GROUTING OF BRIDGE POST-TENSIONING TENDONS

TRAINING MANUAL

Broadway Bridge – Daytona Beach, Florida

JULY 2002

GROUTING OF BRIDGE POST-TENSIONING TENDONS

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To be used as a supplement to the Florida Department of Transportation Video: Grouting of Bridge Post-Tensioning Tendons

Produced by the State of Florida Department of Transportation
State Construction Office - Tallahassee, Florida,
In Cooperation with the Federal Highway Administration

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July 2002

TABLE OF CONTENTS

CHAPTER I - INTRODUCTION

A. Foreword

This training manual and corresponding video have been developed by the Florida Department of Transportation (FDOT) to instruct field personnel and inspectors in the correct procedures for the grouting of post-tensioned structures in the State of Florida. This course is in agreement with the Florida Department of Transportation's latest construction specifications covering grouting, which for reference are B460 (future 462), 938 Grout, 926 Epoxy for Pour Backs, 930 Magnesium Ammonium Phosphate Concrete, and 975 Elastomeric Coatings.

B. Grout Basics - 3 P's of Grouting

It is important to establish a basic understanding of what is being grouted, why grouting is important, and who will be allowed to perform grouting in the state of Florida. As an introduction, the three "P's" of grouting will be discussed.

<u>P</u>ost-Tensioning (PT) systems provide reinforcement to the concrete in the form of steel cable and bar tendons. The tendons are stretched by jacking and are secured (or anchored) to produce compressive forces in the member. The post-tensioning system is a primary structural component whose failure could result in total collapse of the member.

<u>P</u>rotection of the PT system is essential. The protection of the post-tensioning system is directly related to the overall durability and life span of the structure. The concrete that forms the structural member, the duct and the grout are all that separates the PT system from exposure to the air and weather. The high strength steel of the PT system is highly susceptible to corrosion and must be protected from exposure to moist and salt laden air. Additionally, the grout provides transfer of the prestressing force to the structural member in a bonded post-tensioning system. The bonding of the grout to the post-tensioning steel accomplishes this in a manner that is similar to the bond developed by rebar in concrete.

The <u>P</u>eople who will perform the grouting operations are the third "P". Florida construction specifications now require that grouting be done by contractors and post-tensioning suppliers who have been trained and qualified in proper grouting techniques. These personnel will be trained in FDOT approved methods of grouting provided by this training manual and corresponding video. Lead inspectors and contractor foremen are required to be qualified by the FDOT Construction Training Qualification Program (CTQP), which has a "Level I" qualification for inspectors, and a "Level II" qualification for foremen. Level I, CTQP qualification requires successful completion of an accredited grouting technician-training course and Level II, requires the training course plus 3 years of grouting experience.

C. Importance of Grouting

FDOT has experienced several tendon failures caused by corrosion in recent years. These failures were due to poor grouting practices, inferior design details, and inadequate grout specifications.

Grout is the primary protection for the PT system; therefore, careful attention must be given to the grouting process. Cementitious grout provides an alkaline environment that passivates the surface of the steel which inhibits the corrosion process. The grout must surround and be bonded with the steel to be effective. Specially blended grout materials, correctly mixed and effectively pumped into the tendon, are key to a successful grouting operation. The durability of the structure is directly effected by the quality of the grouting. It is essential that an adequate grout plan be developed and executed. The grout plan is an outline of the grouting operation from start to finish and will be discussed at length later.

CHAPTER II - PT SYSTEM REVIEW

What follows is a brief review of prestressed systems which will provide an understanding of how the systems differ and why grouting is required for post-tensioning but not for pre-tensioning.

A. Pre-tensioned / Post-tensioned

Pre-tensioning and post-tensioning refer to the sequence in which the concrete is placed with reference to the stressing of the steel strands. In a pre-tensioned system, the steel strands are stretched and anchored at the ends of a casting bed before the concrete is placed. Pre-tensioning does not use any type of duct to surround the steel strands; the concrete is placed directly on and around the stressed steel strands within forms. After the concrete has reached adequate strength, the strands are cut free from their anchors. The concrete's bond to the strand transfers the prestressing force. Pre-tensioning occurs at a precasting plant or yard generally located at a site separate from the final erection / construction site. Examples of pre-tensioned members are concrete piling and standard AASHTO beams. The contact and bonding of the concrete with the prestressed steel protects it from corrosion.

A post-tensioned system is when anchorages and ducts are positioned in the casting bed prior to concrete placement to accommodate the installation and stressing of the post-tensioning steel at a future date after the concrete has cured adequately. Post-tensioning is often used to make several beams continuous or in hammer-head piers, floor-slabs and in segmental box-girder construction. Since the concrete is not directly bonded with the post-tensioned steel, the PT steel is not bonded or protected in the same way as is pre-tensioned steel. Grout provides the bonding and immediate corrosion protection for post-tensioned steel.

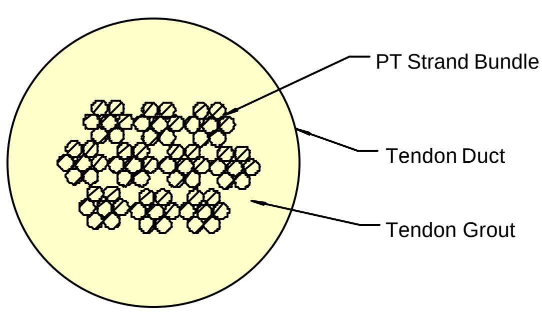

Figure 1, Duct, Grout and PT steel system

B. Tendons

A post-tensioning tendon is a high-strength steel bar or strand bundle combined with anchorages, a duct and grout. The ducts and grout will be addressed separately.

