January 3, 2007
September 10, 2008
REV. May 12, 2011

Tennessee Department of Transportation
Division of Materials and Tests

Procedures for Prestress Concrete Construction (SOP 5-4)

Purpose- The purpose of this manual is to establish uniform procedures and practices for the manufacture and inspection of prestress concrete structural members. The following topics are addressed.

1. Safety
2. General
3. Production
4. Quality Control of Materials
5. Acceptance

Background- The Division of Materials and Tests Prestress standard operating procedures supersedes all previously issued circular letters regarding prestress issues. It is to be followed for the manufacturing of prestress concrete members intended to be utilized on TDOT or TDOT affiliated projects. It shall be used in conjunction with the following when applicable in order of priority;

1. TDOT Project Specific Proposal Contracts
2. TDOT Project Plans
3. TDOT Approved Shop Drawings
4. TDOT Standard Drawings
5. TDOT Supplemental Specifications
6. TDOT Standard Operating Procedures
7. Prestress Concrete Institute Manual

Procedure-

1. Safety

Working in prestressed plants is inherently very hazardous because of the large tensioning forces, debris, heavy equipment, etc., necessary to the operation. The inspector shall comply with all safety requirements at his/her assigned plant, and shall take any other steps he/she deems necessary for safety.

Work areas that are dangerous shall be brought to the attention of the producer’s personnel and the situation shall be corrected before progress of work requiring inspection is resumed.

2. General

All procedures and each facility involved in the manufacture of prestress concrete structural members shall be CERTIFIED by the Prestress Concrete Institute (PCI). Certified producers must submit a copy of their certification. If requested by TDOT, the Producer shall make available documentation and results of desired field review(s) performed by PCI.

The manufacturing process and all materials used in the construction of prestress concrete structural members must meet TDOT requirements. Daily reporting shall be documented on TDOT form DT-0283, Daily report of Prestress Concrete Plant Inspection. Final reporting for acceptance shall be completed on TDOT form DT-0289, Report on Precast/Prestress Concrete. Testing for acceptance and verification shall be performed in accordance with SOP 1-1, Standard Operating Procedure for the Sampling and Testing, and Acceptance of Materials and Products. The producer shall develop for approval an extensive QA/QC Process Control Plan similar to that as described in Standard Specification Subsection 604.03(b). It shall identify the proposed testing and frequency needed to properly assure that a quality product meeting all requirements has been properly produced. Proper documentation of all tests, dimensional checks, stress and elongation calculations, pre and post pour inspections, inventory and shipment reports and certifications of miscellaneous materials shall be maintained and available upon request.

3. Production

A. Placement of Voids in Box Beams

Forms for internal voids shall be held in place during the operations of placing and consolidating concrete. Their correct positions with respect to the horizontal and vertical axes of the beam shall be maintained within the limits of dimensional tolerances in accordance with TDOT Standard Specification, Subsection 615.17 or as indicated on approved shop drawings.

Hold-down devices shall be properly spaced to prevent the void from rising in the beam. Other templates shall be used to keep the void from being displaced laterally. These devices shall not puncture or otherwise damage the void. If pieces of the void become dislodged they shall be removed so as not to be incorporated in the concrete portion of the beam. Hold-down devices and/or other templates shall remain in place a sufficient distance behind the placing of concrete so that the void shall not move when these restraints are removed. The concrete shall be sufficiently plastic so that non-consolidated material resulting from the removal left by the hold down devices and/or other templates shall be filled into the surrounding concrete mass.

Dimension Verification for Box Beams**:**

1). Prior to Fabrication

a. Bottom Slab

Restraints to position the void above the bottom slab shall be capable of supporting the void and concrete during placement without puncturing or damaging the void material. Restraint heights shall be verified to meet the dimensions of the bottom slab as shown on the approved shop drawings.

b. Webs

Girder side forms shall have two (2) holes on each side of the form in areas where each void is located for the length of the void. These holes are to be used as random probe holes during fabrication to verify web thickness. [see Section 1.A.2).b.] Web thickness shall be checked by the inspector at each void corner prior to concrete placement in web areas.

