because the inspection and repair work will be spread out over a period of years. Access and MOT related expenses will be incurred twice, and may be significant. These considerations may increase the total project cost for each bridge relative to the single contract approach, depending on the grout void conditions that are present.
3.3.3 Multiple Contracts

The multiple contract approach intends to address the challenge of the unknown PT tendon conditions by separating the inspection and repair work contracts, and then further dividing the inspection contract into distinct phases with graduating levels of efforts. The initial phase of the inspection contract would typically include the invasive inspection of a limited percentage of the PT tendon high points and anchorages to determine if any grout void or corrosion problems exist, or are likely to exist. The inspection locations can be selected using a statistical sampling approach, or other method, and will typically focus on the locations that would be expected to be most prone to grout void formation. If no significant problems are observed, no further work is performed at that structure. Alternatively, if desired, NDT methods such as impact echo could be calibrated during the limited inspection work and then performed at other locations that did not receive invasive inspection to expand the sample size and provide additional confidence that no significant grout void problems exist. If significant grout voids are discovered, the second phase of work would be initiated or programmed. The second phase would typically consist of more invasive inspection openings at either an additional increment of PT tendon high points and anchorages, or all remaining such locations, at the discretion of the contracting agency.

Repair contracts can be programmed, prioritized, and solicited as needed following the completion of the inspection contracts, and the consolidation of the pertinent findings.

3.3.3.1 Advantages

The primary advantage of the multiple contract approach is that MnDOT has control over the amount of inspection that is performed at each structure. This approach is an efficient use of available resources when the PT tendon conditions are unknown at the time of contract solicitation. It avoids the potentially unnecessary expense of performing extensive inspection work, or repair, on PT bridges with no significant problems. It also allows for more expeditious evaluation of the bridge inventory. Limited inspections of several of the highest priority PT bridges can be combined into one contract, likely allowing for any potential problems to be identified at multiple structures more rapidly than other approaches. The collected information can help bifurcate the bridge inventory into the structures that warrant further inspection and potentially repair, and those that do not, and can help further prioritize all of the bridges that warrant future work. The same re-prioritization process can occur following the completion of comprehensive inspections, once the extent of the tendon conditions and the needed repairs has been fully defined. Similar to the separate contract approach, this information will allow for more accurate budgets and cost proposals to be developed for repair contracts.

3.3.3.2 Disadvantages

The primary disadvantage of this approach pertains to only the certain particular PT bridge structures where significant and widespread grout void problems exist, where decisions will have to be made incrementally with respect to follow-up activities. Such structures will be identified through the initial limited inspection work, but additional work will be required to accurately define and then repair the full scope of the problems. The additional phases of work would be performed through additional contracts that are solicited and procured, first for comprehensive inspection of the bridge, and then for remedial
grouting repair of all grout voids. Relative to the other approaches, the use of multiple contracts will inflate the total time that is required to remediate the bridge structure. The total project cost may also be increased, as potentially the same personnel and the same access, MOT and construction equipment are mobilized to and from the site on multiple occasions. If the necessary access equipment is particularly costly, these additional expenses can be significant and may adversely impact the total project cost relative to other approaches.

### 3.3.4 Hybrid

This approach is a derivative of the multiple contract approach consisting of two phases of work. The first phase or contract would consist of a limited inspection to evaluate PT tendon conditions at representative locations. If warranted, the second phase would be contracted and would consist of a joint scope of both 100 percent inspection of all PT tendon high points and anchorages, and remedial grouting repair of all identified grout voids. For either phase, the number of inspection locations can be determined conclusively. However, assumptions will need to be made regarding the number and size of grout voids to estimate the duration of the work, and the quantity of grout material, that will be required during the repair phase. These estimates would be developed based on the findings of the limited inspection, including both the percentage of inspection locations where grout voids were observed and the average size of those grout voids. Similar conditions would be assumed to exist over the remaining portions of the bridge structure that had not yet been inspected.

#### 3.3.4.1 Advantages

This approach attempts to capture the advantages, and mitigate the disadvantages, of the multiple contract approach. Comprehensive inspection and remedial grouting repair are only pursued on PT bridges where, and after, known problems have been identified through an initial limited inspection phase. Time and cost savings are potentially achieved by eliminating the intermediate contract phase and combining 100 percent inspection of all PT tendon high points and anchorages, and repair of all grout voids. This approach attempts to leverage the fact that either task can be performed by the same TEAM once mobilized to the site, and will generally require the same access, MOT and construction equipment. For PT bridges where significant or widespread grout void problems are known or expected, this approach may result in more expeditious and cost-effective remediation.

#### 3.3.4.2 Disadvantages

All repair projections will be based on only partial information and should be expected to under- or over-estimate the actual conditions. This issue manifested is relation to the work completed at Bridge 02037W where MnDOT pursued a hybrid approach. Initial limited inspection work was performed by UMD at that bridge, and several others. Significant and widespread grout void conditions were observed at Bridge 02037W. A joint contract was solicited for comprehensive inspection and remedial grouting repair of selected bridge spans of Bridge 02037W. The quantity and volume of the grout voids which existed in the PT tendons of the selected spans was estimated based on the reported findings, and experience with similar work on similar structures of a similar vintage. Grout material was procured
based on those estimates. The actual quantity and size of the grout voids that were discovered greatly exceeded the projections, and insufficient grout material was available under the contract to complete the necessary repairs. If the project budget cannot be increased to perform all repairs, the time and total cost for the bridge will increase due to multiple mobilizations.

3.3.5 Summary

In general, four (4) project approaches are available to MnDOT for the development of future specialized inspection and remedial grouting repair contracts for the pre-2003 era PT bridge inventory. Each approach manages the unknowns associated with the potential scope of work differently. Because of these differences, each approach includes distinct advantages and disadvantages that warrant consideration by MnDOT on a per project basis depending on many factors including the size of the bridge, the number of bridges where investigation is desired, the priority rating of the bridge as prescribed by UMD, the available resources and the compensation mechanism incorporated into the contract [7].

3.3.5.1 Single Contract

The single contract approach is not recommended for typical future inspection and remedial grouting work at pre-2003 era PT bridges in Minnesota. This approach carries financial risk because of the unknowns that exist with the grout void conditions. However, this approach may be preferable for certain situations where the risk of overpayment is minimal or outweighed by the risk or cost of delayed action, or where other complicating factors exist. These situations may include emergency work, PT bridges with particularly challenging access conditions or restrictive access windows, or bridges where it is known or strongly suspected that grout voids are present at a majority of PT tendon high points and anchorages. In such instances, MnDOT and potential responders could mutually assume that a significantly high percentage of tendon high points and anchorages will require some remedial grouting repair while developing project budget or cost estimates. The quantity of grout material to be installed at each repair could be assumed (e.g., two bags of grout per grout void). These variables could be incorporated into the base bid. Contract adjustment provisions, potentially including unit price pay items, could also be established to manage deviations in the time required to complete the repairs, and the number and size of the repairs that are required.

3.3.5.2 Separate Contracts

The separate contract approach warrants consideration for future inspection and remedial grouting work at certain pre-2003 era PT bridges. This approach carries some risk of unnecessary expense associated with the inspection phase if no significant grout void conditions exist. However, the comprehensive inspection scope will serve to minimize the unknowns, and thus financial risk, associated with the repair phase. These factors may make this approach preferable for certain bridge structures where MnDOT desires to inspect all PT tendon high points and anchorages regardless of the findings. In general, this approach would allow PT bridge structures to be investigated and repaired, if needed, more
economically than the single contract approach, and more expeditiously than the multiple contract approach.

3.3.5.3 Multiple Contracts

The multiple contract approach likely represents the most cost-effective option for MnDOT for performing future inspection and repair of the pre-2003 PT bridge inventory. This approach is essentially a “pay as you go” method that allows for groups of PT bridge structures to be assessed incrementally. This approach is prudent when the inventory of bridges to be inspected is relatively large, the conditions within the PT tendons of those bridges are generally or completely unknown, and the majority of the bridges are located within the same geographic area. All of these considerations apply to the pre-2003 era bridge inventory in Minnesota. This approach was used by MnDOT for the work performed by UMD in 2012, and was recommended by UMD for the performance of all future inspection work [7]. This approach has also been utilized by several other states when performing similar work on similar PT bridge structures.

3.3.5.4 Hybrid

The hybrid project approach may be preferable to MnDOT for certain PT bridges where significant and/or widespread grout void problems are suspected or have been identified during an initial limited inspection. This option may be more desirable than the multiple contract approach if prompt repair of the voids is the chief project priority, and any potential cost overruns or premiums that may be associated with the repair phase can be accepted and managed in the budgeting and contracting processes. The latter will help avoid the deferral of work, as occurred at Bridge 02037W. Available strategies may include applying a multiplication factor to increase the assumed quantity and size of the grout voids that were identified during the initial limited inspection, or including provisions in the contract to account for discrepancies. Unit price pay items could be incorporated for the repair of a greater quantity, or greater volume, of grout voids than the assumed conditions, with the deviations documented and verified through quality control inspections performed by MnDOT. We understand this method has been used successfully by TxDOT, as discussed in the next section.

3.4 PAST EXPERIENCES

3.4.1 Multiple Contract Approach

In addition to Minnesota, the authors have performed investigations of internal PT tendon conditions in pre-2003 era PT bridges for state transportation agencies in Oklahoma, Oregon, Florida, Texas, and Hawaii. In each case, the condition of the PT tendons was not known prior to contract solicitation. The multiple contract project approach was pursued by each of these states for the desired work.

The scope of the Oklahoma project included thirty-six (36) cast-in-place concrete box girder bridges, all located within the Oklahoma City area, of which eighteen (18) were inspected by the authors and the other eighteen (18) were inspected by another consulting firm. The first contract for each firm included
two phases of inspection work. The first phase included invasive inspection of up to 20 percent of PT tendon high points and anchorages at each bridge. Grout voids, strand corrosion and evidence of moisture intrusion was observed in isolated PT tendon ducts of certain bridges. The second phase included additional invasive openings at the certain bridges where grout voids, strand corrosion and evidence of moisture intrusion were identified in PT tendons. No additional work was performed at the bridges where no significant problems were found during the limited inspection. Additional inspection and repair work is ongoing.

The Oregon, Florida and Hawaii projects were generally similar to Oklahoma but have included only one phase of limited initial inspections to date. The work in Oregon consisted of two (2) concrete box girder bridges, the work in Hawaii consisted of thirteen (13) bridges including both box girders and post-tensioned, precast concrete girder bridges, and the work in Florida included five (5) box girders and post-tensioned, precast concrete girder bridges. At each bridge, in each state, invasive inspection openings were created at approximately 5 to 10 percent of the PT tendon high points and anchorages. In Oregon, numerous grout voids were observed in one bridge, but only one grout void was observed at the other. Recommendations were made for additional inspection of the bridge where numerous grout voids were identified, but no further inspection work was deemed warranted at the other. We have recently been retained by Oregon to inspect more bridges throughout the state. The work order contract includes only inspection services at this point. In Hawaii, only minor grout voids were observed at each bridge and no further inspection or repair was recommended for those structures. The work performed in Florida was focused on the potential for chloride contaminated and/or soft grout material.

We understand similar PT tendon inspection work has been performed by Indiana and Alaska, also using the multiple contract approach [13].

3.4.2 Hybrid Approach

As discussed, the hybrid approach was attempted by MnDOT for inspection and repair work at Bridge 02037W following a limited initial inspection of this structure by UMD. Repair work could not be completed because the actual grout void conditions greatly exceeded projections, and the available project budget could not accommodate the cost increases.

The hybrid approach was also utilized by TxDOT for a recent PT tendon investigation and repair project [14]. The bridge was a box girder bridge that was 16 miles (9.66 kilometers) long and included 7500 PT tendons. The initial inspection efforts consisted of limited invasive inspection of approximately 10 percent of the PT tendon high points and anchorages, and grout voids were discovered at many locations. A second contract was then executed for invasive inspection of 100 percent of PT tendon high points and anchorages, and for repair of all grout voids discovered at the inspection locations. The second contract included repair pay items for inspection openings at anchorages, small void re-grouting, large void re-grouting, and full tendon re-grouting. We understand that TxDOT directed responders to assume that grout voids of a certain volume (i.e., small, large or full) were present at a certain percent of inspection locations, with both figures slightly elevated relative to the initial contract findings. Unit price pay items were also solicited to account for variability above or below the assumed values, for both the
number and size of the grout void repairs. The contract also included formal specifications for the inspection and repair procedures that were to be followed. Quality control inspections were specified to verify the quantity and size of the grout void repairs. We understand that TxDOT pursued this approach to expedite the repair of this structure and to avoid repeat costs associated with the mobilization and de-mobilization of the specialty contractor to the project site.

We understand a hybrid approach was also utilized by the City of Minneapolis with respect to the Plymouth Avenue Bridge after initial limited inspections were performed by Corven Engineering and significant corrosion problems were identified with a number of PT tendons [13]. UMD also performed limited invasive inspection work at this bridge in 2012 [7]. However, this project was unique because the corrosion damage was sufficiently advanced that the bridge was directed to be immediately closed.
CHAPTER 4: PROJECT BUDGET DEVELOPMENT

The cost of future PT tendon investigation and repair projects will be dictated by several key variables that collectively define the duration of the work that is to be performed, and the necessary equipment and materials that will be required. These variables include the approach and scope of each project, the bridge type(s), and the existing conditions. The approach and scope of the project will obviously be the most significant factors for the project cost. This information will include the total number of PT tendon high points or anchorages where work is to be performed and whether that work is to include inspection, remedial grouting repair, or both. The bridge type and its associated MOT and access requirements, including mobility between the work areas, will also significantly affect pricing. Daily rates of productivity will be hindered at certain bridges where access to the work areas, or movement between work areas, is complicated. Variable access requirements may also exist, necessitating the use of different types of equipment to perform work at different portions of the PT bridge. Lastly, and as previously discussed, the number and size of the grout voids will control the pricing of any repair work. This information may or may not be known at the time project budgets are developed by MnDOT, or when cost proposals are developed by prospective responders.

All of the key variables discussed above are project-specific considerations that, once defined, will allow for reasonably reliable pricing information to be developed for each particular project. However, MnDOT identified a need for more general pricing information that could assist with approach and scope decisions and budget forecasting. The desired information included ballpark unit cost values for inspection and/or remedial grouting repairs for the different structure types that exist in the pre-2003 era PT bridge inventory. MnDOT identified eight (8) exemplar PT bridge structures to serve as the basis for the development of this pricing information, and relevant design and shop drawings were provided to the author for review.

4.1 ASSUMPTIONS AND GENERAL CONDITIONS

For each of the eight (8) exemplar bridges identified by MnDOT, the project approach was assumed by the authors to be the single contract option. The scope of work was assumed to include inspection of 100 percent of PT tendon high points and anchorages, and remedial grouting repairs at all identified grout voids. Grout voids were assumed to exist at 25 percent of the inspection locations (i.e., 25% void ratio), and each void was assumed to require two (2) bags of grout material to complete the repair and fill the duct. The authors also assumed the work included the creation of two (2) large inspection openings and the preparation of one deliverable.

Base pricing was developed for each bridge assuming the work is contracted as an individual project and is not grouped with other bridges. All work was assumed to be performed by a TEAM comprised of a consultant and a specialty contractor. All field work performed by the specialty contractor was assumed to utilize a three (3) person crew, comprised of non-union open shop work forces, working between 7:00 am and 3:30 pm daily, Monday through Friday. Mobilization to and from the site and costs of all required materials and construction, access and MOT equipment were included. Confined space requirements were considered for all box girder bridges. Additional cost information was then derived
from the base pricing for other options that may be preferred by MnDOT, including 100 percent inspection work only (i.e., no repair), and exclusion of access and MOT equipment assuming MnDOT is responsible for these services.

4.2 EXAMPLE PRICING

The eight (8) exemplar bridges identified by MnDOT are grouped by structure type. A brief description of each bridge is provided and the various factors that affect pricing for that structure are identified. Ballpark unit costs are then presented for the various scope options.

4.2.1 Box Girder Bridges

4.2.1.1 Bridge 27719

Bridge 27719 is a single span bridge constructed in 1982 that carries four lanes of traffic on Lyndale Avenue over Shingle Creek in Brooklyn Park, Minnesota, as shown in Figure 4.1. The bridge is a cast-in-place PT box girder with ten (10) longitudinal cells. Three (3) draped internally bonded PT tendons are present in each of the eleven (11) girder webs, as shown in Figures 4.2 and 4.3. The tendons included galvanized corrugated metal ducts, cementitious grout and strands. UMD assigned an inspection priority rating of 8 (10 is highest) for this structure based, in part, on cracking and spalling conditions observed in the deck, internal diaphragms and/or bottom slab [7]. The factors that affect pricing on this bridge include:

- The inspection locations for each of the thirty three (33) tendons are limited to only the end anchorages at each abutment, as no other intermediate high points exist. This results in a total of sixty six (66) potential inspection locations.

- Inspection and repair work will require access to the interior of the bridge. Access doors are present in the bottom slab of the bridge at each end of each cell, but no web openings exist to allow lateral movement from one cell to another. A snooper truck will be required to access the bridge interior given site constraints.

- Lane and sidewalk closures will be required, including the placement of road cones, signs, barricades, arrow boards and a crash truck behind the snooper.

- The field work duration was estimated to be three (3) weeks. The limited interior height of the structure will reduce daily production rates to approximately half of typical levels.
Table 4.1 Ballpark Unit Costs - Bridge 27719

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Figure 4.1. Bridge 27719 - Aerial View [15].

Figure 4.2. Bridge 27719 - Tendon Profile.
4.2.1.2 Bridge 02034

Bridge 02034 is a three span bridge that was constructed in 1996 and carries two lanes of on-ramp traffic over the southbound lanes of Minnesota State Highway 47 onto United States Route 10 (US-10) in Coon Rapids, Minnesota, as shown in Figure 4.4. The bridge is a cast-in-place PT box girder with four (4) longitudinal cells. Five (5) draped internally bonded PT tendons are present in each of the five (5) girder webs, as shown in Figure 4.5 and 4.6. There are also PT tendons in the pier capbeam, as shown in Section 4.2.2.4. The tendons include galvanized corrugated metal ducts, cementitious grout and strands. UMD assigned an inspection priority rating of 8 (10 is highest) for this structure based, in part, on the cracking in the deck and inside the cells [7]. The factors that affect pricing on this bridge include:

- The inspection locations for each of the twenty-five (25) tendons includes the end anchorages at each abutment, and the intermediate high points located on both sides of each of the two pier walls, totaling six (6) per tendon. This results in a total of 150 inspection locations.

- Inspection and repair work will require access to the interior of the bridge. Access doors are present in the bottom slab of the bridge at each cell, but no web or pier wall openings appear to exist to allow movement between spans, or lateral movement from one cell to another within the same span.

- A snooper truck will be required to reach the access doors in Span 1, which is over the roadway, and a 35-ft (10.67 m) scissor lift positioned in the median will facilitate access to Spans 2 and 3.

- Lane closure will be required for work at Span 1, including the placement of road cones, signs, arrow boards and a crash truck behind the snooper. Work in Spans 2 and 3 will not require lane closures.

- The field work duration was estimated to be six (6) weeks.
Table 4.2 Ballpark Unit Costs - Bridge 02034

<table>
<thead>
<tr>
<th></th>
<th>100 % Inspection and Repair (unit cost per location)</th>
<th>100% Inspection Only (unit cost per location)</th>
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Figure 4.4. Bridge 02034 - Aerial View [15].

Figure 4.5. Bridge 02034 - Tendon Profile.
4.2.1.3 Bridge 27194

Bridge 27194 is a four span bridge that was constructed in 1998 and carries the two eastbound lanes of Minnesota State Highway 5 over United States Route 212 and a westbound on-ramp lane in Eden Prairie, Minnesota, as shown in Figure 4.7. The bridge is a cast-in-place PT box girder with four (4) longitudinal cells. Three (3) draped internally bonded PT tendons are present in each of the five (5) girder webs, as shown in Figures 4.8 and 4.9. The tendons include galvanized, corrugated metal ducts, cementitious grout and strands. UMD assigned an inspection priority rating of 8 (10 is highest) for this structure based, in part, on the tall vertical rise of the draped tendon profile [7]. The factors that affect pricing on this bridge include:

- The inspection locations for each of the fifteen (15) tendons includes the end anchorages at each abutment, and the intermediate high points located on both sides of each of the three pier walls, totaling eight (8) per tendon. This results in a total of 120 inspection locations.

- Inspection and repair work will require access to the interior of the bridge. Access doors are present in the bottom slab of the bridge at each span, with web openings allowing lateral movement between cells within the same span. An aerial lift will be required to reach the access doors.

- Shoulder closures will be required for work in Spans 2 and 3, including the placement of road cones, signs, arrow boards and a crash truck proximate to the work area.

- The field work duration was estimated to be four and one half (4-1/2) weeks.
Table 4.3 Ballpark Unit Costs - Bridge 27194

<table>
<thead>
<tr>
<th>100% Inspection and Repair (unit cost per location)</th>
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</thead>
<tbody>
<tr>
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Figure 4.7. Bridge 27194 - Aerial View [15].

Figure 4.8. Bridge 27194 - Tendon Profile.
4.2.1.4 Bridge 27217

Bridge 27217 is a four span bridge that was constructed in 1998 and carries one northbound lane of on ramp traffic for Minnesota State Highway 252 over Minnesota State Highway 610 in Brooklyn Park, Minnesota, as shown in Figure 4.10. The bridge is a cast-in-place PT box girder with two (2) longitudinal cells. Three (3) draped internally bonded PT tendons are present in each of the three (3) girder webs, as shown in Figures 4.11 and 4.12. The tendons include galvanized, corrugated metal ducts, cementitious grout and strands. UMD assigned an inspection priority rating of 8 (10 is highest) for this structure [7].

The factors that affect pricing on this bridge include:

- The inspection locations for each of the nine (9) tendons include the end anchorages at each abutment, and the intermediate high points located on both sides of each of the three pier walls, totaling eight (8) per tendon. This results in a total of 72 inspection locations.

- Inspection and repair work will require access to the interior of the bridge. Access doors are present in the bottom slab of the bridge at each span, with web openings allowing lateral movement between cells within the same span. A scissor lift will be required to reach the access doors.

- Shoulder closures will be required throughout the work, including the placement of road cones, signs, arrow boards and a crash truck proximate to the work area.

- The field work duration was estimated to be three (3) weeks.
### Table 4.4 Ballpark Unit Costs - Bridge 27217

<table>
<thead>
<tr>
<th></th>
<th>100 % Inspection and Repair (unit cost per location)</th>
<th>100% Inspection Only (unit cost per location)</th>
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<td><strong>Excluding Access and MOT</strong></td>
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**Figure 4.10. Bridge 27217 - Aerial View [15].**

**Figure 4.11. Bridge 27217 - Tendon Profile.**
4.2.2 Other Bridge Types

4.2.2.1 Bridge 52009 - PT Slab Span

Bridge 52009 is a two span bridge that was constructed in 1985 and carries six lanes of Minnesota State Highway 860D traffic, including two turn lanes, over United States Route 169 in Mankato, Minnesota, as shown in Figure 4.13. The bridge is a cast-in-place slab span with internally bonded PT tendons. Fifty six (56) draped longitudinal tendons are present along the length of the structure, with an additional eight (8) parabolic tendons located over the pier, as shown in Figures 4.14 and 4.15. Twenty-one (21) transverse tendons are also present. The tendons include galvanized, corrugated metal ducts, cementitious grout and strands. UMD assigned an inspection priority rating of 7 (10 is highest) for this structure based on deck cracking and spalling [7]. The factors that affect pricing at this bridge include:

- Two inspection locations exist for each transverse tendons (end anchorages), three for each longitudinal tendon (end anchorages and intermediate high point), and one for each parabolic tendon (intermediate high point). This results in 218 inspection locations.
  - Only one inspection location would be drilled at the high points of longitudinal and parabolic tendons due to the limited vertical drape of the tendon profiles.
  - It should be noted that, while included in the pricing below, inspection may not be prudent or warranted on the transverse or non-structural PT tendons.
- Most inspection locations are positioned approximately 12 in (304.8 mm) below the deck surface, which would be expected to reduce daily production rates below typical levels.
- All work will be performed from the deck so no access equipment is required.
- Daily traffic lane and shoulder closures will be required throughout the work, including road cones, signs, arrow boards and a crash truck proximate to work areas.