1) Material

The high-strength steel used for prestressing is made of a special steel alloy that is heat-treated in accordance with ASTM A 416 standard until it is sufficiently strong. Normal reinforcing steel has a yield strength of 60,000 pounds per square inch, prestressing bars have a yield strength of 150,000 pounds per square inch and prestressing strand yields at 270,000 pounds per square inch (psi). Due to the metallurgy of the steel and the high level of stress, any loss of stressing steel cross-sectional area in the tendon that results in damage or corrosion, can result in failure. Therefore, special care must be taken to protect the stressing steel during storage and installation.

In post-tensioned systems, the anchorage is the point where the prestressing force is applied. There is an anchor assembly at each end of the tendon duct. These anchor assemblies are proprietary designs unique to each supplier. They typically consist of an anchor head (or wedge plate) and wedges, bearing plate, duct transition (or trumpet) and grout tube connection (see Figure 2).

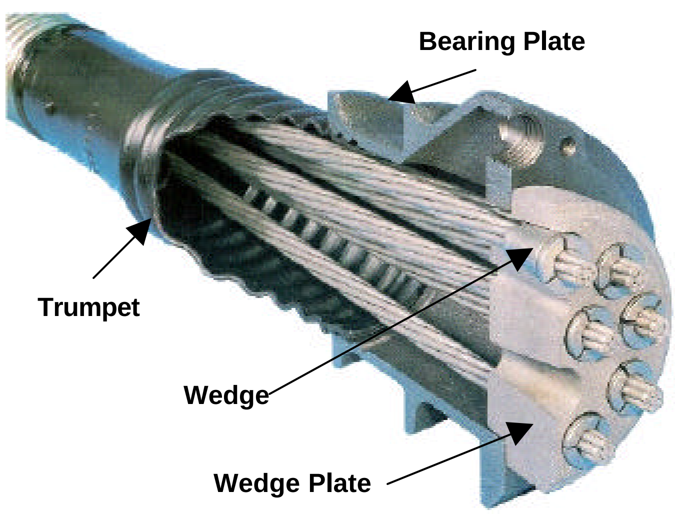

Figure 2, DSI anchor assembly

2) Internal vs. External

An internal tendon, as the name implies, is totally encased from anchorage to anchorage in the structural concrete. These types of tendons are found in hammerhead piers (see figure 3), beams, most slabs and many segmental box-girders. Internal tendons generally have little variation in vertical profile.

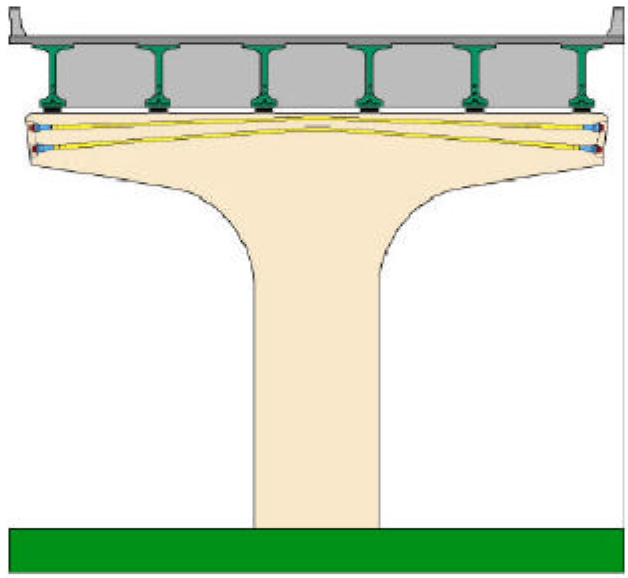

Figure 3, Hammer-Head Pier with internal tendons

External tendons are outside of the structural concrete except at anchorages and deviation blocks. External tendons are generally found in precast segmental box-girders, cable-stays and retrofit repairs. External tendons are in one of two basic configurations. They are either straight between anchorages or they go through deviation blocks to create a "harped" profile. The "harped" profile allows the Design Engineer to put the prestressing force where it is needed to optimize the structural design. The anchorages and deviation blocks are encased within the structural concrete. Because of the large forces that the tendons exert on the anchorages and deviation blocks, they are heavily reinforced. The profile of external tendons can have a dramatic change in height for some applications; the stay-cables of a cable-stayed bridge are the extreme case of a dramatic profile change. In segmental box-girders, the external tendon anchorages are located in the top of diaphragms at the piers and deviation blocks at the bottom of the cross-section hold down tendons at mid-span as shown in figure 4.

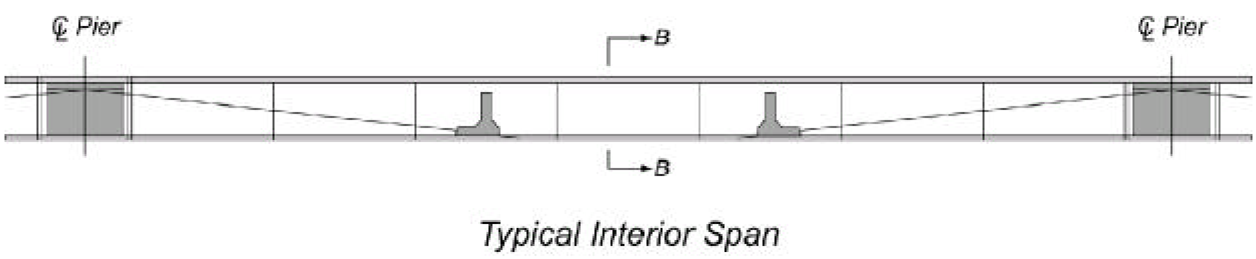

Figure 4, Example of external tendon in a box-girder showing vertical profile

C. Ducts

The duct is the sheath for the PT strand or bar. Because of tendon geometry and profile restrictions, the duct must be accurately fabricated, placed and secured. The duct is not only the conduit for the tendon during installation but also provides a protection layer (see figure 5) and is a grout channel for the tendon.

