

## **602 PRESTRESSED CONCRETE**

### **602-1 Description**

Prestressed concrete construction is specialized work done by experienced crews trained for this type of work. Although the responsibility for prestressing lies with the Contractor, it is important that the Resident Engineer and the Inspector are familiar with the operation.

Prestressed concrete is different from reinforced concrete in that an initial compression load is applied to the structural member. This *prestress* is applied by means of steel strands that run through the structural member. Placing an initial compression stress in a structural concrete member allows it to carry greater loads than normally would be achieved by adding more reinforcing steel. The idea is to keep the structural member from experiencing any tension stresses that might crack the concrete. The higher the compression stress induced into the concrete, the more load the member can carry before going into tension and cracking. ADOT uses prestressed concrete for most bridge girders and sometimes for pier caps and deck slabs. Prestressing allows for lighter and stronger concrete members that do not crack easily.

There are two methods for prestressing concrete—pretensioning and post-tensioning. Precast concrete girders are pretensioned, while cast-in-place box girders are post-tensioned.

*Pretensioning* involves running steel strands along the length of the member to be prestressed. The strands are initially tensioned to a predetermined stress. This causes the strands to stretch. Concrete is then poured all around the strands. Once the concrete has hardened and gained sufficient strength, the ends of the strands are cut. The strands inside the concrete member try to relax and shorten. However there is now concrete bonded to the strands. As the strands shorten, they push the concrete together and induce a compressive stress into the concrete.

*Post-tensioning* involves running steel ducts through the concrete members. Special anchors are placed at each end of the member. Then concrete is poured around the ducts and the anchors. Steel strands are run through the ducts. Once the concrete is strong enough, the strands are pulled at one end while anchored at the other. Pulling (or jacking) of the strands causes the ends of the concrete member to push toward each other. This induces compressive stresses along the entire length of the concrete member. After jacking, grout is injected into the ducts then concrete is poured around the ends of the anchors. Once the grout gains strength, the strand is now bonded to the concrete member in a way similar to pretensioning.

The results of pretensioning and post-tensioning are the same. Compressive stresses are induced into the concrete member. The differences are in the technique used to induce the prestressing.

Prestressed members require the use of additional reinforcing steel. Extra steel is used to control certain types of cracking near the end of a prestressed member.

### **602-2 Materials**

#### **Prestressing Strand**

The Department allows two types of prestressing strands. For precast girders, seven-wire, high-tensile 0.5-inch (12.54-mm) strands are used. For cast-in-place box girders either 0.5-inch (12.54-mm) or 0.6-inch (15.24-mm) strands are used with the 0.5-inch (12.54-mm) strand being the most preferred.

Prestressing strand is more susceptible to corrosion than rebar and should be treated accordingly. After the packaging has been removed from the reels containing the prestressing steel, the reels should be kept off the ground on blocks or timbers and covered with a tarpaulin. The tarpaulins should be wrapped loosely around the reels to permit air circulation and avoid moisture build-ups due to condensation.

The following criteria is a guide for the acceptance or rejection of the prestressing steel strand:

1. Steel that has a thin rust film, removable by light rubbing and leaving only light streaks or spots but no pitting, need not be rejected.
2. If there is an even coating of rust over the entire reel when it is opened, the reel should be rejected.
3. The reel should be rejected if one or more wires in a strand shows extensive rust throughout its length.
4. Any section of strand or wire that contains clinging rust, pits, or other faults should be discarded.

### **Concrete**

Good concreting practices in regards to mixing, placing, and curing are a prerequisite to any prestressing operation. Uniformity and consistency of the concrete is especially important. Variations in concrete properties can lead to excessive camber deflection and pronounced long term creep of prestressed concrete members. The Inspector should carefully monitor batching and placement procedures and reject all concrete that fails to meet slump or other placement related specifications.

## **602-3 Construction Requirements**

### **602-3.01 Shop Drawings**

Extensive shop drawing submittals are required for all prestressed concrete members. The Contractor will submit drawings showing the location of all prestressing strands and detailing any additional hardware needed to secure or anchor the strands to the concrete member. The shop drawings should include:

- a scaled composite drawing showing strand and hardware locations;
- the jacking method and sequence;
- the strand type, size, location and number of strands;
- a calibration chart for the jack, including a calibration certificate that is no more than two years old;
- elongation and stress calculations; and
- details on additional hardware such as plates and bars.

Additional requirements for pretensioned concrete members (precast girders) include:

- the location of all harping points and other hold down locations;
- the location of all lifting points and lifting hardware details; and
- the type of finish on the tops of the girders.

Additional requirements for post-tensioned concrete members include:

- anchorage design details including bursting diagrams and stress calculations;

- duct layout details and vent locations;
- post-tensioning sequence;
- grouting procedures; and
- an approval letter from a recognized authority on post-tensioning systems that conforms to the requirements of subsection 602-3.02.

The Resident Engineer should verify the submittal is complete with all of the required drawings, calculations, and details before sending to the Bridge Designer for review.

Reproducible shop drawings (mylars or sepias) of all prestressed concrete members must be included with the as-built plans when the project is finalized. A set of reproducible drawings should be included in the contractors working drawing submittal (refer to Subsection 105.03).

### **Hardware Installation**

The Contractor is responsible for furnishing hardware that will withstand the prestressing loads transferred from the strands to the concrete girders. The hardware requirements are shown in the approved post-tensioning shop drawings. The Contractor will provide calculations with the shop drawings showing the transfer stresses in the hardware and how the hardware was sized and selected. It is important for the Inspector to ensure that all the hardware shown in the shop drawings is incorporated into the girders. Sizes, spacing, and material grades should all be checked carefully.

A transition cone, usually referred to as a trumpet, is placed at the end of the duct at the bearing plate. The size and the length of the trumpet varies with the size of conduit and the jacking system used. The trumpet section is used because the area of the duct is much smaller than the area of the hardware needed to tension and anchor all of the strands in the duct.