- The work duration was estimated to be twelve (12) weeks.

Table 4.5 Ballpark Unit Costs - Bridge 52009

<table>
<thead>
<tr>
<th></th>
<th>100 % Inspection and Repair</th>
<th>100% Inspection Only</th>
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<td>(unit cost per location)</td>
<td>(unit cost per location)</td>
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<td>Including Access and MOT</td>
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<td>MOT</td>
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</table>

Figure 4.13. Bridge 52009 - Aerial View [15].
4.2.2.2 Bridge 27A58 - PT Slab Span

Bridge 27A58 is a four span bridge that was constructed in 2000 and carries two lanes of County State Aid Highway 101 traffic over Grays Bay channel in Minnetonka, MN. The bridge is a cast-in-place slab span with thirteen (13) longitudinal internally bonded PT tendons. The tendons include galvanized, corrugated metal ducts, cementitious grout and strands. UMD assigned an inspection priority rating of 5 (10 is highest) for this structure based, in part, on fine cracks in the overlay and bottom slab [7]. The factors that affect pricing on this bridge include:

- Five inspection locations exist for each tendon, including the end anchorages and each intermediate high point located over the three piers. This results in a total of 65 inspection locations.
  - Only one inspection location would be drilled at the intermediate high points of each tendon due to the limited vertical drape of the tendon profile.
- All inspection and repair work will be performed from the deck so no access equipment is required.
• Daily traffic lane and shoulder closures will be required throughout the work, including the placement of road cones, signs, arrow boards and a crash truck proximate to the work area.

• The work duration was estimated to be four (4) weeks.

Table 4.6 Ballpark Unit Costs - Bridge 27A58

<table>
<thead>
<tr>
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<th>100 % Inspection and Repair (unit cost per location)</th>
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</table>

Figure 4.16. Bridge 27A58 - Aerial View [15].

Figure 4.17. Bridge 27A58 - Tendon Profile.
4.2.2.3 Bridge 70037 - PT Spliced Girder

Bridge 70037 is a single span bridge that was constructed in 1994 and carries two lanes of eastbound traffic on United States Route 169 over Municipal State Aid Street 131 in Shakopee, Minnesota, as shown in Figure 4.19. The bridge has nine (9) cast-in-place, spliced bulb-tee girders, each with three (3) internally bonded longitudinal PT tendons, as shown in Figures 4.20 and 4.21. The tendons include galvanized, corrugated metal ducts, cementitious grout and strands. UMD assigned an inspection priority rating of 7 (10 is highest) for this structure based, in part, on the depth of the girders [7]. The factors that affect pricing on this bridge include:

- The inspection locations for each of the twenty-seven (27) tendons are limited to only the end anchorages. This results in a total of 54 inspection locations.
- Inspection and repair work will require access to the side faces of the girders, necessitating the use of a 60-ft (18.29 m) aerial lift.
- Shoulder closures will be required throughout the work, including the placement of road cones, signs, arrow boards and a crash truck proximate to the work area.
- Lane closures would be required during repair work, if necessary, to allow the remedial grouting operations, equipment and materials to be staged on the bridge deck. Grout would be pumped to the ends of the girders from the staging locations. The lane closures would include the placement of road cones, signs, arrow boards and a crash truck proximate to the work area.
- The work duration was estimated to be four (4) weeks.
### Table 4.7 Ballpark Unit Costs - Bridge 70037

<table>
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</table>

**Figure 4.19.** Bridge 70037 - Aerial View [15].

**Figure 4.20.** Bridge 70037 - Tendon Profile.
4.2.2.4 Bridge 02034 - Pier Capbeam

Bridge 02034 is a three span bridge that was constructed in 1996 and carries two lanes of on-ramp traffic over the southbound lanes of Minnesota State Highway 47 onto United States Route 10 (US-10) in Coon Rapids, Minnesota, as shown in Figure 4.22. The bridge is supported by a post-tensioned pier capbeam with twelve (12) internally bonded longitudinal PT tendons, as shown in Figure 4.23 and 4.24. There are also PT tendons in the superstructure, as shown in Section 4.2.1.2. The tendons include galvanized corrugated metal ducts, cementitious grout and strands. UMD assigned an inspection priority rating of 8 (10 is highest) for this structure [7]. The factors that affect pricing on this bridge include:

- The inspection locations for each of the twelve (12) tendons includes both of the end anchorages. This results in a total of 24 inspection locations.

- Inspection and repair work will require access to the ends of the pier capbeam. Access can be accomplished to both of these locations using an aerial lift.

- The aerial lift can be positioned in the median and on the embankment to access the ends of the pier capbeam. No lane or shoulder closures will be required for inspection work.

- Lane closures would be required during repair work, if necessary, to allow the remedial grouting operations, equipment and materials to be staged on the bridge deck. Grout would be pumped to the ends of the pier capbeam from the staging locations. The lane closures would include the placement of road cones, signs, arrow boards and a crash truck proximate to the work area.

- The field work duration was estimated to be one (1) week.
Table 4.8 Ballpark Unit Costs - Bridge 02034 Pier Capbeam

<table>
<thead>
<tr>
<th></th>
<th>100 % Inspection and Repair</th>
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</table>

Figure 4.22. Bridge 02034 - Aerial View [15].

Figure 4.23. Bridge 02034 Pier Capbeam - Tendon Profile.
4.3 CONSIDERATIONS FOR FUTURE BUDGET CALCULATIONS

We understand the above pricing information may be used by MnDOT to help develop future project budgets. The specific factors associated with each of the exemplar bridges, and the assumptions that are integrated into the presented costs, must obviously be understood and evaluated for their appropriateness or applicability during any future calculations. Several additional factors should also be considered:

- Unit prices were developed utilizing the single contract approach. As discussed in Chapter 3, this approach is not expected to be the most cost-effective strategy for performing future inspection and repair work on the pre-2003 era PT bridge structures in the MnDOT inventory. While the unit pricing can still guide budget development, alternate approaches warrant consideration.

- The unit cost information assumes each project is performed individually. Cost savings can be achieved by packaging similar work at multiple bridges located within a similar geographic area.

- The unit cost information assumes each project includes 100 percent inspection of all PT tendon high points and anchorages. Higher unit costs should be expected if less than 100 percent inspection is performed, such as with the multiple or hybrid contract approaches.

- The unit cost information assumes 25 percent inspection locations contain voids and the average void requires two bags of grout. Higher unit costs should be expected if more and/or larger voids are found during inspection.

- Unit cost information was presented in 2016 dollars and not modified for possible cost increases in the future.

- PT tendon inspection work can be performed at approximately 10 locations per day, on average, with a typical three person crew size. Higher or lower daily production rates may be achieved depending on the ease of the access to and between the work locations for both personnel and
the necessary equipment. More challenging access conditions should generally be expected to increase unit costs, and vice versa.

- Rates of production for repair work are difficult to project because they are impacted by several variables, including the size of the grout voids and whether vacuum, vacuum-assisted or pressure grouting repair is required. The latter may not be known until after repairs have been attempted.

- Access and MOT considerations can significantly affect project pricing. These costs may be negligible where ladder access from a median is available, or they may be particularly costly if an under bridge inspection vehicle is required for all work. While significant cost savings can be achieved if MnDOT elects to provide these services for the more challenging projects, the efficiency of all field work is entirely reliant upon their timely and complete implementation. Complications have been experienced in certain states resulting in reduced productivity, or lost working days, limiting actual cost savings.
CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

Grout materials and poor grouting practices used in PT bridge construction prior to 2003 frequently resulted in the formation of grout voids inside PT tendons at high points and anchorages. Grout voids have been identified as conditions that can promote a corrosive environment within PT tendons. The presence of grout voids or the initial corrosion of prestressing strands inside a PT tendon is often a latent condition discoverable only through specialized inspection work. Grout voids and corrosion problems have been found in the PT tendons of multiple bridges located in many states, including Minnesota, where specialized investigations have been performed. Approximately 40 PT bridges exist in Minnesota that were constructed prior to 2003 and, thus, may possess grout voids or corrosion problems within PT tendons. MnDOT has identified a need to proactively investigate PT tendon conditions in pre-2003 era PT bridges to determine if grout voids or corrosion conditions are present and, if so, to implement repairs.

The following sections summarize conclusions and recommendations for the development of future investigation and repair contracts for pre-2003 era PT bridges in Minnesota.

5.1 WORK PLAN

5.1.1 General Considerations

- Inspection and remedial grouting repair of PT tendon conditions requires up-close access to the concrete elements in which they are embedded or contained. This typically consists of access to the interior of PT box girder bridges or access to the exterior of PT slab span, spliced girder, pier cap, or straddle bent bridges.
  - The type(s) of access equipment required for each bridge will be primarily dictated by the position of the access hatches or work locations and their vertical distance above grade.
  - Access to the interior of box girder bridges will require that confined space entry protocols be followed.
  - Different access equipment may be required in different spans of the same bridge.

- For most PT bridges, maintenance of traffic (MOT) considerations will be required in and around the work zone.

5.1.2 Document Review

- A detailed review of bridge design drawings and post-tensioning shop drawings, if available, should be performed prior to field work to identify:
  - The number of PT tendons
  - The number of high points and anchorages along each tendon.
  - The means of access that will be required.
The depth of the PT tendons
The length and profile of the tendons

5.1.3 Visual Survey

- A limited visual survey of the bridge, including the interior of box sections, should be performed and include general observations from grade, the bridge deck surface, and close range observations of the concrete elements in which PT tendons are embedded.

- The visual survey should be intended to identify any areas of concern, including any conditions that may indicate the PT system is not performing as anticipated.
  - Concrete distress (e.g., delaminations, spalls, etc.)
  - Moisture staining or evidence of uncontrolled water infiltration
  - Corrosion staining located at or adjacent to the PT tendons or their couplers and anchorages
  - Evidence of grouting issues during construction (e.g., grout leakage)
  - Cracking
    - shear cracking at supports
    - flexural cracking at mid-span or over piers
    - longitudinal cracking parallel to and aligned with the PT tendons

5.1.4 Invasive Inspection

- Invasive inspection locations will typically consist of the end anchorages and high points along the length of each PT tendon.
  - The inspection work may need to be performed “as close as possible” to the actual high point or end anchorage.
  - Inspections should generally performed at the apex, or on both sides of, intermediate high points.

- Ground penetrating radar (GPR) should be utilized to accurately locate the internal PT tendons and mild steel reinforcement at the inspection locations.

- The centerline of the tendon profile should be mapped using chalk or crayon.

- NDT methods such as ultrasonic tomography or IE should be utilized to evaluate whether any grout voids are present, or likely present, within internal PT tendons of PT slab span bridges or PT bridge decks before any invasive openings are created.
5.1.4.1 Drilled Hole Openings

- Drilled hole openings can be created at each inspection location to investigate the conditions within the tendon. Refer to the inspection guide previously developed for MnDOT by UMD to supplement this information [7].
  - Each opening will typically consist of a single hole drilled into the concrete to the depth of the duct using a hammer drill. The recommended hole diameter is 1 in (25.4 mm).
  - The hole should be positioned and drilled to intersect the top of the duct.
  - Caution should be exercised during drilling.
  - The hole should be blown free of dust and debris using oil-free compressed air.
  - The wall of the duct should be opened using a long flat head screwdriver.
    - When the PT tendon is fully grouted, this process may be somewhat difficult due to the presence of the grout.
    - When a grout void is present, or if the grout material is of poor quality, the duct will typically open easily.
- A video borescope (videoscope) should be inserted into the drilled hole to facilitate observations of the tendon conditions.
  - If the PT tendon is fully grouted at the inspection location, grout material that is generally medium to dark gray in color and hard in composition will be visible immediately behind the duct wall.
  - When a grout void is present at the inspection location, the videoscope should be inserted into the hole and then into the PT tendon to allow for observation and documentation of the conditions.
    - The percentage of the duct cross-sectional area that is filled or, conversely, voided should be estimated.
    - The approximate length of the grout void should be determined.
    - The general quality of the grout material should be evaluated.
    - The condition of any exposed prestressing strands should be determined (corrosion or failure).
    - The interior surfaces of the duct should be reviewed for evidence of corrosion.
    - If strand or duct corrosion is present, the extent of any corrosion should be estimated [8].

5.1.4.2 Large Openings

- Large openings should be created when and where the visual survey or a drilled hole opening identifies a potential problem or additional evaluation is desired.
  - Potential problems may include corrosion staining, cracking, duct or strand corrosion or poor quality grout.
  - Additional evaluation may include sampling of the grout material or NDT procedures, such as corrosion rate measurement.
Large openings consist of approximately 8 in (203.2 mm) by 16 in (406.4 mm) areas, or larger if necessary, where concrete is removed to expose the PT tendon.

In general, the opening should be centered about the PT tendon location.

The removal work will typically be performed with small hand tools excavating to the depth of the tendon.

- A concrete saw or grinder should be used to saw-cut the opening perimeter of the opening area.
- Concrete inboard of the saw cut can be removed with a small chipping hammer to the depth of the duct, such that approximately 50 percent of the circumference is exposed.
- Once exposed, a portion of the duct should be opened with a small grinder equipped with a rotary cut-off wheel.
- Caution should be exercised during the work to avoid excessive damage to the concrete element, its mild reinforcement and the strands.

5.1.4.3 Documentation

- Detailed documentation of the conditions observed during the visual survey and at all drilled hole and large openings should be performed.
  - Documentation should consist of field notes and photographs.
  - Include general information regarding type of access equipment used and whether or not traffic control was required.
  - All documentation should be accurately keyed to the inspection locations.
    - This will typically include the development of a nomenclature system that uniquely identifies each inspection location.
    - The nomenclature should include, at a minimum, identification of the bridge, span, element, tendon, and the position of the inspection location.

- Documented information at each drilled hole or large opening should include:
  - The date inspection work was performed
  - The exact position of the drilled hole
  - If the PT tendon is fully grouted or if a grout void exists.
  - If a grout void is present:
    - the approximate length and percentage of the duct cross section that is voided should be estimated
    - the number of prestressing strands that are exposed, if any, should be noted
    - the extent of any duct or strand corrosion that is present should be judged.
    - the number of failed prestressing strands, if any, should be determined
    - the size and location of inspection ports that are installed for future grouting
  - The color and condition of the grout
  - If any material samples were collected
  - The description and results of any NDT procedures performed.
5.1.4.4 Opening Repairs

- Repairs should be immediately performed to seal all openings.

- Drilled hole openings:
  - If no grout void exists, no remedial grouting is needed. Permanent repairs should consist of completely filling the hole with high-quality cementitious repair material or epoxy mortar, as desired by MnDOT.
  - If a grout void exists, remedial grouting should be performed as the permanent repair. An air-tight port should be inserted and completely sealed into the drilled hole using epoxy adhesive.
    - The port is required to perform remedial grouting repair and will allow grout material to be injected into the grout void.
    - The port can also facilitate interim inspections or monitoring of the PT tendon conditions if remedial grouting is delayed. Ports that extend to the deck surface should be grouted prior to a rain event or re-opening the bridge to traffic.

- Large openings:
  - The duct and concrete should be repaired using materials approved by MnDOT.

5.1.5 Remedial Grouting

- Remedial grouting should be performed to completely fill grout voids that exist in the PT tendons, whether or not corrosion is present.
  - A grout material that is compatible with the composition of the existing grout material, and is approved by MnDOT, should be used.
  - The remedial grouting procedure should be selected depending on the void conditions and may consist of vacuum grouting, vacuum-assisted grouting, or pressure grouting.
  - All grouting work should be performed by a grouting technician certified by the American Segmental Bridge Institute (ASBI).
  - All repair grout material should be mixed and field tested in accordance with the recommendations in the Specification for Grouting of Post-Tensioned Structures published in 2012 by the Post-Tensioning Institute (PTI) [12].

- Remedial grouting operations can be staged from a number of different locations depending on the site topography and the type and geometry of the bridge. Staging locations will typically be the interior of box girder bridges, or the surface of bridge decks.

- Quality control procedures should be employed to verify the remedial grouting work was successful, the PT tendon is full of grout and a grout void no longer exists.
The volume of grout injected into each void can be measured during the grouting operation and compared to the air volume that was measured, or estimated, prior to the grouting procedure.

- The ratio of the grout used to the air volume of the grout void should ideally be greater than 90 percent.

At the completion of the grouting operations, all ports should be cut flush with the face of the concrete, and the grout tubes inspected to verify that they are full of grout (after the grout has hardened).

Verification drill holes can be created at the high end of selected grout voids.

- The holes should be drilled no sooner than 24 hours after grouting is completed.
- The holes should be examined like a drilled hole inspection opening, with the conditions observed using a videoscope.

Grouting operations should be performed again if any deficiencies are noted.

Once re-grouting work is complete, all verification holes, inspection ports and grouting ports should be sealed with a repair material approved by MnDOT.

### 5.2 Contracting

#### 5.2.1 General Considerations

- Investigation and repair work should be prioritized in accordance with the recommended inspection priority ratings that were previously developed for MnDOT by UMD [7].

- Where possible, investigation and/or repair work projects should be packaged and performed concurrently or consecutively at multiple bridges under the same contract to achieve economy related to mobilization of the specialty contractor.
  - The majority of the pre-2003 era bridges in the MnDOT inventory are located within the Minneapolis-Saint Paul metropolitan area.
  - The majority of firms with appropriate qualifications and expertise to perform inspection and repair work are currently based outside of the state of Minnesota.

#### 5.2.2 Solicitation

- Several options are available to MnDOT for the solicitation of PT tendon investigation and/or repair projects depending on the scope and cost of the desired work.
  - Direct selection of pre-qualified firms experienced with this type of work
  - Competitive bid approaches (e.g., RFP, RFQ).
  - CMGC or Indefinite delivery/indefinite quantity (IDIQ) delivery methods.
- Competitive bid approaches can allow responders to be ranked and selections made based solely on qualifications, or on best value criteria that includes qualifications and pricing.
• Several other states have elected to use solicitations that generally describe and define the project approach and desired scope of the investigation work, and may or may not identify specific PT bridge structures where work is to be performed.
  o Responders are evaluated based on their understanding of the project, proposed work plan, firm qualifications, and proposed personnel.
  o Pricing agreements are then negotiated with the highest ranked responder(s).

• IDIQ contracts would likely be limited in application to only PT tendon inspection work on bridge structures of a similar type (i.e., box girders), with similar access requirements.
  o Unit price agreements could be negotiated for inspection work on a per PT tendon high point or anchorage basis.
  o Task orders could then be developed for specific bridges based on the total number of desired inspection locations.
  o There are challenges in using IDIQ contracting methods for remedial grouting repairs given the lack of uniformity in the size and volume of the grout voids to be repaired. However, it may be accomplished if adequate pay items are provided.

5.2.3 Approach

• In general, four (4) project approaches are available to MnDOT for the development of future specialized inspection and remedial grouting repair contracts. Each approach includes distinct advantages and disadvantages that warrant consideration by MnDOT on a per project basis.
  o A single contract for comprehensive inspection and repair
  o Separate contracts for comprehensive inspection and then repair
  o Multiple contracts for graduated levels of inspection and then full repair
  o A “hybrid” approach that combines the separate and multiple contract approaches.

• The single contract approach is not recommended for typical future inspection and remedial grouting work but may be preferable for certain situations where the risk of overpayment is minimal or outweighed by the risk or cost of delayed action, or where other complicating factors exist such as emergency work, challenging access conditions, restrictive work windows, or known and widespread grout void problems. One type of bridge that may be well-suited for single contract is post-tensioned slabs, since the inspection ports will extend to the deck surface and need to be filled prior to a rain event or re-opening to traffic.

• The separate contract approach warrants consideration for future inspection and remedial grouting work at certain pre-2003 era PT bridges where MnDOT desires to inspect all PT tendon high points and anchorages regardless of the findings.

• The multiple contract approach likely represents the most cost-effective option for MnDOT for performing future inspection and repair of the pre-2003 PT bridge inventory.
  o This approach allows PT bridges to be assessed incrementally, as warranted.
This approach was recommended by UMD for all future inspection work [7].
This approach has been successfully utilized by several other states when performing similar work on similar PT bridge structures.

- The hybrid project approach may be preferable to MnDOT for certain PT bridges where significant grout void problems have been identified during an initial limited inspection.
  - This option may be more desirable than the multiple contract approach if prompt repair of the voids is the chief project priority, and any potential cost overruns or premiums that may be associated with the repair phase can be managed in the budgeting and contracting processes.
  - This approach has also been successfully utilized by TxDOT when performing similar work on similar PT bridge structures.

### 5.3 BUDGETING

- The cost of future PT tendon investigation and repair projects will be dictated by project-specific variables that affect the nature and duration of the work including the approach and scope of each project, the bridge type(s), access constraints, and existing conditions.

- Ballpark unit pricing information was developed for eight (8) exemplar PT bridges identified by MnDOT to serve as the basis for future budget calculations.
  - Costs for 100 percent inspection and 25 percent voids repair ranged from approximately $1350 to $3000 per tendon high point/anchorage.
  - Costs for 100 percent inspection only work ranged from approximately $1000 to $2100 per tendon high point/anchorage.
  - Access and MOT costs ranged from approximately $200 to $1300 per tendon high point/anchorage.
  - Differences in the costs of the access and MOT equipment, the ease of mobility between the work locations, and the quantity and duration of the work were responsible for the broad spread in the unit cost ranges.

- Several key assumptions are inherent to the pricing presented herein that must be understood and evaluated for their appropriateness or applicability during any future project budget calculations.
  - Unit cost information was developed utilizing the single contract approach which is not expected to be the most cost-effective strategy for performing future inspection and repair work on pre-2003 era PT bridges in Minnesota.
  - Unit cost information assumes each project is performed individually. Cost savings can be achieved by packaging similar work at multiple bridges located within a similar geographic area.
- Unit cost information was presented in 2016 dollars and not modified for cost increases in the future. The authors cannot and do not guarantee that proposals, bids or actual costs will not vary from these estimates.
- Access and MOT considerations can significantly affect project pricing. While significant cost savings can be achieved if MnDOT elects to provide these services for the more challenging projects, the efficiency of all field work is entirely reliant upon their timely and complete implementation.
REFERENCES


APPENDIX A

INSPECTION, REMEDIAL GROUTING AND CORROSION MONITORING OF POST-TENSIONED TENDONS - MN BRIDGE NO. 02037W (SPANS 3 AND 4) AND MN BRIDGE NO. 02037E (SPAN 2)
MINNESOTA DEPARTMENT OF TRANSPORTATION
Inspection, Remedial Grouting and Corrosion Monitoring of Post-Tensioned Tendons

MN Bridge No. 02037W - Spans 3 and 4
MN Bridge No. 02037E - Span 2

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Report
October 18, 2013
WJE No. 2012.6315.1

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1.0 INTRODUCTION

The Minnesota Department of Transportation (MnDOT) retained Wiss, Janney, Elstner Associates, Inc. (WJE) and VStructural LLC (VSL) to perform specialized inspections and repairs to the post-tensioning tendons in portions of Minnesota Bridge Nos. 02037W and 02037E. The primary objectives of the work within the selected spans were to identify and document any grout voids near tendon high points and anchorages, observe any evidence of strand corrosion therein, and fill grout voids using vacuum or pressure grouting repair techniques. In addition, prior to remedial grouting, instrumentation was installed to facilitate long-term corrosion monitoring by MnDOT in two representative post-tensioning tendons where grout voids existed. The work was performed in general accordance with Contract No. 02345 between WJE and MnDOT, executed on April 19, 2013. This report summarizes the results of our work.

1.1 Scope of Work

The contracted scope of work for this project consisted of the specialized inspection of all tendon high points (60 total) and the remedial grouting of any discovered grout voids in Spans 3 and 4 of Bridge 02037W. Additional inspection and/or grouting repair work was to be performed in adjacent spans as time permitted, and depending on differences between actual and projected rates of production. The quantity and volume of the grout voids which existed in the post-tensioning tendons of these two spans was not known prior to the work.