2). During Fabrication

a. Top Slab

After the beam has been screeded and finished to the required depth and grade, the inspector shall probe though the fresh concrete to the top of the void to determine the amount of cover above the void. A minimum of two (2) measurements per void section at opposite ends of the void is required.

b. Webs

Web thickness shall be checked at two (2) random locations directly below the top slab measurements on each side of the girder by probing two (2) of the randomly selected holes in the side of the forms that were predrilled as indicated in Section 1.A.1).b., above.

3). After Fabrication

Random thickness measurements shall be performed by providing approved inserts or by drilling holes in the web of the girder after the forms have been removed. Two (2) holes shall be required per void section.

4). Documentation

All measurements indicated in Sections 1.A.1), 1.A.2), and 1.A.3), above shall be documented in the plant field book. Two measurements per beam for Section 1.A.1), 1.A.2), and 1.A.3) above shall be recorded on the daily report showing the maximum and the minimum measurements as recorded in the plant field book.

B. Pressure Gauges

Pressure gauges shall have a full pressure capacity of approximately twice their normal working pressure. The loads to be gauged shall not be less than one-fourth or more than three-fourths of the total graduated capacity unless calibration data clearly establishes consistent accuracy over a wider range. A separate low-pressure gauge shall be provided for initial tensioning (preload) when the main pressure gauge does not meet the above requirements for the initial tensioning force.

Each pressure gauge shall be capable of indicating loads directly in pounds, or be accompanied by a chart from which the dial reading shall be converted into pounds. Pressure gauges shall have dials at least eight (8) inches in diameter and be clearly readable. The smallest dial graduation shall not be more than 200 pounds. Pressure gauges shall have appropriate bypass pipes, valves, and fittings so that the gauge dial indicator shall not fluctuate but shall remain steady until the jacking load is released. Calibration of hydraulic jacks and pressure gauges shall be repeated at intervals of not more than 6 months per TDOT supplemental specification subsection 615.07. Documentation of calibration is mandatory.

C. Preload and Prestressing Procedure

The amount of stress given to each strand shall be as shown on the Plans and/or approved shop drawings. For all methods of tensioning, force in the tendons shall be determined by monitoring either applied force or elongation and independently checked by measuring the other. The control measurements and computed theoretical values of force and elongation shall agree with each other within ±5%.

1). Initial Tensioning (Preloading)

After the strand has been positioned, an initial force of no more than 5000 lbs. or as approved by the engineer shall be applied to each strand, whether straight or draped.

In a single strand tensioning the initial and final loads may be applied in immediate succession on each strand. The initial load on the strand shall be applied and held momentarily while reference marks are made and measured for elongation and live end slippage. The strand shall then be loaded to its final stress value and anchored as detailed in the following sections.

2). Final Stressing of Straight Strands

a. Single Strand Stressing.

After application of the preload and establishment of reference marks for measuring elongation and slippage, the full load shall be applied to each strand.

b. Multiple Strand Stressing.

Following application of initial stress and seating of each strand on the anchorage header, reference marks shall be established for measuring elongation and slippage. Since elongation is measured by travel of the anchorage, a reference mark shall be made at the face of the anchorage on each side of the bed. Reference marks to determine slippage shall be made by marking a straight line across the strands in each row along the face of the anchorage. For uniform application of load to the strands, the face of anchorage at final load must be in a plane parallel to its position under initial load. Parallel movements shall be verified by equal measurements of movement on opposite sides of the anchorage and a check of its plumb position before and after the application of the final load.

3). Final Stressing of Draped Strands

a. Partial Stressing and Subsequent Strains

Strands are tensioned in a straight position or on a partially draped trajectory to a predetermined intermediate stress value between initial and final stress. The final stress is induced by strains (elongation) resulting from uplifting or depressing strands at all other points of change in strand alignment. This method requires a carefully predetermined layout of members on the bed and definite positions of lifting and hold-down devices in order that the changes in length of strand resulting from its being forced into the draped position can be computed. This method can be used with either single strand or multiple strand tensioning.

