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Precast Segmental Bridge Construction Part 3 - Stressing and Grouting

by

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Introduction



The popularity of precast concrete segmental bridge construction has grown worldwide in the last few decades. A broader understanding of these structures and basic outline of the processes for Precast Manufacturing, Substructure Erection, Superstructure Erection – Span by Span Method, and Superstructure Erection – Balanced Cantilever Method are detailed in the SunCam course; ***Precast Segmental Bridge Construction – An Introduction***. This course gives a more specific look at the post tension Stressing and Grouting Operations. Some of the material from the referenced Introduction course



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is repeated within this course as background information to allow this document to be read as an individual subject. However, as the subsequent courses are added (Precast

Substructures, Balanced Cantilever Erection, Span by Span Erection, Segment Casting and Storage, etc.), each one should be complementary to provide the full scope of this type of construction. The course will be broken down into basic sections: Brief introduction narrative, Common Terms and Definitions, Stressing operations outline, Grouting operations outline, Summary. Due to the step by step nature of stressing and grouting operations, the outline format was better suited than a narrative. It is a little more difficult for reading but provides a good checklist for reference.

Precast Concrete Segmental Bridges offer many benefits to owners like reduced costs, reduced construction time, reduced environmental impacts, and reduced maintenance of traffic. These benefits can be achieved while utilizing local labor and materials, better means of quality control, and with minimum requirements for future maintenance. They also offer additional structural advantages of durability, fire resistance, deflection control, better rider serviceability, insensitivity to fatigue, and other redundancies. These bridges can accommodate highways, railways, and rapid transit, in both urban and rural environments. They can be straight or curved alignments, and can provide long spans for difficult obstructions and terrain. The Post Tension Stressing and Grouting of the individual segmental units provides the compressive loads which causes these individual bridge segments to act as a single continuous unit. Additionally the layout (draping) of the tendons provides an up lift force needed for longer structural spans. These two components, combination of individual segments and post-tensioning, are the defining characteristics of this construction that allows for the versatility and benefits listed above.



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Stressing and Grouting Introduction



After the setting and joining of the segments of a span is complete, the post-tensioning operations will begin. Install permanent internal and external post-tensioning strand and rod longitudinally through the span. The number of strands per duct and the number of ducts per span will vary and a stressing sequence will be provided in order to transfer a uniform load. The strand is stressed using high strength hydraulic jacks. When the



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jacks reach the required pressure (compressive loads will be calculated in terms of hydraulic pressure in the jacks) the strands will be anchored in places with wedges to retain the loaded energy. The stresses applied to the strand will stretch the steel. Elongations will be measured to ensure the stresses occurred over the entire length of the strand (a shortened elongation will mean the strand is pinched somewhere along its length and repairs may be necessary). The ducts are then pressure grouted to both protect the strand from corrosion and to permanently contain the stresses from the jacks. Concrete is then poured around the anchor blocks for further corrosion protection.



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Common Terms and Definitions

General Terms:

Post Tensioning – Applying stressing forces to hardened concrete

Post Tensioning System – Materials and equipment needed to apply stressing requirements to the hardened concrete of the structure. May include: post tensioning steel (bars or tendons), anchor assemblies, duct systems, gout, jacks and gauges, and pumps.

Cantilever Tendons – Longitudinal post tensioning in top slabs of balanced cantilever segments



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Continuity Tendons – Longitudinal post tensioning in the bottom slabs of balanced cantilever segments

External Tendons – Longitudinal post tensioning outside of flanges or webs, usually runs through segment box interior

Internal Tendons – Post tensioning found in the flanges or webs of segments

Temporary Post Tensioning – Process used during segment erection

Transverse Tendons – Post tensioning in the top slab concrete perpendicular to the longitudinal tendons and bridge centerline.

Permanent Post Tensioning – Process required to complete structure erection for intended design purpose

Materials:

Anchor Assemblies – Parts of the post tensioning system which secures and transfers tension force to the hardened concrete, including: embed plates, wedge plates, wedges, nuts (spherical or plain) and washers.

Duct – internal or external conduit of HDPE, PVC, Steel, or Galvanize metal used to create the space needed for post tensioning materials installation and contain grout materials.

Grout – Fluid cementitious material used as corrosion protection for post tensioning system, also improves construction safety once hardened by containing stressing forces within the post tensioning system.

Inlets/Outlets – Ports located in ductwork used to inject and control the flow of the pumped grout and the release of air within the system ductwork

Stressing Steel – Tensioning bars or tendons used to provide temporary and/or permanent post tensioning loads.