Based on the project team’s experience with similar work on similar structures of a similar vintage, fifteen (15) bags of grout were procured to perform the remedial grouting work for this project. This quantity assumed that grout voids were present at twenty-five (25) percent of the inspected tendons, and that the volume of each void measured 13-15 liters, or approximately one bag of mixed grout. As documented herein, the actual quantity and size of the grout voids present in the post-tensioning tendons of Spans 3 and 4 greatly exceeded these projections. Voids were identified at approximately one-third of the tendon high points and the average void size exceeded 30 liters. Therefore, additional grout material beyond the initial procurement was required to regrout all voids in Spans 3 and 4. MnDOT elected to forego the procurement of additional material and instead directed that the remaining site time be used for additional inspection work in Span 2 of Bridge 02037E. This work was performed by WJE/VSL.

The final scope of work for this project consisted of the inspection of all tendon high points and anchorages in Spans 3 and 4 of Bridge 02037W and Span 2 of Bridge 02037E, with remedial grouting performed at only certain voids due to the limited grout material supplies. The findings of this work are discussed in Section 3 of this report. Corrosion monitoring sensors were installed in two tendons, and a laboratory study has been initiated to assist with interpretation of the field data. This work is discussed in Section 4 of this report. Finally, a summary of the work and recommendations for further work are presented in Section 5.
Note that the contract for this project also includes the development of a separate report or manual containing detailed guidelines for the future assessment and repair of similar structures identified by MnDOT. These guidelines will provide MnDOT with a framework to solicit and procure similar engineering and construction services contracts for these additional bridges. The guidelines will be developed considering information gained in this work, our previous experience, and information obtained from the plans of two exemplary bridges identified by MnDOT and likely to be targeted for future work of this kind. The guidelines will include unit cost and time estimates for typical bridge types. These estimates will be developed considering the investigation techniques, repair techniques, and other generalized project guidelines which are applicable. We envision that different estimates will be created based on differing access and MOT conditions, and the extent of required inspection and grouting activities for the identified bridges. This document will be prepared in compliance with MnDOT requirements and guidelines for research reports, with development beginning later this year, and will be provided under separate cover.

1.2 Additional Background

Post-tensioned structures have been used in the United States for over 50 years, and their overall performance has been very good. Typical post-tensioning systems consist of several key components including either high strength threaded bars or prestressing strands, metal or plastic ducts, and a corrosion protection system typically consisting of either cementitious grout or corrosion-inhibiting grease. For bridge structures, the most common system consists of prestressing strands in metal ducts filled with a cementitious grout.

Early grout materials, containing just cement and water, flow through the duct differently than modern thixotropic grouts. The early cement/water grouts filled the duct from bottom to top, like water. Modern thixotropic grouts fill the entire cross section of the duct at one location prior to advancing through the duct. Even with grout vents and drains at the tendon low point, the early grout materials could trap air and water inside the tendon collecting at tendon high points and anchorages. This was caused mostly by bleed water separating from grout material. In some cases, the bleed water would reabsorb back into the grout leaving a void. Thus, by definition, a grout void is defined as an air or water filled void inside a post-tensioning duct or anchorage. In addition, early grouting specifications did not define the rate in which grout pumped inside the tendon. At higher injection rates, turbulence sometimes formed within the duct, entrapping air and water. Excessive water addition to the grout mixture was also a frequent occurrence, and also contributed to the formation of grout voids inside tendons. In summary, the grout materials and grouting procedures employed before 2002 increased the risk for the formation of grout voids, particularly near tendon high points and anchorages.

In numerous studies, grout voids and moist grout have been identified as conditions that can promote a corrosive environment within post-tensioning tendons. The grout voids, which typically occur due to the improper grouting procedures and materials used during construction, allow air, moisture, and other contaminants to come into contact with the prestressing strands, resulting in corrosion. Over time, corrosion can lead to wire or strand failure resulting in a loss of post-tensioning force, and therefore, reduced serviceability or member capacity. Additional factors related to poor detailing, particularly at anchorages, poor workmanship and breaches in the post-tensioning systems (e.g., open vents or duct splices, etc.) have also been identified as significant contributors to tendon corrosion issues.

For strand corrosion to occur, both oxygen and moisture must be present. In addition, typically, the grout pH must be less than approximately 10, or the chloride content within the grout must be relatively high.
Reduction in grout pH typically results from carbonation, a reaction between carbon dioxide and calcium hydroxide, a by-product of cement hydration. As the pH of the grout is lowered, the grout loses its ability to passivate the exterior surface of the strands, allowing corrosion to occur. Note that the presence of chlorides can cause corrosion without the presence of carbonation. In recent years, concerns related to post-tensioning corrosion have been raised in a small number of bridges, most notably in Florida and Virginia, where investigations have linked strand corrosion to grout voids and poor detailing.

It should be noted that post-tensioning tendon corrosion problems have also been observed due to other causes. Significant strand corrosion developed in the bottom slab tendons of a 30-year old box girder bridge in Minnesota as a result of poor drainage conditions which facilitated significant moisture and chloride ingress to bottom slab tendons. Recent research suggests that strand corrosion can also occur rapidly in regions of soft segregated grout with very high pH and moderate sulfate content. This phenomenon was cited as the likely cause of strand corrosion failures on recently constructed bridges in Florida and Europe. Work in this area is on-going.
2.0 PROJECT INFORMATION

2.1 Bridge Description

Minnesota Bridge Nos. 02037W and 02037E are adjacent twin bridge structures, which each carry two lanes of traffic on United States Route 10 (US-10) over University Avenue and the westbound lanes of Minnesota State Highway 610 (MN610) in Coon Rapids, Minnesota. Bridge 02037W carries the westbound traffic lanes and 02037E carries the eastbound traffic lanes. Both bridges are cast-in-place, post-tensioned concrete box girders, which were constructed in 1997. Bridge 02037W is a four-span bridge with a total length of 597 feet, and Bridge 02037E is a three-span bridge with a total length of 479 feet. Refer to Figures 2.1 to 2.4 for views of the bridges.

Although the total length of the two bridges differs, the design geometry and reinforcement of the box girder section of each bridge is the same. The deck width is 49.21 feet, and the total depth of the box girder section is 9 feet. The bridge is a cast-in-place box girder bridge comprised of four (4) longitudinal cells. The five (5) box girder webs are each 1 foot thick and the top and bottom slabs are 7 inches thick. The girders of Bridge 02037W were numbered by WJE/VSL east to west from 1 to 5, consistent with the numbering system shown on the bridge plans. However, the girders of Bridge 02037E were numbered west to east from 1 to 5. Although this numbering system is opposite that shown on the plans, it is consistent with the numbering used in a prior MnDOT sponsored investigation of the structure, discussed in Section 2.3. In other words, Girder 5 of Bridge 02037W is adjacent to Girder 5 of Bridge 02037E, on either side of the expansion joint between these structures.

Three (3) draped internally bonded post-tensioning tendons are located in each girder web. The tendons were numbered by WJE from highest to lowest as T1, T2 and T3. The post-tensioned tendons are comprised of twenty-seven (27) 1/2 inch diameter prestressing strands. Each strand is a seven-wire Grade 270 strand. The tendon is encased in a 4 inch diameter, galvanized, corrugated metal duct filled with cementitious grout. The tendon high points are located at each pier, and tendon anchorages are located at the west and east abutments. Based on the height of the box girder section, the draped profile of the tendons includes an approximately 8-foot vertical rise between the low points (mid span) and high points (piers). Refer to Figures 2.5 and 2.6 for cross-section views of the box girder, and elevation views of the approximate tendon profile, reproduced from the bridge plans.

2.2 Construction Information

Upon review of construction information, MnDOT officials reported that a ready-mix truck was used to mix some of the grout that was used to fill the post-tensioned tendons of Bridges 02037W and 02037E. The grout mix design was Portland cement and water. This grout mixture, and the reported delivery process, created a high potential for excess bleed that could collect at tendon high points and anchorages. The extent of potential bleed water was believed to have been more prevalent at 02037W.

In addition, we understand that issues were encountered during the construction of Bridges 02037W and 02037E in relation to the grouting procedures. For example, MnDOT officials have reported that a blockage, which did not allow for the grout to be pumped throughout the duct from one end, was present in a tendon of Girder 5 on Bridge 02037E. Attempts were then made to fill the remainder of the duct, behind the blockage, by pumping grout from the opposite end of the tendon. Despite these efforts, the construction crew was reportedly not confident that the tendon was completely filled with grout.
2.3 Prior Work

A research project was commissioned by MnDOT circa 2011 to review available information pertaining to the potential for grouting related corrosion problems in forty (40) existing post-tensioned bridges constructed in Minnesota prior to 2003. The work included limited on-site inspections of ten (10) bridges of varying construction types judged to have the highest potential for such problems. The work was performed by a team of University of Minnesota-Duluth (UMD) and VSL personnel, with Dr. Andrea Schokker of UMD serving as the principal investigator and Mr. Bruce Osborn of VSL leading the fieldwork.

Preliminary spot-check inspections of tendons in Bridges 02037E and 02037W were performed on August 31 and September 1, 2011 as a part of the research project. The work included borescope inspection of tendon high points and anchorages of Girders 4 and 5 in Span 4 of Bridge 02037W, and inspection of tendon high points of Girder 5 in Span 2 of Bridge 02037E. Inspection openings were created at two tendon low points in Girders 2 and 5 in Span 2 of Bridge 02037E, at locations where prior repairs, efflorescence and cracking were present. However, contrary to the information presented in the research report, no borescope inspection was performed in Span 3 of Bridge 02037W. This was confirmed by both VSL and our field observations which found no repaired drill holes or PVC grout ports at any location within the span. Refer to Figures 2.7 and 2.8 for views of this work.

The locations and findings of the inspection work are tabulated below - green indicates no void was observed while red indicates a grout void was present.

<table>
<thead>
<tr>
<th>Girder</th>
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<td>Pier 1 - E Side</td>
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No borescope inspection work was performed in 2011 (contrary to prior report information)

In summary, the tendon high point and anchorage inspection work at Bridges 02037W and 02037E identified chalky, poor quality grout at most locations, significant grout voids at some locations, and evidence of light strand or duct corrosion at a few locations. No issues were observed at the two inspection openings made at low points. Based on the inspection results, a full investigation of all tendon high points and anchorages in these structures was recommended by the UMD team to identify and repair all grout voids.
Figure 2.1. Aerial view of Bridges 02037W and 02037E (taken from Bing® maps).

Figure 2.2. East elevation of Bridge 02037W.
Figure 2.3. Underside of Bridge 02037W.

Figure 2.4. Hatch doors in bottom slab (typical).
Figure 2.5. Transverse section - Bridge 02037W and 02037E

Draped Internal Tendons
Three (3) per Girder

Figure 2.6. Idealized tendon profile from the original design drawings - Bridge 02037W and 02037E
Figure 2.7. PVC valves were installed at grout void locations during the previous limited inspection work performed by UMD/VSL in 2011. This photograph shows Girder 5 of Span 2 in Bridge 02037E.

Figure 2.8. Inspection openings were chipped at tendon low points during the previous limited inspection work performed by UMD/VSL in 2011. This photograph shows Girder 5 of Span 2 in Bridge 02037E.
3.0 SPECIAL INSPECTION AND REPAIR

WJE and VSL accessed Spans 3 and 4 of Bridge 02037W and Span 2 of 02037E for the special inspection and repair work between June 17 and 30, 2013. No traffic control measures were required for the work in Span 4 (WB); access to each cell was accomplished using extension ladders to enter the hatch doors in the bottom slabs. Traffic control measures were required for Span 2 (EB) and Span 3 (WB) access and were set up and taken down each day by MnDOT personnel. Traffic control consisted of a partial lane and north shoulder closure at the end of the on-ramp from University Avenue to MN610 westbound. Access to these two spans was accomplished using a 30-foot scissor lift, again entering the hatch doors in the bottom slab. Once within these spans, movement between cells was possible through formed openings in the box girder webs near midspan. The interior of the concrete box girders is considered non-permit required confined space; therefore, interior air quality was monitored prior to entering the boxes and during the course of the work using calibrated air monitors.

3.1 Inspection

3.1.1 Procedures

After gaining access to the interior of the box girder bridge, WJE located and marked the internal tendons and adjacent conventional reinforcement using ground penetrating radar (GPR). The tendon profiles were mapped on the web walls as close to the piers and abutments as practical. Particularly for the highest tendons (T1 and T2), the position of these markings, and their proximity to the piers/abutments, was controlled by the position of the tendon relative to the underside of the top slab.

Following tendon mapping, VSL performed borescope inspection at each tendon high point and anchorage location. A rotary hammer drill was used to drill a 1-inch diameter hole into the web wall to the depth of the galvanized duct. Drill holes were typically located within 4 feet of the pier or abutment for the lowest tendon (T3), and within 15 feet for the highest tendon (T1). The drill holes were positioned to hit the top of the post-tensioning ducts since voids, if present, are typically located within the upper half of the duct. The galvanized metal duct was then opened using a screw driver. At some locations, due to the size of the grout voids, multiple inspection holes were required to properly inspect the conditions inside the duct.

At each inspection location, the span, girder and tendon numbers were recorded on field sheets and on the concrete surface, and the hole location was documented relative to the closest pier or abutment. Grout and strand conditions were then observed using a flexible borescope and documented with field notes and photographs. Where voids were found, conditions were documented along the length of the void as much as was practical. Following inspection work, the drill holes were filled or prepared for remedial grouting. The flowchart below generally illustrates the process.
A total of ninety (90) drill-hole inspection locations were required for specialized post-tensioning inspection of all tendon high points and anchors within the three noted bridge spans selected by MnDOT. This total includes the eighteen (18) locations which were inspected by UMD/VSL in 2011. These sites were inspected again to determine if conditions have changed since that time. Refer to Figures 3.1 and 3.2 for views of the typical tendon markings and drill holes following inspection.

3.1.2 Findings

The findings of the specialized inspection work performed at each tendon high point in Spans 3 and 4 of Bridge 02037W, including photographs, are presented in Appendix A. Similarly, findings from the inspection work in Span 2 of Bridge 02037E are presented in Appendix B. Within each appendix, where relevant, additional photographs of void conditions taken at distances along the length of the void are included. The findings can be summarized as follows:

1. Grout voids were discovered at 29 of the 90 inspected tendon high points (32 percent). The typical voids encompassed approximately one-half of the duct diameter and measured at least 10 feet long.
   a. At Bridge 02037W, the significant grout voids were all present on the east side of Piers 2 and 3. Only two voids were present on the west side of Pier 3 and both were small. No voids were present at the east abutment.
   b. In contrast, the significant voids in Bridge 02037E were all located on the west side of Pier 2, with only two small voids located on the east side of Pier 1.

2. Prestressing steel strands were exposed at approximately half of the grout voids. No significant corrosion of the strands was observed at any location. The strands typically exhibited no corrosion or light surface corrosion, consistent with Class 1 or 2 conditions as defined by Sason.

3. Light to moderate corrosion was typically observed on inside surfaces of the galvanized metal ducts at grout voids.

4. At almost all locations, the grout was white-colored, and its surface appeared to exhibit a flaky composition.

In addition, during the course of our work, general observations of the webs were made proximate to the tendon high points. In Span 4, a crack was observed along the east side of Girder 2, following the profile of Tendon T3. Efflorescence was apparent along the length of the crack. However, no grout voids were present in this tendon. Refer to Figure 3.3. Evidence of grout leakage during construction was also observed at the tendon low points of Girders 4 and 5 in Span 3 of Bridge 02037W, with a significant quantity of grout present on the bottom slab. No other conditions of note were observed.

3.2 Remedial Grouting

3.2.1 Procedures

The purpose of the remedial grouting operations was to completely fill grout voids which existed in the post-tensioning tendons using a zero-bleed prepackaged thixotropic grout material, specified by MnDOT to be EUCO Cable Grout PTX manufactured by Euclid Chemical Company. EUCO Cable Grout PTX

1 Sason, Auguston S., Evaluation of Degree of Rusting on Prestressed Concrete Strand, Precast/Prestressed Concrete Institute, Volume 37 Number 3, May-June 1992.
was used by VSL for all remedial grouting work on this project. The remedial grouting procedure was selected depending on the void conditions. The grout work was performed by VSL with a grouting technician certified by the American Segmental Bridge Institute (ASBI). All repair grout material was mixed and field tested in accordance with the recommendations in the *Specification for Grouting of Post-Tensioned Structures* published in 2012 by the Post-Tensioning Institute (PTI). Grout was field mixed using a paddle mixer and field tested by measuring grout fluidity (flow cone test), grout density (mud balance) and temperature. Material samples were also collected by WJE for chloride testing or potential future material compatibility testing.

Prior to filling the voids, vacuum testing was performed to determine the approximate size of the void and to determine the most appropriate remedial grouting technique. Refer to Figures 3.4 and 3.5 for views of this operation. The void size was approximated by measuring the volume of air removed by the vacuum pump. At locations where the grout void could sustain a vacuum pressure of approximately 20 in-Hg or higher, the vacuum grouting method was selected. This method allowed grouting operations to be performed at the one drilled inspection hole. Vacuum grouting equipment included a volumeter (for measurement of void volume) and a vacuum pump. Following vacuum grouting, the volume of grout injected into each void was measured and compared to the void air volume. In all cases, the grout-to-air volume was greater than 90 percent.

However, at locations where the grout void could not sustain a vacuum pressure of approximately 20 in-Hg, pressure grouting was selected. The inability of the grout void to sustain the required vacuum pressure was likely due to the size of the void and/or air leakage from the galvanized metal ducts. Pressure grouting required the drilling of multiple additional holes, and the installation of additional grout ports, along the length of the void. Grout was pressurized into the void from a lower access hole, akin to conventional tendon grouting techniques. Grout ports were sequentially closed off up the length of the void once a steady outflow of grout was observed, with grout pressure then locked off for a predetermined time period following the closing of all ports. Refer to Figures 3.6 to 3.8 for views of this procedure.

Following remedial grouting, verification drill holes were created at the high ends of two selected grout voids - one repaired by vacuum grouting and one repaired by pressure grouting. The holes were drilled 24 hours after grouting. In both cases, the tendons were found to be full of grout. The verification holes were then sealed with Hilti HY150MAX epoxy.

At the completion of the grouting operations, all PVC valves were cut flush with the face of the concrete, and the grout tubes were inspected to verify that they were full of grout. Refer to Figures 3.9 and 3.10.

### 3.2.2 Results

The remedial grouting work which was performed is summarized alongside the findings of the specialized inspection work in Appendix A and B. The work can be summarized as follows:

1. In Span 4 of Bridge 02037W, all seven (7) grout voids were re-grouted. Pressure grouting was performed at five (5) locations and vacuum grouting was performed at the remaining two (2) locations.
   a. Grout voids in Tendons 2 and 3 of Girder 1 were both small, measuring less than 4 liters each. Both voids were pressure grouted.
   b. Grout voids in Tendons 1 and/or 3 of Girders 2 through 5 were large and measured 13 to 48 liters, requiring approximately 1 to 4 mixed bags of grout each.
2. In Span 3 of Bridge 02037W, remedial grouting was performed to fill voids in Tendons 1 and 2 of Girder 2, and in Tendon 3 of Girder 4. No other remedial grouting work was performed in Span 3.
   a. The grout void in Tendon 1 of Girder 2 measured 44.6 liters and required 3 bags of mixed grout to be filled.
   b. The grout void in Tendon 2 of Girder 2 was not completely filled; the void measured 52.0 liters and 3-1/2 bags of mixed grout were pumped into the void before the project grout supplies were consumed. Special procedures may be required to finish re-grouting of this partially filled tendon.
   c. The grout void in Tendon 3 of Girder 4 was continuous over the top of Pier 3 and was grouted as a result of the Span 4 operations described above.
   d. The volume of the remaining grout voids which were not repaired were measured using the volumeter. Void sizes typically exceeded 20 liters, ranging up to 51 liters.

3. In Span 2 of Bridge 02037E, no remedial grouting work was performed for reasons previously discussed.

3.3 Summary
The following illustrations summarize the inspection and remedial grouting work which was performed at Bridges 02037W and 02037E during this project:

![Graph of inspection locations, grout voids, and voids regrounded for Bridge 02037W and Bridge 02037E]

Note that, for remedial grouting using the pressure grouting technique, additional holes were created to facilitate grout flow. These holes were not included in the borescope inspection quantity.
Figure 3.1. Typical tendon markings by WJE on the web wall. Conventional reinforcement is shown with pink chalk and the position of the post-tensioning tendons is marked with yellow plus signs (dashed lines).

Figure 3.2. Typical borescope inspection drill holes following documentation. A grout void was discovered in Tendon T3 and a PVC valve was installed for remedial grouting. No voids were found at Tendons T1 and T2 and the drill holes were repaired with epoxy.
Figure 3.3. Crack with efflorescence along the length of Tendon T3 in Girder 2 of Span 4 of Bridge 02037W (circle). No grout void was present at this location.

Figure 3.4. Prior to filling the voids, vacuum testing was performed to determine the approximate size of the void and to determine most appropriate grouting method. This photo documents vacuum testing at Tendon T3 of Girder 3 in Span 4 of Bridge 02037W.
Figure 3.5. Close-up view of the volumeter during vacuum testing. A vacuum pressure of approximately 20 in.-Hg was sustained at this void (arrow).

Figure 3.6. Where the grout void could not sustain 20 in.-Hg pressure, additional holes were drilled and grout ports installed to facilitate pressure grouting.
Figure 3.7. View of the pressure grouting procedure.

Figure 3.8. Close-up view of the grout ports during pressure grouting. Steady grout flow was observed from the grout port on the right, and the valve was closed. Several minutes later, grout began flowing from the port on the left, higher up the length of the grout void.
Figure 3.9. The PVC grout ports were cut flush with the face of the concrete following remedial grouting.

Figure 3.10. PVC grout ports were inspected after removal to verify that they were full of grout.
4.0 CORROSION MONITORING

Following the completion of the specialized inspection work, corrosion monitoring sensors were installed within grout voids which existed in Tendon 3 of Girders 4 and 5 in Span 4 of Bridge 02037W. The sensors are intended to facilitate long-term monitoring for corrosion of the prestressing steel strands and the galvanized metal ducts at the two installation locations. Once the installation was completed, remedial pressure grouting was performed as described in the previous section to fill the grout void and encapsulate the sensors. Lastly, the concrete was patched using a repair mortar to seal the area used to access the post-tensioning duct. The following paragraphs describe the sensors, the procedures associated with the installation work, and the preliminary data collected since installation.

4.1 Equipment

WJE discussed the general project constraints and the desired functionality of the corrosion monitoring equipment with MnDOT prior to selecting the sensors which would be installed. Factors which were considered during the selection process included: the nature of the corrosion likely to develop inside the duct after remedial grouting; the project schedule and budget; the effect of electrical continuity between the galvanized metal ducts and steel strands on corrosion monitoring; and the absence of both electrical power and ready access into the targeted bridge spans. The latter conditions limited options for both sensor installation locations and the use of on-site remote data logging equipment. This information guided our research and evaluation of the commercially available corrosion sensor technologies, and their respective capabilities. Corrosion monitoring equipment options which were reviewed included products manufactured by Intertek, Corr Instruments, Rohrback Cosasco, C-Probe and Castle Electrodes, as well as customized systems fabricated in-house by WJE and S.K. Lee Consulting. For this project, corrosion monitoring equipment manufactured by Intertek and available to fit the project schedule was selected by WJE as the best fit.

The selected Intertek system includes two corrosion sensors (Mini M3 probes) which were each placed inside post-tensioning ducts at a location where a grout void existed in the tendon, and portable data logging instrumentation (Concerto Compact and Handheld Unit (HHU)) that is capable of collecting several measurements at each sensor location. The Mini M3 sensors consist of a working electrode, an auxiliary electrode, and a reference cell (silver-silver chloride) on the probe body and a cable to make a connection to an alternate working electrode (the strand/duct system). Refer to Figures 4.1 to 4.4 for views of this equipment. Comments about the nature and significance of each type of data to be collected are as follows:

- **Corrosion potential of probe electrode** – The corrosion potential of the probe working electrode, consisting of a “dummy” length of carbon steel, is measured. This probe electrode, electrically isolated from the strand and duct, is surrounded by the repair grout material. The purpose of this electrode is to assess the corrosivity of the grout. The corrosion potential is expected to become more negative if corrosion of the electrode initiates in this environment.