If this method is to be used, the fabricator must submit plans to the Structures Division, detailing the layout of the beams in the line and showing calculations for the preload and final load induced by deflecting the strands. Final elongation shall be measured by making two marks 30 feet apart on two tendons on the live and dead ends of the bed after initial tensioning. The distance between these marks shall be measured after all tendons are placed in their final position. The acceptable elongation shall be calculated using the following equation with a tolerance of ±5%.

$$\Delta_{Drape} = \Delta_{Straight} \times 360 / L_{Bed}$$

Where:
Δ_{Drape}= Draped Strand Elongation (inches)
$\Delta_{Straight}$= Calculated Straight Strand Elongation (inches)
L_{Bed}= Bed Length (inches)
360=conversion factor, (30 ft x 12 in/ft) = 360 inches

b. Final Stressing in the Draped Position

Strands are stressed to final value in their draped position for full length of the bed. The strands shall pass over pin and roller fixtures, effectively minimizing friction at all deflection points. Support and hold-down devices shall be of sufficient rigidity and have adequate support so that the position of the strands shall remain substantially unchanged under the induced loads.

When using draped strands, if the required elongation has not been attained at one end of the bed when the load value, as indicated by the pressure gauge, is exceeded by 5%, the strand shall be jacked from the other end of the bed to the required elongation. If this requires an overstress as indicated by the gauge in excess of 5%, the number of deflection points and consequently the number of members on the bed shall be reduced until the elongation shall be attained with not more than 5% overload. When final stressing is accomplished by jacking only from one end of the bed, stress shall be measured on at least two strands at the other end. This stress shall not be below the specified value by more than 5%.

D. Elongation Corrections

Losses that are incidental to the operations of tensioning vary between casting beds and shall be evaluated and compensated for in computing elongation. TDOT uses the PCI (Prestressed Concrete Institute) method for determining prestress elongation corrections. The current PCI Quality Control Manual contains detailed procedures for a complete overview of prestress elongation calculations. TDOT provides an Excel worksheet to aid in elongation corrections, located in form DT0283.

Factors that must be taken into consideration during prestress elongation corrections are:

1). Abutment Rotation

Strands being stressed by a hydraulic jack place considerable force on the opposing anchoring abutment. Despite the high design strengths of abutments, slight abutment rotation will occur during stressing operations. If elongation is being measured relative to the abutment, rotation of the abutment will falsely register as strand tensioning movement. The rotation of the abutment must be considered during tensioning computations.

It is important to note that abutment rotation shall be measured at the strand height level. The top of the abutment will experience more displacement than the lower end of the abutment. Thus, strands toward the top of the abutment will experience more deflection than strands located on lower regions.

2). Dead End Slippage

The "dead end" of the prestressing bed refers to the end opposite from which the hydraulic jacking is taking place. "Dead end slippage" refers to the slipping of the strand through chuck holding devices at the "dead end" area due to tensioning by the hydraulic jacks.

Dead end seating occurs between the time that initial tension has been applied to the strand and the achievement of final load. Dead end slippage will falsely register as strand elongation if disregarded in elongation calculations. The effects of dead end slippage shall be included during elongation calculations.

3). Live End Seating

Live end seating occurs when the final load is released from the stressing jack and the strand is wedged into the live end chuck. The strand slips through the chuck before the chuck fully holds the strand, resulting in live end seating. Cleaning, lubrication, and inspection of chucks shall minimize live end seating, but it is not possible to completely eliminate chuck slippage. The effect of live end seating shall be compensated for by over pulling strand during tensioning to compensate for chuck slippage.

4). Temperature Adjustments

Self stressing beds are not affected by thermal differences because the strands, form bed and strand anchors move together with temperature changes. Therefore, losses for temperature adjustments should not be considered when using self stressing beds.