The girder webs are usually flared at the ends to accommodate the trumpet sections and to provide enough concrete cover. The amount and length of the flared section will depend on the prestressing system and size of duct used. The alignment between the duct and trumpet section is critical. A smooth connection is required or problems may arise while tensioning or grouting. The joints between the duct and trumpet must be sealed in the same manner as the other duct joints.

Openings for the injection of grout are placed at the bearing plates and are usually connected to the trumpet cone. The connection is generally brazed, watertight, and must be able to withstand the grout pumping pressures. The grout ports and vents must be anchored securely to the forms or rebar to prevent displacement during the concrete pour.

### **602-3.02 Approval of Prestressing Systems**

When precast girders are used, ADOT's Material Group will approve the pretensioning system. For cast-in-place box girders, the Bridge Designer will approve the Contractor's post-tensioning system.

For post-tensioning, the Inspector should have copies of the approved post-tensioning drawings and calculations. It is important for the Inspector to verify that the Contractor closely adheres to the approved shop drawings. The structural integrity of the entire bridge is dependent on the post-tensioning system. Even the slightest deviation from the approved shop drawings or Project Plans can have serious consequences for the long-term performance of the structure. Daily inspections of post-tensioning hardware (ducts, bearing plates, trumpets, bolts, and bars) during installation are required. Spacing, location, sizes, and material requirements

are key inspection areas. Inspectors should strictly enforce the installation tolerances shown in Subsections 601-4.02 and 602-3.05.

### **602-3.03 Sampling and Testing**

Inspectors are required to sample each reel of prestressing strand that arrives on the project site. Steel bars, wires, and couplers should be sampled at the rate shown in the Standard Specifications. Steel plates should be sampled at the rate shown in the Sampling Guide. Testing is usually performed by the Structural Material Testing Section of ADOT's Material Group.

Certificates of Compliance must accompany all prestressing materials. All materials are required to have a lot number assigned by the manufacturer that must be referred to on the Certificate of Compliance. The Inspector should document where these materials are placed in the structure and should not allow any materials to be used that are not properly tagged and certified.

### **602-3.05 Duct Installation for Post-Tensioned Structures**

Ducts are generally placed after the stirrups are in place in the girder webs and before the side forms have been placed. The utmost care must be exercised in the storage, handling, and transporting of ducts, as they are relatively flimsy compared to other bridge components and damage easily.

Two types of ducts are used in bridge construction. Smooth wall rigid conduit is made from galvanized strip steel held together longitudinally with a continuous resistance weld or a continuous interlocking seam. They are normally furnished in 20-foot (6-meter) lengths with one end of each length enlarged to form a slip type connection. The other type of duct is galvanized ribbed sheet steel with helically wound interlocking seams. It is generally furnished in 40-foot (12-meter) lengths and connected by larger rigid conduit couplers.

All of the joints in the duct, whether they are couplers or interlocking seams, should be taped with durable waterproof tape to prevent the intrusion of mortar while placing concrete. A careful inspection should be made at all joints to verify they are well sealed to prevent problems due to a plugged duct.

The correct positioning of the ducts is most critical at the high and low points of the duct profile and at the points of contra-flexure. The profile between these points should form a smooth parabolic curve. As discussed in Subsection 602-3.02 of this manual, strict adherence to installation tolerances is extremely important. Misaligned ducts can severely affect the amount of prestressing transferred to the bridge structure. Ducts that are installed too low in a girder can cause additional uplift stresses on a post-tensioned bridge that can crack the bridge deck and tops of the girder webs. On the other hand, ducts installed too high can cause a post-tensioned bridge to sag due to a lack of adequate uplift stress.

The horizontal alignment of the ducts is important and should be carefully checked. Ducts that are out of horizontal alignment can cause a wobbling effect on the girder webs when they are post-tensioned. This effect can cause the girder webs to twist out of alignment resulting in severe cracking and even spalling of the web concrete around the ducts.

The ducts should be tied securely (vertically and horizontally) to the stirrups and other rebar to prevent displacement during the concreting operation. Ducts have a tendency to float during concreting causing the joints to open up if the conduit is not properly secured.

Grout vents are usually attached to the ducts by brazing or using metallic structural fasteners. The vents should be mortar tight and taped when necessary to prevent the intrusion of mortar. Grout vents are used to ensure that a steady and continuous flow of grout is being pumped through the duct. Vents must be placed according to the approved shop drawings that are usually within 6 feet (2 meter) of the high point of the duct profile in continuous structures. Grout vents may be placed at the low points of the duct profile. Usually this is not done unless specified because of the difficulty in access due to falsework obstructions. The advantage of using low point vents is to allow water that has collected in the ducts to drain.

Ends of the ducts should be covered after installation to prevent entry of water and debris.

### **Duct Inspection**

After the installation of the ducts, rebar, and forms, a thorough inspection should be made to locate possible duct damage prior to placing concrete. The Inspector should be aware of the most common sources of duct damage. Some of the common forms of duct damage are:

- separation due to dragging the duct;
- punctures due to threading rebar;
- indentation due to dropped rebars;
- indentation due to workmen walking on, or placing equipment or material on the ducts; and
- punctures caused by carpenters drilling forms for snap ties while buttoning up side forms.

Two alternative methods that have been successfully used to locate duct damage prior to concrete placement are described below:

#### Method No. 1:

Through visual inspection by the use of angle-mirrors and flashlights.

#### Method No. 2:

Check the ducts with compressed air. This method is described as follows:

While introducing a large volume (3 cubic yards per minute) of air continuously at one end of the tendon (note the dynamic pressure on a gauge at the opposite end). Since the duct is not closed, no specific gauge pressure is required. Large holes or openings in the duct will allow more air to escape than an undamaged duct and will result in a lower dynamic air gauge pressure. It is necessary to compare the noted pressures between similar tendons.