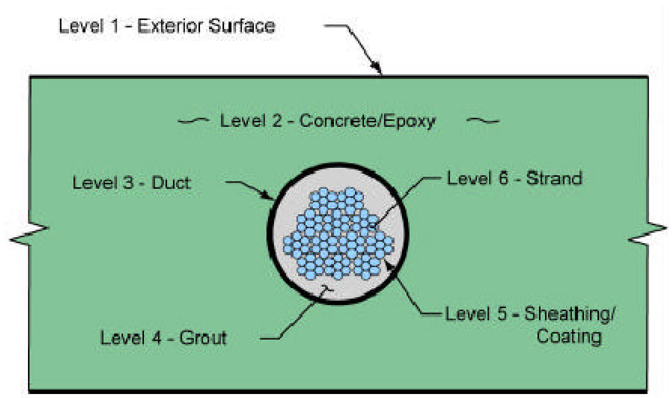

Figure 5, The levels of protection for PT steel

1) Duct Materials

Duct materials are required to be high-density polyethylene (HDPE), polypropylene or schedule 40 galvanized steel pipe, meeting the minimum properties allowed by FDOT construction specification B460.

2) Internal vs. External

Internal ducts are completely encased by the concrete and must be corrugated polypropylene. The corrugated duct provides better force transfer between the grout and surrounding concrete. The duct is placed in the concrete forms prior to concrete placement and must be securely fastened to maintain proper position, alignment and to prevent damage during concrete placement.

External ducts are only partially contained by the structural concrete. The anchorages and deviation blocks are encased within the structural concrete. In the deviation blocks and anchor areas, schedule 40 galvanized steel pipes are used for ducts because of their strength and because they can be accurately bent to the correct shape. HDPE pipe is used for external portions between the anchorages and any deviation blocks.

One difficulty with external tendons is keeping the tendon steel centered within the duct during grouting. The duct often sags and without careful effort will rest directly on the tendon, which prevents grout from covering the top of the tendon. This reduces the level of protection and f bleed-water is present, the probability of tendon corrosion and failure will increase.

D. Grout Pipes

The grout inlet pipes and outlet pipes are attached to the ducts. This is where the grout is pumped into the tendon and where air and excess water are expelled as the duct fills with grout. These pipes are attached to the ducts prior to placing concrete for internal tendons. They are attached to the external ducts during their assembly at the construction site.

1) Inlets and Outlets

The inlet is where the grout is pumped into the tendon. The outlet is where air, excess water and grout are discharged from the tendon. Depending on the length and profile of the tendon, the number of inlets and outlets will vary. For short and straight tendons, 1 inlet and outlet is adequate.

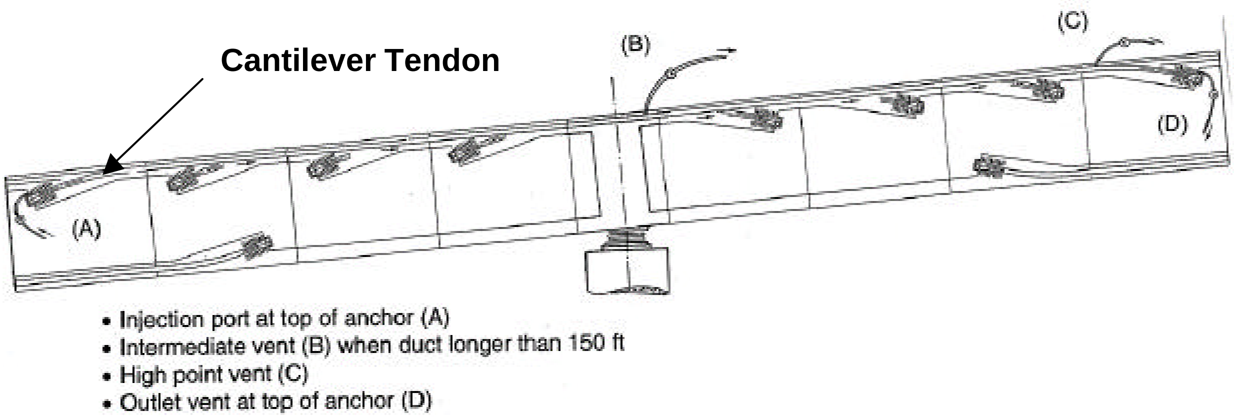

Figure 6, Layout of pipes for grouting of cantilever tendons

For complex tendon geometry, the inlets and outlets must be addressed on a case-by-case basis.

2) Locations

The position of the inlets and outlets depends on the direction in which the grout flows, the inclination (vertical rise and fall) of the ducts, and the allowable grout pressure.

