STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
ENGINEERING SERVICES

PRESTRESS MANUAL

A GUIDE FOR FIELD INSPECTION OF CAST-IN-PLACE POST-TENSIONED STRUCTURES

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INTRODUCTION

A large percentage of the bridges built in California are prestressed, post-tensioned type structures. As a bridge engineer working for the Divisions of Structure Construction, you should understand the construction principles relating to prestressed, post-tensioned bridge construction.

This *Prestress Manual* has been compiled to provide the field engineer with the necessary information and the background to perform three basic duties:

1. Check the contractor's working drawings.
2. Provide thorough and complete inspection during the construction of the bridge with respect to the prestressing operation.
3. Understand and enforce Section 50 titled "Prestressing Concrete" of the Standard Specifications and any pertinent references.

The information included herein is to be considered as both a reference and guideline for structure representatives and assistant structure representatives. This manual should be reviewed both prior to working drawing review and during the prestressing operation. This manual should be available to the field engineer during the post-tensioning operation.

This manual, along with good communication between the structure representative, Structure Design, Materials Engineering and Testing Services (METS), and the contractor, will provide a finished product consisting of sound structural integrity with a minimal amount of construction related problems.

SAFETY

The prestressing operation can be a potentially dangerous one. Due to the tremendous forces involved, if a failure occurs, there is a good possibility that high velocity projectiles will be produced. The field engineer should always stay alert and be aware of the contractor's operations.

General "common sense" rules to be practiced around and during the prestressing operation are as follows:

1. Stay clear of the area when the contractor is unpacking the strands. Securing bands may spring in any direction when released, causing injury.
2. Before the contractor begins the stressing operation, check all of the high-pressure hoses for leaks and/or poor condition. Worn or damaged hoses are to be replaced only with hoses that can withstand the high pressures involved.
3. Never stand behind, along side, or directly above the prestressing jack during the stressing operation. Never stand behind the "dead" end of the tendon during the stressing operation. Use caution around tendons until after they are grouted. For additional information and safety requirements, refer to Cal/OSHA Construction Safety Orders, Section 1721.
4. Always be aware of the contractor's operation and equipment during the stressing operation.
5. The pressure cell indicator box is an expensive piece of equipment. Do not leave the box unattended, and make sure the contractor does not damage it with his equipment. After verifying gage pressures, the pressure cell and readout box should be relocated to a safe location away from the immediate area.
6. If the contractor uses a corrosion inhibitor, avoid contact with the eyes or skin. Have the contractor provide a product data sheet and a material safety data sheet. Goggles, coveralls, boots, and impervious gloves should be worn for protection.

PRESTRESS WORKING DRAWINGS

Section 50-1.02, "Drawings", of the Standard Specifications requires that the contractor submit working drawings of the prestressing systems that will be used on the project. It is the contractor's responsibility to use post-tensioning systems that are pre-approved by Caltrans or obtain approval from METS for the systems that are proposed for use.

The prestress working drawings are to be submitted by the contractor to the documents unit in Sacramento. The documents unit will distribute the various sets of drawings for review and approval. The distribution process is outlined in Bridge Memos to Designers, Section 11-1. All OSD technical publications are available at http://www.dot.ca.gov/hq/esc/techpubs/.

The responsibility for checking the working drawings is shared by the designer and the structure representative. Working drawings shall not be returned to the contractor until the designer has discussed and resolved the details with the structure representative. The comments returned to the contractor must be acceptable to both the designer and the structure representative.

The normal time allowed for prestress working drawing review by Caltrans is six weeks for structures not involving railroads, and eight weeks for structures involving railroads.

The Standard Specifications, special provisions, contract plans, *Bridge Records and Procedure Manual*, and the resident engineer's pending file should be carefully reviewed before and during the working drawing review process. All dimensions, layouts, and calculations shall be checked. Items of specific concern are as follows:

1. Prestressing force and theoretical elongations.
2. The initial and final force variations between girders.
3. Bearing plate stresses and concrete stresses behind the bearing plates.
4. Whether one or two end stressing is used.
5. Conflicts between the layout of the ducts and bar reinforcing steel.
6. Block-out sizes, duct alignment at anchorage, and possible utility conflicts.

Bridge Memos to Designers, Section 11-1, defines the roles and responsibilities of the Prestressed Concrete Committee, designer and structure representative for post-tensioning working drawing review. In addition, a checklist for reviewing working drawings is included in Appendix C, titled "Inspection Checklist".

It is important that all parties involved (designer, structure representative, assistant structure representative, contractor, and prestressing subcontractor) are working from an approved set of working drawings.

It is possible that the contractor will begin construction from an unapproved set of working drawings. The contractor should be reminded (and noted in the daily report) that all work will be checked with an approved set of working drawings and any deficiencies will require correction and that no concrete will be placed until the corrections have been made.

At the completion of each structure on the contract, the contractor shall submit to the engineer one set of reduced prints of the corrected original tracings of all working drawings for each structure (Std. Spec. 50-1.02). Reduced prints of drawings that are common to more than one structure are required to be submitted for each structure. The first drawing of each reduced plan set shall contain an index. The index sheet shall be prepared specifically for the set of drawings and list sheet numbers and titles for each structure. Reduced prints for each structure shall be arranged in order of drawing numbers shown on the index. The structure representative shall review the drawings for accuracy and then forward the drawings, if complete, to the Offices of Structures Design, Documents Unit, 1801 30th Street, Mail Station 9-4/4I, Sacramento, CA 95816, as outlined in Memo 2-12.1 of the *Bridge Construction Records and Procedures Manual*.

PRESTRESSING DUCTS

Section 50-1.07 of the Standard Specifications requires that the duct enclosures for prestressing steel be rigid ferrous metal, galvanized, mortar tight, and accurately placed as shown on the contract plans or as approved by the Engineer.

Rigid duct is used to take advantage of the low tendon-to-duct friction inherent with rigid duct. The rigid type duct is stiff enough to eliminate horizontal wobble, but flexible enough to bend and meet the required tendon profiles. The reduced friction coefficients associated with rigid duct as compared to that of flexible duct can result in a 10% to 50% reduction of prestressing steel required, depending on the length of the structure.

Rigid duct is available in various types and diameters. One type of duct is the smooth wall type, made from strip steel held together longitudinally with a continuous resistance weld or a continuous interlocking seam. The duct is normally furnished in 20-foot lengths with one end of each length enlarged to form a slip-type connection. Another type of rigid duct is made from ribbed sheet steel with helically wound interlocking seams. This duct is generally furnished in 40-foot (12.2 m) lengths and is connected by larger rigid duct couplers. A third type of rigid duct that is approved for State use is the VSL shallow elliptical or rectangular type. This type is used occasionally for transverse deck stressing.

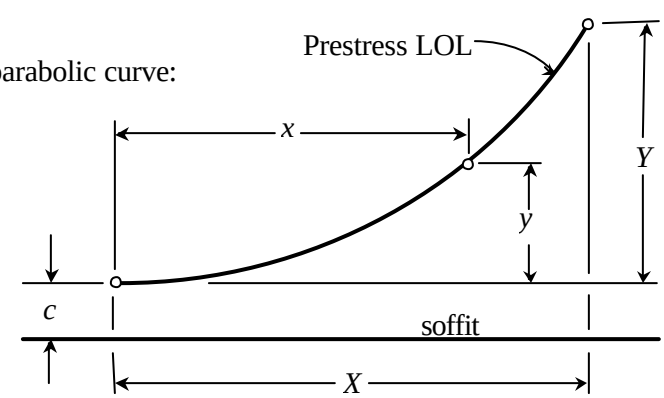
The rigid ducts are to be field released by the structure representative. The ducts will not have release tags attached when they arrive on the jobsite. The ducts are to be checked for specification compliance and any damage that may have occurred during shipping. Damaged duct can be repaired if the damage is minor but shall be rejected if the damage is extensive. The placement of the ducts can be checked by using the "duct checker", (*Bridge Construction Records and Procedures Memo* 145-7.0) or with an engineer's rule and level. Most tendon paths are parabolic and the distance from the soffit forms to the center of gravity (CG) of the path can be calculated as shown below:

Calculation of points along a parabolic curve:

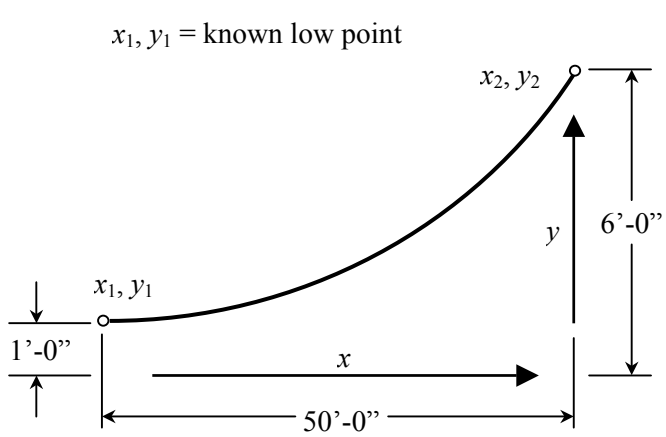
Where:

$$a = Y / X^2$$

$$y = ax^2 + c$$



Example: Given the tendon profile shown below, find the equation to calculate y.



$x_1 = 0$

$y_1 = 1'\text{-}0''$

$x_2 = 50'\text{-}0''$

$y_2 = 6'\text{-}0''$

Solving for y: $6 = a(50)^2 + 1$

Solving for a: $a = 5/2500$

$a = 0.002$

$\boxed{y = 0.002x^2 + 1}$

The final check for the duct alignment should be verified by visually observing a smooth tendon path. It is recommended that the taped duct joints be staggered for multiple tendon girders so that a misalignment of the ducts does not occur. Section 50-1.07, "Ducts", of the Standard Specifications requires that waterproof tape be used at all duct connections.

Once the ducts have been properly aligned, check to verify that the ducts have been properly secured to the bar reinforcing steel to prevent displacement during concrete placement. Ducts are typically secured to the bar reinforcing steel using tie wire spaced at 5 feet intervals along the duct path. Tie wire spacing intervals should be reduced if conditions warrant.