When using abutment stressing beds, the effect of temperature is significant and compensation shall be made if the net force differential is greater than 2.5%. Abutment stressing beds are utilized at the majority of prestressing plants that produce for TDOT. Thermal losses are caused by the strands and abutments acting independent of the form bed and thereby not moving with the form bed during thermal expansion and contraction. This most commonly occurs on a cold morning when strands are tensioned then, later in the day, when fresh concrete is poured onto the strands. The warm concrete causes the strands to expand and tension in the strands will decrease.

The opposite temperature situation will also cause tension problems in strands. For instance, if strands were tensioned at elevated temperatures and then cooler concrete was later placed on the strands, the strands would contract and tension in the strand would increase.

To compensate for thermal variations, a general rule shall be followed: for every 10°F rise in temperature expected in the strand, a 1% decrease in stress will occur. For instance, if the strand temperature rises 30°F from the time of stressing to the time it is surrounded by concrete, the strand stress will decrease by 3%. The opposite is true when the temperature of the concrete is colder than the stressing temperature. The strand would contract and increase in stress by 1% for every 10°F temperature change. It requires a 25°F change in temperature to affect the force 2.5%. Thus, this adjustment is made only if the temperature of the strand at the time of tensioning differs by more than 25°F from the anticipated temperature of the concrete that will surround the strand(s) at the time the concrete is placed. Consideration shall be given to partial bed length usage and adjustments made when the net effect on the length of bed used exceeds the allowable 2.5% force differential. If sequential pours are to be performed, the anticipated temperature difference at the time of concrete placement of each sequential pour shall not vary by more than 20°F of the anticipated temperature difference used at the time of stressing. If the time elapsed between final tensioning and the time concrete is placed in any sequential pour is greater than 1 week, the stress in at least 2 strands from the far abutment shall be verified. For example, if a 35ºF rise is expected between a 50ºF ambient temperature at the time the strands are stressed and a 85ºF concrete temperature at the time of casting when only 75% of the bed is utilized, then the strands should be overstressed by (1%)(35/10)(0.75) = **2.63%** to offset the expected loss of stress. The table below shows the percent of strand stress change due to temperature differentials. Compensation for the amount of bed usage greater than 75% is normally ignored. If the amount of bed usage in the example above was 70%, the stress change would be 2.45% and no correction is necessary because it is not greater than the allowable 2.5%.

Temperature Variation (degrees Fahrenheit)

% of Bed Used	25	30	35	40	45	50
5	0.13	0.15	0.18	0.20	0.23	0.25
10	0.25	0.30	0.35	0.40	0.45	0.50
15	0.38	0.45	0.53	0.60	0.68	0.75
20	0.50	0.60	0.70	0.80	0.90	1.00
25	0.63	0.75	0.88	1.00	1.13	1.25
30	0.75	0.90	1.05	1.20	1.35	1.50
35	0.88	1.05	1.23	1.40	1.58	1.75
40	1.00	1.20	1.40	1.60	1.80	2.00
45	1.13	1.35	1.58	1.80	2.03	2.25
50	1.25	1.50	1.75	2.00	2.25	2.50
55	1.38	1.65	1.93	2.20	2.48	2.75
60	1.50	1.80	2.10	2.40	2.70	3.00
65	1.63	1.95	2.28	2.60	2.93	3.25
70	1.75	2.10	2.45	2.80	3.15	3.50
75	1.88	2.25	2.63	3.00	3.38	3.75
80	2.00	2.40	2.80	3.20	3.60	4.00
85	2.13	2.55	2.98	3.40	3.83	4.25
90	2.25	2.70	3.15	3.60	4.05	4.50
95	2.38	2.85	3.33	3.80	4.28	4.75
100	2.50	3.00	3.50	4.00	4.50	5.00

E. Breaking Bond Strands

When using bond breaking, it is essential that no grout find its way inside the bond breaking material. If using solid plastic tubing, the ends shall be taped. If using split plastic tubing, both the ends and the entire length of the split joint shall be taped. The use of tape alone shall not be allowed.