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Tensioning Bar – High Strength Steel coarse or fine threaded rod used as post tensioning materials

Tensioning Wire, Strand, Tendons – High Strength Steel single wires wound together to make strand, and placed in bundles as tendons used as post tensioning materials.

Wedge Plate – High Strength Steel Plate with tapered holes used to engage wedges against the tensioning strands to transfer loading to the hardened concrete.

Wedges – High Strength Steel clamps used to transfer post tension loads to the hardened concrete

Stressing Outline

I INTRODUCTION

The following sections of the document will describe the materials, equipment, procedures, and testing for post-tension stressing for precast segmental bridges. The procedure incorporates DOT special provisions for post-tensioning system(s) and post-tensioning institute (PTI) specification for post-tensioned structures.

II STRESSING CREW CERTIFICATION

Many groups offer certifications for post-tensioning crew supervisors, different owners and designers will specify the required certifications. If none are specified, the material supplier may state preferences.

III POST-TENSIONING MATERIALS

Various manufacturers are available; product data is available to identify a material meeting the contract specifications.



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Prestressing Steel:

High Strength wire strand tendons: Usually 7 strand wire, ASTM A416 – 270 ksi
Ultimate strength – Primarily 0.60"Ø for Multistrand but special sizes may be designed.



Strand may be coated or uncoated with a smooth or abrasive PVC sheath for added corrosion protection and increase bonding for grout.

PT Bars: Coarse or Fine threaded rods – 1" to 3" in dia., ASTM A722 - 150 ksi, Galvanized or Plain Steel depending on corrosion protection requirements.

Anchor System: Reinforcing Steel for Local Zone Confinement, Embed Bearing Plates, Anchor Plates, Wedges, Protective Covers



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Duct Systems: Pipe - May be Flat or Round, Corrugated or Smooth, PVC, HDPE, Galvanized Metal, or Steel

Connections - Trumpets, Valves, Bends, Couplers, Fittings, & Transitions, Heat Shrink Waterproof Wraps

Various manufacturers are available; product data is available to identify a material meeting the contract specifications.





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IV STRESSING EQUIPMENT

Strand pushers & tuggers, strand uncoiler racks, and stressing platforms are specialized equipment to aid access and installation of the tensioning materials.



Stressing Platforms – Provide access and support for material installation and equipment use, some equipped with chain falls and trolleys for the hydraulic jacks



Strand Uncoilers – safely transport, protect, and facilitate installation of tensioning strands and prefabricated tendon bundles.



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Calibrated hydraulic stressing jacks for threaded bars and multistrand tensioning.



Note: Spare equipment should be onsite for “stand-by” during grouting operations in case of mechanical failure of the main unit.

V GENERAL STRESSING PROCEDURE

PREPARATION

Training: Along with personnel certifications requirements, the materials manufacturer and equipment supplier will be required to provide specific hands on training in the use and protection of their systems.



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Submit QA/QC Plans, Sample Logs, Material Certifications and Delivery Information, Record Coil Numbers for Each Tendon, Strand/Bar Samples per Specifications with Heat / Lot Numbers, Equipment Certification and Calibration Information.

Material Storage:

Ductwork – Provide protection from UV, & physical damages, provide end caps to prevent moisture and contaminants from duct interior.

Steel Materials – Prevent physical damages, prevent rust and corrosion, and be careful around coiled strand when removing bindings

Grout – Store in temperature/moisture controlled container, prevent contamination.

INSTALLATION

Install exterior tendon ductwork in the interior of the segment box section, embedded unistrut with chains provide an easy hanging system to set the ducts to the correct height and alignment.





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Prefabricating tendon bundles by number of strand and design length at the source of supply is a time/cost saving option. Pulling eyes can be factory welded to the bundle ends to facilitate loading the tendons into the ductwork. An uncoiler rack will safely hold and protect the tendons while loading.



Ensure Strands are not Crossed, Install anchor plates and seat wedges on dead end of tendons, install anchor plates, wedges, and prepare hydraulic jacks for tensioning on live end of tendons.





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STRESSING

Jack Support Perpendicular to tendon path and slid on to the tendon strands.



Pre-stressing Jack check – Jack and gauges will have been calibrated together, ensure the gauge corresponds to the correct jack and the calibrations are up to date and correct, verify service gauge with supplied master gauge. Visually inspect gauge and jack for wear and damage. Review Safety precautions. Cycle through jack operations to confirm it is working properly.