Duct vents are required on ducts with a total length of 400 feet (122 m) or more and shall be located within 6 feet (1.8 m) of a high point in the duct profile. Locating these vents on either side of the bent cap centerline may avoid possible conflicts with the top cap steel.

The contractor is required to protect the ducts from any water or debris entering them prior to the placement of the stressing steel. Section 50-1.07, "Ducts", of the Standard Specifications states that the ducts shall be covered at all times after installation into the forms. The contractor is required to prove that the ducts are free and unobstructed twice as follows:

1. Prior to placing forms for closing slabs of box girder cells, Std. Spec. 50-1.08.
2. Immediately prior to installation of prestressing steel, Std. Spec. 50-1.07.

All holes or openings in a duct (large enough to let grout out or concrete in) must be repaired prior to concrete placement. Holes less than ¼ inch in diameter can be repaired with several wraps of waterproof tape. Holes or openings larger than ¼ inch should be repaired with an overlapping split metal sleeve.

Photo 1 – Check of Tendon Profile

Photo 2 – Smooth Duct Profile

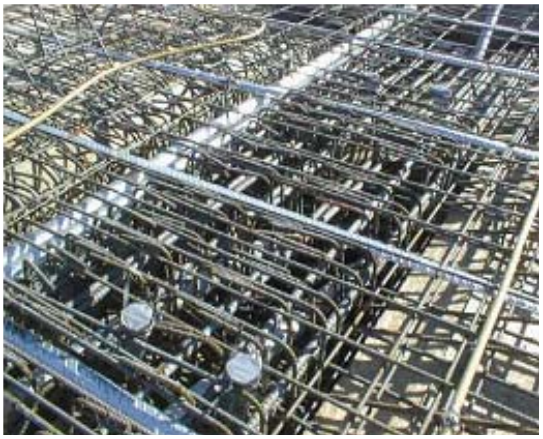


Photo 3 – Transverse Ducts in Place

Photo 4 – Transverse and Longitudinal Ducts

Photo 5 – 12 Ducts in One Girder at Midspan

Photo 6 – Part and Full Length Duct Profiles

PRESTRESSING STRANDS/BARS

The base material used to fabricate prestressing steel must conform to the requirements of ASTM Designations A416, A421, or A722, as well as Section 50-1.05, "Prestressing Steel", of the Standard Specifications. The A416 designation covers the requirements for both 0.5" (12.70 mm) and 0.6" (15.24 mm) strand. The A421 designation gives requirements for prestressing wire. The A722 designation gives requirements for high-strength steel bars. Figures 2, 3, and 4 show typical stress-strain curves and physical properties for 0.5" (12.70 mm), 0.6" (15.24 mm) strand, and grade 150 ksi (1030 MPa) bars.

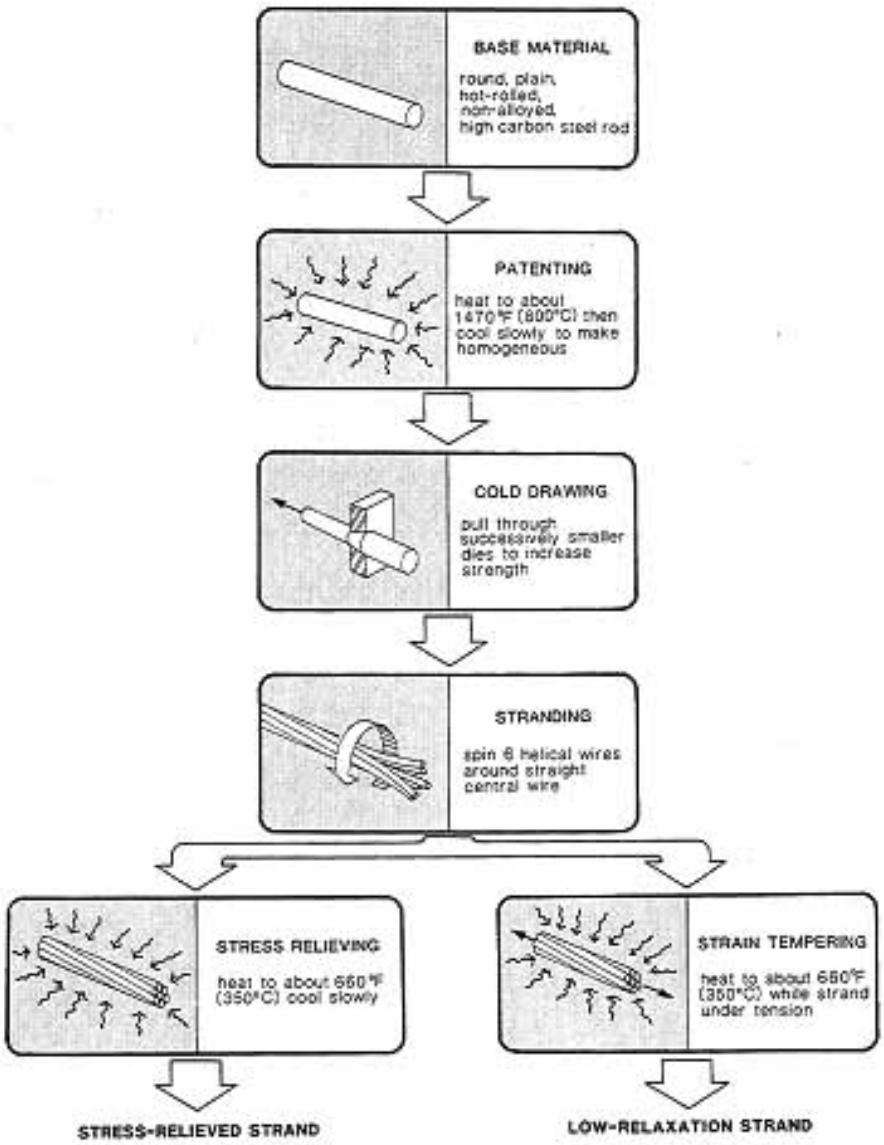


Figure 1 – Low-Lax Strand Manufacturing Process

All strand is the seven wire type with a center wire enclosed by six helically placed outer wires. The center wire is slightly larger than the outer six wires. Strand is stress relieved by continuous heat treatment, a process that produces a slight bluish tint to the strands. The process of fabricating low-lax strand is schematically shown in Figure 1. The ASTM specifications allow one butt-welded wire per 150 feet (45.72 m) of strand, but only during the fabrication process. Under no circumstances should welding of joints in strands or wires be allowed in the field.

The Standard Specifications allow the use of couplers for extending plain or deformed bars. The coupled unit shall have a tensile strength of not less than the manufacturer's minimum guaranteed ultimate tensile strength of the bars. The locations of couplers are subject to approval of the Engineer and shall be shown on the contractor's working drawings.

Effective packaging of prestressing steel is necessary to protect the material from physical damage and corrosion.

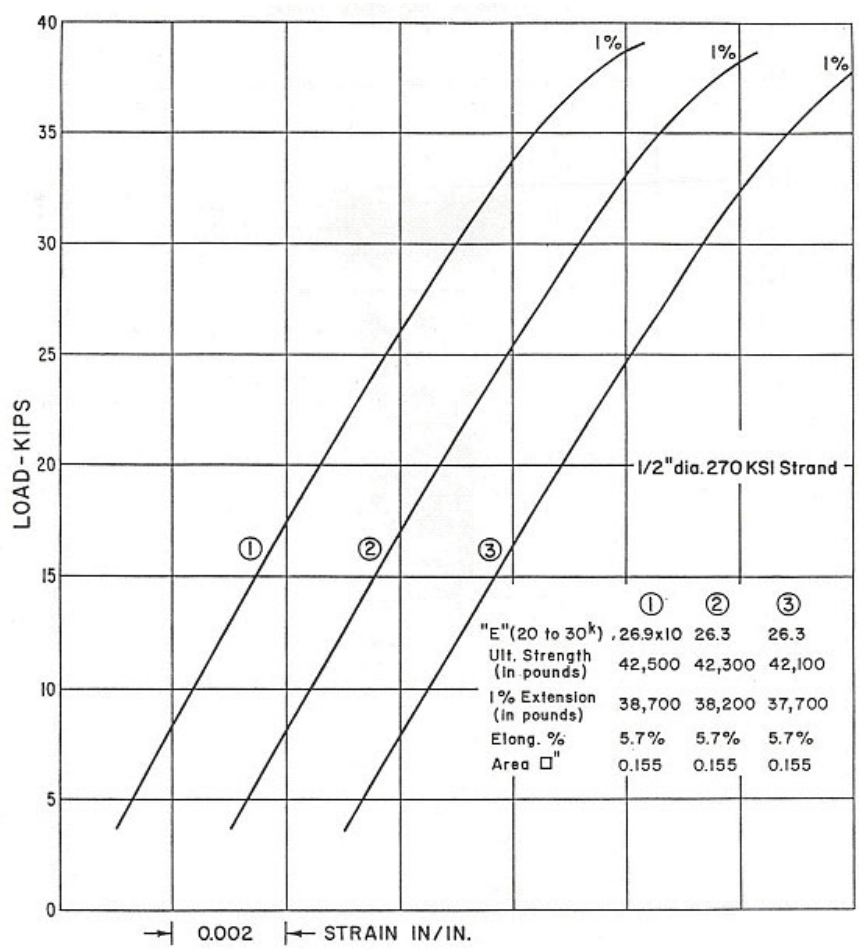


Figure 2 – Typical Stress-Strain Curve for 0.5 inch (12.70 mm) 270 ksi (1860 MPa) Strand