Any large holes or openings can be located by the disturbance (sound, dust, etc.) caused by the escaping air.

After inspection of the ducts, all holes or openings found in the ducts must be repaired prior to concrete placement. The following methods of repairing damaged ducts can be used as a guideline. Holes less than 1/4 inch (6 mm) can be repaired by several wraps of waterproof tape. Holes or openings larger than 1/4 inch (6 mm) should be repaired with a split metal sleeve extended at least 3 inches on each side of the hole. The sleeve should be secured to the duct and be sealed with waterproof tape. Extreme care must be exercised while repairing damaged ducts so there is no further damage.

### **Duct Protection During Concrete Pours**

After a thorough inspection of the ducts, hardware, rebar, and forms, the bottom deck and webs of the bridge can be poured. Problems often occur while pouring the webs and the Contractor must exercise extreme care in placing and vibrating the concrete. Generally with the ducts installed, there is not much room in the webs to place and vibrate the concrete. Unless the utmost care is exercised, honeycomb or complete void areas may result. Consolidation of the concrete is especially important around the trumpets since most of the prestressing loads will be transferred to the concrete in this area. Damage to the ducts can occur from wedging the vibrator against the duct. Pencil vibrators are sometimes used and recommended when there is a high risk of getting the vibrator jammed between the reinforcement and the ducts.

All of the web walls must be checked after the forms have been removed. Any honeycomb or void areas must be repaired. Minor imperfections can be repaired by chipping away the defective area and patched in a manner approved by the Resident Engineer. The size of the damaged area will govern the materials used for patching. If the Resident Engineer deems that the integrity of the member has been affected by extensive honeycombing, part or the entire web may have to be removed. The Contractor must be careful and not damage the duct while chipping defective concrete.

### **Duct Blockages**

Before closing the bridge cells to construct the top deck, the ducts must be tested again to verify there are no holes in the duct and that the ducts are unblocked. A common way to verify that the ducts are unblocked is to blow an object (a rubber ball is excellent for this purpose), slightly smaller than the inside diameter of the duct, through the duct with compressed air. If the object cannot be blown completely through the duct, the duct has a blockage and the location of the blockage must be determined and corrective measures must be taken (repair the duct). A method of checking the amount or size of blockage is to use smaller diameter balls to see if they can be blown through.

Sometimes blockages can be removed by see-sawing a strand back and forth in the duct. However be careful not to damage or nick the strand while trying to clear the duct. If this method or any other method the Contractor uses is not effective then the blockage must be repaired by chipping the girder web before the top deck is poured.

### **Pressure Testing**

Once the Inspector is satisfied that all possible blockages have been investigated and repaired, the Contractor must demonstrate to the Department that the ducts will not leak. This is done by pressure testing the ducts. Either air or water is pumped into a closed duct until the "charging pressure" is attained, then the valve is shut-off and the "retained pressure" is measured after five minutes. The specified charging and retained pressure depends upon whether the duct will be partially, or completely encased by concrete during the pressure test. Ducts that are not completely encased in concrete must have exposed areas sealed with epoxy before pressure testing.

If the performance of the pressure test is unacceptable, the Contractor must take some action to find and repair any leaks. If after testing, the duct is still unacceptable, the Resident Engineer has the option of approving the ducts or requiring more repairs.

It should be a very rare occasion when a Resident Engineer approves a post-tensioning duct that fails the pressure test. The Resident Engineer should insist that the Contractor make all the necessary repairs to fix any

leaks. Once the deck forms are placed and the deck poured, it is much more difficult to access the girder webs to repair any leaking ducts.

If you find a duct that cannot pass the pressure test, some steps you can take are:

- try switching between the two types of pressure test (water vs. air);
- air test during the very early morning when it is quieter;
- hydrostatic test the duct for several hours (the leaking water will eventually reveal the location of the leak); and
- use dye in the water to make it easier to trace the leak (be careful about staining all exposed concrete).

Occasionally the Contractor will have made a good faith effort to fix all the leaks but the duct may still fail the pressure test. If this is the case, the advice of Bridge Group and the Bridge Designer should be sought prior to approving the duct.

After all the ducts have been checked for blockages and leaks, the cells can be closed and the top deck can be poured. The strands may be placed in the duct prior to pouring the top deck. However the strands should be protected from rust by using an approved corrosion inhibitor. The better method is to install the strands after all of the concrete has been placed and has developed the required compressive strength for tensioning.

### 602-3.06 Prestressing

The following terms should provide the Inspector with a better understanding of the concept of prestressing:

1. *Anchorage Device*

The hardware assembly at the ends of each post-tensioning duct used for transferring a post-tensioning force from the strands to the concrete.

2. *Curvature Friction*

The friction resulting from bends or curves in the specified post-tensioning duct profile.

3. *Effective Prestress*

The stress remaining in the concrete due to prestressing after all losses have occurred excluding the effects of dead load and superimposed loads.

Effective Prestress equals Jacking Stress minus Loss of Prestress

4. *Friction (Post-Tensioning)*

The surface resistance between the strands and duct in contact during post-tensioning. It includes curvature friction.

5. *Jacking Force ( $P_{jack}$ ) or Jacking Stress*

The temporary force exerted by the jack that introduces tension into the strands.

## 6. *Loss of Prestress*

The reduction in prestressing force resulting from the combined effects of:

- elastic shortening of the concrete and rebar due to the jacking force;
- relaxation of the strands;
- friction;
- anchorage losses due to seating of post-tensioning strands and movement of the anchorage device; and
- long term creep and shrinkage of the concrete.

## 7. *Pre-compressed Zone*

That portion of the flexural member's cross section compressed by the post-tensioning force ( $P_{jack}$ ).

## 8. *Relaxation of Tendon Stress*

The time-dependent reduction of stress in the strands at a constant strain.

## 9. *Tendon*

The post-tensioning duct and the strands and grout within the duct used to impart a prestress to the concrete or each strand in a prestress, precast concrete girder.