Installing Jack – Install correct tendon pattern plate, check hole pattern alignment, install dead-end keeper plate, make sure piston is in correct initial position, slide jack over tendons, ensure strands are not crossed, and make sure jack is fully positioned over anchor plate.

Test communications with personnel positioned at dead end of tendons and make sure all personnel are clear of the jacking operations before initiating jack pressurization.

Stressing loads are applied to the tendons and are measured by the pressure gauges of the jacks to produce a jacking force: $0.9 F_y$ or 80% MUTS. These loads will stretch the tendons approximately 8" elongation per 100' check. The strand elongations are measured and documented to ensure the stressing force is distributed over the entire length of cable, shorter elongations indicate a possible pinch point in the cable, longer



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elongations indicate a possible tendon failure. Elongations are measured before & after seating wedges. Elongation measurement procedure is as follows:

- Set Datum at 20% Jacking Pressure (slack removal)
- Stress to 100% Jacking Pressure (difference is 80% of calculated elongation)
- Reduce to 20% (verify wedge seat loss)
- Measure Dead End draw-in

Elongation = PL / AE

Concerns for Under-elongated tendons

Concerns for Over-elongated tendons

Several Factors may affect the tension in the system -

Immediate Losses: Friction Losses, Seating Losses, Elastic Shortening

Time Dependent Losses (Long Term Losses): Shrinkage, Creep, Relaxation

If individual strands fails or elongation measurements are not within tolerance during stressing, the engineer should be consulted to evaluate the actual load for a factor of safety and the tendon may still be acceptable to remain in place. If not, the jacks can be used to back-off the pressure loaded into the tendon and a new tendon assembly must then be installed and stressed.

VI STRESSING DOCUMENTATION

Each owner may have a preferred document for the stressing record, if not a typical form can be obtained from the materials supplier, the equipment rental specialist, or from certifying agencies such as, PTI. Typical information provided on the forms include:

General Project/Location Data:

- A.) Project name, Financial Project ID;
- B.) Contractor and/or subcontractor;
- C.) Tendon location, size and type;
- D.) Date tendon was first installed in ducts;
- E.) Reel number for strands and heat number for bars;
- F.) Tendon cross-sectional area;



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- G.) Modulus of elasticity;
- H.) Date Stressed;
- I.) Stressing sequence
- J.) Stressing mode

Testing Specific Data:

- A.) Jack and Gauge numbers per end of tendon
- B.) Required jacking force
- C.) Gauge pressures
- D.) Elongations (theoretical and actual)
- E.) Anchor sets (anticipated and actual)
- F.) Witnesses to stressing operation (Contractor and inspector)
- G.) Date grouted
- H.) Comments

VII REQUIRED TESTING

The Jacking Equipment must be tested and calibrated prior to use, and the service gauges must be compared to the master gauge as specified or as conditions may indicate. Information needed: equipment Jack and Gauge model and serial numbers, date calibrated, load cell and strain indicator used to calibrate, and gauge pressure corresponding to required jacking force.

In-Place Friction Test: Purpose - To demonstrate the friction characteristics, losses and resulting tendon forces are in agreement with the design assumptions. Performed by measuring the dead end force while stressing.

Lift-off Testing and Seating Measurements – Confirm elongation measurement differences from operations, losses and resulting tendon forces are in agreement with the design assumptions.

Elongation Measurements – Confirm tension loads are distributed along entire tendon length.



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VIII PROTECTION AND STORAGE

Finishing: Once the loads and elongations are verified, and there is no reason to re-use the jacks, the tendon tails are cut off at both end anchors. Permanent Plastic Grout Caps are bolted to the embed plate cast into the concrete and the voids surrounding the cable ends and anchor plate are filled with grout as part of the grouting operations.



Reinforcing steel is drilled and epoxied into the segment face, a protective concrete block is cast around the plastic grout caps, and finally covered with an elastomeric moisture barrier.





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Grouting Outline

I INTRODUCTION

The following sections of the document will describe the mixing procedures of grout, equipment capacity, and grouting procedures for precast segmental bridges. The procedure incorporates DOT special provisions for post-tensioning system(s) and post-tensioning institute (PTI) specification for grouting of post-tensioned structures.

II GROUTING CREW CERTIFICATION

Many groups offer certifications for grouting crew supervisors, such as the post-tensioning institute (PTI), different owners and designers will specify the required certifications. If none are specified, the grout supplier may state preferences.