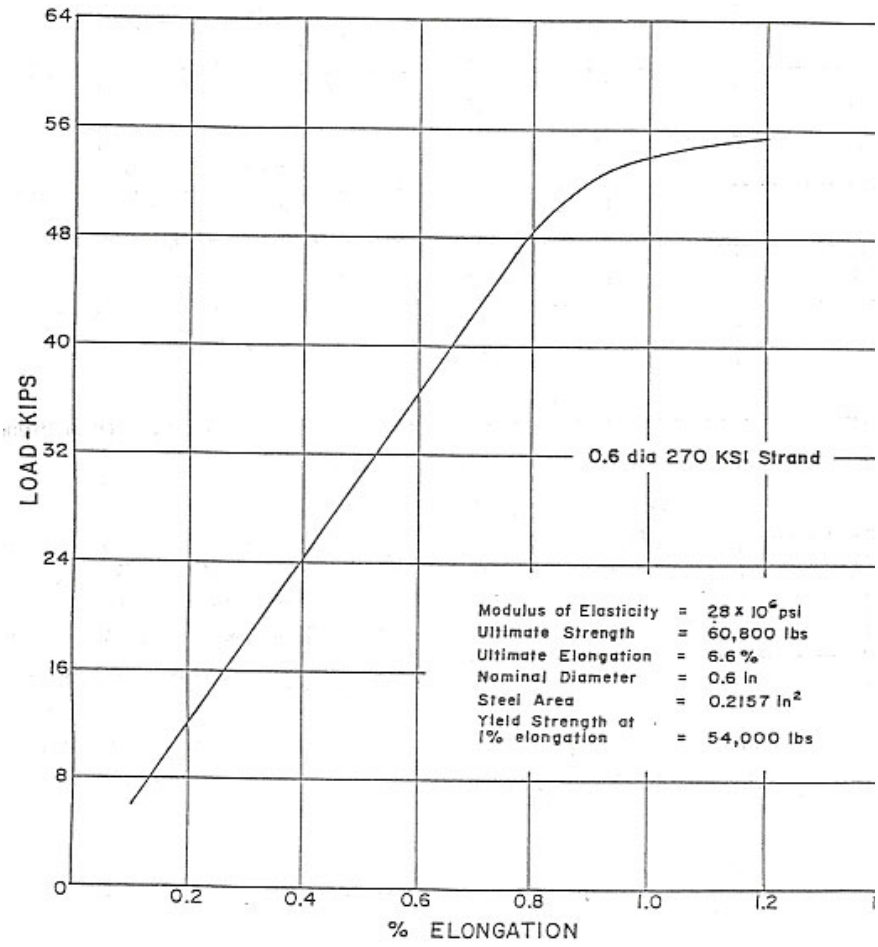


Figure 3 – Typical Stress-Strain Curve for 0.6 inch (15.24 mm) 270 ksi (1860 MPa) Strand

The packs should be inspected for physical damage immediately upon arriving at the jobsite. Any damaged pack must be replaced or restored to its original condition. The shipping package or form shall be clearly marked with a statement that the package contains high-strength prestressing steel, and the type of corrosion inhibitor used, including the date packaged. A release tag will be delivered with the strand. The release tags, which will have the area, (A), and the modulus of elasticity, (E), of the strand, as determined by METS, will be attached to the individual packs. Collect one of the tags and initial the remaining tags. On the collected tag, record the (A's and E's), and attach to a TL-29 for the job records. In addition, obtain the material properties (A's and E's) as determined by the manufacturer from each individual strand pack. The manufacturer's material properties will be used to calculate elongations during the stressing operation.

Prior to placement, it is important that prestressing steel be checked for corrosion or damage. A very small pit or crack in high-strength wire or bar will allow a stress concentration at that point and

could cause an abrupt failure of an individual bar or wire. Tests performed by METS on rods with 1/32" (0.8 mm) deep pits resulted in reductions of strength varying up to 50 percent.

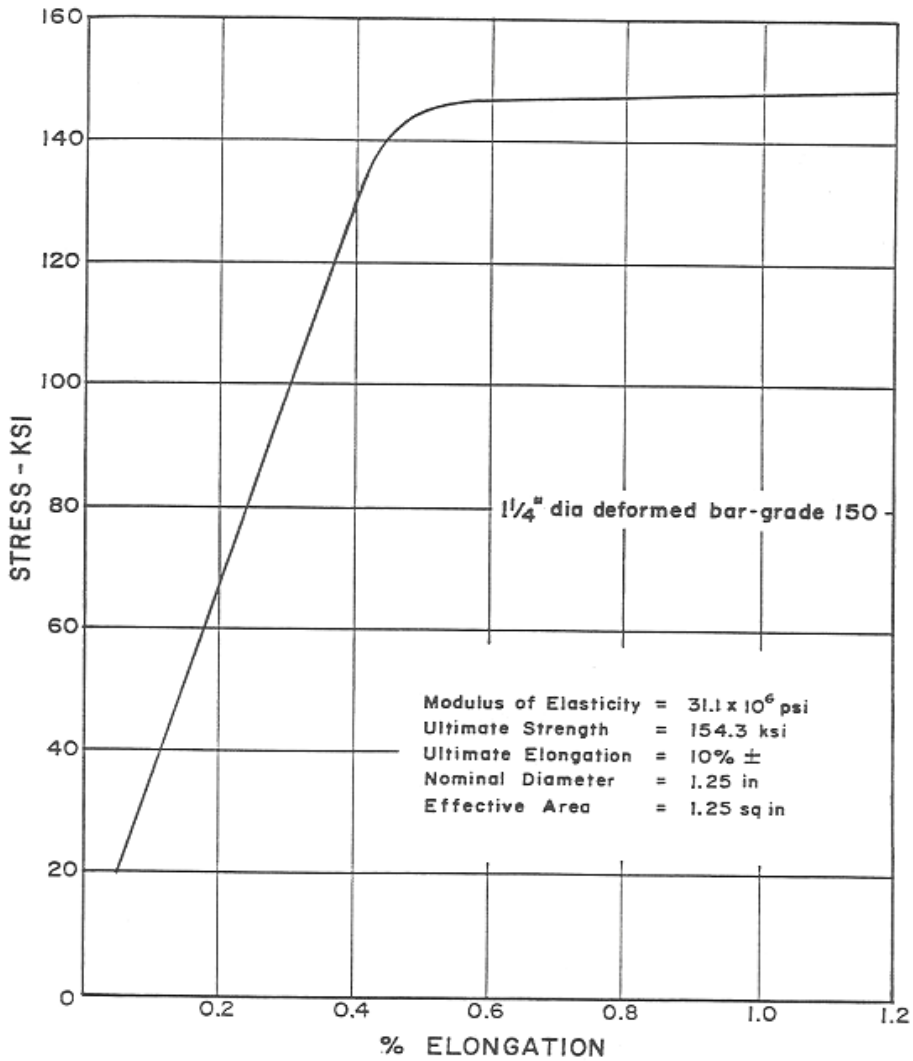


Figure 4 – Typical Stress-Strain Curve for 1 ¼ inch (32.0 mm) Grade 150 (1030 MPa) Deformed Bar

Section 50-1.05, "Prestressing Steel", of the Standard Specifications states that all prestressing steel be protected at all times against physical damage and rust or other results of corrosion from manufacture to grouting or encasing in concrete. Prestressing steel that has sustained physical damage at any time shall be rejected.

The following is presented as a guide for inspection of prestressing steel for rust before installation in ducts:

1. Upon opening, if there is an even coating of rust over the strands in the entire pack, the pack should be rejected. This situation indicates improper handling or storage.
2. If there are one or more wires in a strand that shows extensive rust throughout its length, the entire pack should be rejected. The wire was probably rusty when the strand was wound.
3. When there are spots of rust on a portion of strands in the pack, especially on the inside of the coil, this is the likely effect of condensation, usually caused by temperature changes during shipment or storage. If rubbing or scraping with your fingernail can remove these spots, the steel is acceptable. If light streaks of rust remain, the steel is still acceptable if pitting is not present.
4. Short sections of strand that contain clinging rust, pits, or other flaws should be rejected without rejecting the entire pack.

The above criteria can generally be applied to bars as well as strand. In addition, loose mill scale on bars should be removed in a manner that will not damage the material. Prior to rejecting prestressing steel, contact the structure representative or bridge construction engineer.

It is required that the prestressing steel be checked for rust and other flaws, as described above, while the tendons are being made up and before placing in the ducts. During the placement operation, inspection should also be provided for proper make-up of tendons, and for care in keeping the steel and ducts clean and free from any foreign material or damage from handling. Prestressing steel should preferably be cut with a carborundum blade. Flame cutting may be used provided proper care can be exercised near anchorages. Cold chiseling should be avoided near anchorages. Exposure to electrical current, for example arc welding, as a general practice is currently not allowed in the specifications. However, on a recent precast segmental bridge project, arc welding was used as a tendon installation method. If the contractor proposes arc welding, the circumstances and method must be reviewed and approved by the Headquarters Office of Structure Construction and the State Bridge Engineer, with approval on a case-by-case basis.

A corrosion inhibitor must be applied, if prestressing steel is placed in ducts prior to placing and curing of concrete. If the steel is placed after placement of the concrete, a corrosion inhibitor shall be required if the stressing and grouting are not completed within 10 days. The contractor shall provide an approved corrosion inhibitor that prevents rust or corrosion.

V.P.I. Powder, which stands for “Vapor Phase Inhibitor” Powder, is a common method used by contractors to protect prestressing strand. When properly applied, the powder is absorbed onto the metal surfaces to form an invisible film. This film passivates the metal and inhibits corrosion.

The manufacturer’s recommendations should be used when applying the powder. The ducts shall be reasonably dry. The powder is applied into the ducts by use of a floc gun. The application

concentration for V.P.I. Powder is typically one gram (0.035 ounces) per cubic foot (0.028 m^3) of enclosed space, or one gram per square foot of metal surface, whichever is greater.

V.P.I. Powder contains dicyclohexylamine nitrite and is moderately toxic. Repeated exposure may cause damage to the kidneys, liver, central nervous system, and blood. Avoid contact with eyes or skin. Goggles, coveralls, impervious gloves, and boots should be worn when handling the powder.

The contractor shall include provisions for placing V.P.I. powder on the working drawings. The provisions shall include the manufacturer's technical data, application rate, and a Material Safety Data Sheet.