The details for their location may be addressed in the plans; but regardless, the inlets and outlets shall be placed as follows:

a) At all anchorages – Figure 7, locations A and G

b) At the high points of the duct, when the vertical distance between the highest and lowest point is more than 20 inches – location D

c) An inlet shall be placed at or near the lowest point of the tendon – locations B and F

d) At major changes in the cross-section of the duct, such as couplers and anchorages – location labeled "Sealed duct connector"

e.) At other locations recommended by the Design Engineer or the FDOT Construction Engineer such as Figure 7, locations C and E

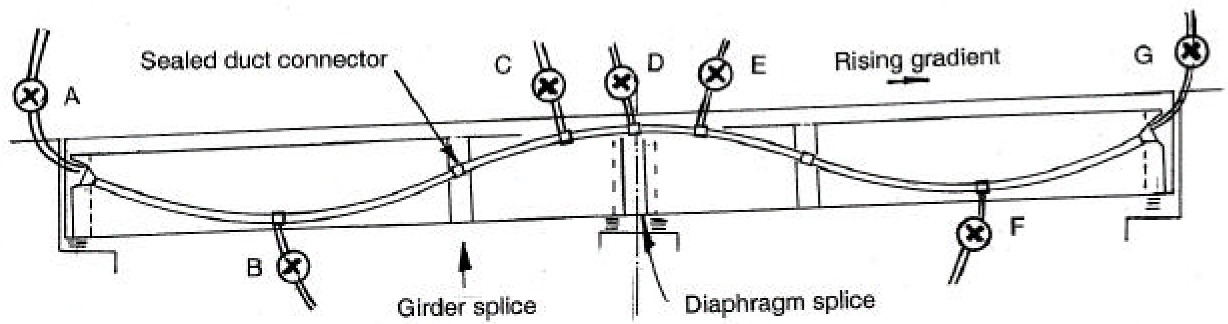

Figure 7, Grouting Details for a 2 span-spliced girder system

3) Valves and Plugs

The grout pipes are conduits used to get the grout into the tendon and the air, water etc., out. Mechanical valves and plugs are used to seal the grout pipes. They also keep debris from getting into the ducts, inlets or outlets prior to grouting. During grout pumping, the outlets are closed sequentially until the duct is filled with grout and the tendon is pressurized.

CHAPTER III - GROUTING FUNDAMENTALS

A. Materials

The basic grout materials are Portland cement, potable water and admixtures. FDOT construction specification 938 sets minimum performance standards for pre-approval of pre-bagged grout materials. These pre-bagged grout mixes have Portland cement with mineral and chemical admixtures in proprietary formulas. To ensure consistent grout properties, the grout shall be used as soon as possible and must be used within 6 months of its date of manufacture. Onsite grout storage is limited to a maximum of 1 month.

B. Problems

The problems that have been experienced with grouting are bleed water, voids and recharge of voids.

1) Bleed Water

Bleed water is the water that comes to the surface of concrete and grouts while they are still plastic. It is the result of the component materials settling, allowing water to separate and rise to the surface. The occurrence of bleed water is a function of the water cement ratio of the mix and improper or incomplete mixing. The higher the water cement ratio the more likely it is that bleed water will accumulate. In a typical concrete placement, the bleed water can evaporate or be removed from the surface. Since PT systems are closed, the bleed water cannot escape. The bleed water will try to flow to the highest point available and create a void. In vertical tendons, the bleed water can also create intermittent pockets or lenses where it is trapped and cannot continue upwards.

2) Voids

During the grout curing process, bleed water will usually be reabsorbed into the grout, leaving air voids in the areas where the water had accumulated. These voids are of concern because they are generally inter-connected. Being inter-connected, they may provide a channel to allow contaminants to be transported inside the duct. Air voids may be formed in the grout in several other ways. The duct may be improperly vented allowing a pocket of air to be trapped without an available exit. The grout pump can pump air into the system if the grout is allowed to get low in the hopper. Pumping grout too fast through the duct may cause turbulent flow entrapping air bubbles in the grout.

Voids that cannot be recharged may not become a problem but they can leave an area of the tendon without grout protection, which increases the risk of tendon corrosion.

3) Recharge

Recharge is the phenomenon that occurs when moisture and/or contaminants are carried into the PT duct system after it is grouted. Recharge can only take place if there is an opening (i.e. voids) in the duct system. Conversely, if the duct system is completely sealed then recharge cannot take place.

C. Placing Methods

The most efficient ways of placing grouts are positive pressure pumping and vacuum injection grouting.

1) Pumping

The standard method for placing grout in a tendon duct is by pumping. The pumps used for grouting are typically screw or auger type pumps. The mixed grout is discharged into a hopper, which feeds the pump directly. The pump is connected to the duct inlet pipe with a hose and valve. The air and water are pushed out of the duct as the grout displaces it. The pumping pressure at the inlet shall not exceed 145 psi. However, for normal grouting operations, the inlet pressure should be 10 to 50 psi.

Figure 8, ChemGrout 600 Colloidal grout mixer and pump

2) Vacuum Injection

Vacuum injection is the specified technique for filling voids after initial grouting. It can also be used for the initial grouting but the sealing of an entire tendon is more problematic than sealing a small void. The vacuum injection method requires the duct system to be sealed. The air is drawn out of the void by a vacuum pump. A calibrated meter then measures the volume of air drawn back into the void as the vacuum is released. The final step is to re-establish the vacuum and inject the measured volume of grout into the evacuated void.