- **Corrosion rate (linear polarization resistance) of probe electrode** – The corrosivity of the grout will be further evaluated by measurement of the linear polarization resistance of the probe electrode. Since the surface area of the electrode is known, the instantaneous corrosion rate density (in terms of microamps per cm$^2$) of the probe electrode can be calculated. Higher corrosion rate densities will be associated with greater corrosivity.
- **Corrosion potential of strand/duct system**: Since the strand and duct are electrically continuous, the potential of each component cannot be separated, and the mixed corrosion potential of the strand/duct system will be measured. The zinc galvanizing will result in a more negative potential than would be expected for the carbon steel strand itself. Corrosion of the strand would also be expected to result in more negative corrosion potentials. These affects will be difficult to separate, and interpretation of this potential may not be possible. However, changes in corrosion potential may indicate corrosion activity and prompt further investigation. This test should be considered inconclusive in this setting.

- **Corrosion rate (linear polarization resistance) of strand/duct system**: A linear polarization test can be conducted on the combined strand/duct system. Interpretation of this result may not be possible, since the area of the tested metal elements is unknown. Further, the presence of dissimilar metals means some of the base assumptions behind linear polarization resistance testing are not applicable. Nevertheless, as with the corrosion potential, changes in polarization resistance may provisionally indicate corrosion activity and prompt further investigation.

- **Grout resistivity**: Corrosion activity of embedded metals is dependent on the resistivity of the grout system. Therefore, the resistivity of the repair grout material is measured.

- **Temperature**: The internal temperature of the duct is measured. The rates of corrosion, as well as the other measured properties, are affected by temperature; this property is measured to support interpretation of the other data.

The two types of instrumentation compatible with these sensors are described as follows:

- The Concerto HHU is a portable, hand held, battery powered data logger with on-board data storage (Flash memory). Connection to each sensor is made by manually swapping the cable connection between the cable end terminations. Following field collection with the unit, data can be downloaded to a computer via a USB connection. However, the HHU can only be used to collect manual measurements and cannot log data for a defined period of time.

- The Concerto Compact data logger possesses on-board data storage capabilities (SD Card) and can collect data in either desired format – manual readings of each type of data at both sensors or logged data from one sensor (multiple types of data) for a defined duration. The Compact data logger also possesses greater capacity to measure corrosion rate of the strand/duct system. However, the Compact does not have onboard power. Therefore, field use of the unit requires the provision of 110V power or a battery system. Field use will likely also require a laptop for collection of logged data for a defined duration. WJE is currently evaluating the functionality of this unit during a companion laboratory-based study, discussed later herein, and will evaluate adaptations that can facilitate more convenient field usage.

### 4.2 Sensor Locations

The locations selected by WJE to install the corrosion monitoring sensors were chosen based on the discovered grout void conditions and the site constraints. Grout voids equal to approximately half of the duct were required to accommodate the sensors, based on their size, and locations exhibiting evidence of corrosion of the strand or duct were preferred. With respect to site constraints, three factors were relevant. First, it was preferred to avoid the need for entry into the bridge to collect data due to confined space considerations, as well as the associated needs for both special access equipment (i.e., bucket truck) and
maintenance of traffic (MOT). Second, it was preferred to have only one location for data collection, and to avoid mounting the enclosure which housed the sensor end terminations in a visible location which may be subject to vandalism. Third, the sensors were procured by WJE with 115 feet of cabling, approximately the maximum length which could be used without potentially affecting the accuracy of the data. Considering all of these parameters, WJE identified the grout void conditions on the east side of Pier 3 in Span 4 of Bridge 02037W as the most desirable locations for sensor installation.

The corrosion sensors were installed in Tendon 3 of both Girders 3 and 4, within Cell 3 of Span 4. At Girder 3, borescope inspection revealed that the grout void was equal to approximately half the duct and the inside surface of the duct exhibited corrosion, although the two strands which were exposed did not. At Girder 4, the grout void was also equal to approximately half the duct and three strands were exposed. The strands were judged to exhibit Class 2 corrosion when viewed with the borescope, while the duct did not. A complete summary of the borescope inspection findings at these two locations are included in Appendix A. A description of the conditions observed upon opening of the ducts to install the sensors is provided in the next section.

4.3 Installation Procedures

The two corrosion monitoring sensors were installed at the selected locations on June 25, 2013. The tendon profiles were marked on the surface of the girder and the position of the adjacent conventional reinforcement was identified using GPR. Inspection openings measuring approximately 10 inches high by 20 inches long by 4 to 5 inches deep were created to access the tendons. The perimeter of the opening was saw cut to a minimum depth of 1/2 inch, and concrete was removed using a 15 lb electric chipping hammer to expose the full side face of the galvanized metal duct. A section of the duct measuring approximately 12 inches long by 4 inches high was cut out using a small rotary tool, and was preserved for reinstallation. Refer to Figures 4.5 to 4.8 for views of this work.

Removal of the duct allowed for up-close examination of the conditions at the grout voids where sensors were to be installed. At Girder 3, borescope inspection had revealed that two strands were partially exposed at the void and the grout appeared soft, porous and crumbling. Up-close inspection revealed that a thin film of crumbling or powdery grout was present on the surface, but the remaining grout was hard and of good quality. No corrosion was observed on the two partially exposed strands. At Girder 4, borescope inspection revealed that three strands were fully exposed and were coated with a thin film of grout, with light corrosion (Class 2) present on the strands. Close-up inspection revealed that, at most, Class 1 levels of corrosion were present on the strands. Refer to Figures 4.9 to 4.12 for views of these conditions.

The corrosion monitoring sensors were installed within the tendons by WJE in accordance with Intertek installation recommendations. Plastic shims, taped to the plastic body of the sensor, were used to elevate the probes off the strand or grout surface, and the sensors were embedded in a dry-pack mixture of the EUCO Cable Grout PTX within the duct. The external cable for the alternate working electrode was connected to the duct after it was confirmed that the duct and strand were electrically continuous. The removed duct section was re-installed, with the sensor cabling running out a small notch cut in the duct wall. The perimeter of the cut duct section, and the cable penetration, were sealed with Hilti HY150 MAX epoxy. Concrete surfaces at the inspection opening were then cleaned and prepared, and the opening was repaired using SikaTop 123 Plus, a concrete repair mortar. Pilgrim Uroflex 65 elastomeric coating was applied over the inspection opening and adjacent concrete surfaces. Refer to Figures 4.13 to 4.22 for views of this work at each sensor location.
As noted, the sensors were procured with 115 feet of cable to extend from the install locations to a data collection point selected by MnDOT. The selected data collection point is located on the west face of Girder 5 at Span 4 of Bridge 02037W, approximately 25 feet west of the east abutment. The data collection point consists of a padlocked NEMA enclosure which was mounted by WJE to the outside surface of the girder, approximately 6 feet above the slope paving. The enclosure contains the two sensor end terminations which allow for data collection. Within the bridge, cabling was run from the sensor installation locations in Cell 3, through a vent hole and into Cell 4, and then along the girders toward the east abutment. A 1 inch diameter hole was drilled through Girder 5 near the bottom slab by WJE at the selected data collection point, to allow the cables and their end terminations to extend through to the bridge exterior. Access to the bridge interior is not required to collect data from this location, as was preferred by MnDOT. Refer to Figures 4.23 to 4.26 for views of the cabling and enclosure.

Two days following installation, remedial grouting was performed by VSL to fill the grout voids at the corrosion monitoring sensor installation locations. This work was performed as previously described, with pressure grouting required at both locations. Following grouting, a verification hole was drilled into the grout void near the Girder 4 sensor. The void was found to be fully grouted and the hole was repaired with epoxy.

4.4 Data Collection and Processing
Step-by-step instructions on the data collection, downloading, conversion and graphing process are included in Appendix C. Manufacturer’s operation instructions for the Concerto HHU and Concerto Compact data loggers are attached for reference in Appendix D.

4.5 Preliminary Data
WJE has collected data from the corrosion monitoring sensors on eleven (11) occasions since June 27, 2013, the date remedial grouting was completed at the sensor locations. Data has been collected approximately bi-weekly. On each occasion, WJE has utilized the HHU. Illustrations 4.1 to 4.4 represent graphs of the data. The Microsoft Excel file containing the attached graphs and the data collected to date will be provided to MnDOT under separate cover.

The following observations have been made regarding the instrumentation and the data collected to date:

- The monitored post-tensioned tendon systems include various conditions of the steel strands, the galvanized duct, the original grout material, and the repair grout material. Given this complexity, individual corrosion readings from the sensors cannot be readily interpreted. As a result, the overall approach for using these sensors in the tendons of Bridge 02037W must be to track long-term performance and to look for changes over time not explainable by temperature variations. Because of the temperature dependence of corrosion and of the specific measured properties, data should be collected at sufficient frequency so that comparisons can be made between readings taken at similar temperature and moisture exposure conditions. For example, early spring readings within about 10°F should be compared over successive years.

- The interaction of the galvanized metal duct and prestressing steel strands complicates data interpretation with respect to corrosion potential and corrosion rate tests of the strand/duct system. However, WJE expects that corrosion activity at either of the sensor installation locations will manifest in the form of significant and coincident changes in the trendline values of the various measurements being collected at both the duct and sensor, particularly corrosion rate (increase),
corrosion potential (increase or decrease) and resistivity (decrease), with those changes sustained through multiple subsequent monitoring events.

- The actual area of the alternate working electrode, the strand/duct system (identified by the HHU as Working Electrode 2), is uncontrolled and not known. WJE has programmed the HHU to assume the area is 100 cm², however, this is simply a placeholder value. Therefore, the units of the measured corrosion rate values for the strand/duct system should be disregarded. Instead, as discussed above, trends in the corrosion rate should be monitored for evidence of possible corrosion activity. Because the area of the probe working electrode (identified by the HHU as Working Electrode 1) is known (1.92 cm²), the measured corrosion rate of this electrode can be analyzed.

- Curious data values have been sporadically recorded during the monitoring work performed by WJE to date. The variability is limited to grout resistivity measurements of the Girder 4 probe (both working electrodes) and, to a much lesser extent, corrosion rate measurements of the Girder 3 probe with respect to Working Electrode 2 (duct/strand system). The source of the variability in the grout resistivity data is not clear. We will continue to evaluate the results and the equipment and are working towards a solution with Intertek.
Illustration 4.1 - Corrosion Rate

Illustration 4.2 - Corrosion Potential

Illustration 4.3 - Temperature

Illustration 4.4 - Resistivity
4.6 Companion Study

The Intertek corrosion monitoring system was selected by WJE as the most consistent with the project objectives and schedule. However, neither WJE nor the manufacturer has prior experience using this equipment to monitor corrosion of prestressing strands within galvanized ducts. As discussed, the interaction of the galvanized metal duct and prestressing steel strands complicates data interpretation with respect to corrosion potential and corrosion rate of the steel elements in the two monitored post-tensioning tendons. Although it is anticipated that interpretation of the field collected monitoring data will allow for identification of corrosion activity in the tendons, uncertainty remains. It is not clear if pitting corrosion, a potential form of corrosion for the strands, will be distinguishable at early to intermediate stages of advancement.

WJE purchased three (3) Intertek Mini M3 probes for this project. Although only two sensors were installed in the field, WJE ordered a reserve unit to account for possible sensor operation issues (i.e., faulty unit) or possible damage to the sensor, cabling or sensor end termination during the shipping and installation processes. Because the lead time for these sensors was two weeks, and the installation work required the assistance of VSL, any issues would have resulted in significant project complications. Fortunately, no issues were encountered with the probes or the installation work.

Rather than returning the unused probe, WJE has proposed to MnDOT that it be utilized in a companion laboratory study to be conducted in the Janney Technical Center (JTC) at the Northbrook, Illinois office of WJE. MnDOT agreed with this proposal and gave approval to proceed with the work. The study will be jointly funded by WJE and MnDOT, using reserve project funds which were budgeted for the corrosion monitoring equipment but not used.

4.6.1 Objectives

The objectives of the laboratory study will be to:

1. Assess the influence of the galvanized duct on strand corrosion conditions and develop an understanding of corrosion activity in this setting.

2. Evaluate the Intertek equipment and its effectiveness at monitoring corrosion in both passive and active conditions of: i) grouted prestressing strand, ii) strand in contact with galvanized duct, iii) mild steel reinforcing.

3. Assist with interpretation of the field-collected corrosion monitoring data.

4.6.2 Test Plan

Three (3) time-to-corrosion test slab samples will be cast in the JTC in October 2013. The Mini M3 corrosion monitoring sensor will be cast into one slab, while the other two slabs will be monitored for corrosion using conventional methods. The slabs will be constructed as shown in Illustration 4.5, on the next page. The section of the galvanized metal duct included in each sample will be equivalent to 1/27th of the perimeter of the 4-in. diameter duct, considering the typical tendons of Bridge 02037W contain 27 prestressing strands. All test slabs will be subjected to the “southern exposure” test regime based on FHWA-RD-98-153 with wet/dry cycling and chloride exposure. An additional slab containing no reinforcement will also be cast for chloride concentration measurements.
Data collection will consist of the following:

- With Mini M3 probe in instrumented slab, *automatically* measure temperature, corrosion potential, and corrosion current (with linear polarization) every 3 hours of the probe electrode, connected strand and galvanized duct section, and the mild reinforcing bar.
- With Mini M3 probe in instrumented slab, *manually* measure corrosion potential, and corrosion current (with linear polarization) every 2 weeks of the disconnected strand and the disconnected galvanized duct section.
- With data logger support, macrocell corrosion current will be measured (as voltage drop across resistor) every 12 hours between cathode bars and the strand (connected with duct), galvanized duct section (connected to strand), and the mild reinforcing bar.

Data reduction will consist of:

- Corrosion rate by lin. pol. (Mini M3) vs. by macrocell for all steel types
- Corrosion potential (Mini M3) vs. corrosion rates for all steel types
- Compare macrocell corrosion currents
- Steel type vs. time to corrosion initiation
- Steel type vs. chloride concentration at initiation

Chloride concentration will be tested at the depth of the steel when corrosion initiation is indicated by the macrocell corrosion current. After approximately 48 weeks of exposure, all samples will be autopsied. Following completion of the study, a summary report will be provided to MnDOT.
Figure 4.1. Intertek Mini M3 corrosion monitoring sensor

Figure 4.2. Shop drawing of a typical Intertek Mini M3 probe showing dimensions (in millimeters).
Figure 4.3. Intertek Compact Handheld Unit (HHU) and the cable end terminations of the two installed corrosion monitoring sensors inside a NEMA enclosure at the bridge.

Figure 4.4. Intertek Compact Concerto data logging unit.
Figure 4.5. Inspection Opening - Girder 3 (Tendon 3, Cell 3, Span 4 of Bridge 02037W).

Figure 4.6. Inspection Opening - Girder 4 (Tendon 3, Cell 3, Span 4 of Bridge 02037W).
Figure 4.7. Post-tensioning duct removal - Girder 3 (Tendon 3, Cell 3, Span 4 of Bridge 02037W).

Figure 4.8. Post-tensioning duct removal - Girder 4 (Tendon 3, Cell 3, Span 4 of Bridge 02037W).
Figure 4.9. Thin surficial film of powdery grout - Girder 3. (Tendon 3, Cell 3, Span 4 of Bridge 02037W).

Figure 4.10. Strand partially exposed with no corrosion observed (arrows) - Girder 3. (Tendon 3, Cell 3, Span 4 of Bridge 02037W). Note that flakes of duct corrosion are present on the grout bed adjacent to the strand in the foreground of the picture.
Figure 4.11. Thin film of grout on strands - Girder 4 (Tendon 3, Cell 3, Span 4 of Bridge 02037W).

Figure 4.12. Thin film of grout on strands - Girder 4 (Tendon 3, Cell 3, Span 4 of Bridge 02037W).
Figure 4.13. Sensor fit testing - Girder 3 (Tendon 3, Cell 3, Span 4 of Bridge 02037W).

Figure 4.14. Sensor fit testing - Girder 4 (Tendon 3, Cell 3, Span 4 of Bridge 02037W).
Figure 4.15. Dry-pack grout embedment of sensor - Girder 3 (Tendon 3, Cell 3, Span 4 of Bridge 02037W).

Figure 4.16. Dry-pack grout embedment of sensor - Girder 4 (Tendon 3, Cell 3, Span 4 of Bridge 02037W).
Figure 4.17. Corrugated metal duct re-installation - Girder 3 (Tendon 3, Cell 3, Span 4 of Bridge 02037W).

Figure 4.18. Corrugated metal duct re-installation - Girder 4 (Tendon 3, Cell 3, Span 4 of Bridge 02037W).
Figure 4.19. Concrete repair of inspection window - Girder 3 (Tendon 3, Cell 3, Span 4 of Bridge 02037W).

Figure 4.20. Concrete repair of inspection window - Girder 4 (Tendon 3, Cell 3, Span 4 of Bridge 02037W).
Figure 4.21. Elastomeric coating applied to inspection window - Girder 3 (Tendon 3, Cell 3, Span 4 of Bridge 02037W).

Figure 4.22. Elastomeric coating applied to inspection window - Girder 4 (Tendon 3, Cell 3, Span 4 of Bridge 02037W).
Figure 4.23. Corrosion sensor installations at Girders 3 and 4 in Cell 3 of Span 4 in Bridge 02037W.

Figure 4.24. Sensor cabling in Cell 4 exiting through a hole drilled in Girder 5 to the exterior (circle).
Figure 4.25. Enclosure housing the two sensor end terminations which facilitate testing and data collection.

Figure 4.26. Enclosure position relative to the east abutment (background).
5.0 SUMMARY AND RECOMMENDATIONS

5.1 Inspection and Remedial Grouting

Drill-hole inspection openings were made near all 90 tendon high points and anchorages in Spans 3 and 4 of Bridge 02037W and Span 2 of Bridge 02037E. Grout voids were identified at 29 inspection locations, or 32 percent of all inspection locations. The majority of the observed grout voids were relatively large in size, ranging from approximately 33 to 50 percent of the post-tensioning duct cross section and extending for over 10 to 20 feet along the tendon length. Where exposed, the prestressing steel strands were in good condition and free of any significant corrosion. However, light to moderate surface corrosion was observed on the interior walls of some corrugated metal ducts. No signs of bulk moisture intrusion were observed, though the grout consistently appeared white and powdery, indicating the presence of bleed water or an elevated grout water/cement ratio during construction. Several tendons were never fully filled with grout during construction.

Remedial grouting was performed at 10 of 19 grout voids which were discovered in Bridge 02037W, including all seven voids in Span 4 and three voids in Span 3. However, one of the Span 3 voids was not completely regROUTed before the project allotment of grout material was consumed; special procedures may be required to finish re-grouting of this partially filled tendon in the future. The remedial grouting work typically consisted of pressure grouting due to air leakage issues with the galvanized metal ducts - this prevented the voids from sustaining the required pressure to facilitate vacuum grouting. The volumes of the grout voids in Spans 3 and 4 were determined using either a volumeter, or during the regrouting work, and averaged 31 liters, or approximately 2 to 2-1/2 bags of mixed grout material.

Overall, the bridge and its post-tensioning components appear to be in good condition. None of the observed conditions significantly compromise the structure. However, grout voids of appreciable size are present in numerous post-tensioning tendons at the high points, and potentially the anchorages, and they should be addressed to limit the potential for future moisture ingress and premature deterioration. Accordingly, WJE recommends that the borescope inspection and remedial grouting program initiated with this work be completed at Bridge 02037W and Bridge 02037E.

Inspection and remedial grouting should be completed at the remaining 120 tendon high points and anchorages in Spans 1 and 2 of Bridge 02037W, and Spans 1 and 3 of Bridge 02037E. Based on the findings of the work completed to date on these structures, it should be assumed that grout voids averaging 31 liters in size will be present at one third of these inspection locations (i.e., 40 grout voids). In addition, although inspection has been completed, remedial grouting remains to be performed at the 20 grout voids which were discovered in Span 2 of Bridge 02037E and Span 3 of Bridge 02037W, but have not yet been regROUTed or were only partially regROUTed (02037W-Span 3-Girder 2-Tendon 2). Using these assumptions, up to approximately 140 bags of grout material may be required to perform comprehensive remedial grouting of these bridges.

Considering the rates of production achieved during this project, and the more varied access requirements associated with work in the remaining spans, we believe the completion of inspection and grouting work at Bridge 02037W and 02037E will require approximately 30 field days. This estimate consists of 12 days of additional borescope inspection and 18 days of remedial grouting.
5.2 Corrosion Monitoring

Corrosion monitoring sensors manufactured by Intertek were installed within grout voids in Tendon 3 of Girders 4 and 5 in Span 4 of Bridge 02037W. The sensors are intended to facilitate long-term monitoring for corrosion of the prestressing steel strands and anchorages and galvanized metal ducts at these locations. Measurements are to be manually collected at the bridge using a handheld data collection unit and patch cable, provided by Intertek, which are compatible with the sensor end terminations. The sensor end terminations are housed in a NEMA enclosure mounted on the west face of Girder 5 in Span 4 of Bridge 02037, approximately 25 feet west of the east abutment.

The sensors are capable of measuring corrosion potential and corrosion rate of both the strand/duct post-tensioning system and an exemplar piece of steel incorporated into the probe, as well as grout resistivity and temperature. However, the interaction of the galvanized metal duct and prestressing steel strands complicates the interpretation of corrosion potential and corrosion rate data obtained from these sensors. WJE expects that future corrosion activity at either of the sensor installation locations will manifest in the form of significant and coincident changes in the trendline values of the various measurements being collected, with those changes sustained through multiple subsequent monitoring events. This expectation, and the general functionality and reliability of the Intertek probes, will be further evaluated through a companion laboratory study underway at the WJE Janney Technical Center in Northbrook, Illinois. The results of this study will be provided to MnDOT upon completion, expected to be in approximately 12 months.

WJE has collected data from the corrosion monitoring sensors on nine occasions since June 27, 2013, the date remedial grouting was completed at the sensor locations. Some questionable data values have been sporadically recorded during the monitoring work to date, and some performance issues have been experienced with the handheld data collection unit. WJE will continue to evaluate these issues with Intertek, the probe and data collection unit manufacturer.