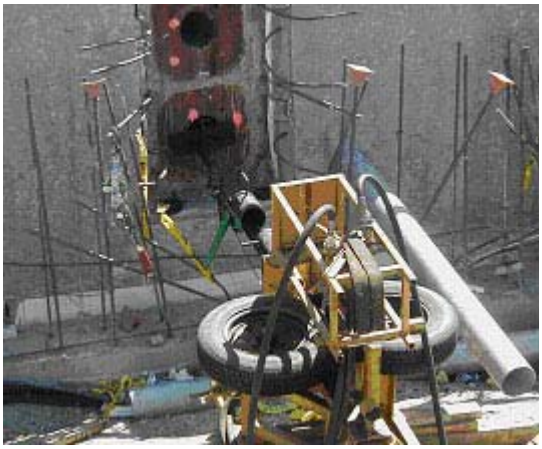


Photo 7 – Installation of Individual Strands by Pushing

Photo 8 – Strand Packs on Bridge Deck

Photo 9 – Dirt Free Prestressing Tendon

Photo 10 – Tendon Installed with Pulling Cuff

Photo 11 – Tendon Pulling Machine

Photo 12 – Cal-Wrapped Strand Packs

Photo 13 – Strand, Wedge and Anchor Head

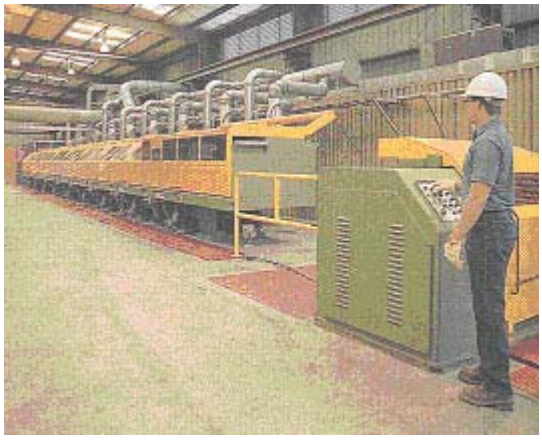


Photo 14 – Sumiden Cold-drawing Process

ANCHORAGE DEVICES

Approved permanent type anchorage devices shall be shown on the pretress shop drawings. Section 50-1.06, "Anchorage and Distribution", of the Standard Specifications requires that the final unit compressive strength stress on the concrete behind the bearing plate shall not exceed 3000 psi (21 MPa). The bending stresses in the plates shall not exceed the yield point of the material when 95% of the guaranteed ultimate tensile strength (GUTS) of the tendon is applied.

Anchorage devices must be preapproved by METS prior to their use on State contracts. The bearing plates shall be tested and released by METS. A TL-29 release form and a release tag are required prior to incorporating the bearing plates into the work.

The bearing plates are to be placed perpendicular to the slope of the prestress duct. The batter of the bearing plate should be checked during the working drawing review and confirmed while the prestress blockouts are being formed.

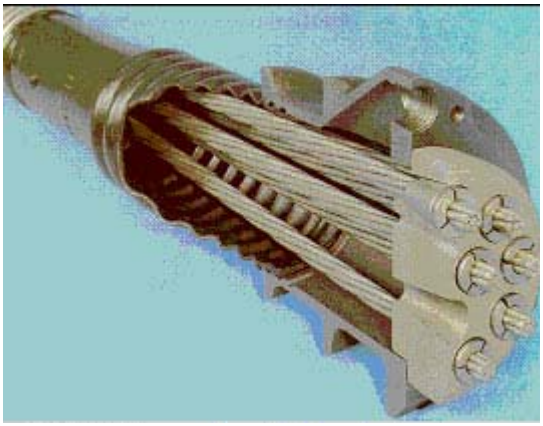


Photo 15 – DSI Multi-Plane Anchorage

Photo 16 – Anchorage System Testing

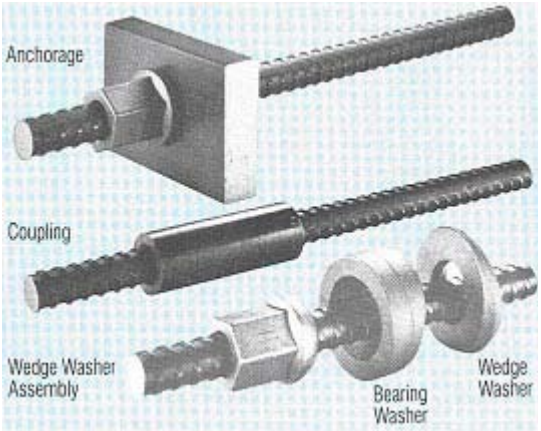


Photo 17 – AVAR Threadbar System

Photo 18 – Blockout for Anchorage Devices

STRAND WEDGES

The specifications require all permanent anchorage devices for post-tensioning to develop at least 95% of the guaranteed ultimate tensile strength (GUTS) of the prestressing steel. The anchorage systems develop the required strength through the interplay between wedges and prestressing steel, and between the wedges and anchor plate. Characteristics that effect this interplay are wedge angle, wedge teeth amplitude and spacing, type of steel, type of heat treatment, and general strand configuration in the anchor plate.

The care, cleanliness, lubrication, surface condition, and finish also effect the efficiency of wedge systems. All manufacturers have quality control procedures that should eliminate obvious manufacturing defects. On-the-job care is left to the discretion of the individual field crews. The contractor must use wedges that have been approved by METS. Pulling wedges may not be used as permanent wedges.

The wedge holes of the anchor block should be clean prior to placing the permanent wedges. Sand or foreign particles located in the wedge area of the anchor block can cause the wedges to fail.

Photo 19 – Wedges Inserted into Jack

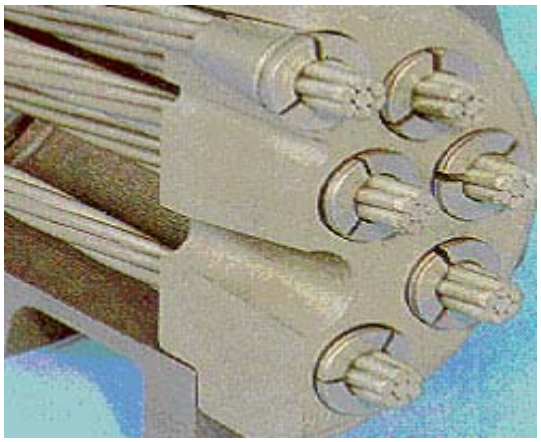


Photo 20 – Wedges in Anchor Head

PRESTRESSING JACKS

Jacks used in typical post-tensioning systems are generally the center hole variety (see Figure 5 for an example). Prestressing jacks have more wearing surface, longer jack stroke, and packing than conventional jacks of the same capacity. This increases the potential of variations in the accuracy of the applied force. Other conditions which may affect accuracy and efficiency of hydraulic units are: use of unfiltered oil, exposure of the system to dust or grit, eccentric loading, type of packing, ram position, oil temperature, hydraulic valves, ram and packing maintenance, and readout equipment. Care and effort must be exercised to maintain accuracy in the jacking equipment.

A condition that must be considered when using hydraulic jacks is hysteresis. Hysteresis is an energy loss due to a hydraulic pressure change inside the jack, causing inaccurate load values when the ram pressure is static or decreasing. An increase of hydraulic pressure also causes an energy loss, but this loss is taken care of by calibrating the jack and pressure gage with a load cell during this increase of pressure.

Improper gage readings occur when the ram is fully extended and the hydraulic pressure is dissipated against the jack case. This condition can cause harm only if it damages the jack or gage and if the gage reading is mistaken for actual tendon stress.

The contractor should monitor the stroke of the jack. Typically, jacks have a 12-inch (300 mm) stroke and if the ram is extended beyond this limit the jack will be damaged.

Fittings and valves are a common source of problems. The fittings are equipped with spring-loaded, self-closing ball valves that occasionally will not open when joined together. If this occurs anywhere except in the gage line, the system will not work and a high gage reading will show immediately. If the stuck valve is in the gage line, everything will work except the gage. Valves and fittings that leak or will not hold the load should be replaced. When fittings are replaced, it is imperative that high-pressure type fittings are used (e.g. Schedule 80). If there are any questions concerning high-pressure fittings, contact METS immediately.

In general, jacks are about 95% efficient, but actual efficiency will vary depending on the age and condition of the jack. Be cautious of any calibration chart that shows jacking forces much greater than 95% of pressure multiplied by the piston area. Load cells and pressure gages are available to check any questionable equipment.

Section 50-1.08 of the Standard Specifications requires that the jacks used to stress tendons that are permanently anchored at 25% or more of the specified minimum ultimate tensile strength of the prestressing steel, such as box girder tendons, be calibrated by METS within one year prior to use and after each repair. Jacks used to stress tendons that are permanently anchored at less than 25% of the specified minimum ultimate tensile strength of the prestressing steel, such as footing tie-downs, shall be calibrated by a private laboratory approved by METS within six months prior to use and after each repair. The Structure Construction web site, listed under "Field Resources", has current information for jacks used with all State approved stressing systems.