Bridge Deck Panels

1). General

Prestressed bridge deck panels are to be constructed according to D.O.T. Standard Drawings M-164-24 and M-164-25, the producer's approved shop drawings, the Standard Specifications, and the applicable special provisions.

2). Dimensional Tolerances

These are set forth on Standard Drawings M-164-24 and M-164-25

3). Cracking

A minor amount of shrinkage cracking is to be expected and shall not be cause for rejection of the panels. Care in pouring and curing shall eliminate most of the causes for these. Structural cracks shall be the cause for rejection.

Refer to the PCI manual: "A Manual for the Repair of Precast/Prestressed Bridge Beams and Deck Panels" for detailed information on structural diagnosis.

4). Finishing

Finishing shall be in accordance with standard drawing M-164-24.

5). Handling and Storage of Panels

Panels shall be removed from the forms in such a manner that no damage is done to the concrete or the protruding shear ties. When stacking panels, wood spacers thick enough to protect the shear ties shall be used.

Refer to the PCI manual: "A Manual for the Repair of Precast/Prestressed Bridge Beams and Deck Panels" for detailed information on handling structures.

6). Placing of Concrete

Since the concrete in these members is relatively thin, proper care must be taken to keep the concrete within the allowable temperature ranges given in Subsection 501.11 of the Standard Specification. It could conceivably be necessary to heat or cool the steel forms prior to pouring. Freshly placed concrete must be protected from sun and wind, therefore, concrete is to be covered as soon as possible. A support for the cover shall be used that will allow for free circulation of steam.

7). Removal of Grout from Shear Ties

All exposed steel shall be cleaned of concrete, other than light deposits of cement paste, immediately after placing and consolidation is complete.

4. Quality Control of Materials

A. Form Release Agents

Since the integrity of pre-tensioned members is based on development of uniformly high bond on all strands, the necessity of clean strands cannot be over emphasized.

Form release agents manufactured from resin, paraffin, or vegetable oil bases will be permitted, provided the release agent be a type that dries to a degree that it cannot contaminate any strand that comes in contact with it.

Special care shall be taken when pulling strands across prestress beds to make certain that the release agent shall be of the approved type and that it has dried sufficiently.

B. Cylinders

- Concrete testing cylinders for pre-stress concrete shall be either:
- 4 inches in diameter and 8 inches in length
- 6 inches in diameter and 12 inches in length

C. Temperature

The temperature of concrete used in prestressed applications shall not drop below 50°F or rise above 95°F during pouring operations.

5. Acceptance

A. Reporting Prestress and Precast Items for Payment

When a contractor or producer requests payment on prestressed or precast items produced for a specific project, the inspector will accomplish the following:

1). All units will meet the requirements of the specifications and shop drawings. Dimensional tolerances shall be in accordance with TDOT Standard Specification 615.16.

2). All units must be ready for shipment (steel bent, 28-day strength met, unit marked correctly, holes filled, drains opened, all honeycombed areas, etc., repaired).

3). When partial payment is required, the inspector will mark each unit with plant letter and report number at one end of each unit accepted. The inspector is to make out a test report for the units on which partial payment is to be made. The inspector must state on the report the following: The material listed above is stockpiled at the producer's plant and may be paid for on a partial payment basis.

4). No material is to be stamped or stenciled before it is loaded for shipment. After loading and prior to shipping, the inspector shall perform a final inspection of the units, and if found acceptable, shall stamp showing final acceptability.

B. Marking of Precast/Prestress Items

Each precast or prestress item, (beam, panel, piling), shall be identified by etching the top surface. As small an area as possible is to first be troweled and then etched. The lettering shall be a minimum of two (2) inches in height. Information included in the marking shall be the project number, county, station number or bridge number, unit mark number and date made.

It is understood that some items, such as piling, are poured for stock (poured for no specific project) and stored on the producer's yard. When these items are assigned to a project, or before shipment to a project, the above identification will be put on each piece with waterproof ink or paint.