Figure 9, Vacuum volumetric meter

D. Inspection

Grouting is an installation-sensitive operation, requiring skill and care on the part of all concerned. Inspectors are a helpful tool to owners as well as contractors since they provide another quality assurance check and a different set of eyes for reviewing grouting procedures. Inspectors monitor the overall operation of the grouting to assure compliance with the plans and specifications.

CHAPTER IV - PRE-GROUTING

A. Grouting Operation Plan

The FDOT, B460 construction specification, requires that the Contractor submit a Grouting Operation Plan 6 weeks prior to the beginning of any scheduled grouting operations. The grout plan must include the information that follows.

1) Personnel – Training

The new specification requires that the contractor personnel in charge of grouting operations – such as the foreman of the grouting crew – be qualified by the FDOT. The qualification requirement also applies to the lead construction inspector responsible for inspection of the grouting operation. To become qualified, a foreman must have three years of grouting experience and attend a grouting training course accredited by the FDOT and pass the course examination. Proof of qualification must be submitted with the grouting plan. All other construction workers and construction inspectors involved with grouting will be required to view a one hour grouting training video for which this manual is a reference. The FDOT will provide the grouting training at a location and time convenient to the Contractor seven days prior to the beginning of stressing and grouting operations on the project.

2) Materials- W/C Ratio

A grout material from the FDOT Qualified Products List (QPL), which is a list of materials tested and approved by the Florida Department of Transportation for use on State Projects, must be used. In addition, the manufacturer's recommendations found on the bag and on technical data sheets must be included with the grout plan.

3) Equipment

The equipment to be used for the grouting, including but not limited to the grout mixer, pump, power source, length and types of hoses, location of pressure gauge and water meter, re-circulation system and backup equipment, shall all be detailed in this plan.

4) Procedures

Written general grouting procedures shall be provided, describing the entire grouting operation from start to finish. This narrative shall describe the grout operation including tendon preparation, grout mixing, direction of flow, patching of grout outlets or inlets, pour back forming materials, and waterproofing coatings. The grouting procedure shall indicate each crew station or location and define the tasks and procedures for them to follow. This written procedure shall indicate the communication methods that will be used between crewmembers that are not in close proximity of each other as well as the number of workers at each location of the grouting operation.

The methods and equipment used to pressure test the tendon/duct system prior to grouting shall be addressed in the Plan. All post-tensioning ducts shall be tested for leaks prior to grouting. This will require pressure testing with air to assure the continuity and pressure tightness of the duct system. The pressure test prior to grouting can identify any leaks or crossovers in the system, allowing repair or modification to the grouting procedure to improve grouting results. A crossover is when the grout physically crosses over to an adjacent post-tensioning duct that is not intended to be grouted at that time. All inlets and outlets shall be located and identified in the shop drawings.

5) Grout Volumes – Flow Rates

Theoretical grout volumes shall be submitted in the Grout Operation Plan and will be used to check the flow rate of the grout in each of the tendons. If the grout is pumped too quickly, air and water can be trapped due to turbulent flow in the ducts and cause voids in the grout. If pumped too slowly, blockages and other problems may occur.

B. Pre-Grouting Meeting

Prior to the beginning of grouting operations on a project, a pre-grouting meeting shall be held. The purpose of the pre-grouting meeting is to familiarize the grout crew and inspection staff with the planned procedures of the grouting operation and the applicable specifications.

1) Procedure Review

A review of the grouting plan and the operation of the equipment will be discussed. It is important that everyone on the grouting crew understand the importance of getting the tendons completely filled with high quality grout. The equipment will be checked to make sure it is in good working condition.

2) Corrective Procedures – Worst Case Plan

The crew will be advised of the corrective procedures to be taken if problems occur. The safety of all personnel associated with the grouting operation shall be addressed. This meeting will be specific to each job and must provide meaningful instruction and information to the laborers and inspectors. The CEI and Contractor shall discuss "what if" scenarios that focus on effective actions to be taken if something unplanned happens.

3) Inspection Requirements and Records

The Contractor and inspector must maintain accurate records of the grouting operations. Information to be noted in the records shall include, but not be limited to, the following:

a) Date grouted
b) Time started and finished
c) Temperatures of air and grout
d) Number of days from stressing to grouting
e) Type of grout mix
f) Tendon designation
g) Pumping end and applied pressure
h) Summary of any problems encountered and corrective action taken

These records can be referenced to facilitate future maintenance of the structure and to help determine any causes of voids or defects in the grout.

4) Minutes or Discussion Summary

The CEI staff shall produce a written record of the items covered in the meeting and emphasize any noteworthy issues brought up during the meeting. Copies shall be distributed to the Contractor and CEI staff.

CHAPTER V - GROUTING OPERATIONS

A. Leak Testing

After the pre-stressing steel is installed and stressed, the duct system shall be checked for possible leaks. This testing is to be done with oil-free air to assure the continuity and pressure tightness of the duct system. All leaks shall be repaired in an approved fashion before pumping of grout. If water is present in the duct system, oil-free air shall be used to clear it from the duct.

B. Mixing

The grout must be mixed and pumped in accordance with the grout manufacturer's recommendations. The batch water shall be metered to accurately measure the water added and water shall never be added in excess of the manufacturer's recommendations. The over or under mixing of grout can compromise the consistency and density of the grout as can adding too much or too little water. The grout shall be mixed to produce a homogeneous grout without excessive temperature increase or loss of properties. The grout shall be continuously agitated until pumped. Water shall never be added to increase flowability of the grout. The grout shall be used within 30 minutes of the first addition of water.