## 10. *Wobble Friction*

The friction caused by the post-tensioning ducts (or the stands in precast girders) that are misaligned (horizontally and vertically) from their intended alignment and profile. (This is the primary reason ADOT requires formwork drawings for interior girder webs on post-tensioned bridges.)

Prestressing takes place in two increments. The first increment, referred to as the initial pull, is applied to straighten the strands and to eliminate slack. The initial pull is usually between 5 to 10 percent of the initial stress and can be applied either by a hydraulic jack equipped with a pressure gauge or load cell or by a fence stretcher and dynamometer.

Immediately following the initial pull, the Contractor must mark both the dead ends of the strands for slippage and the stressing end for elongation measurements. If spliced strands are used, the splices must be marked for slippage.

After the reference marks for elongation and slippage have been placed, the strands can be tensioned and anchored at the required initial stress. The jacking stress must be applied with a hydraulic jack equipped with a pressure gauge or load cell.

At the end of the stressing operation, the elongation must be measured and compared to the theoretical calculated elongations. The calculations must be submitted to the Bridge Designer for approval. In pretensioned members, each strand elongation should be recorded. For cast-in-place post-tensioned members, the elongation of the strand group in each tendon should be recorded.



**(A) General****Prestressing Equipment**

Each jack must be equipped with either a pressure gage, or a load cell with a digital display that is readable at a distance of 10 feet. Pressure gauges used for measuring the stressing load should have a dial at least 6 inches (150 mm) in diameter, and increments with an accuracy within 2 percent. Gauges must be calibrated by an approved laboratory prior to being used. A certified calibration curve should be furnished by the laboratory for each gauge and jacking device. Gauges should be calibrated for the jacks they are to be used with.

Gauges should read in pounds (newtons) or be accompanied by a chart from which the dial reading can be quickly converted to pounds (newtons). All gauging devices should be recalibrated at least as often as specified. During the post-tensioning, if any gauging system appears to be giving erratic or erroneous results or if the gauge readings and elongation measurements indicate materially different stresses, the jack and gauges should be recalibrated.

**Welding**

Welding should not be permitted in the vicinity of any prestressing strand, steel, or duct. Spatter from welding can pit the steel wire. Very minor pitting can cause failure of the strand even at a low stress. Damage of this type is extremely difficult to detect so adequate precautions must be taken when welding near any strands.

**(B) Pretensioning Precast Concrete**

In precast girder manufacturing long pretensioning beds are generally used allowing several members to be made with one strand. The tension must be the same for each member but when strands are draped, friction develops during stressing at hold-down or hold-up points that may reduce the tension in the members toward the non-jacking end. This stress reduction should be checked by computing the elongation of some convenient lengths, say 20 to 25 feet (7 to 10 meters), which may be measured on a straight section of strand near the non-jacking end. The length should be marked on the strand in two or three locations before stressing. Then, after stressing, the elongations are determined and compared. Corrective measures should be taken if results indicate non-uniformity of tension.

The usual procedure for stressing is to place a small initial stress, about 5% of the total, into the strands before marking them for elongation measurements. This is to take the slack out of the strands, seat the opposite end anchor, and tighten up the bearing surfaces. The initial stress produces some elongation. The manufacturer's recommended modulus of elasticity should be used in all elongation computations. One set of stressing calculations may be used for more than one member, if the members are identical. However the Inspector should be satisfied that the stressing setup is the same for which the calculations are based.

The strands should not be tensioned more than 72 hours ahead of placing the concrete.

Metal chairs or small precast concrete blocks may be used to support the strands and stirrups.

**Reinforcement and Anchorage Details**

The centerline of bearings or the beam centerline should be marked on the form soffit and used as a reference for spacing of stirrups, drape supports, bearing devices, diaphragm connections, etc. Tack welding of reinforcing steel will not be permitted unless approved in writing by the Resident Engineer. If the Contractor requests to

tack weld, the proposal should be included with the shop drawings. Details provided in these drawings should include compliance with ASTM A 706 for welding rebar.

Positioning of the reinforcing should be performed carefully to make certain that the correct distance from the forms is maintained. End bulkheads and bearings should be set out far enough to compensate for elastic shortening of the member when tension is released.

The alignment of prestressing anchorages to ducts is critical. As a general rule, the anchorage should be within 2 percent of perpendicular to the centerline of the duct. Larger variations can cause failure of the strands due to shifting of the stressing head toward the centerline of the duct.

### **Placing Concrete (See Sections 601 and 1006)**

The Inspector should not permit the placing of concrete in any member until the forms, reinforcing steel, and prestressing strands have been verified for compliance with the Standard Specifications and the approved working drawings. When the forms or the steel are hot, they should be sprayed with water ahead of the placement of concrete.

The consistency of the concrete should be closely controlled through frequent moisture tests of the aggregate and slump tests of the concrete. No more water should be used in the mix than is necessary for good placement. Inconsistent concrete produces large variations in girder camber growth. These variations can result in significant changes for both deck build-up and deck concrete quantities that have not been anticipated by the Designer and reflected in the Project Plans.

Concrete should be deposited in its final position as nearly as possible without resorting to moving the concrete appreciably by use of vibrators. Concrete should be placed in at least two continuous horizontal layers for "I"-shaped beams of depths not exceeding 3 feet (1 meter) and at least three such layers for beams of greater depth. The first layer of concrete should completely fill the bottom flange and extend 2 to 4 inches (50 to 100 mm) up into the web.

Care should be exercised to see that all parts of the forms are completely filled with concrete. The coarse aggregate should be worked away from the form faces by use of the vibrators and spades. The concrete should be worked under and around the prestressing tendons and the reinforcing bars without moving them. There should be at least one spare vibrator in case of a breakdown.

Unless otherwise specified on the Project Plans, the top surface of I-beams, box beams, and flat slabs must be roughened with a hand tine rake while the concrete is still plastic.