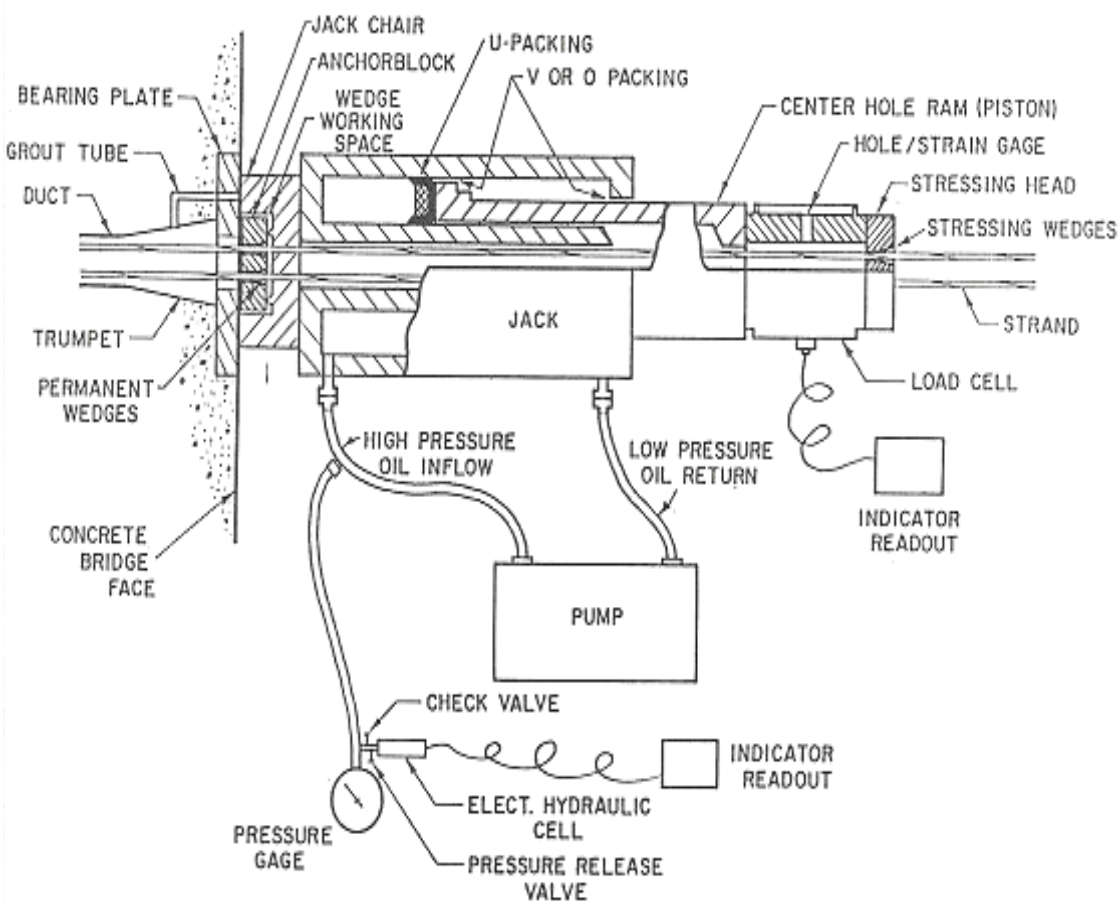


Figure 5 – Schematic Of A Typical Post-Tensioning System

Photo 21 – DSI Post-Tensioning Operation

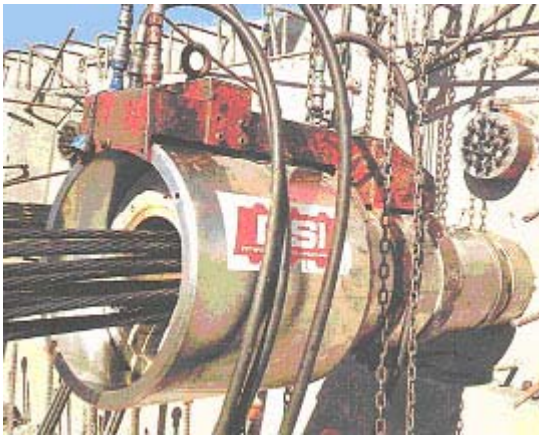


Photo 22 – High Capacity Prestressing Jack

Photo 23 – High Strength Bar Stressing Operation

PRESTRESSING OPERATION

a. Preparation for Stressing Inspection

One of the most essential preparations for stressing inspection is the calculation of theoretical elongations due to jacking. Recommended practice is to calculate 80% of theoretical elongation, to compare with field measurements taken between 20% and 100% of jacking force. A measurement taken at 20% should eliminate the effect of dead end seating loss, cable slack, and variation in the modulus of elasticity (E) of the strand at lower stress ranges. This is not a hard and fast rule. If variations are encountered or long cable lengths are to be stressed, one can base comparisons on a calculated 70% or 75% of the theoretical elongation.

It is the responsibility of the contractor to submit elongation calculations as part of the working drawings. Structure Design and the structure representative then check the contractor's calculations. Appendix D gives an acceptable method of calculating elongations as well as force factors.

Tendon elongations are calculated on the basis of an assumed modulus of elasticity (E) – usually 28,000 ksi (193,000 MPa) for strand. The strand area is commonly assumed to be 0.153 in^2 for 0.5-inch strand, and 0.207 in^2 for 0.6-inch strand. The actual Young's modulus (E) and cross-sectional area (A) for the individual strand packs shall be used to re-calculate tendon elongations. While the values of (E) and (A) from the quality assurance testing performed by METS will be recorded on the materials release tag for the prestressing steel, these values represent averages as determined from the limited samples performed on the lots. Therefore, the current policy is to utilize the actual values for (E) and (A) provided by the strand fabricator on the individual strand packs. The actual (E) and (A) provided by the fabricator must be used to calculate elongations. However, do not recheck the minimum required area of steel for the tendons and re-calculate the number of strands per tendon based upon the actual values. Often packs of strand arrive with varying (E) and (A). In this case, it is best to separate the strand so that all strand in a given tendon are the same. However, if the variations are small, tracking the varying strands in each tendon and using an average (E) and (A) is acceptable. Appendix D gives examples of elongation calculations.

Prior to stressing, it is also necessary to make preparations for monitoring the jacking force. Section 50-1.08, "Prestressing", of the Standard Specifications requires the contractor to have two pressure gages or one pressure gage and a load cell for each jack. During the stressing operation, the contractor does not have to use both pressure gages at the same time. The intent of

the extra gage requirement is to have a calibrated back-up gage on hand if needed. Re-certification of the contractor's gages and jacks is required every 12 months. State pressure cells usually monitor the contractor's jack and gage during the stressing operation. Up to date information regarding jack calibration is available by accessing the structure construction web page.

The structure representative or assistant structure representative should be familiar with the calibration chart and pressure cell prior to stressing. Appendix B gives instructions in the use and care of the pressure cell, and the *Bridge Construction Records and Procedures Memo* 160-3.0 gives administrative instructions relevant to the pressure cell.

b. <u>Field Inspection</u>

The practice of stressing both simple span, and shorter continuous frames from one end only is common, and must be shown on the contract plans or specifications. When two-end stressing is required, the contractor must stress both ends to P_{jack} and show the actual method and sequence of stressing on the working drawings.

In order to minimize the possibility of undesirable construction stresses, Standard Plan B8-5 states, "No more than one-half of the prestressing force in any girder may be stressed before an equal force is stressed in the adjacent girders. At no time during the stressing operations will more than 1/6 of the total prestressing force be applied eccentrically about the centerline of the structure." However, note that the 1/6 factor is often modified for railroad structures.

Structure Design is responsible for checking for compliance to the requirements of Standard Plan B8-5. In addition, Structures Design will check the working drawings to confirm the correct duct profiles, prestressing force, elongation calculations, and anchorage systems used before approval. If compliance with these requirements is overly difficult because of field conditions, Structure Design should be consulted before deviating in any manner from the approved working drawings.

Duct ties are always required in girder flares near the exterior girder prestress anchorages. Refer to Standard Plan B8-5 for limits and details of these ties. Duct ties are also required in *Bridge Memos to Designers* when the radius of the bridge is less than 800 feet (250 m), or the $P_{jack}/Radius$ per girder ≤ 7 (U.S. customary units). The limits of, and details of these ducts ties should be included in the contract plans.

In order to efficiently monitor stressing operations, a record in chart form must be kept for each tendon stressed. Figure 7 shows Form OS-C87 titled "Post-Tensioning Field Monitoring

Chart". Note that some of the information shown can be entered prior to stressing. Remember, that this form is a guide. You may custom design your own chart. After completion, place this form in the job files.

Each individual strand should be marked or painted at both ends of the structure to measure elongation and check for slippage. Tendons should be checked during and after stressing for any strand slippage or dead end seating loss. The actual area of ½" prestressing strand typically varies between 0.151 (97.4 mm^2) and 0.154 (99.4 mm^2) square inches. However, some strand have been received with an area as small as 0.149 square inches (96.1 mm^2). Such small strand has presented problems with proper seating of the wedges. Particular care should be used when stressing any strand with an area below 0.151 square inches (97.4 mm^2). With the Dywidag bar system, counting the turns of the anchor nut during stressing can also monitor the elongation.

An important requirement of prestressing inspection is obtaining the anchor set shown on the plans. Anchor set is the amount of strand movement at the time of force transfer to the bridge. This is usually 3/8" (10 mm) for continuous structures and per shop plans for simple spans. In most prestress systems, elongation of the tendon occurs within the jack itself. At 0.75 f'_s the tendon elongates approximately 1/12" per foot (0.72% strain) of jack measured from the anchorage to the pulling head. When measuring or computing anchor set loss, do not include the length of the tendon within the jack. Refer to Appendix D for calculating the effect that anchor set has on tendon stress. For a complete jacking sequence including anchor set, see Figure 6, which is provided by the VSL Corporation.

Structure Construction procedures state that the pressure cell is used at the start of stressing to verify the contractor's calibration chart and at least one calibration curve be made per structure of frame. The structure representative may require additional monitoring of the prestressing operation as needed. Figures 8 and 9 are examples of completed forms DS-C 86 and 86A for recording the contractor's gage readings versus pressure cell readings. After completion, place these forms in the job files.