Data from the corrosion monitoring system should be collected at sufficient frequency so that long-term comparisons can be made between readings taken at similar temperature and moisture exposure conditions. We recommend that measurements be collected once per month for the remainder of the first year, or through June 2014, to evaluate the sensors and data during varying temperature conditions. Following the initial year, we recommend that data be collected four times annually in April, June, August and October of each year of the monitoring program. More frequent data collection should be performed in the event possible corrosion activity is suspected, or other data anomalies arise.
APPENDIX A - BRIDGE 02037W SPANS 3 AND 4

Specialized Inspection Findings and Remedial Grouting Results
Bridge 02037W - SPANS 3 and 4 - Summary of Inspection Findings

Figure A1. Bridge No. 02037 Westbound Spans 3 and 4 - Summary of Inspection Findings
<table>
<thead>
<tr>
<th>TENDON</th>
<th>INSPECTION</th>
<th>REPRESENTATIVE PHOTOGRAPH</th>
<th>RE-GROUTING</th>
<th>PIER 3 (High Point)</th>
<th>INSPECTION</th>
<th>REPRESENTATIVE PHOTOGRAPH</th>
<th>RE-GROUTING</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>The inspection hole was drilled 5 inches below the top slab, 13 feet west of Pier 3. The tendon was found at a depth of 4 inches. NO VOID</td>
<td><img src="image1" alt="Image" /></td>
<td>N/A</td>
<td>The inspection hole was drilled 3 3/4 inches below the top slab, 8 1/2 feet east of Pier 2. The tendon was found at a depth of 5 inches. NO VOID</td>
<td><img src="image2" alt="Image" /></td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grout Color: White</td>
<td></td>
<td></td>
<td>Grout Color: White</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grout Consistency: Chalky</td>
<td></td>
<td></td>
<td>Grout Consistency: Chalky</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Strands Exposed: None</td>
<td></td>
<td></td>
<td>Strands Exposed: None</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T2</td>
<td>The inspection hole was drilled 6 inches below the top slab, 9 1/2 feet west of Pier 3. The tendon was found at a depth of 4-1/4 inches. VOID - Duct is 90% Full Size: No borescope access due to size. Void is 1/4 inch high. Grout Color: White (top) to Brown (bottom) Grout Consistency: Chalky (top) to Creamy (Bottom) Strands Exposed: None</td>
<td><img src="image3" alt="Image" /></td>
<td>MnDOT elected to defer regrouting of this location to a future repair project. VSL was unable to pull a vacuum at this void to determine the void size due to duct air leakage. Void size = n/a</td>
<td><img src="image4" alt="Image" /></td>
<td>The inspection hole was drilled 4 inches below the top slab, 7 feet east of Pier 2. The tendon was found at a depth of 4-1/4 inches. NO VOID</td>
<td><img src="image5" alt="Image" /></td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>Grout Color: White</td>
<td></td>
<td></td>
<td>Grout Color: White</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grout Consistency: Chalky</td>
<td></td>
<td></td>
<td>Grout Consistency: Chalky</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Strands Exposed: None</td>
<td></td>
<td></td>
<td>Strands Exposed: None</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T3</td>
<td>The inspection hole was drilled 8 inches below the top slab, 6 feet west of Pier 3. The tendon was found at a depth of 4-1/2 inches. NO VOID</td>
<td><img src="image6" alt="Image" /></td>
<td>N/A</td>
<td>No vacuum at this void to determine the void size due to duct air leakage. Void size = n/a</td>
<td><img src="image7" alt="Image" /></td>
<td>MnDOT elected to defer regrouting of this location to a future repair project. VSL was unable to pull a vacuum at this void to determine the void size due to duct air leakage. Void size = n/a</td>
<td><img src="image8" alt="Image" /></td>
</tr>
<tr>
<td></td>
<td>Grout Color: White to light gray</td>
<td></td>
<td></td>
<td>Grout Color: White</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grout Consistency: Chalky</td>
<td></td>
<td></td>
<td>Grout Consistency: Chalky</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Strands Exposed: None</td>
<td></td>
<td></td>
<td>Strands Exposed: None</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### T1

**Inspection**
- The inspection hole was drilled 8-1/2 inches below the top slab, 16-1/2 feet west of Pier 3. The tendon was found at a depth of 5 inches.

**N/A**

**No Void**
- Grout Color: White
- Grout Consistency: Chalky
- Strands Exposed: None

**Inspection**
- The inspection hole was drilled 3 inches below the top slab, 11.25 feet east of Pier 2. The tendon was found at a depth of 5 inches.

**NO VOID**
- Duct is 50% Full
- Size: 20+ feet long by 2 inches high
- Grout Color: White
- Grout Consistency: Chalky
- Strands Exposed: (3) - No visible corrosion.

**Note:** Spots of light corrosion visible on inside surface of duct.

### T2

**Inspection**
- The inspection hole was drilled 4-1/2 inches below the top slab, 8.75 feet west of Pier 3. The tendon was found at a depth of 4-1/2 inches.

**N/A**

**No Void**
- Grout Color: White
- Grout Consistency: Chalky
- Strands Exposed: None

**Inspection**
- The inspection hole was drilled 6 inches below the top slab, 8.25 feet east of Pier 2. The tendon was found at a depth of 4-3/4 inches.

**VOID**
- Duct is 50% Full
- Size: 20+ feet long by 2 inches high
- Grout Color: Dark Gray
- Grout Consistency: Solid
- Strands Exposed: None

**Note:** Spots of light corrosion visible on inside surface of duct.

### T3

**Inspection**
- The inspection hole was drilled 4 inches below the top slab, 5 feet west of Pier 3. The tendon was found at a depth of 4 inches.

**N/A**

**No Void**
- Grout Color: Cream to brown
- Grout Consistency: Chalky
- Strands Exposed: (1) - No visible corrosion.

**Inspection**
- The inspection hole was drilled 6-1/2 inches below the top slab, 4.75 feet east of Pier 2. The tendon was found at a depth of 6 inches.

**VOID**
- Duct is 50% Full
- Size: 18+ feet long by 2 inches high
- Grout Color: Dark Gray to white (at lowpoint)
- Grout Consistency: Solid to flaky (at lowpoint)
- Strands Exposed: (1) - No Visible corrosion.

**Note:** Moderate corrosion visible on inside surface of duct.

**MnDOT elected to defer regrouting of this location to a future repair project.**

**VSL**

**Regruotd:** VSL was unable to pull a vacuum at this void. VSL performed pressure grouting on June 28, 2013:

- Void size = 44.6 liters (3 bags used)
- Grout Properties:
  - Temperature: 84°F
  - Flow Cone: n/a
  - Mud Balance: n/a

**Partially Regruotd:** VSL was unable to pull a vacuum at this void duct air leakage. VSL performed pressure grouting on June 28, 2013:

- Void size = 52.0 liters (3.5 bags used)
- Grout Properties:
  - Temperature: 84°F
  - Flow Cone: 15.5
  - Mud Balance: 1.84

**The project allotment of grout was consumed during this work with the void not yet completely filled.**

**VSL**

**MnDOT elected to defer regrouting of this location to a future repair project.**

**VSL**

**Regruotd:** VSL was able to pull a vacuum to -22 in.-Hg and hold to determine void size.

- Void size = 23.9 liters
## Minnesota Department of Transportation

### Inspection, Remedial Grouting and Corrosion Monitoring of Post-Tensioned Tendons

October 18, 2013

<table>
<thead>
<tr>
<th>TENDON</th>
<th>PIER 3 (High Point)</th>
<th>PIER 2 (High Point)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>T1</strong></td>
<td>The inspection hole was drilled 5-1/2 inches below the top slab, 13 feet west of Pier 3. The tendon was found at a depth of 4 inches.</td>
<td>The inspection hole was drilled 4-1/2 inches below the top slab, 13-1/2 feet east of Pier 2. The tendon was found at a depth of 4 inches.</td>
</tr>
<tr>
<td>NO VOID</td>
<td>The tendon was found at a depth of 4 inches.</td>
<td>The tendon was found at a depth of 4 inches.</td>
</tr>
<tr>
<td>Grout Color: Creamy Brown/White</td>
<td>Grout Color: White</td>
<td>VSL was able to pull a vacuum to -20 in-Hg and hold to determine void size.</td>
</tr>
<tr>
<td>Grout Consistency: Chalky</td>
<td>Grout Consistency: Chalky</td>
<td>Void size = 34.4 liters</td>
</tr>
<tr>
<td>Strands Exposed: None</td>
<td>Strands Exposed: (1) - Class 2 corrosion (PCI)</td>
<td>MnDOT elected to defer regrouting of this location to a future repair project.</td>
</tr>
<tr>
<td><strong>T2</strong></td>
<td>The inspection hole was drilled x inches below the top slab, x feet west of Pier 3. The tendon was found at a depth of x inches.</td>
<td>The inspection hole was drilled 4 inches below the top slab, 7-1/2 feet east of Pier 2. The tendon was found at a depth of 3-3/4 inches.</td>
</tr>
<tr>
<td>NO VOID</td>
<td>The tendon was found at a depth of 4 inches.</td>
<td>The tendon was found at a depth of 3-3/4 inches.</td>
</tr>
<tr>
<td>Grout Color: Cream/Tan</td>
<td>Grout Color: White</td>
<td>VSL was able to pull a vacuum to -23 in-Hg and hold to determine void size.</td>
</tr>
<tr>
<td>Grout Consistency: Solid</td>
<td>Grout Consistency: Solid</td>
<td>Void size = 41.5 liters</td>
</tr>
<tr>
<td>Strands Exposed: None</td>
<td>Strands Exposed: (4) - Class 2 corrosion (PCI)</td>
<td>MnDOT elected to defer regrouting of this location to a future repair project.</td>
</tr>
<tr>
<td><strong>T3</strong></td>
<td>The inspection hole was drilled 7 inches below the top slab, 21 inches west of Pier 3. The tendon was found at a depth of 3 inches.</td>
<td>The inspection hole was drilled 8 inches below the top slab, 27 inches east of Pier 2. The tendon was found at a depth of 3 inches.</td>
</tr>
<tr>
<td>NO VOID</td>
<td>The tendon was found at a depth of 3 inches.</td>
<td>The tendon was found at a depth of 3 inches.</td>
</tr>
<tr>
<td>Grout Color: Tan</td>
<td>Grout Color: Dark gray</td>
<td>VSL was unable to pull a vacuum at this void to determine the void size due to duct air leakage.</td>
</tr>
<tr>
<td>Grout Consistency: Solid</td>
<td>Grout Consistency: Solid</td>
<td>Void size = n/a</td>
</tr>
<tr>
<td>Strands Exposed: None</td>
<td>Strands Exposed: None</td>
<td>MnDOT elected to defer regrouting of this location to a future repair project. Ports were drilled by VSL for future pressure grouting.</td>
</tr>
<tr>
<td>TENDON</td>
<td>PIER 3 (High Point)</td>
<td>PIER 2 (High Point)</td>
</tr>
<tr>
<td>--------</td>
<td>---------------------</td>
<td>---------------------</td>
</tr>
<tr>
<td><strong>INSP</strong></td>
<td><strong>RE-GROUTING</strong></td>
<td><strong>INSP</strong></td>
</tr>
<tr>
<td><strong>INSPECTION</strong></td>
<td><strong>REPRESENTATIVE PHOTOGRAPH</strong></td>
<td><strong>INSPECTION</strong></td>
</tr>
<tr>
<td>T1</td>
<td>The inspection hole was drilled 3-1/2 inches below the top slab, 13 feet west of Pier 3. The tendon was found at a depth of 4-1/4 inches.</td>
<td>NO VOID</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Grout Color: Cream/tan</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Grout Consistency: Solid</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Strands Exposed: None</td>
</tr>
<tr>
<td>T2</td>
<td>The inspection hole was drilled 5 inches below the top slab, 8-1/2 feet west of Pier 3. The tendon was found at a depth of 3-1/2 inches.</td>
<td>NO VOID</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Grout Color: White/cream</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Grout Consistency: Solid</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Strands Exposed: None</td>
</tr>
<tr>
<td>T3</td>
<td>The inspection hole was drilled 5 inches below the top slab, 20 inches west of Pier 3. The tendon was found at a depth of 5-1/4 inches.</td>
<td>VOID - Duct is 90% Full</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Size: 4 feet long by 1/4 inch high, continues over Pier 3 into Span 4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Grout Color: White/light gray</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Grout Consistency: Solid</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Strands Exposed: None</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RE-GROUTED: VSL was able to pull a vacuum to -18 and hold to determine void size. Duct was pressurized to 20psi and locked off. Pressure grouting was performed on June 27, 2013:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Void size = 39.2 liters (3.5 bags)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Grout Properties:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Temperature - 85°F</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Flow Cone - 17.2 seconds</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Mud Balance - 1.81</td>
</tr>
<tr>
<td></td>
<td></td>
<td>14:29 18/06/2013</td>
</tr>
<tr>
<td></td>
<td></td>
<td>15:03 18/06/2013</td>
</tr>
</tbody>
</table>
## 02037W - SPAN 3 - Girder 5

<table>
<thead>
<tr>
<th>TENDON</th>
<th>PIER 3 (High Point)</th>
<th>PIER 2 (High Point)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>INSPECTION</td>
<td>REPRESENTATIVE PHOTOGRAPH</td>
</tr>
<tr>
<td></td>
<td>RE-GROUTING</td>
<td></td>
</tr>
<tr>
<td><strong>T1</strong></td>
<td>The inspection hole was drilled 3-1/2 inches below the top slab, 13.75 feet west of Pier 3. The tendon was found at a depth of 3-3/4 inches. NO VOID</td>
<td>![Representative Photograph of T1]</td>
</tr>
<tr>
<td></td>
<td>Grout Color: Cream/tan</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grout Consistency: Chalky</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Strands Exposed: None</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>T2</strong></td>
<td>The inspection hole was drilled 4 inches below the top slab, 4-1/2 feet west of Pier 3. The tendon was found at a depth of 4-1/2 inches. NO VOID</td>
<td>![Representative Photograph of T2]</td>
</tr>
<tr>
<td></td>
<td>Grout Color: Cream/tan</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grout Consistency: Chalky</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Strands Exposed: None</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>T3</strong></td>
<td>The inspection hole was drilled 7 inches below the top slab, 2 feet west of Pier 3. The tendon was found at a depth of 5 inches. NO VOID</td>
<td>![Representative Photograph of T3]</td>
</tr>
<tr>
<td></td>
<td>Grout Color: White/tan</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grout Consistency: Chalky</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Strands Exposed: None</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Note:**
- VAL was able to pull a vacuum to -18 in-Hg and hold to determine void size.
- Void size = 30.6 liters
- MnDOT elected to defer regrouting of this location to a future repair project.

**Note:**
- VAL was able to pull a vacuum to -21 in-Hg and hold to determine void size.
- Void size = 50.9 liters
- MnDOT elected to defer regrouting of this location to a future repair project.
### 02037W - SPAN 4 - Girder 1

<table>
<thead>
<tr>
<th>TENDON</th>
<th>EAST ABUTMENT (Anchor)</th>
<th>PIER 3 (High Point)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>INSPECTION</td>
<td>INSPECTION</td>
</tr>
<tr>
<td></td>
<td>RE-GROUTING</td>
<td>RE-GROUTING</td>
</tr>
<tr>
<td></td>
<td>REPRESENTATIVE PHOTOGRAPH</td>
<td>REPRESENTATIVE PHOTOGRAPH</td>
</tr>
<tr>
<td>T1</td>
<td>The inspection hole was drilled 20 inches below the top slab, 21-1/2 inches west of the east abutment. The tendon was found at a depth of 5 inches.</td>
<td>The inspection hole was drilled 3 inches below the top slab, 10 feet east of Pier 3. The tendon was found at a depth of 3-1/4 inches.</td>
</tr>
<tr>
<td></td>
<td>NO VOID</td>
<td>NO VOID</td>
</tr>
<tr>
<td></td>
<td>Grout Color: Cream</td>
<td>Grout Color: White</td>
</tr>
<tr>
<td></td>
<td>Grout Consistency: Chalky</td>
<td>Grout Consistency: Chalky</td>
</tr>
<tr>
<td></td>
<td>Strands Exposed: (2) - No visible corrosion.</td>
<td>Strands Exposed: None</td>
</tr>
<tr>
<td></td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>T2</td>
<td>The inspection hole was drilled 37 inches below the top slab, 22-1/2 inches west of the east abutment. The tendon was found at a depth of 4-3/4 inches.</td>
<td>The inspection hole was drilled 3 inches below the top slab, 6 feet east of Pier 3. The tendon was found at a depth of 4 inches.</td>
</tr>
<tr>
<td></td>
<td>NO VOID</td>
<td>VOID - Duct is 90% Full</td>
</tr>
<tr>
<td></td>
<td>Grout Color: Cream</td>
<td>Size: 2 feet long by 1/4 inch high</td>
</tr>
<tr>
<td></td>
<td>Grout Consistency: Chalky</td>
<td>Grout Color: White</td>
</tr>
<tr>
<td></td>
<td>Strands Exposed: None</td>
<td>Grout Consistency: Chalky</td>
</tr>
<tr>
<td></td>
<td>N/A</td>
<td>Strands Exposed: None</td>
</tr>
<tr>
<td></td>
<td>Note: Small spot of corrosion on duct</td>
<td>Note: Light surface corrosion visible on inside surface of duct.</td>
</tr>
<tr>
<td>T3</td>
<td>The inspection hole was drilled 55 inches below the top slab, 25-1/2 inches west of the east abutment. The tendon was found at a depth of 4-1/2 inches.</td>
<td>The inspection hole was drilled 5-1/2 inches below the top slab, 15 inches east of Pier 3. The tendon was found at a depth of 5-1/2 inches.</td>
</tr>
<tr>
<td></td>
<td>NO VOID</td>
<td>VOID - Duct is 90% Full</td>
</tr>
<tr>
<td></td>
<td>Grout Color: Cream</td>
<td>Size: 4 feet long by 1/4 inch high</td>
</tr>
<tr>
<td></td>
<td>Grout Consistency: Chalky</td>
<td>Grout Color: Cream</td>
</tr>
<tr>
<td></td>
<td>Strands Exposed: None</td>
<td>Grout Consistency: Soft, porous, and crumbling</td>
</tr>
<tr>
<td></td>
<td>N/A</td>
<td>Strands Exposed: None</td>
</tr>
<tr>
<td></td>
<td>Note: Moderate surface corrosion visible on inside surface of the duct.</td>
<td>Note: Moderate surface corrosion visible on inside surface of the duct.</td>
</tr>
</tbody>
</table>

**VSL** was unable to pull a vacuum at this void due to duct air leakage. Duct was pressurized to 20psi and locked off. Pressure grouting was performed on June 26, 2013:

- **Void size**: 3.4 liters (1/4 bag)
- **Grout Properties**:
  - Temperature: 79°F
  - Flow Cone: 14.5 seconds
  - Mud Balance: 1.98

---

**Note**: Small spot of corrosion on duct.
### INSPECTION, REMEDIAL GROUTING AND CORROSION MONITORING OF POST-TENSIONED TENDONS

#### Overview

- **Location:** Minnesota Department of Transportation
- **Date:** October 18, 2013
- **Project:** Inspection, Remedial Grouting and Corrosion Monitoring of Post-Tensioned Tendons

#### TENDON 02037W - SPAN 4 - Girder 2

<table>
<thead>
<tr>
<th>TENDON</th>
<th>EAST ABUTMENT (Anchor)</th>
<th>PIER 3 (High Point)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>INSPECTION</strong></td>
<td><strong>RE-GROUTING</strong></td>
<td><strong>INSPECTION</strong></td>
</tr>
<tr>
<td>The inspection hole was drilled 20 inches below the top slab, 17 inches west of the east abutment. The tendon was found at a depth of 5 inches.</td>
<td>N/A</td>
<td>The inspection hole was drilled 3-1/2 inches below the top slab, 12-1/2 feet east of Pier 3. The tendon was found at a depth of 5 inches.</td>
</tr>
<tr>
<td>NO VOIDS</td>
<td>Grout Color: Cream</td>
<td>VOID - Duct is 50% Full</td>
</tr>
<tr>
<td>Grout Consistency: Chalky</td>
<td>Grout Consistency: Cream</td>
<td>Size: 11+ feet long by 2 inches high</td>
</tr>
<tr>
<td>Strands Exposed: (1) - No visible corrosion.</td>
<td>Grout Consistency: Chalky</td>
<td>Grout Color: White</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Grout Consistency: Crumbled</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Strands Exposed: (5) - No visible corrosion.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Note: Light surface corrosion visible on inside surface of duct.</td>
</tr>
<tr>
<td><strong>T1</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The inspection hole was drilled 35 inches below the top slab, 17 inches west of the east abutment. The tendon was found at a depth of 5 inches.</td>
<td>N/A</td>
<td>The inspection hole was drilled 5 inches below the top slab, 7-1/2 feet east of Pier 3. The tendon was found at a depth of 3-1/2 inches.</td>
</tr>
<tr>
<td>NO VOIDS</td>
<td>Grout Color: Cream</td>
<td>NO VOIDS</td>
</tr>
<tr>
<td>Grout Consistency: Chalky</td>
<td>Grout Consistency: White/cream</td>
<td>Grout Consistency: Chalky</td>
</tr>
<tr>
<td>Strands Exposed: (1) - No visible corrosion.</td>
<td>Strands Exposed: None</td>
<td>Strands Exposed: None</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Note: Crack observed following T3 tendon profile on girder. Efflorescence is present along entire crack length (see Figure 3.3).</td>
</tr>
<tr>
<td><strong>T2</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The inspection hole was drilled 53-1/2 inches below the top slab, 16 inches west of the east abutment. The tendon was found at a depth of 4 inches.</td>
<td>N/A</td>
<td>The inspection hole was drilled 6 inches below the top slab, 9-1/2 inches east of Pier 3. The tendon was found at a depth of 5-1/4 inches.</td>
</tr>
<tr>
<td>NO VOIDS</td>
<td>Grout Color: Cream</td>
<td>VOID - Duct is 50% Full</td>
</tr>
<tr>
<td>Grout Consistency: Chalky</td>
<td>Grout Color: White</td>
<td>Size: 16+ feet long by 2 inches high</td>
</tr>
<tr>
<td>Strands Exposed: None</td>
<td>Grout Consistency: Crumbling</td>
<td>Grout Consistency: Chalky</td>
</tr>
<tr>
<td></td>
<td>Strands Exposed: None</td>
<td>Strands Exposed: None</td>
</tr>
<tr>
<td></td>
<td>Note: Moderate surface corrosion visible on inside surface of the duct.</td>
<td>Note: Moderate surface corrosion visible on inside surface of the duct.</td>
</tr>
<tr>
<td><strong>T3</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
# Inspection, Remedial Grouting and Corrosion Monitoring of Post-Tensioned Tendons

**October 18, 2013**

<table>
<thead>
<tr>
<th>TENDON</th>
<th>EAST ABUTMENT (Anchor)</th>
<th>PIER 3 (High Point)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>INSPECTION</td>
<td>RE-GROUTING</td>
</tr>
<tr>
<td></td>
<td>REPRESENTATIVE</td>
<td>PHOTOGRAPH</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T1</td>
<td>The inspection hole</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>was drilled 20-1/2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>inches below the top</td>
<td></td>
</tr>
<tr>
<td></td>
<td>slab, 13 inches west</td>
<td></td>
</tr>
<tr>
<td></td>
<td>of the east abutment.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>The tendon was found at</td>
<td></td>
</tr>
<tr>
<td></td>
<td>a depth of 5-1/4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>inches.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>NO VOIDS</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grout Color: White</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grout Consistency:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Chalky</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Strands Exposed: None</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Note: Rebar present</td>
<td></td>
</tr>
<tr>
<td></td>
<td>at top of inspection</td>
<td></td>
</tr>
<tr>
<td></td>
<td>hole.</td>
<td></td>
</tr>
<tr>
<td>T2</td>
<td>The inspection hole</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>was drilled 38 inches</td>
<td></td>
</tr>
<tr>
<td></td>
<td>below the top slab, 12</td>
<td></td>
</tr>
<tr>
<td></td>
<td>inches west of the east</td>
<td></td>
</tr>
<tr>
<td></td>
<td>abutment. The tendon</td>
<td></td>
</tr>
<tr>
<td></td>
<td>was found at a depth</td>
<td></td>
</tr>
<tr>
<td></td>
<td>of 4-1/2 inches.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>NO VOIDS</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grout Color: White</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grout Consistency:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Chalky</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Strands Exposed: (1) -</td>
<td></td>
</tr>
<tr>
<td></td>
<td>No visible corrosion.</td>
<td></td>
</tr>
<tr>
<td>T3</td>
<td>The inspection hole</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>was drilled 58 inches</td>
<td></td>
</tr>
<tr>
<td></td>
<td>below the top slab, 12</td>
<td></td>
</tr>
<tr>
<td></td>
<td>inches west of the east</td>
<td></td>
</tr>
<tr>
<td></td>
<td>abutment. The tendon</td>
<td></td>
</tr>
<tr>
<td></td>
<td>was found at a depth</td>
<td></td>
</tr>
<tr>
<td></td>
<td>of 4 inches.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>NO VOIDS</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grout Color: White</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grout Consistency:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Chalky</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Strands Exposed: (1) -</td>
<td></td>
</tr>
<tr>
<td></td>
<td>No visible corrosion.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Note: Rebar present</td>
<td></td>
</tr>
<tr>
<td></td>
<td>at top of inspection</td>
<td></td>
</tr>
</tbody>
</table>

**Grout Color: White**

**Grout Consistency: Chalky**

**Strands Exposed: None**

**Note:** Rebar present at top of inspection hole.

**Size:** 11+ feet long by 1-2 inches high

**Regrouted:** VSL was unable to pull a vacuum at this void due to duct air leakage. Pressure grouting was performed on June 27, 2013:

- Void size = 36 liters (2.5 bags)
- Grout Properties:
  - Temperature: 85°F
  - Flow Cone: 17.2 seconds
  - Mud Balance: 1.81

**Corrosion monitoring sensor installed at this void prior to re-grouting.**
<table>
<thead>
<tr>
<th>TENDON</th>
<th>EAST ABUTMENT (Anchor)</th>
<th>PIER 3 (High Point)</th>
<th>INSPECTION</th>
<th>RE-GROUTING</th>
<th>REPRESENTATIVE PHOTOGRAPH</th>
<th>INSPECTION</th>
<th>RE-GROUTING</th>
<th>REPRESENTATIVE PHOTOGRAPH</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>Previously inspected by UMD/VSL in 2011. No change in conditions since 2011.</td>
<td></td>
<td></td>
<td></td>
<td>NO VOID</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>NO VOID</td>
<td></td>
<td></td>
<td></td>
<td>Grout Color: White</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grout Consistency: Chalky</td>
<td></td>
<td></td>
<td></td>
<td>Strands Exposed: None</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>T2</td>
<td>Previously inspected by UMD/VSL in 2011. No change in conditions since 2011.</td>
<td></td>
<td></td>
<td></td>
<td>NO VOID</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>NO VOID</td>
<td></td>
<td></td>
<td></td>
<td>Grout Color: White</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grout Consistency: Chalky</td>
<td></td>
<td></td>
<td></td>
<td>Strands Exposed: (1) - No visible corrosion.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>T3</td>
<td>Previously inspected by UMD/VSL in 2011. No change in conditions since 2011.</td>
<td></td>
<td></td>
<td></td>
<td>NO VOID</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>NO VOID</td>
<td></td>
<td></td>
<td></td>
<td>Grout Color: White</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grout Consistency: Chalky</td>
<td></td>
<td></td>
<td></td>
<td>Strands Exposed: (1) - No visible corrosion.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Previously inspected by UMD/VSL in 2011. No change in conditions since 2011.