### **Concrete Tests**

Compression tests are important in prestressing because they determine the time of detensioning or post-tensioning. They show the ultimate strength of the concrete. This makes it more imperative that the sampling, handling, fabrication, curing, and testing shall be in strict conformance with the Materials Testing Manual.

Field cure the cylinders in the same manner as the members are cured. The cylinders should be placed in areas representing the average curing condition of the member or members that they represent. All other cylinders are to be cured and stored according to standard procedures.

**Curing (See Subsection 1006-6.02)**

Ordinary moist-curing methods are satisfactory if properly performed. Accelerated curing to increase the production of precast members is often used. However steam curing is the most common method.

Steam curing must be performed properly to accomplish the desired results. However even under the best control, there is a loss in ultimate strength of 5 to 15 percent when compared with good moist-curing. The rate of temperature rise, the average temperature, the maximum temperature, and the rate of drop in temperature must be carefully controlled to keep strength loss to a minimum. The rate of rise in temperature of the air surrounding the concrete member should not exceed 40 °F (22 °C) per hour. Maximum temperature must not exceed 175 °F (79 °C), and the average temperature must not exceed 160 °F (71 °C). Effective acceleration in the curing is not accomplished unless the temperature surrounding the member is above 120 °F (50 °C). The rate of cooling should not exceed 40 °F (22 °C) per hour. Usually 12 to 18 hours at a temperature near 160 °F (71 °C), will result in the required minimum strength of release of the tendons. Coverings or hoods over the members should be at least 6 inches (150mm) above the concrete surface to provide circulation, and be secure enough to prevent heat and moisture loss.

**Stress Release**

The required compressive strength for stressing the concrete, as indicated by cylinder strength tests, must be reached before this operation is permitted to begin. For members cast end-to-end on a pretensioning bed, the strands should be cut in a pattern and at selected locations along the bed so as to keep the eccentricity of stress loading and longitudinal movement to a minimum. If some of the strands are draped, they should be cut first then the hold-down apparatus released. The straight strands should be cut last.

If the hold-downs are released first, the beam may camber up and crack due to the end moments. If the straight strands are cut first, the unbalanced pull on the beam might shear off the hold-down bolts with resulting damage to the beam and casting bed.

**Inspection**

Each member should be inspected carefully for conformance with the requirements of subsection 602-3.08 of the Standard Specifications. The following are among the important features that should be checked:

- concrete cleaned off of exposed reinforcing bars;
- spacer holes and form tie holes should be repaired;
- tendons should be trimmed at the girder ends; and
- any necessary finishing and patching done.

The Project Plans may require the Contractor to monitor the camber growth of each girder. This can be done by taking elevation readings with a level along the bottom flange of the girder. Only three shots need to be taken; one at each end of the girder and one at the midspan. If the girder will remain undisturbed, only a single elevation reading is needed at midspan. These readings should be done immediately after the girder is removed from the casting bed and again just prior to shipping. The camber growth rate is simply the change in the midspan elevation divided by the elapsed time between the two sets of readings. This information should be given to the Bridge Designer who can check the design assumptions concerning camber growth. Camber growth serves as an early warning to the Designer about potential deck build-up problems before much of the deck formwork is placed.

Beams should be inspected for voids or honeycombs before they are shipped or erected. Small voids or honeycomb on the sides of beams may be repaired and accepted if the repair work is performed and properly cured before any stress is released.

Small voids or honeycomb in the bottom of a beam may be repaired and the beam accepted under the same conditions except when the voids are over or near the bearings. Voids or honeycomb in the bearing areas should be considered probable grounds for rejection of the beam. The Resident Engineer should investigate the defect and request the assistance of the Materials Group and Bridge Group.

### **Transporting**

Transporting and erecting precast, prestressed girders are the responsibility of the Contractor. A permit is usually required from MVD to haul girders on ADOT highways. Municipalities and county governments may require additional permitting.

Various kinds of devices are anchored in the concrete for the purpose of lifting the members. The members should not be lifted in any way other than by use of the lifting devices provided. Members should always rest in an upright position setting on blocks located near the ends—just as they would be sitting when installed in the structure. The Inspector should observe the handling of the members but the prime responsibility for proper handling is the Contractor's. The Inspector should record and report any suspected improper handling or damage to the Resident Engineer.

Girders that fall on to their sides or are completely flipped over are usually severely damaged. This is due to the fact that the weight of the beam offsets the bowing action of the prestressing strands. This bowing action gives the girder its camber. If the beam falls on its side or is flipped over, there is nothing restraining the bowing action of the strands. The girder will arch until it cracks all the concrete around the strands. The strands then become de-bonded causing the girder to lose most of its prestress.

## **(C) Post-Tensioning Cast-in-Place Concrete**

### **Time and Curing Requirements**

Tensioning cannot take place until the required concrete compressive strength has been reached for jacking and seven calendar days have passed since the last deck concrete has been placed. The seven day requirement cannot be waived even if the concrete cylinders meet the strength requirement in less time. The seven days ensure the concrete has matured enough so that it will not be susceptible to excessive long-term creep after post-tensioning. Young concrete can creep excessively when loads are applied too early causing the bridge superstructure to sag with time.

Once these requirements have been met, the stressing operation can be started. Compressed air will generally blow most of the water out of the ducts.

### **Installing the Strands**

The strands may be placed in the duct prior to pouring the top deck, or after completion of concrete curing. The better method is to install the strands after all of the concrete has been placed and has developed the required compressive strength for tensioning. For protection of the steel from corrosion, the Standard Specifications state that the prestressing steel placed after curing is acceptable if it is tensioned and grouted within ten calendar days after placement of the steel in the ducts. Usually this is not a hardship on the Contractor because ten days is

generally sufficient time to tension and grout tendons. Strands placed prior to curing must be protected from rust by using an approved corrosion inhibitor, and the contractor must demonstrate that strands are free and unbonded in the duct before tensioning. The Resident Engineer should be notified when the Contractor runs into these difficulties. The Engineer should obtain advice from the Bridge Group, and the Bridge Designer before allowing the contractor to make any attempt to free a bonded strand. If the Contractor fails to meet the corrosion requirement, then it is left to the judgment of the Inspector whether to re-inspect the prestressing steel for rust.