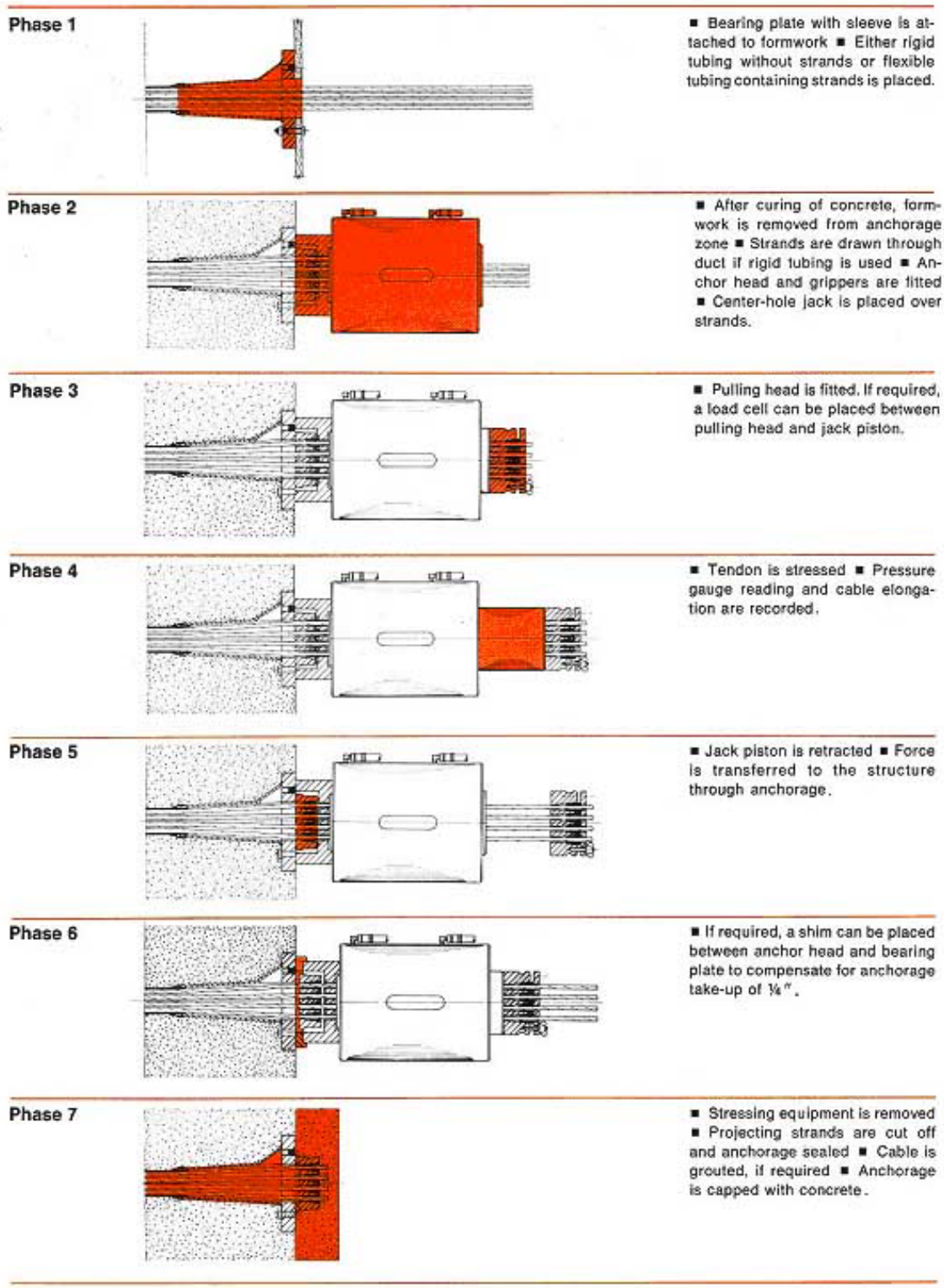


Figure 6 – The Complete Jacking

STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
Post-Tensioning Field Monitoring Chart
Form No. OS-C87 1/2005

Post-Tensioning Field Monitoring Chart

Br. Name _____ Contract # _____ Date Tendons Placed _____

Br. Number _____ Prestress System _____ Date Tendons Stressed _____

Stressing Sequence									
Tendon Number									
Jack & Gage No.									
Date Stressed									
Date Grouted									
P_j / No. of Strands									
Gage @ P_j									
20% P_j/Gage									
Meas. Elong. @ P_j - ¼"									
Meas. Elong @ 20% P_j									
Elongation (ΔL)									
Meas. After Seating									
Anchor Set									
Total Meas. Elong.									
Theor. 80% Elong.									
% Dev. From Theor. (±)									

Notes:
1. Subtracting ¼" from the measured elongation is due to the strand elongation inside the jack. This is calculated by multiplying 1/12 inch per foot of strand between the anchor and pulling wedges at P_{jack}.
2. For two end stressing, use a second form for the second end. Summarize the data in the last three lines on one of the two forms.
3. For non-simultaneous two-end stressing, the anchor load will be in excess of 20% Pj at the second end. However, it is suggested that the measurement be taken at 20%Pj to be consistent.

Figure 7 – Post-Tensioning Field Monitoring Chart (Form OS-C87)

DEPARTMENT OF TRANSPORTATION

JOB STAMP

PRESTRESS CALIBRATION
MONITORING SHEET

04 - SC1 - 85 - 3.0/5.3
04 - 123454
Wide River Bridge

DS-C86 wp50

DATE: 08 - 31 - 90 STR. REPRESENTATIVE: Joe Bridge

NAME OF SYSTEM: VSL INSPECTOR(S): I. Girder, T. Beam, I. M. Lost

JACK NUMBER: 6 - 10 - 43

GAGE NUMBER: 6 - 10 - 43 B

FOR 1/2" 270 KSI STRAND ABSOLUTE MAX..Pj=31 Kip/Strand X #Strands/Tendon: _____ = 31 Kips X 48 = 1488 K

FOR 0.6" 270 KSI STRAND ABSOLUTE MAX..Pj=44 Kip/Strand X #Strands/Tendon: _____ = 31 Kips X ____ = _____

CONTRACT REQUIRED .....Pj = 1488 K

Theoretical Maximum Gage Pressure:.....= $\frac{Pj}{\text{Ram Area}}$ = $\frac{1488\ K}{179.1\ in.^2}$ = 8308 psi

Maximum Gage Pressure From Latest Contractors Calibration: 8750 psi

Strain Gage Indicator CHC 13686

Electro Hydraulic Cell Number: 18 , Numerical Display Setting: 1094 , Actual Gage Factor: 0.72

Measurable Elongation = 80% Total theoretical Elongation: 28.5"

Gage Reading	Load from Indicator		Load from Calibration Chart				Remarks
1680	297		300				20% P_j
2000	352		350				
3000	523		520				
4000	692		690				
5000	855		855				
6000	1025		1025				
7000	1198		1195				
8000	1365		1360				
8720	1488		1480				Meas Elong = 29"

Figure 8 – Prestress Calibration Monitoring Sheet (Form DS-C86)

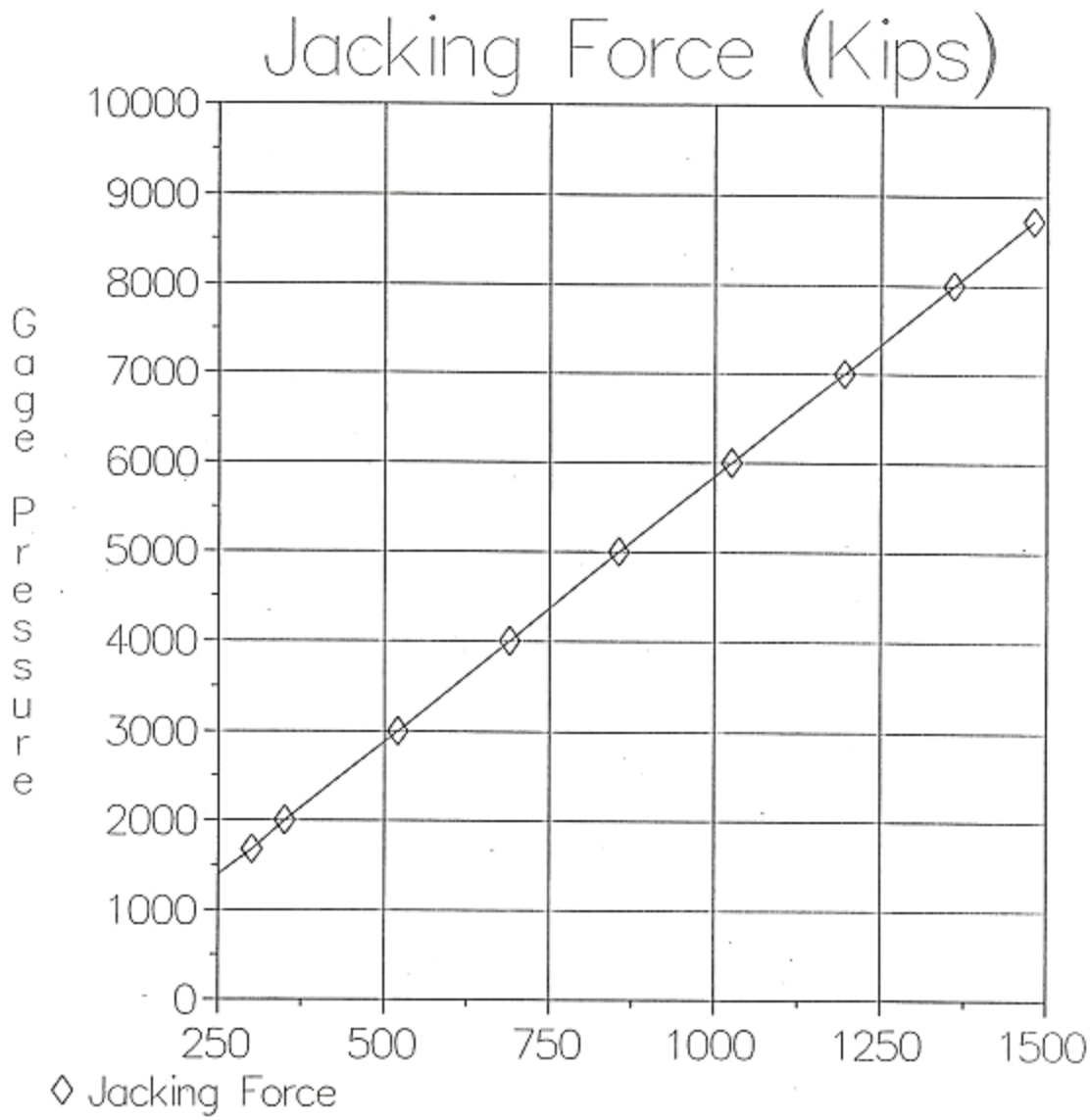


Figure 9 – Gage Pressure vs. Jacking Force (Form DS-C86A)

c. Overstressing of Prestressing Steel

Technically, prestressing wire and strand develop high strength and excellent creep characteristics through cold drawing. During the cold drawing process, the grain structure is elongated and aligned into a condition resulting in specific physical and mechanical properties.