NO VOID - Duct is 50% Full
Size: 6+ feet long by 2 inches high
Grout Color: N/A
Strands Exposed: (3) - Class 2 corrosion (PCI)

REGROUTED: VSL was unable to pull a vacuum to <20 in-Hg and hold to determine void size. Pressure grouting was performed on June 27, 2013:

Void size = 39.2 liters (3.5 bags)

Grout Properties:
- Temperature: 85°F
- Flow Cone: 17.2 seconds
- Mud Balance: 1.81

Corrosion monitoring sensor installed at this void prior to re-grouting.
<table>
<thead>
<tr>
<th>TENDON</th>
<th>EAST ABUTMENT (Anchor)</th>
<th>PIER 3 (High Point)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>INSPECTION</td>
<td>RE-GROUTING</td>
</tr>
<tr>
<td>T1</td>
<td>Previously inspected by UMD/VSL in 2011. No change in conditions since 2011.</td>
<td>NO VOIDS</td>
</tr>
<tr>
<td></td>
<td>NO VOIDS</td>
<td>Grout Color: White</td>
</tr>
<tr>
<td></td>
<td>Grout Consistency: Chalky</td>
<td>Strands Exposed: None</td>
</tr>
<tr>
<td>T2</td>
<td>Previously inspected by UMD/VSL in 2011. No change in conditions since 2011.</td>
<td>NO VOIDS</td>
</tr>
<tr>
<td></td>
<td>NO VOIDS</td>
<td>Grout Color: White</td>
</tr>
<tr>
<td></td>
<td>Grout Consistency: Chalky</td>
<td>Strands Exposed: None</td>
</tr>
<tr>
<td>T3</td>
<td>Previously inspected by UMD/VSL in 2011. No change in conditions since 2011.</td>
<td>NO VOIDS</td>
</tr>
<tr>
<td></td>
<td>NO VOIDS</td>
<td>Grout Color: White</td>
</tr>
<tr>
<td></td>
<td>Grout Consistency: Chalky</td>
<td>Strands Exposed: (1) - No visible corrosion.</td>
</tr>
<tr>
<td></td>
<td>Note: Moderate surface corrosion visible on inside surface of the duct.</td>
<td>Void size = 13.2 liters (1 bag)</td>
</tr>
</tbody>
</table>
# 02037W - SPAN 3 - Additional Photographs of Grout Voids

<table>
<thead>
<tr>
<th>GIRDER</th>
<th>LOCATION</th>
<th>TENDON</th>
<th>TOWARD HIGH POINT</th>
<th>TOWARD LOW POINT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>12&quot; inside void toward highpoint, strands partially exposed, no corrosion visible</td>
<td>41&quot; inside void, all strands covered, grout white and chalky, small spot of corrosion on duct</td>
<td>92&quot; inside duct, grout white and chalky, strands covered, no corrosion visible</td>
</tr>
<tr>
<td>2</td>
<td>Pier 2</td>
<td>36&quot; inside duct, no strands exposed, duct 1/2 empty</td>
<td>84&quot; inside duct, duct 1/2 empty, small spots of corrosion on duct, no strands exposed</td>
<td>120&quot; inside duct, duct 1/2 empty, no strands exposed, small spots of corrosion on duct</td>
</tr>
<tr>
<td>3</td>
<td>12&quot; inside duct, no strands exposed, grout appears solid, small corrosion spots on duct</td>
<td>48&quot; inside duct, no strands exposed, grout solid and good colored, void getting smaller</td>
<td>84&quot; inside duct, no strands exposed, no corrosion, grout solid and dark colored, void getting smaller</td>
<td>12&quot; inside duct, spots of corrosion on duct, grout white and chalky, no strands exposed</td>
</tr>
</tbody>
</table>

A-57
## 02037W - SPAN 3 - Additional Photographs of Grout Voids

<table>
<thead>
<tr>
<th>GIRDER</th>
<th>LOCATION</th>
<th>TENDON</th>
<th>TOWARD HIGH POINT</th>
<th>TOWARD LOW POINT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td>12&quot; inside void toward highpoint, no strands exposed, duct 1/2 full, grout has white chalky color, visible grout line on sides of duct</td>
<td>72&quot; inside duct, duct does not appear to have ever been completely filled</td>
</tr>
<tr>
<td>2</td>
<td>Pier 2</td>
<td></td>
<td>12&quot; inside duct, no strands exposed, grout white and chalky</td>
<td>108&quot; inside duct, void continues, one strand partially exposed with Class 1-2 corrosion, grout solid and good colored, void getting smaller</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td>12&quot; inside duct, no strands exposed</td>
<td>12&quot; inside duct, 1/3 of duct empty, no strands exposed</td>
</tr>
</tbody>
</table>

**Notes:**
- Grout voids observed in various duct sections.
- Observations include grout color, presence of strands, and corrosion levels.
- Duct sections labeled with measurements in inches and location descriptions.

**Corrosion Levels:**
- Class 1-2 corrosion
- Corrosion spots visible on duct wall
- Moderate corrosion of duct wall

**Grout Conditions:**
- Solid and good colored
- Grout solid and good colored, void getting smaller

**Additional Observations:**
- Grout line on sides of duct
- Visible grout line on side wall of duct
- Top surface clean
- Moderate corrosion of duct wall

**Duct Fill States:**
- Duct never filled during construction
- Duct partially filled during construction
<table>
<thead>
<tr>
<th>GIRDER</th>
<th>LOCATION</th>
<th>TENDON</th>
<th>TOWARD HIGH POINT</th>
<th>TOWARD LOW POINT</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>6&quot; inside duct, two strands partially exposed, corrosion visible on duct, grout appears white and chalky</td>
<td>18&quot; inside duct, one strand starting to drop into grout bed, moderate corrosion on duct with flakes on grout bed</td>
<td></td>
</tr>
<tr>
<td>@ Pier 2</td>
<td>1</td>
<td>6&quot; inside duct, void still at 1/2 duct, grout white and chalky, no strands exposed</td>
<td>24&quot; inside duct, strands visible below grout bed surface but covered, no corrosion visible</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>3</td>
<td>12&quot; inside duct, no strands exposed, grout white and chalky</td>
<td>48&quot; inside duct, no strands exposed, grout white and chalky, void getting much smaller</td>
<td></td>
</tr>
</tbody>
</table>

**Additional Observations:**

- 18" inside duct, moderate duct corrosion with flakes on grout bed, strand exposed but dropping into grout bed.
- 48" inside duct, spots of corrosion on duct with flakes on grout bed, grout appears white and chalky.
- 72" inside duct, no corrosion on duct, no strands visible, grout white and chalky.

- 67" inside duct, void becoming smaller, no strands exposed, no corrosion on duct, grout white and chalky.
- 48" inside duct, spots of corrosion on duct with flakes on grout bed, grout appears white and chalky.
- 72" inside duct, no corrosion on duct, no strands visible, grout white and chalky.
- 120" inside duct, void is 1/2 duct and continues, grout appears to be turning a creamy tan color, corrosion on exposed strand Class 1-2.
- 84" inside duct, two different layers of grout - white and chalky on right, raised solid and darker colored on left. No strands exposed.
### 02037W - SPAN 4 - Additional Photographs of Grout Voids

<table>
<thead>
<tr>
<th>GIRDER</th>
<th>LOCATION</th>
<th>TENDON</th>
<th>TOWARD HIGH POINT</th>
<th>TOWARD LOW POINT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>2&quot; inside duct, five strands exposed with no corrosion, small spots of corrosion on duct wall</td>
<td>2&quot; inside duct, corrosion spots on duct wall, three strands exposed but no visible corrosion</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>48&quot; inside duct, three strands exposed with no corrosion, small corrosion spots on duct, grout very white and crumbly</td>
<td>12&quot; inside duct, two strands exposed with no corrosion, corrosion spot on duct, grout white, flaky and chalky</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>96&quot; inside duct, two strands exposed with no corrosion, very white and crumbly</td>
<td>24&quot; inside duct, one strand exposed with no corrosion, grout is white and crumbly</td>
</tr>
<tr>
<td></td>
<td>Pier 3</td>
<td>3</td>
<td>12&quot; inside duct, no strands exposed, void approximately 1/4 duct and getting smaller, grout white and chalky</td>
<td>12&quot; inside duct, void less than 1/2 inch high, grout white and very chalky, no strands exposed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>36&quot; inside duct, no strands exposed, possibly one small spot of corrosion on duct wall</td>
<td>48&quot; inside duct, no strands exposed, void approximately 1/3 duct, grout white and chalky</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>72&quot; inside duct, void less than 1/2 inch high, grout white and very chalky, no strands exposed</td>
<td>96&quot; inside duct, one strand partially exposed along left side of duct, no corrosion visible</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>120&quot; inside duct, grout white and chalky, exposed strand along left side of duct, duct 1/2 empty</td>
<td>120&quot; inside duct, one strand partially exposed, spots of corrosion on duct with small corrosion flakes on grout bed</td>
</tr>
</tbody>
</table>

<p>|        |          | 3      | 6&quot; inside duct, no strands exposed, grout white and chalky, small spots of corrosion on duct | 2&quot; inside duct, no strands exposed, corrosion on inside surface of duct with flakes on grout bed. Void tapering to zero just beyond this point |
|        |          | 3      | 36&quot; inside duct, no strands exposed, corrosion on inside surface of duct with flakes on grout bed. Void tapering to zero just beyond this point | 48&quot; inside duct, one strand partially exposed, moderate corrosion on duct with corrosion flakes laying on grout bed |
|        |          | 3      | 2&quot; inside duct, no strands exposed, corrosion on inside surface of duct with flakes on top of grout bed, 1/2 empty | 120&quot; inside duct, one strand partially exposed, spots of corrosion on duct with small corrosion flakes on grout bed |</p>
<table>
<thead>
<tr>
<th>GIRDER</th>
<th>LOCATION</th>
<th>TENDON</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Pier 3</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes were recorded during 2011 UMD/VSL work.

<table>
<thead>
<tr>
<th>5</th>
<th>Pier 3</th>
<th>3</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes were recorded during 2011 UMD/VSL work.

****No new inspection notes taken by VSL along with borescope images.******
APPENDIX B - BRIDGE 02037E SPAN 2
Specialized Inspection Findings and Remedial Grouting Results
Bridge 02037E - SPAN 2 - Summary of Inspection Findings

KEYPLAN

LEGEND

- Drilled inspection opening (fully grouted)
- Drilled inspection opening (voided)
- Corrosion sensor location

T1 = Top Tendon
T2 = Middle Tendon
T3 = Bottom Tendon

Figure B1. Bridge No. 02037 Eastbound Span 2 - Summary of Inspection Findings
### 02037E - SPAN 2 - Girder 1

<table>
<thead>
<tr>
<th>TENDON</th>
<th>PIER 2 (High Point)</th>
<th>PIER 1 (High Point)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>INSPECTION</td>
<td>REPRESENTATIVE PHOTOGRAPH</td>
</tr>
<tr>
<td>T1</td>
<td>The inspection hole was drilled 4-1/2 inches below the top slab, 13-3/4 feet west of Pier 2. The tendon was found at a depth of 4-1/2 inches.</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>NO VOID</td>
<td>Grout Color: White</td>
</tr>
<tr>
<td></td>
<td>Grout Consistency: Chalky</td>
<td>Grout Consistency: Chalky</td>
</tr>
<tr>
<td></td>
<td>Strands Exposed: None</td>
<td>Strands Exposed: None</td>
</tr>
<tr>
<td>T2</td>
<td>The inspection hole was drilled 3-1/2 inches below the top slab, 9-3/4 feet west of Pier 2. The tendon was found at a depth of 3-3/4 inches.</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>NO VOID</td>
<td>Grout Color: Cream</td>
</tr>
<tr>
<td></td>
<td>Grout Consistency: Chalky</td>
<td>Grout Consistency: Chalky</td>
</tr>
<tr>
<td></td>
<td>Strands Exposed: None</td>
<td>Strands Exposed: None</td>
</tr>
<tr>
<td>T3</td>
<td>The inspection hole was drilled 9 inches below the top slab, 17-1/2 inches west of Pier 2. The tendon was found at a depth of 4-1/4 inches.</td>
<td>MalDOT elected to defer regrouting of this location to a future repair project.</td>
</tr>
<tr>
<td></td>
<td>VOID - Duct is 70-75% Full</td>
<td>Grout Color: Gray (at high point) to white (at low point)</td>
</tr>
<tr>
<td></td>
<td>Size: 10+ feet long by 1-1/4 inch high</td>
<td>Grout Consistency: Solid (at high point) to chalky (at low point)</td>
</tr>
<tr>
<td></td>
<td>Grout Color: Gray (at high point) to white (at low point)</td>
<td>Strands Exposed: (1) - No visible corrosion. Other strands are visible but covered by grout</td>
</tr>
</tbody>
</table>
### 02037E - SPAN 2 - Girder 2

<table>
<thead>
<tr>
<th>TENDON</th>
<th>INSPECTION</th>
<th>RE-GROUTING</th>
<th>REPRESENTATIVE PHOTOGRAPH</th>
<th>PIER 1 (High Point)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>T1</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>The inspection hole was drilled 2 inches below the top slab, 15 feet west of Pier 2. The tendon was found at a depth of 3-1/2 inches.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>NO VOID</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grout Color: White</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grout Consistency: Chalky</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Strands Exposed: None</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>T2</td>
<td>MnDOT elected to defer regrouting of this location to a future repair project.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>The inspection hole was drilled 1-1/2 inches below the top slab, 10 feet west of Pier 2. The tendon was found at a depth of 3-1/2 inches.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>VOID - Duct is 50% Full Size: 15+ feet long by 2 inches high Grout Color: Dark gray Grout Consistency: Solid Strands Exposed: None, covered by grout</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>T3</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>The inspection hole was drilled 6 inches below the top slab, 20-1/2 inches west of Pier 2. The tendon was found at a depth of 3 inches.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>NO VOID</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grout Color: White</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grout Consistency: Chalky</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Strands Exposed: None</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TENDON</td>
<td>INSPECTION</td>
<td>PIER 2 (High Point)</td>
<td>RE-GROUTING</td>
<td>REPRESENTATIVE PHOTOGRAPH</td>
</tr>
<tr>
<td>--------</td>
<td>------------</td>
<td>----------------------</td>
<td>-------------</td>
<td>----------------------------</td>
</tr>
<tr>
<td>T1</td>
<td>The inspection hole was drilled 2 inches below the top slab, 14 feet west of Pier 2. The tendon was found at a depth of 3 inches.</td>
<td>MnDOT elected to defer regrouting of this location to a future repair project.</td>
<td><img src="image1" alt="Photo" /></td>
<td></td>
</tr>
<tr>
<td></td>
<td>VOID - Duct is 50% Full</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Size: 18+ feet long by 2 inches high</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grout Consistency: Chalky</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Note: Moderate corrosion visible on inside surface of duct. Corrosion flakes from duct present on grout bed.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T2</td>
<td>The inspection hole was drilled 2 inches below the top slab, 9.25 feet west of Pier 2. The tendon was found at a depth of 3 inches.</td>
<td>MnDOT elected to defer regrouting of this location to a future repair project.</td>
<td><img src="image3" alt="Photo" /></td>
<td></td>
</tr>
<tr>
<td></td>
<td>VOID - Duct is 50% Full</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Size: 16 feet long by 2 inches high</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grout Consistency: Solid</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T3</td>
<td>The inspection hole was drilled 6 inches below the top slab, 15-1/2 inches west of Pier 2. The tendon was found at a depth of 2 1/4 inches.</td>
<td>NO VOID</td>
<td><img src="image4" alt="Photo" /></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grout Color: White</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grout Consistency: Chalky</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Strands Exposed: None</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TENDON</td>
<td>INSPECTION</td>
<td>RE-GROUTING</td>
<td>REPRESENTATIVE PHOTOGRAPH</td>
<td>PIER 1 (High Point)</td>
</tr>
<tr>
<td>--------</td>
<td>-------------</td>
<td>-------------</td>
<td>---------------------------</td>
<td>---------------------</td>
</tr>
</tbody>
</table>
| T1     | The inspection hole was drilled 2 inches below the top slab, 16 feet west of Pier 2. The tendon was found at a depth of 5-1/4 inches. | NO VOID | Grout Color: Cream/tan  
Grout Consistency: Chalky  
Strands Exposed: None  | N/A | The inspection hole was drilled 1 inches below the top slab, 14 feet east of Pier 1. The tendon was found at a depth of 4-1/2 inches. | NO VOID | Grout Color: White  
Grout Consistency: Chalky  
Strands Exposed: None  | N/A |
| T2     | The inspection hole was drilled 2-1/2 inches below the top slab, 11-1/2 feet west of Pier 2. The tendon was found at a depth of 4-1/2 inches. | VOID - Duct is 50% Full  
Size: 20 feet long by 2 inches high  
Grout Color: Gray (at high point) to White (at low point)  
Grout Consistency: Solid (at high point) to chalky (low point)  
Strands Exposed: (2) - Class 1-2 corrosion (PCI)  | MnDOT elected to defer regrouting of this location to a future repair project. | | The inspection hole was drilled 1-1/4 inches below the top slab, 10 feet east of Pier 1. The tendon was found at a depth of 4-1/2 inches. | NO VOID | Grout Color: White/cream  
Grout Consistency: Chalky  
Strands Exposed: None  | N/A |
| T3     | The inspection hole was drilled 5-1/2 inches below the top slab, 16-1/2 inches west of Pier 2. The tendon was found at a depth of 4-1/2 inches. | NO VOID | Grout Color: White  
Grout Consistency: Chalky  
Strands Exposed: (1) - No visible corrosion.  | N/A | The inspection hole was drilled 4 inches below the top slab, 27-1/2 inches east of Pier 1. The tendon was found at a depth of 5 inches. | VOID - Duct is 95% Full  
Size: No borescope access due to size.  
Void is less than 1/4 inch high.  
Grout Color: White  
Grout Consistency: Chalky  
Strands Exposed: None  
Note: Possible surface corrosion on inside surface of duct. | MnDOT elected to defer regrouting of this location to a future repair project. |
### 02037E - SPAN 2 - Girder 5

<table>
<thead>
<tr>
<th>TENDON</th>
<th>INSPECTION</th>
<th>RE-GROUTING</th>
<th>REPRESENTATIVE PHOTOGRAPH</th>
<th>PIER 1 (High Point)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>Previously inspected by UMD/VSL in 2011</td>
<td>MnDOT elected to defer regrouting of this location to a future repair project.</td>
<td><img src="image" alt="Representative Photograph" /></td>
<td>Previously inspected by UMD/VSL in 2011</td>
</tr>
<tr>
<td></td>
<td>VOID - Duct is 50% Full</td>
<td></td>
<td></td>
<td>NO VOID</td>
</tr>
<tr>
<td></td>
<td>Size: 10+ feet long, 2 inches high</td>
<td></td>
<td></td>
<td>Grout Color: White</td>
</tr>
<tr>
<td></td>
<td>Grout Consistency: Chalky</td>
<td></td>
<td></td>
<td>Grout Consistency: Chalky</td>
</tr>
<tr>
<td></td>
<td>Strands Exposed: None</td>
<td></td>
<td></td>
<td>Strands Exposed: None</td>
</tr>
<tr>
<td></td>
<td>Note: Moderate corrosion visible on inside surface of duct. Corrosion flakes from duct present on grout bed.</td>
<td></td>
<td></td>
<td>No change in conditions since 2011.</td>
</tr>
<tr>
<td></td>
<td>No change in conditions since 2011.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| T2     | Previously inspected by UMD/VSL in 2011 | MnDOT elected to defer regrouting of this location to a future repair project. | ![Representative Photograph](image) | Previously inspected by UMD/VSL in 2011 |
|        | VOID - Duct is 50% Full | | | NO VOID |
|        | Size: 10+ feet long, 2 inches high | | | Grout Color: White |
|        | Grout Consistency: Chalky | | | Grout Consistency: Chalky |
|        | Strands Exposed: None | | | Strands Exposed: None |
|        | No change in conditions since 2011. | | | No change in conditions since 2011. |

| T3     | Previously inspected by UMD/VSL in 2011 | MnDOT elected to defer regrouting of this location to a future repair project. | ![Representative Photograph](image) | Previously inspected by UMD/VSL in 2011 |
|        | VOID - Duct is 50% Full | | | NO VOID |
|        | Size: 10+ feet long, 2 inches high | | | Grout Color: White |
|        | Grout Consistency: Chalky | | | Grout Consistency: Chalky |
|        | Strands Exposed: None | | | Strands Exposed: None |
|        | No change in conditions since 2011. | | | No change in conditions since 2011. |

MnDOT elected to defer regrouting of this location to a future repair project.
## 02037E - SPAN 2 - Additional Photographs of Grout Voids

<table>
<thead>
<tr>
<th>GIRDER</th>
<th>LOCATION</th>
<th>TENDON</th>
<th>TOWARD HIGH POINT</th>
<th>TOWARD LOW POINT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>@Pier 2</td>
<td>3</td>
<td>12&quot; inside duct, good colored, duct approximately 1/4 empty, no strands exposed</td>
<td>24&quot; inside duct, good colored, void getting smaller, no strands exposed</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>24&quot; inside duct, good colored, void getting smaller, no strands exposed</td>
<td>36&quot; inside duct, good colored, void getting smaller, no strands exposed</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>36&quot; inside duct, one strand visible just below grout, duct approximately 1/4 to 1/3 empty, grout white and starting to get chalky</td>
<td>24&quot; inside duct, one strand rising out of grout with no corrosion, duct approximately 1/3 empty, grout white and chalky</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>84&quot; inside duct, strand diving back under grout, duct approximately 1/3 empty, grout very white and chalky</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>@Pier 2</td>
<td>2</td>
<td>12&quot; inside duct, spots of corrosion visible on top of duct, grout good colored and solid, no strands exposed, duct approximately 1/2 full</td>
<td>36&quot; inside duct, one strand visible just below surface apparent, no corrosion on duct, grout white and chalky</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>30&quot; inside duct, no strands visible, no corrosion on duct, great white and chalky, void tapering down</td>
<td>6&quot; inside duct, no strands visible, no corrosion on duct, great white and chalky</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>60&quot; inside duct, no strands visible, no corrosion on duct, great white and chalky</td>
<td>24&quot; inside duct, no strands visible, no corrosion on duct, great white and chalky</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>36&quot; inside duct, no strands visible, no corrosion on duct, great white and chalky</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>@ Pier 1</td>
<td>3</td>
<td>12&quot; inside duct, no strands visible, no corrosion on duct, great white and chalky</td>
<td>30&quot; inside duct, no strands visible, no corrosion on duct, great white and chalky</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>30&quot; inside duct, no strands visible, no corrosion on duct, great white and chalky</td>
<td>6&quot; inside duct, no strands visible, no corrosion on duct, great white and chalky</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>60&quot; inside duct, no strands visible, no corrosion on duct, great white and chalky</td>
<td>24&quot; inside duct, no strands visible, no corrosion on duct, great white and chalky</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>36&quot; inside duct, no strands visible, no corrosion on duct, great white and chalky</td>
<td></td>
</tr>
</tbody>
</table>
## 02037E - SPAN 2 - Additional Photographs of Grout Voids