There are many methods employed in the installation of the prestressing steel in the ducts. The strands must first be pulled from the reels and cut to the required lengths needed for tensioning. Care must be exercised while laying out the strands to prevent them from collecting foreign material. The strands must be clean when installed in the ducts. Stringing the strands over blocks of wood is one effective way of keeping the strands off the ground and free of dust and dirt. The strands cannot be cut with an acetylene torch. An abrasive bit can be used as long as a clean cut is made to allow the prestressing steel to fit through the hardware being used.

The prestressing steel is installed by first blowing a piece of tie wire, nylon cord, or cable through the duct. This may or may not be adequate to pull all of the strands through the duct. If it is not, a heavier cable capable of pulling all the strands is fed through the duct.

A winch is the most common piece of equipment used in pulling the strands. The required numbers of strands for each tendon are pulled using a kellum grip placed over the ends of the strands.

On occasion, the Contractor will fail to place the correct number of strands in the duct. If this happens, the Contractor must add or take out strands until the correct amount is in the duct. This can be an extremely difficult process.

Split wedges are the most common means used for holding the strand during stressing and for the final anchorage of the strands in the bearing plate after stressing. All of the friction wedges have teeth or small serration's that make small notches on the material being gripped. All wedges and pulling chucks must be kept clean so as not to alter the efficiency of the system.

### **Post –Tensioning Procedure**

The sequence of stressing is shown on either the approved shop drawings or the Project Plans. The sequence of stressing is usually determined by the Designer in order to keep the stresses within a predetermined symmetry about the axes of each member.

The Standard Specifications allow stressing from one end only for simple span bridges. Prestressing continuous structures must be done by jacking at each end of the tendon, unless otherwise specified on the Project Plans. Such stressing need not be done simultaneously even though some Contractors may choose to do so.

OSHA Standard 1926.701(c) prohibits anyone from standing behind the hydraulic jack during post-tensioning. Poorly anchored or broken strands can shoot through the jacking head. The area several hundred feet behind the jack should be kept clear of all personnel. If this is not practical, suitable barriers should be erected to protect adjacent work, passing vehicles, and pedestrians.

The Inspector should measure and record the jacking forces applied to each tendon. A load cell meter is available at ADOT Materials Group for measuring jacking forces during post-tensioning. An instruction manual comes with the meter to calibrate the meter at the project site. The manufacturer's recommended modulus of elasticity should be used in all elongation computations.

The usual procedure for stressing is to place a small initial stress, about 5 percent of the total, into the strands before marking them for elongation measurements. This small initial stress takes the slack out of the strands, seats the opposite end anchor, and tightens the bearing surfaces. The initial stress does produce some minor elongation.

Uniform tension in all of the strands in a post-tensioned tendon is difficult to achieve because of the varying amounts of friction, length, and the modulus of elasticity between the individual strands. Due to inevitable weaving of strands within a tendon, some of the strands may be stressed close to their yield strength before others. This can occur when the jacking force approaches only 78 percent of the ultimate tensile strength of the prestressing strands. Therefore when jacking force exceeds the 78 percent, some of the strands in the tendon may be over-stressed. This is the main reason that the Standard Specifications do not permit stressing beyond 78 percent of the minimum ultimate tensile strength of the prestressing steel (see Subsection 602-3.06[A]).

### **Elongation Measurements**

The stress induced in the prestressing strands must be measured both by gauges and by elongation of the tendons. Occasionally there are differences between the measured elongation and the elongation shown in the calibration chart for a given jacking force. This is because strain (elongation) versus stress (gauge reading) differs due to variations in modulus of elasticity in the steel, variation in tightness of twist in the strands, variations in friction between the supports or ducts, or friction and losses in the jack and pumping system.

If the variation is more than 5 percent, the Contractor must take corrective action before proceeding (see Subsection 602-3.06[A]). This includes finding the source of the error, which could be an improperly seated jack, incorrect assumptions about the amount of twist in the strands, or using the wrong modulus of elasticity. It may even be necessary to have the jacks and gauges recalibrated.

Regardless of the error, it is up to the Contractor to find the source and correct it. The Resident Engineer should be notified when the Contractor runs into these difficulties. ADOT's Bridge Project Engineer and the Bridge Designer should only be contacted after the Contractor has performed all reasonable checks on the post-tensioning operation and cannot rectify the more than 5 percent variation.

If the difference in indicated stress between the jacking pressure and the pressure computed from the elongation is less than or equal to 5 percent, the lower of the two pressures should be increased to the specified value. This would result in a slightly over-stressed strand that is preferable to an under-stressed strand.

### **Strand Breakage**

Occasionally while stressing strands in a prestressed member, a wire in a strand will break. Generally failure of wires is acceptable provided that not more than 2 percent of the total area of the prestressing steel has failed. If a wire failure occurs after the strand has been anchored at its initial stress and the 2 percent criteria has not been violated, the strand should be acceptable subject to approval of the Bridge Designer. If failure occurs while jacking and before initial stress, a new jacking stress can be computed and the strand tensioned to this calculated stress. If failure occurs and the required jacking force cannot be obtained, that strand should be rejected and replaced.

The ends of the stressed strands should not be cut until just prior to grouting so that the Inspector can put reference marks on the strand to note any slippage of strands or failures in the hardware system.

### **602-3.07 Grouting of Post-Tensioned Members**

The purpose of grouting is to have the entire void space within the ducts filled with grout. This protects the tendon from corrosion and continuously bonds the tendon to the girder web.