III GROUTING MATERIALS

Various manufacturers are available; product data is available to identify a material meeting the contract specifications.

IV GROUTING EQUIPMENT

For precast segmental bridge construction, the equipment used should include a self contained colloidal grout plant system (i.e. mixer and pump are built-in together on same unit.). The system should have a grouting capacity of 20 gallon/ minute at 261 psi. An air compressor unit is required to operate such equipment. The minimum capacity of the air compressor requires an air flow rate of 375 CFM or higher with a pressure of 100 psi.

The grouting equipment includes a mixer capable of continuous mechanical mixing which will produce a grout free of lumps and undispersed cement (colloidal grout). The grouting equipment will utilize gravity to feed the pump inlet from a hopper. During the



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pumping operation, the hopper shall be kept at least partially full of grout at all times to prevent air from being drawn into the tendon duct.

1/8-inch screen shall be provided between the mixing hopper and the holding hopper. This screen shall be used to remove unmixed lumps of grout.

A 1”diameter - 300-psi grout hose is needed to deliver the grout to the duct inlets. The length of hose depends on the location of the grouting equipment from site accessibility at the time of grouting. If longer hoses in excess of 100 feet (30 meters) are needed, place two gauges, one at the pump and one at the duct inlet to monitor pumping pressures. A water source and hose is needed to fill the water tub in the self-contained mixer. The water tub should be equipped with an overflow valve set to the required water level determined for the needed volume. Lastly, a pressure gauge is needed to monitor pumping pressure.

Note: Spare equipment should be onsite for “stand-by” during grouting operations in case of mechanical failure of the main unit.



V GENERAL GROUTING PROCEDURE

PREPARATION

- A.) calibrate water level gauge in the grouting plant prior to shipment (64.47 lbs equals 8.1 gal.)
- B.) Install grout caps immediately following cutting of strand tails.
- C.) Blow-out all tendons with oil-free compressed air.
- D.) Setup grout plant and materials. (the grout plant must be level)



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- E.) Perform routine maintenance for grouting equipment and air compressor, and checking mechanical parts for wear.
- F.) Layout grout hose capable of reaching furthest tendon to be grouted.
- G.) Clear areas around pump, header, and outlet.
- H.) Hook up grout header to inlet end of grout tube connected to the low point of the tendon.
- I.) Safety items (PPE) to be worn at all times – safety glasses, dust masks, rubber gloves, water for washing cleaning, eyewash station, tyvek suits.



MIX GROUT

ALL MIX DESIGNS SHALL BE IN ACCORDANCE WITH MANUFACTURER RECOMMENDATIONS:

DAILY PRODUCTION TESTING

Testing equipment and personnel capable of performing the following tests plus any other tests specified by the manufacture of the grout or designer.



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- 1.) **FLUIDITY TEST (MODIFIED)** – flow cone (modified) – one test per 2 cubic yards of grout or 2 hours, whichever comes first. At this interval, 1 test will be conducted at the hopper, and 1 test will be conducted at the outlet of the tendon being pumped at that time. Efflux times after mixing will be as specified by the grout manufacturer.
- 2.) **MUD BALANCE TESTS** (two per day, or when an apparent change is visible in the grout.) criteria – 1.95 g/cm³ or greater.
- 3.) **PREPARE GROUT CUBE SPECIMENS** ASTM C942. collect 6 specimens, 3 each – 7 day breaks (minimum 3000 psi). 3 each – 28 day breaks (5000 psi). **ONE TEST PER DAY.**





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GROUTING RECORD

grouting records submitted to the owner should include the following information:

- A.) certification of complete grouting for each tendon
- B.) lot number
- C.) grout materials and proportions
- D.) worker's names
- E.) date, time and number of days from tendon installation to grouting
- F.) ambient temperature
- G.) weather conditions
- H.) concrete temperature
- I.) grout temperature for grout used for the fluidity of grout tests in both the newly mixed and 30 minute rested grouts.
- J.) special cases- leaks, blockage, interruptions, and corrective procedures
- K.) injection end and applied grouting pressure
- L.) ratio of actual to theoretical grout quantity
- M.) fluidity of grout (flow cone) per batch for both newly and 30 minutes rested grout.
- N.) density of grout per batch of fresh mix
- O.) location of the injection port and direction of flow
- P.) theoretical volume of anticipated grout to be used
- Q.) actual volume of grout placed
- R.) additional witnesses to the grouting, including inspector
- S.) grout strength test results at 7 and 28 days, in accordance with astm 924

VI DUCT REPAIR PROCEDURE

preparation

Identify the extent of the damage to the duct.

exterior duct repair procedure

All damaged duct shall be removed and replaced.