Due to the possibility of wires or strands being of unequal length within a tendon, some of the wire or strands could be stressed to their yield strength, even when the tendon is not overstressed. Therefore, when the jacking force exceeds the 75% limitation, some of the wire or strands in the tendon may be seriously overstressed. When steel such as prestressing wire or strand is stressed beyond its elastic limit or yield strength, some of its physical characteristics change. The most significant changes are in the modulus of elasticity (E) and the creep rate. If these properties are changed by permanently overstressing, the significance of elongation measurements is questionable. Remember, if it appears that the 75% limit is being exceeded - **STOP!**

The effect of permanent overstressing on physical properties of strand has been demonstrated by laboratory tests in a 100 ft. pretensioning bed as follows:

Initial Jacking Force (kips)	Initial Percent of Ultimate Load (%)	Residual Load at 72 Hours (kips)	Percent Stress Loss At 72 Hours (%)
34	82.3	26	23.5
28	67.8	27	3.6

This example indicates that strand, when kept in an overstressed condition (greater than 0.75 f'_s), results in a significant reduction of prestressing force due to the change in creep properties of the strand. This is one reason why the maximum anchor stress may not exceed 70% of the ultimate strength of the steel; and the jacking force must not be exceeded.

d. Elongation Measurements and Calculations

The measured elongation should substantially agree with the calculated elongation. Since the last edition of the *California Prestress Manual (May 1992)*, the friction coefficient (μ) changed from 0.20 to a frame length dependant value (0.15 to 0.25 and higher), and the wobble coefficient (K) has been reintroduced as 0.0002/foot (0.00066/meter).

Frame Length (feet)	Wobble Coefficient "K"	Friction Coefficient "μ"
0 - 600	0.0002	0.15
600 - 900	0.0002	0.20
900 - 1200	0.0002	0.25
> 1200	0.0002	See P/S Committee

However, due to a variety of different reasons, field measured elongations can differ by as much as 5% to 10%, even with the updated coefficients. This is acceptable as long as the variations are understood and explained; but deviations between elongations of similar tendons of the same bridge should not vary more than 4% +/-. Remember, each case must be carefully examined to ensure compliance with the working force required.

The following are possible reasons for elongations not being within the calculated range:

1. Incorrect number of strands placed in the tendons.
2. Excessive wobble of ducts increases friction and decreases elongation.
3. Unusually smooth duct placement decreases friction and increases elongation.
4. Even, layered strand placement reduces friction and increases elongation, particularly when strands are 'pushed' into the duct.
5. A pressure cell does not detect a change in jack efficiency. This may cause faulty readings.
6. Elongation calculations may be wrong due to the following:
   a. Incorrect modulus of elasticity (E) or area of strand (A).
   b. Incorrect or varying tendon lengths due to skew or sharp radii.
   c. Differing coefficient of friction between girders on sharply curved structures.
   d. Different tendon paths in a girder.
7. Incorrect method of measuring elongations.
8. Slippage of strand during stressing, especially if the strand area is small (below 0.151 in^2 or 97.4 mm^2).

9. Gage damaged or indicator not zeroed.

The cause of any inconsistent elongations among the tendons of a structure must be determined as soon as possible. Do not cut off excess strand until the problem is resolved. In the event it is necessary to de-tension a tendon, stressing contractors must have suitable equipment available for this purpose. The contractor's de-tensioning plan must be acceptable to the engineer. It is recommended that the engineer discuss the de-tensioning procedure with the Prestressed Concrete Committee.

When a frame is stressed from two ends, first end stressing results should be compared to theoretical first end calculations. Including the first and second end results will usually make any discrepancies less apparent, because second end results tend to offset some of the difference.

As a general practice, strands should not be cut off until all tendons in the structure are fully stressed.

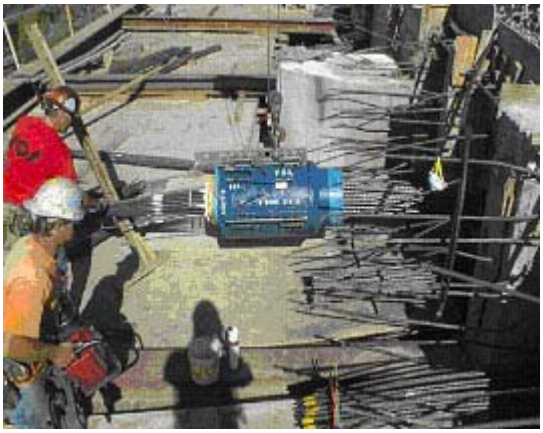


Photo 24 – Long Frame Stressing

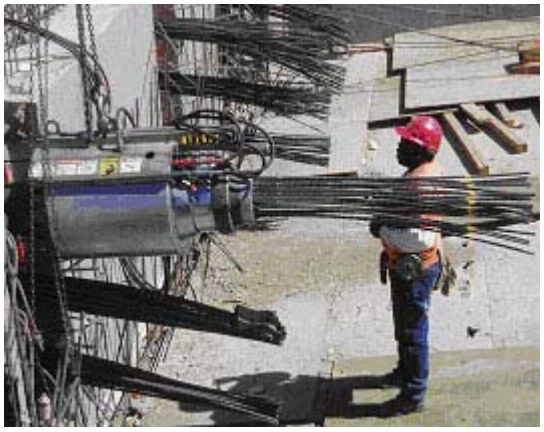


Photo 25 – Paint Marks Show 4 ft. Elongation

GROUTING OPERATION

Grouting of post-tensioned structures has a dual purpose:

1. To protect the strands from corrosion and slippage,
2. To develop the required ultimate moment capacity of the structure.

Grouting is a very important step in the overall stressing operation. There are four essential elements to a successful grouting job:

1. Ducts that are fully incased in well consolidated concrete, free of cracks.
2. Proper materials that have been approved by METS.
3. Proper equipment in good working order.
4. Procedures that produce good results.

Grouting material consists of Type II Modified cement mixed with not more than five gallons of water per sack of cement. Be sure to check the contractor's gage or calibration marks to ensure compliance with the five gallons per sack maximum limit. The addition of an approved admixture is optional, but must be approved by the Engineer (see Std. Spec. 50-1.09). Admixtures, if used, are generally designed to increase or sustain the fluidity of the grout and may become necessary in order to comply with the maximum water requirements.

The grout mixture, including any approved admixtures, should be checked in accordance with California Test No. 541 (see Appendix F). This test is required as a check at both the inlet and outlet ends. The flow cone is plugged, plumbed, and filled with a known quantity of grout. Then the time required to empty is measured with a stopwatch that reads to the nearest 0.1 second or less (a minimum efflux time of eleven seconds is required). A record should be kept of test results. The twenty-minute quiescence test should also be performed when appropriate. Remember that this and all other equipment must be cleaned and maintained regularly.

While the specifications do not currently establish a maximum efflux time, a test resulting in excess of fifteen seconds may be undesirable as this increases the chances of a blockage. A slow efflux time can be attributed to several possible problems: 1) loss of water in the equipment due to poor seals, hose connections, etc., 2) hot weather conditions, 3) insufficient mixing time, 4) hot cement or old cement.

The water cement ratio must not be increased to accommodate grouting. If this is a problem, try to detect and correct the problem before proceeding. Also, be sure to receive a certificate of compliance for the cement used. Cement used for grouting should not contain any lumps or other indication of hydration or "pack set". Pack set can occur when cement is too old and/or exposed to moisture. Lumps and trouble are synonymous.

Equipment used for grouting is generally at the option of the contractor. However, the specifications do require equipment capable of grouting at least to a pressure of 100 psi (700 MPa), a pressure gage having a full-scale reading of not more than 300 psi (2000 MPa), and standby flushing equipment provided on structures requiring duct vents. Also a screen with .07" (1.78 mm) maximum clear openings (approx. 14 mesh) must be used prior to pumping to eliminate lumps and foreign material. Grout must be continuously agitated during pumping.

Photo 26 – Large Scale Grouting Operation

Photo 27 – DSI Grout Pump

Initial pumping pressure should be small (less than 40 psig) and should gradually increase due to friction between the grout and the duct until the duct is filled.

The practice of flushing the prestressing ducts prior to grouting, while not addressed in the specifications, is at the option of the contractor. It is recommended that flushing of strand systems be discouraged under normal conditions. In some structures, particularly those with large ducts, it is extremely difficult to completely remove all flushing water. The entrapped water evaporates leaving a void that prevents bonding of the prestressing steel and increases the chances of rusting. On the other hand, it is preferable to flush the monobar ducts just prior to grouting to improve groutability in the restrictive space between bar and duct. The quantity of entrapped water is minimal.

Couplers pose a grout problem inherent to bar systems. If care is not exercised when positioning them in their enlarged duct housing, they can jam against the housing during stressing. If this occurs, it not only produces an incorrect stress distribution in the bar, but also seals the duct. Pre-flushing or blowing air through the ducts after stressing are a means of discovering blockages. An inspection checklist for the grouting operation is available in Appendix C.

Blockage or leakage of a duct during grouting of tendons with strands has become less common since the advent of rigid ducts. However, in the event of blockage or leakage, it is the responsibility of the contractor to propose and execute a successful solution. Attempting to grout a blocked duct by simply injecting grout from both directions is unacceptable, as this tends to create a pocket of compressed air in

the duct. Building up the grout pressure to free a blockage may also be detrimental as the pressure forces out water and the cement particles can form a plug, which cannot be removed by flushing or blowing with air.