C. Fluidity, Temperature and Bleed Testing

Fluidity is a key indicator of grout quality and workability. Fluidity is measured by the efflux time based on ASTM C939 standard and modified tests. The efflux test essentially measures the length of time required to empty a given volume of grout through the orifice of a standard flow cone. Grouts with a low w/c ratio will typically have higher efflux times than those with a higher w/c ratio for a given grout product under standard conditions. Acceptable efflux times are listed in FDOT construction specification 938.

Figure 10, Efflux testing

Efflux testing performed consistently and accurately is an important part of the quality control of the grout batching, mixing and placing process.

The temperature of the grout is critical and grouting must not proceed if the ambient temperature is too low or if the grout temperature is too high. The temperature of the grout must be checked where the grout hose connects to the inlet pipe and if high temperature becomes a problem then provisions must be made to lower the temperature. Some ways that this can be achieved include the use of chilled mix water, cooling of the bagged material prior to mixing, and shading of the grout materials, mixer, pump and hoses.

Bleed testing indicates whether the grout is performing its anti-bleed function as it is designed. In the bleed test, a sample of grout is put into a tall transparent cylinder, the initial fill height is recorded and any changes in height of the grout and any water on top of the grout are recorded for several hours. The test is based on ASTM C940, with a single length of 7-wire strand added vertically to the center of the cylinder, to simulate the wicking action of the strand in an actual tendon.

D. Pumping

Tendon grouting must continue without interruption so that grout flows continuously from the inlet to the outlets. Grout flow in the tendon shall be in one direction starting from the lowest

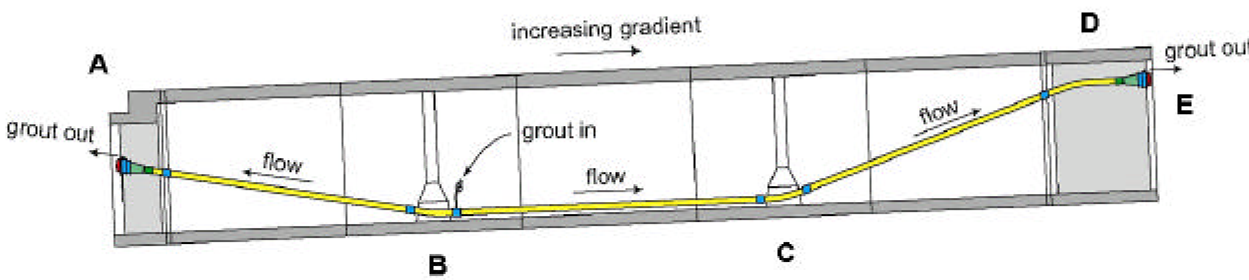

Figure 11, Inject grout at the lowest point of the tendon

inlet and progressing along the tendon. This requires the sequences for the use of inlets and outlets to be well defined. Contingency plans shall be developed to address blocked tendons and crossovers. With corrective actions worked out in advance and approved in the plan, a repair or modified grout procedure can proceed without delay.

1) Flow Rates

The optimum speed or rate of grouting will depend on ambient air temperature, grout temperature, type of grout, size of duct, amount of prestressing steel in the duct, duct surface profile (smooth vs. corrugated), and equipment size.

2) Profile

While the grout moves as a solid column in uphill slopes of the duct, it can exceed the pumping rate in downhill portions of the duct. Hence, it will fill the descending portion of the duct from the next low point moving backward uphill again. This will likely entrap air at or near the high point, which needs to be expelled via the outlet located at the high point.

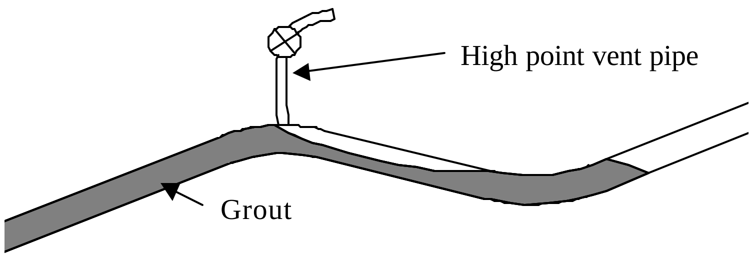

Figure 12, Vent at high point to expel trapped air

3) Pressure

The grout pressure needed to adequately pump the grout depends on the diameter and length of the grout hose, the “head” or vertical rise of the duct and the length of the tendon being grouted. Experience and field judgment are needed to balance the need for adequate pressure to pump the grout at an acceptable rate, and at the same time, to limit the pressure so as not to segregate the grout, rupture the duct, burst the grout hose or inlet, or split concrete sections.

The pumping pressure shall not exceed 145 psi at the grout inlet. However, for normal grouting operations the pressure shall run approximately 10 to 50 psi. If the actual grouting pressure exceeds the maximum allowed, the inlet shall be closed and the grout pumped into the next outlet, which already has good grout flowing and has been or is ready to be closed as long as one-way flow is maintained. Grout shall not be pumped into the next outlet unless acceptable grout is already flowing from it.

Figure 13, Discharging good grout from vent pipe

4) Venting and Bleeding

All grout outlets shall be open when grouting starts. Grout shall be pumped from the lowest point in the duct in an uphill direction. It is a good practice to discharge approximately 1 gallon at each intermediate outlet and 2 gallons at the last outlet pipe. This will generally allow most of the trapped air and bleed water to clear the system. If necessary, additional grout shall be discharged until an efflux time consistent with the grout at the inlet is obtained. Specific requirements for closing and bleeding of the outlets, testing of discharged grout and pressurizing the tendon are addressed in detail in FDOT construction specification B460. The outlet valves shall not be closed until the grout flowing from them is of similar consistency to the grout being injected.