<table>
<thead>
<tr>
<th>GIRDER</th>
<th>LOCATION</th>
<th>TENTON</th>
<th>TOWARD HIGH POINT</th>
<th>TOWARD LOW POINT</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Pier 2</td>
<td>1</td>
<td>24&quot; inside duct, grout white and chalky, spots of corrosion on inside of duct with flakes on grout bed surface. Duct 1/2 empty.</td>
<td>24&quot; inside duct, moderate corrosion on duct, grout very white and chalky, three strands becoming visible.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>72&quot; inside duct, small spots of corrosion on duct, portions of one strand exposed with Class 1-2 corrosion, duct approx. 1/2 empty.</td>
<td>60&quot; inside duct, strand exposed along left side of duct with Class 1-2 corrosion, duct corrosion flakes on grout bed.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>96&quot; inside duct, strand exposed along sidewall has very thin film of grout on it, no strand corrosion.</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>2</td>
<td>24&quot; inside duct, one strand partially exposed with Class 1-2 corrosion, duct very white and chalky, no corrosion on duct, duct 1/2 empty.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>96&quot; inside duct, one strand partially exposed with spots of thin grout films in most areas, rest of strand bundle covered by grout bed.</td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX C - INSTRUCTIONS FOR DATA COLLECTION AND PROCESSING

Step-By-Step Instructions for Field Using the Intertek HHU
### C.1 Data Collection

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
<th>Images</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><strong>VERIFY POWER</strong>&lt;br&gt;Prior to leaving the office, verify that the HHU battery is sufficiently charged. To check battery status:&lt;br&gt;○ Turn the unit on using the red power button in the upper right corner of the keypad. If the unit does not turn on and displays the Intertek home screen, it has no remaining battery life.&lt;br&gt;○ With the unit turned on, arrow down the Main Menu page (Fig. C1) to “System Menu” and press the select button in the middle of the arrow keys.&lt;br&gt;○ In the System Menu page, arrow key down to “Battery Status” and press the select button (Fig. C2).&lt;br&gt;○ Power status of the unit is displayed in the top line “Battery Level %” (Fig. C3). If the battery level is less than 25%, charge the unit for at least 1 hour prior to leaving for the site.&lt;br&gt;&lt;br&gt;To charge the unit, connect the power supply to a wall outlet using the provided power adapter, and connect the power cord to the right side of the HHU (Fig. C4).&lt;br&gt;&lt;br&gt;<strong>Tip:</strong> Battery life is consumed even when the unit is powered off. If data collection is performed monthly, assume that the unit will need to be charged for at least 1 hour prior to every data collection event.</td>
<td><img src="image1.png" alt="Fig. C1. Main Menu" /> <img src="image2.png" alt="Fig. C2. System Menu" /> <img src="image3.png" alt="Fig. C3. Battery Level %" /> <img src="image4.png" alt="Fig. C4. Charging equipment" /></td>
</tr>
<tr>
<td>2</td>
<td><strong>AT THE SITE</strong>&lt;br&gt;The enclosure which houses the corrosion sensor end terminations is mounted on the south face of Span 4 of Bridge 02037W, approximately 20 feet west of the east abutment (Figs. C5 and C6).&lt;br&gt;&lt;br&gt;<strong>Tip:</strong> WJE parks in the grass on the north shoulder at the top of the University Avenue on-ramp to MN610 westbound, and then walks across MN610 and up the slope paving to the enclosure.</td>
<td><img src="image5.png" alt="Fig. C5. Bridge 02037W" /> <img src="image6.png" alt="Fig. C6. Enclosure" /></td>
</tr>
<tr>
<td>3</td>
<td><strong>CONNECT HHU</strong>&lt;br&gt;In the field, unlock the padlock on the side of the enclosure and unscrew the four screws which hold the perimeter enclosure securement brackets in place. The padlock key and a Philips screwdriver are included in the HHU case.&lt;br&gt;&lt;br&gt;With the enclosure opened, connect the smaller end of the patch cable to the connection at the bottom of the HHU (Fig. C7), and the larger end to the sensor end termination, inside the enclosure, from where data collection is desired (Fig. C8). The sensor end terminations are labeled by sensor.&lt;br&gt;&lt;br&gt;<strong>Tip:</strong> The padlock can be tight to remove if all securement screws are loosened first. We recommend unlocking the padlock, loosening the screw/bracket on the top of the enclosure, and removing the padlock, before loosening remaining screws.</td>
<td><img src="image7.png" alt="Fig. C7. Patch cable and connection to HHU" /> <img src="image8.png" alt="Fig. C8. Patch cable and connection to sensor end termination." /></td>
</tr>
<tr>
<td>Step</td>
<td>Description</td>
<td>Images</td>
</tr>
<tr>
<td>------</td>
<td>-------------</td>
<td>--------</td>
</tr>
<tr>
<td>4</td>
<td><strong>DATA COLLECTION</strong>&lt;br&gt;With both ends of the patch cable connected, power the unit on and perform data collection.  &lt;br&gt;• Arrow down to “Sequencer” and press the select key (Fig. C.9).&lt;br&gt;• On the next screen, the selected sequence should read “Preset M3” (Fig. C.10). This sequence consists of the following thirteen (13) steps:&lt;br&gt;  1. Temperature&lt;br&gt;  2. Voltage - Working Electrode 1&lt;br&gt;  3. Delay (10 seconds)&lt;br&gt;  4. Voltage - Working Electrode 2&lt;br&gt;  5. Delay (10 seconds)&lt;br&gt;  6. LPR - Working Electrode 1&lt;br&gt;  7. Delay (5 minutes)&lt;br&gt;  8. LPR - Working Electrode 2&lt;br&gt;  9. Delay (5 minutes)&lt;br&gt; 10. Resistivity - Working Electrode 1&lt;br&gt; 11. Delay (5 minutes)&lt;br&gt; 12. Resistivity - Working Electrode 2&lt;br&gt; 13. Delay (5 minutes)&lt;br&gt;• Select the “Site and Probe” option at the top of the menu (Fig. C.11).&lt;br&gt;• On the next screen, verify that the “Probe Type” says “User” (Fig. C.12).&lt;br&gt;  o This type has been set as the default for both probes and should not change unless the HHU is reconfigured.&lt;br&gt;  o If the probe type does not say “User,” please contact WJE for additional instructions.&lt;br&gt;• Verify that the “Current Probe” name matches the sensor end termination the patch cable is connected to (Fig. C.12).&lt;br&gt;  o If yes, press the “Escape” key in the upper left hand corner of the keypad.&lt;br&gt;  o If no, press the select key, arrow up or down to the correct probe on the next screen (Fig. C.13), and press the select key again. This will return you to the Site &amp; Probe display.&lt;br&gt;• Press the escape key to return to the “Sequencer” display page.&lt;br&gt;• Arrow down to “Run Sequence” and press the select key (Fig. C.14). This begin the data collection process and the “Progress” screen will appear (Fig. C.15). Not&lt;br&gt;• Upon completion of the sequence, the “Sequence Ended” screen will appear (Fig. C.16).&lt;br&gt;Tip: The Preset M3 data collection sequence takes approximately 28 minutes to complete per sensor. The HHU can be left unattended during the entire sequence. As shown in Figure C.15, the stage and total progress are shown on the display during the operation. However, WJE has found that the total progress is not accurate and should be ignored.</td>
<td>Fig. C9. Select Sequencer&lt;br&gt;Fig. C10. Preset M3&lt;br&gt;Fig. C11. Select “Site &amp; Probe”&lt;br&gt;Fig. C12. “User” probe type.&lt;br&gt;Fig. C13. Select correct probe&lt;br&gt;Fig. C14. Select correct probe&lt;br&gt;Fig. C15. Sequence progress screen&lt;br&gt;Fig. C16. Sequence ended screen</td>
</tr>
<tr>
<td>Step</td>
<td>Description</td>
<td>Images</td>
</tr>
<tr>
<td>------</td>
<td>-----------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------</td>
</tr>
<tr>
<td>5</td>
<td><strong>SWITCH TO SECOND SENSOR</strong></td>
<td><img src="image1.png" alt="Fig. C17. Change “Current Probe” before collected data from the second probe" /> <img src="image2.png" alt="Fig. C18. Change “Current Probe” before collected data from the second probe" /></td>
</tr>
<tr>
<td></td>
<td>Upon completion of the sequence, disconnect the patch cable from the sensor end termination where data collection was just performed and connect it to the other sensor end termination. Once connected, repeat Step 4. <strong>Ensure that the “Current Probe” name is changed accordingly (Fig. C.17 and C.18).</strong></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td><strong>CLOSE AND SECURE ENCLOSURE</strong></td>
<td><img src="image1.png" alt="Fig. C17. Change “Current Probe” before collected data from the second probe" /> <img src="image2.png" alt="Fig. C18. Change “Current Probe” before collected data from the second probe" /></td>
</tr>
<tr>
<td></td>
<td>Disconnect the patch cable and close, secure and padlock the enclosure.</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Tip:</strong> The padlock can be tight to latch if all securement screws are tightened first at the perimeter brackets. We recommend looping the padlock through first, tightening the screw/bracket on the top of the enclosure, latching the padlock, and then tightening the remaining screws.</td>
<td></td>
</tr>
</tbody>
</table>

### C.2 Data Processing

WJE has experienced some periodic data reporting issues with the HHU. We have noticed that, on occasion, grout resistivity measurements are not loaded into the CSV data files which can be extracted from the HHU using a USB cord connection between the unit and a laptop or desktop computer using provided Intertek software. The data is available on the unit for manually transcribing. In light of this issue, and for convenience associated with manipulation of the CSV files, WJE has instead been using manual data extraction. This process is described in step-by-step format below.

Additional information on the process to download the complete data files (in CSV format) using the Intertek software and a USB Cord is found in the HHU instruction manual and can be further explained by WJE on request. Intertek software for performing this operation, and a USB cord, are included in the HHU carrying case on a thumb drive. The software must be installed on the computer where data is to be downloaded.

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
<th>Image</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Open the provided Microsoft Excel file containing the corrosion monitoring data which has been collected to date. Data values are to be entered into each of the three (3) sheet tabs at the lower left corner of the screen - LPR Data, Resistivity Data and Temperature Data.</td>
<td><img src="image1.jpg" alt="Image" /></td>
</tr>
</tbody>
</table>
| 2 | **INSERT ROWS.** On each tab, right-click on a cell in the bottom line of the existing data to insert a new row to facilitate data entry, as shown to the right. The number of new rows to be inserted per data collection event is:  
  - Temperature Data = 2 new rows (one per sensor)  
  - LPR Data = 4 new rows (2 working electrodes per sensor)  
  - Resistivity Data = 4 new rows (2 working electrodes per sensor)  

Each new row must be inserted individually on each tab. After the new rows have been added, the “Converted Date” field should say “#VALUE!” and the remaining cells should be blank. | ![Image](image2.jpg) |
| 3 | **ACCESS THE DATA STORAGE AREA ON THE HHU**  
Turn on the HHU and select “Site & Probe” from the Main Menu. Note the “Current Probe” which is listed.  
Arrow down to the bottom of the menu to “Last Readings” (circle). All recently collected data from the “Current Probe,” shown as S4_G4_T3 in the adjacent image, from only the most recent data collection event is accessible by entering this area. Push Select.  
Four options are presented on the next screen: LPR, Voltage & Current, Resistivity and Temperature. Use the up and down Arrow keys and the Select key to access each of these types of data from the most recent data collection event, using the Escape key to get back to the Last Options menu.  
*Note that, although it contains data, the Voltage and Current data area is not used as the Excel data spreadsheet is set to extract the necessary voltage data and information from the LPR data which is entered in the LPR tab.* | ![Image](image3.jpg) |
| 4 | **DATA ENTRY**  
Manually enter the Last Readings data for LPR, Resistivity and Temperature displayed on the HHU into the new rows which were created in Excel data spreadsheet. The data only applies to the “Current Probe” previously noted. | ![Image](image4.jpg) |
### Step 4A: All Data Tabs

**Site** - This is the probe name, or Current Probe. Type in or copy/paste following the appropriate name in the existing format. Note that the probe name is entered once for temperature and twice for LPR and Resistivity data (one row for each of the two Working Electrodes), per sensor.

**Raw Time** - Enter the date, and time if desired, of data collection. Data must be entered in the format shown (day/month/year). Once complete, the Converted Date column will automatically change from #VALUE! to the date of data collection in the desired format (month/day/year).

### Step 4B: Temperature Data Tab

Enter both the Degrees Celsius and Degrees Farenheit temperature data values displayed on the HHU into the appropriate data columns in the spreadsheet (boxed at right).

### Step 4C: Resistivity Data Tab

Enter the Initial mV and Resistivity Ωcm values into the appropriate data columns in the spreadsheet, including entry of the number 1 or 2 for the noted Working Electrode (WE1 or WE2) displayed at the top of the HHU screen. All other data columns are to be copied-pasted to match the existing. The column for temperature, in degrees Celsius, can be filled using the appropriate value which was entered in the Temperature Data tab.

Once data has been transcribed to the spreadsheet, press the select key on the HHU to access a new screen where the other Working Electrode (Working 1 or Working 2) can be selected. Data for the second working electrode is now available and the data entry process can be repeated. Note that Working 1 & 2 is not used.

### Step 4D: LPR Data Tab

Enter the Initial mV, RsΩ, RpΩ, Rate Mm/py and Rate Mil/py data values shown into the appropriate data columns in the spreadsheet, and the number 1 or 2 for the noted Working Electrode (WE1 or WE2) displayed at the top of the HHU screen. All other data columns are to be copied-pasted to match the existing. The column for temperature, in degrees Celsius, can be filled using the appropriate value in the Temperature Data tab.

Switch electrodes following the above LPR procedure and enter data for the second working electrode.

### Step 5: Repeat Data Entry for 2nd Sensor

Use the Escape key to get back to the Main Menu screen. Select “Site & Probe” to open that screen. Arrow down to the “Current Probe” line and press Select. Arrow up or down to the other sensor and press Select. This process will make data from the second sensor available in the Last Readings area. Repeat Step 4 for this sensor.
### Minnesota Department of Transportation

### Inspection, Remedial Grouting and Corrosion Monitoring of Post-Tensioned Tendons

**October 18, 2013**

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
<th>Image</th>
</tr>
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| 6    | **SWITCH TO PIVOTTABLE TAB**  
Once data entry has been completed in each of the three tabs for both sensors, click on the Pivottables tab.  
*The Pivottables tab contains the master tables for all pertinent temperature, voltage, resistivity and LPR data collected from the two Intertek corrosion monitoring sensors installed in Span 4 of MN Bridge No. 02037W since installation.* | ![Image](image1.png) |
| 7    | **ADD THE NEW DATA TO THE MASTER TABLES**  
Click on any cell in one of the data tables. The Pivottable Tools menu will appear at the top of the spreadsheet. Click on the Options tab in the Pivottable Tools menu.  
Within the Options tab, click the Refresh icon (circled). The data table should populate with the new data values which were entered in the LPR data tab.  
Repeat for the other two master data tables on this tab. | ![Image](image2.png) |
| 8    | **CHECK GRAPHS**  
The new and existing temperature, LPR, voltage and resistivity data is graphically displayed as a line chart on the four green shaded tabs (titled Resistivity, Temperature, Corr_Pot, Corr_Rate).  
These graphs will automatically incorporate the new data values which were entered once those values populate the pivottables, as described in Step 7.  
If any apparently erroneous data values are noted in the graphs:  
- Check the Last Readings for the appropriate sensor on the HHU (Step 3)  
- Correct the data value in the data tables tabs (Step 4)  
- Refresh the master data table in the Pivottables tab (Steps 6 and 7)  
- Revisit the respective graphs to verify the error has been corrected. | ![Image](image3.png) |

Please contact WJE if any issues are encountered with the use of the HHU or the Excel spreadsheet, including working with the data tables, pivottables and data graphs.
APPENDIX D - INTERTEK PRODUCT DATA

Mini M3 Probes, Concerto HHU and Concerto Compact
CIS4K4 Concerto Mini Handheld Corrosion Monitoring Tool - User Manual

Intertek CAPCIS Ref. T08B001
Rev 2
January 2012
This document has been prepared for the titled project or named part thereof and should not be relied upon or used for any other project without an independent check being carried out as to its suitability and prior written authority of Intertek CAPCIS being obtained. Intertek CAPCIS accepts no responsibility or liability for the consequences of this document being used for a purpose other than the purposes for which it was commissioned. Any person using or relying on the document for such other purposes agrees, and will by such use or reliance be taken to confirm his agreement to indemnify Intertek CAPCIS for all loss or damage resulting therefrom. Intertek CAPCIS accepts no responsibility or liability for this document to any party other than the person by whom it was commissioned.


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<th>Date</th>
<th>Revision Details</th>
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<td>1</td>
<td>July 2009</td>
<td>First Draft</td>
<td>Andrew James</td>
<td>Tom Gooderham</td>
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<tr>
<td>2</td>
<td>Jan 2012</td>
<td>Logo Change</td>
<td>Andrew James</td>
<td>Tom Gooderham</td>
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Product Disclaimer

Intertek CAPCIS reserves the right to change or modify any of Concerto products and their inherent physical and technical specifications without prior notice. Since the use of this information and the conditions by which the products are used are beyond the control of Intertek CAPCIS, it is the obligation of the owner and/or the equipment operator to determine the correct and safe selection and settings and conditions of use of the equipment and products.

To the extent that the law permits, any liability which may be incurred as a result of the use or future use of a product manufactured or sold by Intertek CAPCIS is limited to the cost of repairing or replacing the failed product or component at the discretion of Intertek CAPCIS, either within, or outside of, warranty periods, and does not extend to any loss or damage which may be caused as a consequence of misuse or failure of the equipment or products. Intertek CAPCIS shall not in any event be liable for economic loss of profits, indirect, special, bodily injuries or consequential damages.

FCC Statement

This equipment has been tested and found to comply with the limits for a Class A digital device, pursuant to Part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference when the equipment is operated in a commercial environment. This equipment generates, uses and can radiate radio frequency energy and, if not installed and used in accordance with the instruction manual, may cause harmful interference to radio communications. Operation of this equipment in a residential area is likely to cause harmful interference in which case the user will be required to correct the interference at his own expense.

WEEE Statement for Product After-Life Disposal

Registration number for UK WEEE Regulations:- WEE/FK0196VQ

The Waste Electrical and Electronic Equipment Regulations (WEEE), EU Directive 2002/96/EC, were adopted into UK law on 2nd January 2007 with full implementation from 1st July 2007. These regulations require that electrical and electronic equipment, when being disposed of at the end of its useful life in an EU Member State, must be recycled and/or disposed of in accordance with the EU directive as it is applied in local laws of that State. These regulations go further by making the manufacturer or importer (the producer) of the goods responsible for their disposal/recycling in the correct manner.

Intertek CAPCIS products manufactured in compliance with UK Statutory Instrument 2006 No. 3289 (the UK law) feature the approved crossed out wheeled bin symbol clearly marked on the products.

Although there are exemptions permitted within the regulations, particularly pertaining to contaminated and unsafe items, many of Intertek CAPCIS products potentially fall within the scope of EU 2002/96/EC.

Therefore all pricing and quotations issued, unless specifically indicating to the contrary, includes no allowance for costs or charges for WEEE disposal. Where customers wish Intertek CAPCIS to retain WEEE disposal responsibility there will be a chargeable
service the cost of which will depend on the size of the item to be disposed of. These costs will not generate a profit for either Intertek CAPCIS or it's compliance partner, and will be reviewed regularly in the light of experience and improved efficiency.

All customers wishing to return product at end-of-life should contact Intertek CAPCIS to arrange return of their WEEE. Intertek CAPCIS has a policy to briefly inspect all WEEE in order to assess any opportunity for it to be repaired and/or refurbished for reuse as complete equipment.

**RoHS Statement**

Intertek CAPCIS products are currently exempt from the Restriction of Hazardous Substances Directive (RoHS) as these fall into Category 9 defined in Annex 1A of directive 2002/95/EC, Monitoring and control instruments (including machines and fixed systems or products for the intended use in fixed industrial applications).

We are, however, monitoring the changes in both technology and legislation with the Intention of working towards the reduction of the hazardous substances defined by the directive in our products.
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1 INTRODUCING THE CIS4K4

The Handheld Corrosion Monitoring Tool allows an engineer to take instant precision corrosion readings in the field or in the laboratory, and analyse the results from the comfort of their desktop computer.

The unit has been engineered by Europe’s leading Materials Consultancy and Specialist Testing company, Intertek CAPCIS, which has over 35 years experience in the field of corrosion monitoring, investigation and consultancy.

Based on the high precision Concerto MK2 technology, the Handheld Corrosion Monitoring Tool is suitable for the condition monitoring of both new and existing reinforced or pre-stressed concrete structures and ideal for use by structural engineers, asset maintenance engineers, and corrosion engineers.

1.1 KEY FEATURES

- Measurements include: LPR, Voltage Potential, Current, Resistivity, Electrochemical Noise and Temperature.
- Comprehensively editable measurement settings.
- 2Gb non-volatile internal flash memory.
- USB connectivity for data recovery.
- Internal rechargeable battery.
- 32 sites each with 32 probes (1024 probes in total).
- Flexible 16 step sequencer.
- Storage for 8 preset or user defined sequences.
- Auto standby.
- Connection to 1 Reference, 1 Auxiliary and 2 Working electrodes.
- Support for PT100 and NTC type BT10K3A temperature sensors.
- Supports Intertek CAPCIS corrosion probes.

- Measurements include: LPR, Voltage Potential, Current, Resistivity,
2 CONNECTIONS

2.1 PROBE CONNECTIONS

<table>
<thead>
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<th>Connection Name</th>
<th>Purpose</th>
<th>Comments</th>
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<td></td>
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<td>6</td>
<td>Reference</td>
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</tr>
</tbody>
</table>

Special Note for Working Electrode 2

For use in reinforced or pre-stresses concrete environments, working electrode 2 is typically connected to the rebar in the concrete which can then treated as a secondary working electrode.

2.2 USB CONNECTION

The USB connector is used to recover data from the CIS4K4 to a PC.

2.3 POWER CONNECTION

The supplied charger is connected here and can be used to charge the CIS4K4 or operate it on mains power.

3 OPERATING THE CIS4K4

The CIS4K4 is operated by the user by navigating menus on the LCD and the keypad is used to move between screens, enter values and start/stop measurements.

3.1 SWITCHING THE UNIT ON/OFF

The red Standby button is used to turn the CIS4K4 on and off, unless a measurement or sequence is running. The CIS4K4 will automatically turn itself off if it is unused after approximately 10 minutes.
3.2 THE KEYPAD

The keypad is mainly used to navigate the on screen menus by using the yellow arrow buttons. The ‘Up’, ‘Down’ and ‘Select’ keys are used to navigate menus and handle measurements.

The alphanumeric keypad is used to enter measurement settings values, site names and probe name. It also doubles up as shortcut keys for editing sequences.

The top left ‘Escape’ key is used to return to the previous screen except when a measurement(s) are in progress where the user should select the ‘Stop’ or ‘Abort’ option on the screen.

3.3 USING THE CIS4K4 ON SITE

The CIS4K4 is designed to be taken onto site by the user and take measurement(s) on each probe in turn at whatever interval (daily, monthly etc) is suitable. Once completed, the user returns to the office to recover the data recorded onto a PC for further analysis.

The CIS4k4 allows the user to select the site where the measurements are being recorded plus the name of the individual probe. These would be selected prior to measurement starting.

For each probe the user can view the last reading performed on that probe.

3.4 USING THE CIS4K4 IN A LABORATORY

When using the CIS4K4 in the laboratory, the procedure is the same as on site but it is suggested the user edits a site name to “Lab” followed by the date or
the user’s name, and the names all the probes to reflect the individual experiment attempted.
As measurements are recovered by USB, the results will automatically be organised by experiment.