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VII METHODS FOR SEALING DUCTS

All connections to ducts shall be made with stainless steel or plastic structural fasteners. 25 mil, 3m (or equivalent) water proof tape will be used to seal joints between the inlet/outlet pipes and the ducts and between the grout saddles and grout hoses. In accordance with the project specifications, pressure testing of all ducts must be done before grouting. Pressurize the duct to 10-psi and lock-off the air source, record the pressure loss over 5 minutes. If pressure loss exceeds 10%, all sources of leakage shall be identified and repaired such that upon repeating the pressure test the pressure loss is limited to less than 10% in five minutes.

VIII METHODS TO CONTROL RATES

Varying the pumping pressure can control the grout flow rate. Pumping pressures should not exceed 100 psi at the header. The flow rate shall be continuously adjusted to ensure optimum grout speed in the ducts.

IX TYPES AND LOCATION OF INLET/ OULET PIPES

Inlet and outlet pipes will be located as shown on the contract plans and manufacturer's shop drawings. All grout inlets and outlets shall be equipped with positive shut-off valves. Grout inlets and outlets shall be placed in the following positions:

- A.) Top of tendon anchorage
- B.) At the high points of the duct, i.e. as close to the inside face of the diaphragms as possible, located on top of duct.
- C.) At a location of 3 feet past the high points of the duct on the downstream side opposite the direction of grouting (as required)
- D.) At all low points
- E.) On either side of any couplers

Outlet pipes will be connected to the tendon through 1-inch grout tube and saddle.

X DUCT CLEANING METHODS PRIOR TO GROUTING

ALL DUCTS SHALL BE FLUSHED WITH OIL FREE COMPRESSED AIR OF ADEQUATE CAPACITY TO REMOVE ANY FOREIGN OBJECTS AND WATER.



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XI MIXING AND PUMPING PROCEDURES, COMMUNICATION

Communication during grouting shall be accomplished using radios between the individuals pumping and shutting off the grout outlets. Radio priority will be given to the individual who is attending the grout hookup that is expected to overflow next in sequence.

All mix designs shall be in accordance with manufacturer recommendations:

For example:

GROUT FORMULA FOR EUCLID CABLE GROUT

2.0 – 2.3 GALLONS PER PREPACKAGED BAG

add 18.3 gallons of water maximum, 16.0 GALLONS NOMINAL

add 8 bags of prepackaged grout @ 50 LBS EACH.

- A.) 16.0 gallons of water will be added to the mixer first, followed by 8 bags of prepackaged grout (euclid cable grout).
- B.) Mixing will be such duration as to obtain a uniformly blended grout. Mixing time may vary from 3 to 5 minutes. Note: no water shall be added to improve the grout flowability that has been decreased by delayed use of the grout. Grout temperature should not be lower than 40 degrees F or above 90 degrees F during mixing and pumping. If necessary, the mixing water shall be cooled.
- C.) Open all grout outlets before grouting operations begin.
- D.) Grout must flow from the first outlet and subsequent outlets until any residual water or entrapped air have been removed prior to closing the outlet.
- E.) Continue pumping grout through the duct and discharge it at the anchorage and grout cap outlet until all free water and air are discharged and the consistency of the grout is equivalent to that of grout being pumped into the inlet. Once this is achieved, continue to pump an additional 3 gallons out of the first outlet.
- F.) Close the anchorage outlet once all residual water and trapped air has been removed.
- G.) Wait for grout to be expelled out of the bleed hole in the grout cap.
- H.) A tendon fluidity test shall be performed on the grout discharged from the anchorage outlet.



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- I.) After all outlets have been bled and sealed, hold the grouting pressure on the tendon at 75 psi for approximately 1 minute. If leaks are detected, repair and repeat this step.

Repeat the above steps on all pt tendons/ pt bars.

XII DIRECTION OF GROUTING

Direction of grouting shall be from tendon low point towards tendon anchorage at either end of the tendon. All tendons shall be grouted from the tendon low point.



XIII SEQUENCE OF USE OF INLETS AND OUTLETS

The grout hose will be attached to the tendon inlet, which is located at the low point inlet. Once the grouting has begun, the outlets at the high points and outlets on the anchorages of the tendon will be monitored in accordance with the procedures outlined in section XI mixing and pumping procedures.