Bleeding of the outlets, sometimes referred to as Burping, is essentially the closing of the outlets while maintaining low pressure (in the range of 5 psi) for at least 10 minutes to allow air and bleed water to collect. Burping is done by increasing the pressure, opening the first high point outlet and allowing the air and water that have accumulated during the low pressure period to be discharged or burped, and then resealing the outlet. This process is repeated, one outlet at a time, for all remaining high point outlets until all have been burped and resealed. The details of this procedure are covered in FDOT construction specification B460.

E. Outlet Testing

When checking outlets after pumping, venting and bleeding, it is very important to ensure enough time passes for the pressure to force grout between the strand wires and allow the bleed water to accumulate, but before the grout has set. A minimum wait of 10 minutes is specified in the FDOT construction specification B460; otherwise, the grout manufacturer's guidelines shall be followed.

The efflux time, or mud balance results, of the grout discharged from the outlet must be tested and meet the requirements of FDOT construction specification 938 before tendon grouting can be accepted.

CHAPTER VI - INSPECTION

The inspection of PT ducts, grout inlet and outlet pipes, and the entire grout related system shall be a continuous and seamless operation. Inspection may take place in multiple locations, namely at a precasting yard and at the final project site. In the precast yard, the inspector will monitor the placement and location of grout related hardware (i.e. inlets, outlets, ducts, etc.) prior to casting of the concrete and will verify these after the concrete is cast. At the project site, the inspector will observe and verify the alignment of the PT ducts at the segment joints, proper sealing of the ducts and proper grouting of the tendons.

A. Pre and Post Casting

Inspection prior to casting is to provide assurance that the product being produced is in compliance with the project plans and specifications. The inspectors must verify that the approved materials are used and that they are properly positioned and supported prior to placing concrete. If not properly secured, the post-tensioning duct system will deviate from planned location during the concrete placement. With this in mind, the following duct support spacing shall be used:

(a) Steel pipes: less then or equal to 2 ft 6 inches

(b) Round plastic duct (no strands installed): less then or equal to 2 ft.

(c) Flat plastic duct (Strand installed): less then or equal to 2 ft.

(d) Flat plastic duct (no strands installed): less then or equal to 1 ft.

Ducts should be bent to the correct radius taking care to prevent kinking or damaging them. Any kinks or incorrectly placed tendon ducts can result in the intrusion of grout during concrete placement and/or damage to the prestressing steel. Any repair of the ducts must be done with mechanical couplers or shrink-wrap methods.

Upon completion of concrete placement, the grout related hardware must be checked for alignment to verify that there are no blockages and that the ducts and inlet/outlet pipes are properly sealed. It must also be demonstrated that the post-tensioning ducts are free and clear of any obstructions or damage and are able to accept the intended post-tensioning tendons. This is done by passing a torpedo having the same cross-sectional shape as the duct, ¼" smaller all around than the clear nominal inside dimensions of the duct. Proving the ducts by use of a manually inserted torpedo is primarily intended for precast segmental elements such as box girder segments, pier segments, and longitudinal girders (AASHTO, Bulb-T, etc.). For cast-in-place construction, an alternate method acceptable to the Engineer may be proposed.

To avoid any contamination, water, or construction debris from getting into the post-tensioning duct system after the concrete is placed, the ducts shall have plugs installed and maintained at all times except during post-tensioning installation and stressing. If the ducts and inlet/outlet pipes are not properly sealed, contaminants or water might get into the ducts prior to grouting. Ducts should be plugged prior to and during transport, and maintained after the erection of precast segmental units. After a tendon is installed and stressed, the elongations must be approved and the strand tails must be cut off at the live and dead ends within 4 hours.

B. Sampling and Testing

1) Efflux

For quality control on site, the flowability of the grout shall be checked in accordance with ASTM C939. The efflux time of the grout sample immediately after mixing shall be between 20 and 30 seconds for the standard ASTM C939 or from 9 to 20 seconds for the modified ASTM C939 test. Grouting shall not proceed until this test has been passed. The ASTM C939 tests were conceived to ensure the proper consistency of grout. Tests on grout mixes utilized by the FDOT have demonstrated that flowability and hence pumpability, can be maintained with an efflux time within the ranges noted above.

2) Bleed

The wick induced bleed test is also used for on-site quality control. The wick induced bleed test is a modification of ASTM C940, described in FDOT construction specification 938. The maximum allowable bleed is 0.0%. This test should be done on a daily basis in conjunction with the initial efflux testing.

Figure 14, Wick induced bleed tests

3) Density

Another viable measure to be used in concert with the efflux test is the mud scale or mud balance. This measures the variations of density in the grout. Again, a homogenous and consistent mix is what we are trying to achieve. The mud balance will indicate the specific gravity of the grout mixture. Variations in the grout density may indicate a change in the grout constituents, w/c ratio or air content. Significant density changes should be investigated to determine what has changed before using the batch of grout tested.

Figure 15, Mud-balance density test equipment

4) Temperature

The temperature of the grout is critical and grouting must not proceed if the ambient temperature is below 40 degrees F (4 degrees C) or if the grout temperature is above 90 degrees F (32 degrees C). On an hourly cycle, the temperature of the grout must be checked where the grout hose connects to the inlet pipe and if high temperature becomes a problem then provisions must be made to lower the temperature.