Just prior to grouting, the strands can be cut and the grout caps installed. The grout injection and ejection pipes should be fitted with positive mechanical shut-off valves. The grout vents should be fitted with shut-off valves. Once this has been done, the tendons are ready to be grouted.

#### **Equipment**

The grouting equipment must be capable of continuously mixing and pumping grout that is free of lumps and undispersed cement. The mixing tanks, storage tank, pump, and hoses must be in good working condition to provide a satisfactory grouting job. It is essential that the ducts be free of holes and unblocked to accomplish a good grouting job.

Usually two grout mixers are used. Both discharge into a single storage agitator just prior to pumping. The storage agitator should utilize gravity to feed grout to the pump inlet. This avoids additional air being entrapped in the grout mix if pressurized lines are used. Just before the grout is introduced into the grout pump, a 1/8-inch (3 mm) maximum size screen should be installed to keep any lumps or foreign matter out of the grout mixture. The screen should be easily accessible for inspection and cleaning.

The grout mixers and pump should be driven by separate motors. The pump should have a minimum pumping pressure of 150 psi (1 MPa) with a gauge having a full scale reading of 300 psi (2.1 MPa). Maximum grouting pressure must not exceed 250 psi (1.7 MPa). The pump must prevent any introduction of oil, air, or other foreign substance into the grout and prevent any loss of grout or water.

Standby equipment capable of flushing out any partially grouted tendons must be available at the job site. The standby equipment must be capable of developing a pumping pressure of at least 250 psi (1.7 MPa) with sufficient volume to flush out the duct. Flushing equipment should have a power source separate from the grouting equipment. Any flushing should be from the ejection end of the tendon. The standby equipment should be inspected prior to grouting to verify it is operational.

#### **Materials and Testing**

It is necessary to check the consistency of the grout to verify that the correct proportions of materials have been used and that the grout can be easily pumped and will not take a false set in the duct.

The consistency of the grout must be tested with a flow cone (ARIZ. Test No. 311) prior to being introduced into the tendon. Only one test is required per structure since the grouting is usually completed in one day. If grouting is not completed in one day, a test shall be taken at the beginning of each day the Contractor is grouting. The flow time, immediately after mixing, should not be less than 11 seconds. The flow time is defined as the time it takes the grout to discharge from the flow cone. The Contractor should provide initial set times for the grout at various temperatures. The set time can be of extreme value when dealing with leaky post-tensioning ducts.

#### **Procedure**

All vents in the tendon should be open when grouting begins. The flow of the grout should be in one direction only. Any intermediate vents must be closed as soon as a steady flow of grout, without any residual water or entrapped air, is maintained. The grout should be continuously wasted at the outlet until no visible slugs of air or

water are ejected. The pumping pressure should then be increased and the inlet valve should be closed. The maximum pressure must not exceed 250 psi (1.7 MPa), and the minimum pressure after one minute must be at least 75 psi (0.5 MPa).

Occasionally the anchor blocks do not make a tight seal with the bearing plates. When this happens, grout leaks may occur. To control leaking, the pumping can be stopped momentarily to let the grout seal the leak. If this procedure does not stop the leak, then the tendon must be flushed and re-grouted.

The initial pumping pressure should be small (less than 40 psi [280 kPa]) and should gradually increase in pressure until the duct is filled. The maximum grouting pressure should not exceed 250 psi (1.7 MPa). If the grouting pressure exceeds the maximum, the grouting may continue at one of the upstream vents as long as one-way flow has been sustained at that vent. If a one-way flow of grout cannot be maintained, then the grout should be immediately flushed out of the duct.

### Leaks

Leaks in the ducts may prevent the Contractor from maintaining the required 75 psi (0.5 MPa) pressure for one minute. The pressure will drop off gradually as the Contractor tries to hold the pressure. If there is a small leak, the Contractor may try to:

- close the valves at both ends (do not pressurize);
- wait for approximately 30 to 60 minutes (do not let the grout set up in the ducts; check grout set time and temperature);
- grout the adjacent duct(s) while you are waiting;
- return to the original duct and increase the pressure to 75 psi (0.5 MPa);
- check for grout flow at the outlet; and
- hold pressure at 75 psi (0.5 MPa) for one minute.

If the 75 psi (0.5 MPa) pressure cannot be held then:

- thoroughly flush the ducts and blow the water out with oil-free compressed air;
- immediately refill with fresh grout;
- check for grout flow at the outlet; and
- pressure test again.

If these procedures fail to seal the leak or if there is a rapid drop in pressure, the Contractor has no alternative but to find the leak through air or water testing and physically repair the leak.

Judgment needs to be used when trying to seal leaks through the grouting process. General principles to keep in mind are:

- the grout must always be able to flow through the outlet before pressure testing (this indicates that the grout has not set in the ducts and there are no voids or blockages);
- leaking between ducts can happen (so pressurizing one duct may force grout into an adjacent, yet-to-be grouted duct or into an open, leaky duct you are trying to fix);
- large cracks and holes cannot be sealed during the grouting process (no matter how hard the Contractor tries);
- pressurizing the grout reduces its set time, so does increasing the temperature;
- don't ever allow the grout to set up in the ducts before passing the pressure test; and
- when in doubt, flush the grout out!