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XIV PROCEDURES FOR HANDLING BLOCKAGES

It is very unlikely that any blockage will occur during the grouting operation. Threading the strands in the duct, followed by flushing ducts with compressed air will generally supersede any possibility of blockage during grouting. In the unlikely event of blockage during grouting, additional inlet holes will be drilled to locate the beginning of the “blocked” section of duct. Inlet pipes are then secured and pumping will proceed from that point onwards. Any voids trapped due to blockage shall be vacuum grouted using the procedure in section xvi of this submittal.

XV METHODS FOR INSPECTING BEHIND THE ANCHOR HEAD

Inspection shall be conducted by drilling into the inspection port located at the top of the cast bearing plate and inserting a tube that will be used to probe the tendon after grouting. Use of a borescope can provide a visual report of inspection.

XVI PROCEDURES FOR POST-GROUTING REPAIRS OF VOIDS

In the event voids are detected in the post-tensioning system upon completion of grouting, the following vacuum grouting operation shall be conducted:

- A.) Install necessary airtight connections to the 1-inch npt hole in grout cap to connect to vacuum grouting pump.
- B.) Mount shut-off valves and manifold connections.
- C.) Reset vacuum meter.
- D.) Evacuate air to 29-inches of mercury, or as high as possible and close vacuum valve on manifold.
- E.) Close vacuum line valve and zero out the air flow meter.
- F.) Open the air inlet valve to allow air to return to and fill the void.
- G.) Record volume from air flow meter (in liters) and apply correction formula:
 - i. $V_{actual} = v_{read}(t_{current}/294)$
where: v_{actual} = actual volume of void
 v_{read} = volume read from air flow meter
 $t_{current}$ = current air temperature in kelvin (k)
($k = c + 273$)



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- ii. Note: air flow meter is calibrated at 70 degrees f = 294 k.
actual volume calculation is accurate to within +/-4%,
per air flow meter manufacturer recommendations.
- H.) Grout shall be re-circulating prior to evacuation to ensure the air is purged from grout lines.
- I.) Close re-circulating line (pump speed may have to be reduced to avoid pressurizing line).
- J.) Reset grout meter.
- K.) Slowly open grout valve to 'cracked' position and let grout flow into void at approximately 2 liters per minute. Adjust pump speed, monitoring flow and pressure. Do not exceed 100 psi.
- L.) Record volume when flow stops.
- M.) Pressurized grout to 50 psi and hold for 1 minute.
- N.) Shut-off grout to port and open recirculation valve.
- O.) Remove and thoroughly clean vacuum section of manifold.
- P.) Remove all grout ports and replace all npt plugs.

XVII METHOD FOR PROTECTION OF UNGROUTED TENDONS

In the unlikely event that grouting is not able to proceed due to temperature concerns, the installed tendon will be protected by means of plugging, sealing, or otherwise capping all duct connections and openings. The low point vent shall remain open to allow condensation to escape.

Summary Conclusion

This course gives a more specific look at the Stressing and Grouting Operations for precast segmental bridges, broader information can be found in the SunCam course ***Precast Segmental Bridge Construction – An Introduction***. This construction is very specialized and no matter how in-depth the courses are written there is no substitute for experience. Many specialty subcontractors and suppliers offer onsite consulting services as a supplement to the construction staffing. To organize a new



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construction project, managers should strongly consider these additions as well as the support of an experienced construction engineering firm. The consulting experience will help train the project personnel, troubleshoot problems, and give confidence to the owner. Additionally, a well-structured quality control program is a must. From design to casting to erection, unaccounted errors can have significant impacts to cost, schedule, and **SAFETY**.

Lastly, safety must be a constant focus of every operation. Because of the versatility of these bridges (mostly described in the opening paragraphs of the course) they are often chosen to be constructed in some of the most adverse and inaccessible areas imaginable. Working with extreme weights at excessive heights requires safety diligence from every stakeholder. The materials and operations of the post-tensioning phase are very dangerous. High energy loading of the tendons and rods, high pressure grouting, chemical exposure, and heavy abrasive materials require constant safety monitoring. Personal protective devices must be worn at all times, never overstress tensioning materials, and never position a person in front of tensioned material. The combined potential energy stored in the tendons of a large enough segmental bridge could launch the space shuttle into orbit, each individual strand can shoot like a bullet through any obstruction if failure occurs. Please be safe.