C. Pre-Grouting

Prior to each grouting operation, the inspector shall verify each of the tendons to be grouted. The inspector shall use a checklist as a guide to ensure that no items are overlooked prior to grout being mixed. Items on the checklist shall include the grout date of manufacture; date and result of tendon pressure tests; water supply availability; primary, backup and testing equipment onsite; location of all inlets and outlets; verification of all valves and other hardware; and other items as may be determined by the Engineer.

D. Grouting

During the grouting operations, the inspection staff shall monitor the batching, testing, pumping, discharge of grout, outlet closing sequence, tendon pressurization and documentation of all of the above as outlined in FDOT construction specification B460. The objective of the inspector is to ensure that the tendon is completely filled with grout in compliance with the plans and specifications.

E. Post-Grouting

Valves, caps and pipes at the inlet and outlet shall not be removed or opened after "burping" until the grout has set. The filled ducts shall not be subjected to shock vibration within 24 hours of grouting.

Figure 16, Borescope photo showing ungrouted stands

1) Void Detection

When the grout has set, the grout outlets shall be reopened and inspected in accordance with FDOT construction specification B460.

2) Void Repair

The vacuum grouting method is required for the filling of any preexisting void. However, a void that is created by drilling out an inlet or outlet pipe in order to inspect for voids may be filled by pouring epoxy grout directly into the drilled void provided that a preexisting void is not found. One of the most important parameters influencing successful vacuum re-grouting of ducts is the volume and disposition of the void to be filled. There are several methods by which the volume can be measured and each of these involves air pressure. These methods require a hole to be drilled to intersect the duct or the opening of an outlet or inlet. A pressure-tight connection to the drilled hole

Figure 17, Vacuum grouting for Mid Bay Bridge repair

is then required. The duct is vacuumed to the lowest vacuum pressure that can be achieved and the volume is measured. If a vacuum cannot be achieved due to a leak then the leak must be sealed before proceeding. The volume is determined to ensure that the proper amount of grout is placed in the duct. This method has successfully been used on several Florida projects.

CHAPTER VII - POST-GROUTING

This involves final sealing operations after grouting has been completed, inspected and any repairs have been satisfactorily performed. Dense pour backs are installed using materials in compliance with FDOT construction specification 926 for sealing the tendon anchorages. The pour backs are coated with an elastomeric material specified in FDOT construction specification 975. Any repairs or patching that may be required to seal the tendons and grout pipes shall be done in accordance with good practice and per the plans and specifications. Grout pipes must be closed with a permanent cap and then covered with epoxy patching material. External tendons may require shrink wrapping if cracks exist in the ducts.

Figure 18, Anchorhead pourbacks for external tendons that exit the opposite side of the diaphragm

CHAPTER VIII - SUMMARY

The three P's of grouting to be considered are Post-tensioning systems, Protection of the PT system and People doing the grouting. The proper and complete grouting of post-tensioned tendons is vital to the long-term durability and serviceability of post-tensioned structures. The alkaline properties of grouts develop a passive layer on the PT steel that inhibits the development of corrosion.

Pre-tensioning and post-tensioning are both methods used to prestress structural members to increase their strength and capacity. The difference between the two systems relates to when the steel is stressed in relation to the placing of the concrete. Pre-tensioning steel does not require grouting while post-tensioning steel does. The post-tensioned systems have multiple components including ducts, grout and anchorages.

The basic grout materials are Portland cement, potable water and admixtures. FDOT construction specification 938, sets minimum performance standards for pre-approval of pre-bagged grout materials. These pre-bagged grout mixes have Portland cement with mineral and chemical admixtures in proprietary formulas.

The problems that have been experienced with grouting relate to bleed water and voids due to entrapped air and/or bleed water. The occurrence of bleed water is related to w/c ratio, grouting pressure and the performance characteristics of the specific grout used. Good materials and practice can limit these problems.

The submission and approval of a grout installation plan and conducting a pre-grouting meeting are both now required by the FDOT construction specification B460. The Grout Operation Plan requires a narrative of the overall grout operation and will cover the personnel, training, materials, equipment and procedures to be used for the grouting operations. A pre-grouting meeting is to be conducted to provide meaningful instruction for the grouting crew and inspection staff and to familiarize them with the specifics of the grout installation plan.

The grouting operation involves leak testing of the tendons, mixing, testing and pumping of the grout. Leak testing proves whether the tendon outlets are open and reveals leaks and crossovers so they may be repaired prior to grouting. A contingency plan should be established prior to the start of grouting that covers effective methods for dealing with problems that may arise while the grouting operation is underway. The mixing of the grout shall be in accordance with the manufacturer's recommendation and the water content shall not exceed the specified maximum. Grout shall be tested in accordance with FDOT construction specification 938.

The inspection of grouting should be a continuous and seamless operation. Inspection may take place in multiple locations, namely the precast yard and the final project site. In the precast yard the inspector will monitor the placement and location of hardware prior to casting concrete and verify their location afterwards. At the project site, the inspector will observe and verify segmental joint alignments, sealing of the ducts and the actual grouting of tendons.

Post-grouting operations include the inspection and verification of complete grouting, void detection and filling, and final sealing of the tendon systems.

The objective of grouting is to completely fill the post-tensioning duct with high quality non-shrink, non-bleed grout in order to protect the prestressing steel from damage or failure due to corrosion, thereby providing a serviceable structure throughout its design life.