**Grouting Curves**

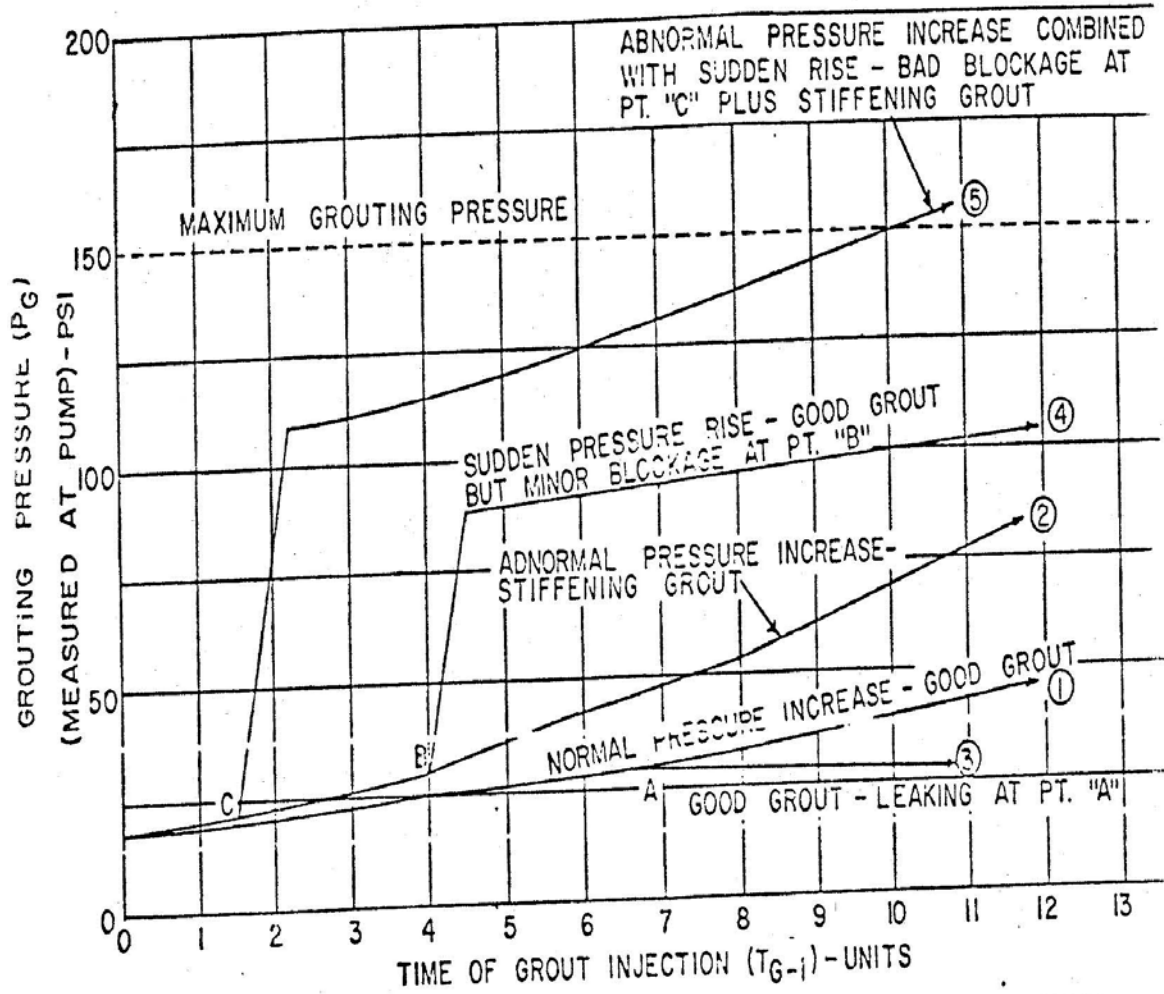
A great deal of useful and often times critical information can be obtained by monitoring the grout pressure gauge and analyzing the information (see Exhibit 602-3.07-1). Grout injection time and the length of duct filled with grout are interrelated and are dependent on two constants: the duct void volume and the pumping rate (see the formula in Exhibit 602-3.07-1). During pumping, grout will conform to known principles of hydraulics.

Good grout will exhibit a gradual increase in pumping pressure due to:

- friction in the duct,
- any head which exists, and
- normal stiffening (see Curve 1 in Exhibit 602-3.07-1).

A grout that tends to “flash-set” in the duct will still exhibit a gradually increasing pressure but at a greater rate (see Curve 2). A constant pressure as shown in Curve 3 will indicate a hole in the duct, which allows grout to leak. A minor blockage will be indicated by a sudden jump in pressure followed by a continued gradual increase as shown in Curve 4. It should be determined whether:

- the entire duct can be filled without exceeding maximum recommended pressure;
- grouting should be transferred to a vent; or
- grouting should be discontinued, the duct immediately flushed, and the blockage repaired.



NOTE: GROUTED DUCT LENGTH AND GROUT INJECTION TIME HAVE THE FOLLOWING RELATIONSHIP:

$$T_{G-i} = \frac{V_v \times L}{C_p}; \text{ OR } L = \frac{T_{G-i} \times C_p}{V_v}$$

- WHERE:
- $T_{G-i}$  = GROUT INJECTION TIME (MINUTES)
  - $V_v$  = DUCT VOID VOLUME (FT<sup>3</sup>/FT)
  - $C_p$  = RATE OF GROUT PUMP (FT<sup>3</sup>/MINUTE)
  - $L$  = LENGTH OF DUCT FILLED WITH GROUT (FT)

Exhibit 602-3.07-1 Grout Injection Time Graph

A bad blockage, possibly combined with stiffening grout, would be indicated by a large jump in the pressure curve as shown in Curve 5. As illustrated in Curve 5, there is nothing to be gained by allowing pressure to build up and hoping that a miracle will happen. Grouting should be stopped at a low pressure so the grout can be flushed out easily.

Successful grouting of one or more tendons will establish the "normal" pressure versus time relationship. Thus, any "abnormal" conditions existing in other tendons can be detected.

The valves and grout caps shall not be opened or removed until the grout has set. Usually caps and valves can be removed the morning following grouting operations.

#### **602-4 & 5 Method of Measurement & Basis of Payment**

Prestressed concrete is considered part of the lump sum structure payment and no separate measurements or payments are made for this work. A sub-item under the lump sum structure item is listed in the bidding schedule for precast girders or for prestressing cast-in-place concrete. The sub-items exist for partial payment purposes only.