4 MEASUREMENT TYPES

The CIS4K4 features six important corrosion measurements which can either be run individually by the user or form part of a sequence.

With exception of Potential, Current and electrochemical noise, after the measurement is completed the results will displayed and logged. Potential, Current and electrochemical noise will run until the user stops the measurement or the battery runs low.

All measurements can be recorded against a user selected site and probe and the electrode combinations for each measurement can be selected.

4.1 MEASUREMENT TYPES

4.1.1 LPR (Linear Polarisation Resistance)
DC step(s) are applied on the electrodes in order to obtain both Solution Resistance and Polarisation Resistance from which a corrosion rate can be derived. The corrosion rate is reported as mm/y and mpy.
An LPR can be started by the user immediately or the user can observe the potential between reference and working electrode(s) prior to starting the step(s) to ensure they are ready.

4.1.2 Resistivity
Applies a 135Hz square wave between auxiliary electrode and either working electrode(s) and measures the AC resistance. From this a resistivity value is derived.

4.1.3 Voltage Potential
The voltage potential of either or both the working electrodes is measured with respect to the reference electrode.

4.1.4 Current
The current between various combinations of the working electrodes and auxiliary electrode can be measured.

4.1.5 Electrochemical Noise & VT
Both potential and current are measured and pitting and instability measurements are derived from the current in real time. This measurement typically runs for long periods in excess of 1 hour.

4.1.6 Temperature
The temperature of either PT100 or Negative Temperature Coefficient (NTC) Thermistors of the type BT10K3A, can be read and reported as degrees Celsius and Fahrenheit.
4.2 **MEASUREMENT SETTINGS**

Each of the measurements featured on the CIS4K4 can be edited by the user to suit the electrode environment.

### 4.2.1 LPR

![LPR settings](image)

**Electrodes**
Specifies the working electrode to be used - either Working 1 or Working 2/Rebar.

**Step Size**
The amplitude in millivolts of the potentiostatic step to be imposed on the electrodes. Its anodic or cathodic direction is decided by the polarity setting.

**Step Length**
The length in second of the each discrete LPR step.

**No of Cycles**
Specifies the number of steps to be imposed on the electrodes. If the polarity is set to ‘anodic & cathodic’ the resulting number of steps will be twice that of this setting.

**Step Spacing**
The length of time in seconds between each step, irrespective of the polarity setting.

**Polarity**
Specifies if the step(s) are either all anodic, all cathodic or alternating anodic/cathodic.

**Correction Mode**
Specifies whether the solution resistance is to be subtracted from the total resistance to produce a ‘corrected’ corrosion rate.

### 4.2.2 Resistivity

![Resistivity settings](image)

**Amplitude**
Specifies the amplitude of the 135Hz square wave to be imposed on the electrodes.

**Length**
Specifies the length in seconds the square wave will be imposed.
4.2.3 Voltage Potential

**Working Electrode**
Specifies the electrode to be measured against the reference.

4.2.4 Current

**ZRA Configuration**
Specifies which 2 electrodes should be connected across the CIS4K4s internal Zero Resistance Ammeter.

4.2.5 Electrochemical Noise & VT

**Electrode Configuration**
Specifies which 2 electrodes should be connected across the CIS4K4s internal Zero Resistance Ammeter on which VT analysis is to be performed.

4.2.6 Temperature

**Sensor Type**
Specifies whether the thermistor being used is either a PT100 or an NTC-BT10K3A.

Intertek CAPCIS manufactured probes mostly feature BT10K3A thermistors.
5 SITES AND PROBES

Each time a measurement is taken it is recorded to the internal flash memory as being data taken from a specific site and probe within this site. When the measurements are recovered from the CIS4K4 to a PC the measurements are automatically sorted according to the site and probe. Each of the 32 sites contains 32 probes allowing the user to store measurements against 1024 probes in total.

Before any measurement or sequence is performed the site and probe should be selected beforehand.

5.1 SELECTING

Select the ‘Site & Probe’ menu option to access the Site and Probe menu. This option appears on multiple other menu screens for convenience.

The site can be selected from the list of 32 possibilities.

The probe can be selected from the list of 32 possibilities.

Use the ‘Escape’ key to return to the previous menu.

5.2 EDITING

The two main editable parameters for each probe are its name and the geometry of the probe itself. The user can also enter the geometry quicker by using presets for commonly supplied Intertek CAPCIS probes.

5.2.1 Editing the Site or Probe Name

1. Select the desired Site and Probe.
2. From the Site & Probe menu select either ‘Edit Site Name’ or ‘Edit Probe Name’.
3. Use the alphanumeric keys and the left and right arrow keys to edit the text.
4. Press the text entry mode button to cycle through upper case, lower case and numerical characters.

Once the user is happy with the new text, press the ‘Select’ key to accept the new text. If the user presses the Escape key, the new text is not accepted.
If a probe type is set to any option other than ‘User’ and the geometry is edited the name may automatically change to reflect this.

5.2.2 Editing the Probe Type

5.2.3 Editing the Geometry

Once a probe type is selected it can be edited if required by selecting the ‘Edit Geometry’ menu option.

If the selected probe was one of the present probes, editing the geometry will automatically change the probe name to ‘User’.

5.3 SITES WITH >32 PROBES

It is not recommended to name multiple sites with the same name unless the user is sure the 32 probe names within each are unique. This may happen if a site has more than 32 probes.

5.4 LABORATORY USAGE

When using the CIS4K4 in a laboratory the concept of Sites and Probes appears irrelevant but users should read the section 0 for suggestions.
6  TAKING A MEASUREMENT

Firstly the user should decide on taking a single measurement or running a sequence of measurements.

Next the user should select the site and probe which this measurement(s) should be recorded against. It is important to do this prior to taking the measurement otherwise the results will not be correctly sorted when recovered via USB.

6.1  SINGLE MEASUREMENT

6.1.1  Starting

1. From the Main Menu select ‘Single Measurement’.
2. Select the top entry ‘Site & Probe’ to specify the site and probe.
3. Select the specific measurement from the list.
4. Edit the settings for the specific measurement (if required) and select the appropriate electrode combination.

Normally select the ‘Start Measurement’ option, but LPR allows the user to monitor the potential beforehand, also.

6.1.2  Running

During the measurement the user is kept informed of any values (depending on the measurement type).

6.1.3  Results

At the end of the measurement the results are reported to the user.

6.1.4  Aborting Measurement

Any measurement can be aborted mid-measurement by selecting the abort option on the screen

6.2  SEQUENCED MEASUREMENT

Also see the Sequencer section of this user guide for details on setting up sequences.
6.2.1 Starting

1. From the Main Menu select ‘Sequencer’.
2. Select the top entry ‘Site & Probe’ to specify the site and probe.
3. Move the cursor down 1 to select the sequence required, which can be edited once selected.
4. Move cursor down to ‘Run Sequence’ to start the sequence.

6.2.2 Running

Once running, the user is kept informed of the progress of the sequence but not the results of the measurements as they are performed. Normally the user wouldn’t wait around for a sequence to complete as it may take up to an hour, depending on the sequence.

6.2.3 Results

On completing a sequence, all measurements are already logged to the internal flash memory and they can be viewed from the ‘Last Readings’ menu option.

6.2.4 Aborting the Sequence

A sequence can be aborted at any time by the user and results of the measurements completed so far will be recorded to flash memory.

6.3 POST MEASUREMENT

Once a single measurement or sequence is complete, the user is free to move the CIS4K4 to another probe, site or take additional measurements at the current location. Alternatively the CIS4K4 could be returned to the PC and recover the data via USB.

All measurements are stored to internal flash memory and will not be lost until either the memory is full or it is recovered via USB. If the memory was to become full, the oldest measurements would be deleted and overwritten.

7 LAST MEASUREMENT RESULTS

All measurements are logged to the internal flash memory and the last measurement of each type can be recalled from the front panel using the ‘Last Readings’ option.
8 SEQUENCER

The CIS4K4 can store 16 sequences in memory at any one time and these can be created by the user, or a preset sequence copied and edited if required. Each sequence contains up to 16 measurement steps.

8.1 SELECTING A SEQUENCE

From the Sequencer menu screen select the ‘Selected sequence:’ option and select from the list of 16.

8.2 EDITING A SEQUENCE

All operations during editing can either be performed using the up/down/select keys or using the submenus on the alphanumeric key pad.

Select the desired sequence and select ‘View Edit’.

Move the cursor to one of the 16 steps within the sequence to be edited.

At this point the user has the choice of editing using the cursor keys or the shortcuts on the alphanumeric keypad which involves slightly fewer key presses.

8.2.1 Using Cursor Keys

1. Choose the desired step and press the ‘Select’ key.
2. Set the required type of measurement (LPR, Temperature etc…)
3. Select the edit option to edit the measurement.

To insert a new measurement before or after that currently selected, press the ‘Select’ key and then select either ‘Insert Before’ or ‘Insert After’.

The type of measurement that is automatically inserted is ‘Nothing’ which can then be changed as above.

To remove a sequence step press the ‘Select’ key and select ‘Remove’. Subsequent steps will then be moved up one.

8.2.2 Using Shortcuts

Choose the desired step and press the ‘Select’ key.

- Press the ‘5’ key to select the type.
• Press ‘8’ to edit the selected step.
• To insert a new measurement before or after that currently selected, press the ‘Select’ key and then select either keys ‘3’ or ‘6’.
• The type of measurement that is automatically inserted is ‘Nothing’ which can then be changed as above.
• To remove a sequence step press ‘9’. Subsequent steps will then be moved up one.

8.3 PRESET SEQUENCES
To set the selected sequence to be reconfigured as a preset sequence, select the ‘Restore to Defaults’ menu option. On reconfiguring to a preset, all 16 steps are overwritten.

Once reconfigured to preset values, the user is free to edit the sequence.

8.4 RUNNING A SEQUENCE
Select the desired sequence as already described, and select the menu option ‘Run Sequence’.

While the sequence is running progress of each step is displayed.

By pressing the ‘Stop/Abort’ the sequence can be ended at that current state.
If a sequence is contains no measurements it will end immediately and report an error.

9 RECOVERING DATA TO PC
All measurements performed on the CIS4K4 are logged to an internal flash memory and can only be recovered via USB to a host PC.

9.1 INSTALLING SOFTWARE
Double click on the installation icon and the required software will be installed. Unless the user requires the software to be installed to a location other than the usual ‘Program Files’ location, simply click next and OK until completed.

9.2 ESTABLISHING A USB CONNECTION
The first time a CIS4K4 is connected to a PC, the PC will need to scan the USB connections to establish a connection.

Ensure the CIS4K4 is connected to the PC via a standard USB cable, and is fully powered up.

MS Windows should normally report a connection to a new device has been detected in the bottom right of the screen with a pop-up message “Found new Hardware” or similar.

Press the ‘Recover data via USB’ button.

Once the software has detected the CIS4K4 it will ask the user if they wish to continue with recovering data.

On the first connection to a PC it may take about 30 seconds to fully detect.

If initially the USB connection isn’t made, the user should try unplugging the cable.

At this point selecting the ‘No’ option will merely confirm the USB connection works.

9.3 RECOVERING DATA

Once a successful connection is established, selecting the ‘Yes’ option will initiate the transfer.

Depending on how much data needs to be recovered this may take some time but the bar graph will give the user an indication of remaining time, and updates every couple of seconds.

Once all data is transferred, a pop-up message box will notify the user.
After all data is transferred, the only copy will be saved on the user's PC. The memory space used in the CIS4K4 is automatically freed up for future data.

During a transfer it is not recommended to detach the CIS4K4 from the PC as this may cause data loss. The user should press the cancel button first to ensure a 'clean' cancellation.

### 9.4 DATA FILE ORGANISATION

As data is recovered to the user's PC, it is automatically sorted into folders stored with filenames corresponding to the site and probe names against which the readings were logged.

These folders will normally be found in the location “c:\capcis cis4k2 Data” or maybe “c:\documents and settings\all users\capcis cis4k2 data” if “c:" is write-protected for that current user.

### 10 SYSTEM SETTINGS

#### 10.1 DATE AND TIME

The time and date are adjustable and are retained after going into stand-by.

To change the date and time, select ‘Change Date & Time’ from the menu and enter the new time and date. Once complete select the ‘Store’ menu option to ensure the new time and date take effect.

#### 10.2 BATTERY STATUS

The most important feature about the battery is how much charge it has remaining and this is indicated by an icon in the top right of the LCD screen. When the external PSU is attached and the battery is charging the icon is animated.
Further information about the battery can be found by selecting the ‘System’ menu option followed by ‘Battery Status’.

10.3 MEMORY STATUS

From the ‘System’ menu option the current state of the Data Memory can be found, and the only action the user may need to take is to clear the data memory by selecting the ‘Clear Memory’ option, but it should be noted that this data will no longer be available to be recovered via USB.

10.4 CALIBRATION

Calibration is performed at the factory and there is no normal requirement for the user to recalibrate.
11 SPECIFICATIONS & RANGES

Max potential (Reference to Working): +/- 1000mV
Max ZRA Current: +/- 1000µA
Max potentiostatic Step: +/- 100mV
Flash Memory: 2Gb
Flash Memory: 33million data points (Approximate)*
Battery Life (Measuring): 14 Hours (Approximate)*
USB Serial Baud Rate: 460.8kbs via FDTI Driver.

*Based on continuous use of Electro Chemical Noise.
CIS4K5 User Guide

For the attention of:
Concerto Users

CAPCIS Ref. -
Rev 1
Aug 2013
### LIST OF REVISIONS

<table>
<thead>
<tr>
<th>Rev No.</th>
<th>Date</th>
<th>Revision Details</th>
<th>Author(s)</th>
<th>Issued by</th>
</tr>
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<tr>
<td>1</td>
<td>Aug 2013</td>
<td>First draft based on units supplied</td>
<td>AJ</td>
<td></td>
</tr>
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1.0 INTRODUCTION

The CIS4k5 is a compact self-contained LPR measuring module, capable of measuring and recording LPR corrosion rate and storing these to its local SD card, or (optionally) send it via SMS text message via GSM modem.

1.1 ASSOCIATED PC SOFTWARE APPLICATIONS

CIS4K5s are typically used with Intertek’s own Windows PC applications.

To collect the measurement data from the unit, and changing settings either Intertek’s 4K Utility PC application is used for the SD card, or if using SMS via modems Intertek’s DCRS PC application is used.
To analyze this data either Intertek’s RCC Graph Viewer can be used for basic graphing, but all data files are copied to the PCs hard drive as comma separated text files, which can be opened by most spreadsheet and many database applications.

(Optional) RCC Graph Viewer used to perform quick data analysis.

2.0 EXTERNAL CONNECTORS

2.1 POWER SUPPLY CONNECTOR

<table>
<thead>
<tr>
<th>PIN Id</th>
<th>Connection</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>+V(12 to 24VDC)</td>
</tr>
<tr>
<td>N</td>
<td>0V</td>
</tr>
<tr>
<td>E</td>
<td>Not Connected</td>
</tr>
</tbody>
</table>

2.2 PROBE CONNECTOR

The Probe connector supplied to connect to the probe port on the CIS4K5 is a Bulgin PX0410/08P/6065. It is an 8 pin plug connector.

<table>
<thead>
<tr>
<th>Pin No</th>
<th>Connection</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Reference</td>
</tr>
<tr>
<td>2</td>
<td>Working 2 (Not Used for standard LPR)</td>
</tr>
<tr>
<td>3</td>
<td>Aux/Counter</td>
</tr>
<tr>
<td>4</td>
<td>Working 1</td>
</tr>
<tr>
<td>5</td>
<td>CS Ext/T- (Not Used for standard LPR)</td>
</tr>
<tr>
<td>6</td>
<td>CS Ext/T+ (Not Used for standard LPR)</td>
</tr>
<tr>
<td>7</td>
<td>0V/screen</td>
</tr>
<tr>
<td>8</td>
<td>Earth</td>
</tr>
</tbody>
</table>

The PIN Contacts for use on the Probe connectors are identified by the RS part number 462-1322 (Bulgin part number SA3348/1).
2.3 COMMS CONNECTOR

The Comms connector supplied to connect to the com port on the CIS4k5 is a Bulgin PX0410/06P/4550. It is a 6 pin plug connector.

<table>
<thead>
<tr>
<th>Bulgin Pin No</th>
<th>Connection</th>
<th>9 way Male Dtype Pin No</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>TX</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>RX</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>0V</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>RTS</td>
<td>7</td>
</tr>
<tr>
<td>5</td>
<td>Not Connected</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>Not Connected</td>
<td>-</td>
</tr>
</tbody>
</table>

The PIN Contacts for use on the Probe connectors are identified by the RS part number 462-1322 (Bulgin part number SA3348/1)

3.0 OPERATION

3.1 CONFIGURING SETTINGS

Normally all but one of the configurations of the units LPR measurements are left at their default setting unless there is reason to change them.

The most likely to be changed is the electrode surface area value which may vary depending on user application, which would improve scaling the corrosion rates for this area.

In remote applications VT and Scada settings are not used, thus don’t need changing anyway.

3.1.1 Changing the Electrode Area

Open up the CIS4k5 unit and remove the SD card and note when inserted into a PC which drive letter it assigns to it (eg “g:").

Start up 4K Utility application, and select the same drive letter, and the system Name textbox in the bottom left should identify the card associated with CIS4K5. Typically this is the serial ID of the unit.
3.1.2 Changing LPR Times Scheduling.

On pressing the “Times” button in the “Change Measurement Times” panel, bring up the hourly schedule, where the measurement activity for each hour is listed.

Normally LPR is measured twice a day, but can be changed but care should be taken doing this as depending on the electrodes and solution chemistry this may produce unexpected results.

3.2 RUNNING

- Ensure the Probe cable is connected to the probe.
• Ensure a DC supply is available.
• Ensure the SD card is present within the unit.
• Ensure the GSM modem is connected in (optional)
• Turn On DC supply.

The three LEDs on the top of the CIS4K5 should light up and flash as below:

<table>
<thead>
<tr>
<th>LED</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green</td>
<td>Power is On and unit running.</td>
</tr>
<tr>
<td>Yellow</td>
<td>Successful internal comms between internal circuit boards.</td>
</tr>
<tr>
<td>Blue</td>
<td>Communicating to external devices (such as optional GSM modem).</td>
</tr>
</tbody>
</table>

Unless an LPR measurement is taking place the unit normally ‘hibernates’ to save battery power, and during this period only Green LED will flash after only a few minutes after power up.

4.0 MEASUREMENT DATA

4.1 RECOVERING DATA VIA SD CARD.

The measurement data logged to the supplied SD card, is stored in the pre-created files which are numbered 0,1,2,3, etc, and these can’t be opened by any other application other than 4K Utility because the data is stored as a proprietary binary file format to maximise space usage.

Open up the CIS4k5 unit and remove the SD card and note when inserted into a PC which drive letter it assigns to it (eg “g:"), as in the previous section.

Start up 4K Utility application, and select the same drive letter, and the system Name textbox in the bottom left should identify the card associated with CIS4K5. Typically this is the serial ID of the unit.

On the next dialog box, the serial ID of the system should be recognisable, and the “Destination Folder” will list the preferred folder location data will be copied to. This can be changed only if needed, and it is not recommended to change this too often as it can result in data split across multiple folder locations making keeping track to the files harder.

Press the “Go…” button in the “Recover Data From Card” and the storage space used should be over 0% and not “Empty” is any data has been stored.

Pressing the “Start” button will initiate the extracting process to this folder and the time taken will depend on how much there is.

4.2 RECOVERING DATA VIA GSM MODEM.
Normally a CIS4k5 in a remote location would send its latest reading via SMS messaging as each of these measurements are taken, but would in parallel store these values on its local SD card, but normally the SMS text’ed values are stored by D.C.R.S on a PC acting as a ‘corrosion data hub’.

Setting up and configuration of this is further covered in guide “T13A009 CIS4K5+GSM Modem with DCRS V1.3 Setup Guide.pdf”.

4.3 ANALYZING CORROSION MEASUREMENT RESULTS.

4.3.1 FOLDER STRUCTURE & FILE NAMING

Assuming the Destination Folder was not changed earlier, data files should now appear in this folder, within a sub folder whose name is the same as the serial ID. All data appears in the further sub folders “Channel1”, and “LPR”. There will be no data in the other folders.

Example of the folder structure for unit with the serial ID “233/11” on PC’s HDD.

For each month there will be an “_LPR_” file and a corresponding “_RAWLPR_” file. Normally the former is of most use as it contains the vital corrosion rate, but the latter contains the more detailed raw voltage and current response of the LPR steps used for expert analysis.

4.3.2 MS EXCEL ANALYSIS

The data files can be analyzed in MS Excel (or equivalent) and if MS Office is already installed, clicking on .CSV files typically will be opened automatically.

Example of the main LPR file (not the raw LPR) in MS Excel
The columns are as follows:

<table>
<thead>
<tr>
<th>Column</th>
<th>Name</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Time Stamp</td>
<td>Date of measurement in DD/MM/YYYY hh:mm:ss format.</td>
</tr>
<tr>
<td>B</td>
<td>Measurement ID</td>
<td>Always ‘L’ in LPR</td>
</tr>
<tr>
<td>C</td>
<td>V mV</td>
<td>Potential measured between Referance and Working Electrodes immediately before LPR step imposed.</td>
</tr>
<tr>
<td>D</td>
<td>Rs</td>
<td>Solution Resistance in Ohms</td>
</tr>
<tr>
<td>E</td>
<td>Rp</td>
<td>Polarization Resistance in Ohms (not Ohm.M)</td>
</tr>
<tr>
<td>F</td>
<td>Cor Rate mm/py</td>
<td>Corrosion rate derived from Rp in mm/py</td>
</tr>
<tr>
<td>G</td>
<td>Cor Rate mil/yr</td>
<td>Corrosion rate derived from Rp in milpy</td>
</tr>
<tr>
<td>H</td>
<td>Temperature</td>
<td>- Not used -</td>
</tr>
<tr>
<td>I</td>
<td>Error Code(^\d)</td>
<td>0 = OK, 1 = Rs too fast to measure, 2 = Rs &gt; Rt, 3 = Rs &gt; Rt, 4 = Unreliable LPR current slope (may just be a low current due to high Rp)</td>
</tr>
<tr>
<td>J</td>
<td>Working Electrode</td>
<td>0 = Default (Working 1), 1 = Working 1, 2 = Working 2, 3 = Working 1 &amp; 2 as joint electrode</td>
</tr>
<tr>
<td>K</td>
<td>Galvanic Current</td>
<td>- Not used -</td>
</tr>
</tbody>
</table>

4.3.3 RCC GRAPH VIEWER

A quick method of checking the data from the unit is to use RCC Single Graph Viewer.

4.3.3.1 Loading LPR Measurements

Start it up from the Start menu and ensure the “Data Folder” matches that used by 4K utility- it should by default anyway.

From the “System ID” select the appropriate serial ID of the unit (more than one may be listed).

Typically only error codes 1 or 4 are usually seen, and the latter either means the probe is not correctly connected or the the solution resistance is so high the resulting LPR current’s response isn’t the classic decaying signal thus may make results less reliable.
Select “Channel 1”.

From the Measurement Type option select LPR, then from “Electrodes” “WE1”.

Select the date period, of interest, and press “Load” button.

The basic graph can be printed, exported as an image file from the File menu, and copied to the clipboard from the Edit menu.

4.3.3.2 Adjusting Graph Ranges

The horizontal zoom level can be changed using the “Zoom” drop down at the bottom and the scroll bar used to slide the ‘window’ that is visible.

The Green and Gold colour boxes at the top can be used to input manual range for the Rs and Corrosion Rate traces respectively, but the “Auto Range” would need to be unselected first.
If the Rs trace is not required by un-checking the overall box it can be made to vanish. The other four traces are not drawn or needed in typical CIS4K5 applications.

Additionally multiple instances of this application can be run in simultaneously to aid analysis.

5.0 USING SMS VIA GSM MODEM

Setting up and configuring multiple CIS4K5’s to send data back to a single PC acting as a ‘data hub’ is covered in the user guide “T13A009 CIS4K5+GSM Modem with DCRS V1.3 Setup Guide.pdf” because this is a more complex procedure than can be covered here.