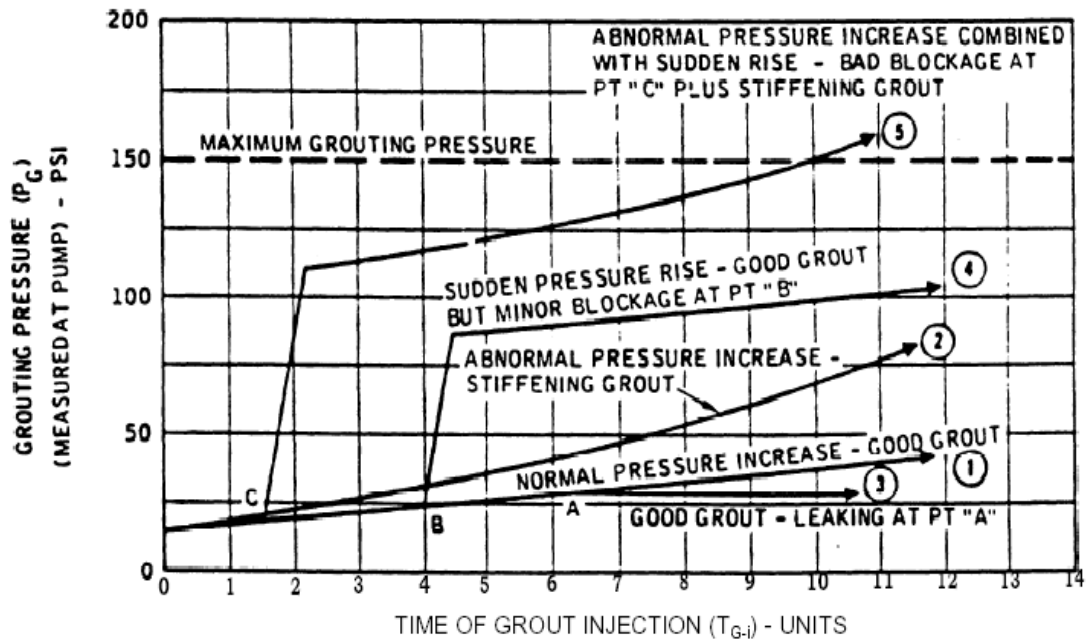
Upon grouting a tendon, it is necessary to see that the outlet valve is closed before the inlet valve. Remember, positive shut-off valves are required at injection pipes. Vents and ejection pipes also are required to be fitted with valves capable of withstanding the pumping pressures. Prior to closing the outlet valve, the wasted grout should be checked for equivalent consistency, especially in the case of ducts that had been previously flushed with water. All vents should be open when grouting begins. Grout should be allowed to flow from each vent until any residual water or entrapped air has been removed. Once a smooth stream of grout is achieved, the vent should be capped or otherwise closed. Remaining vents should be closed in sequence in the same manner.

Care should be taken with the wasted grout. Avoid running grout into pervious backfill, traffic, structural or highway drainage, etc. Discuss with the contractor prior to beginning the grouting operation how the wasted grout and spillage will be cleaned up and define the location of disposal. The grouting operation, cleanup and disposal, shall be in accordance with the approved Storm Water Pollution Prevention Plan (SWPPP) and Construction Policy Directive CPD 04-5 "Disposal of Portland Cement Concrete Liquid Residues".

A great deal of information can be obtained by monitoring the grout pressure gage and analyzing the information. Grout injection time and the length of duct are interrelated and are dependant on two constants; the duct void volume and the pumping rate, as shown in Figure 10. During pumping, grout will conform to known principles of hydraulics. Good grout will exhibit a gradually increasing pumping pressure due to friction in the duct, any head that exists, and normal grout stiffening (Figure 10, Curve 1). A grout that "flash sets" in the duct will still exhibit increasing pressure, but at a greater rate (Figure 10, Curve 2). A relatively constant pressure (Figure 10, Curve 3) is a characteristic of a leaky duct. A minor blockage will be indicated by a sudden jump in pressure, followed by a continued gradual increase in pressure (Figure 10, Curve 4). Monitoring the grouting pressure can help determine whether (a) the entire duct can be filled without exceeding the maximum recommended pressure, (b) the grouting operation should be transferred to a vent, or (c) the grouting operation should be discontinued, with the duct immediately flushed, and the blockage repaired. An excessive blockage, possibly combined with stiffening grout, would show up as a large increase in pressure (Figure 10, Curve 5). As illustrated in Curve 5, there is little to be gained by allowing excessive pressure to build and hoping that the problem will correct itself. Grouting should be stopped at a low pressure so the grout can be flushed out easily.

Although grout will conform to known principles of hydraulics, there are too many variables, and not enough test data to establish reliable flow coefficients, thereby allowing pumping pressures to be

predetermined by calculation. However, successful grouting on one or more tendons will establish the "normal" pressure vs. time relationship, which can be expected, and thus any "abnormal" conditions existing in other tendons can be detected.



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^3/FT)
C_p	=	RATE OF GROUT PUMP (FT^3/MINUTE)
L	=	LENGTH OF DUCT FILLED WITH GROUT (FT)

Figure 10 – Pressure vs Rate of Grout Injection

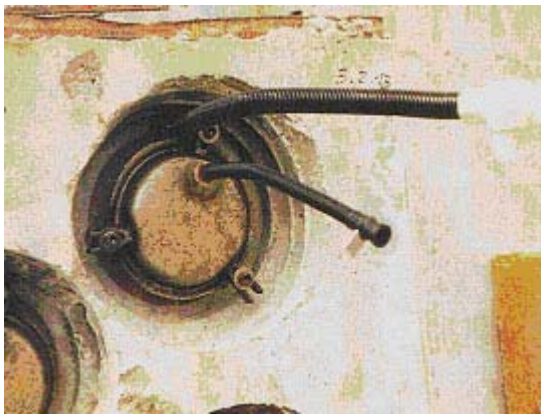


Photo 28 – Grout Cap and Tubes in Place

Photo 29 – Grout Vents

APPENDIX A – PRESTRESSING SYSTEMS

a. New System Proposals

The following checklist includes the minimum required information necessary for approval by the METS for a new or modified post-tensioning system:

All prestressing systems that are proposed for use in the State of California shall be submitted in the following form to expedite approval of the system or systems.

Seven copies of the final submittal are required by Caltrans and shall be bound or stapled together with a title page indicating the name or names of the systems being submitted. The individual numbered sections shall be tabbed and listed in the following order:

1. DESCRIPTION
   - a. Current product description literature of the system or systems being proposed.
   - b. Prior listing of the system. Include specific details of projects where it has been used.
   - c. Complete records of tests run on the system independent of Caltrans' witness tests.
   - d. Explain how seating loss is to be controlled and measured.
2. HARDWARE
   - a. Anchor head.
     - 1) Detailed drawing.
     - 2) Mill certificates – showing material composition, strength and manufacturer.
     - 3) Quality control document.
   - b. Bearing Plate
     - 1) Detailed drawing.
     - 2) Mill certificate.
     - 3) Quality control statement.
   - c. Wedges or Nuts
     - 1) Detailed drawing.
     - 2) Mill certificate.
     - 3) Quality control document.
   - d. Trumpet detail drawings.

3. CALCULATIONS
   a. Stress behind bearing plate at service load after losses.
   b. Stress behind bearing plate at 95% specified ultimate tensile strength.
   c. Maximum bending stress in bearing plate of 95% specified ultimate tensile strength.
4. SYSTEM
   a. Detailed drawings of the anchorage system, jacking system, and duct and grouting details.
   b. Complete information on grouting procedures and equipment to be used.
   c. Description of how system components are protected from physical damage and corrosion.
   d. Description of tendon repair or replacement should a failure occur.
   e. Description of how qualified technical assistance is provided in the field for the contractor performing the work.

b. <u>Presently Used Systems</u>

Following is a summary of the State approved prestress systems. The summary is considered complete and includes both systems used in bridges and as tieback anchors. However, it should be remembered that new developments in the prestress industry necessitate change. Therefore, the various systems may revise capacities, improve anchorages, develop new jacks, etc. Of course, changes such as these may void prior system approval. Many of the companies also have system capacities (smaller and larger) that have not been approved for State use. Both METS in Sacramento and the Division of Engineering Services' Prestressed Concrete Committee have current files for all approved systems. Check the Structure Construction web site for a current list of those contractors with currently approved systems.

<u>AVAR Construction Systems, Inc.</u>

The currently used AVAR Systems utilize 0.6" (15.24 mm) strand anchored with split wedges at both the anchor plate and the pulling head. For box-girder applications, AVAR presently uses anchorage systems utilizing 12, 19, 22, and 27 – 0.6 inch (15.24 mm) strands (see AVAR Systems sheet). In combination, these systems can deliver the precise amount of prestressing force required on the contract plans, in a combination that is economically advantageous to both the contractor and the State. A single ACS – 27.6 anchorage provides up to

1188 kips (5290 KN) of prestressing force. AVAR also has a variety of anchorage systems utilizing fewer strands for applications other than box-girder construction.

Photo 30 – AVAR

Photo 31 – AVAR Spliced Girder Stressing

Dywidag – DSI (Dyckerhoff and Widmann, Inc.)

Dywidag systems include both deformed bar and strand systems. The Dywidag threaded bar prestressing system was developed in Europe. It's use, including a broad application as a rock anchor, has greatly expanded in this country since its introduction a decade ago. The bars have cold-rolled, thread-type deformations continuous along two opposite sides of the bar. The continuous deformations are especially adaptable to segmental construction. The bars can be cut to any length to fit field conditions and yet retain a threaded end for splicing or anchoring. Splicing is performed very simply with threaded couplers. The deformations are also used to transfer the prestress load in the bar to the anchor nut, and to bond the bar to the structure when grouted.

The bars are available in various diameter sizes. They may be used as a single tendon (monobar) or in multiple groups. State approved applications use 1" (25.4 mm), 1-1/4" (31.8 mm) or 1-3/8" (34.9 mm) monobar. A bell-type anchorage is normally used with the monobar. The bell consists of a steel cylindrical section with a thin steel plate attached to one end. The principle behind the design of the anchor is to confine concrete within the cylinder and let the confined concrete transmit the majority of the anchor load to the structure.

Stress is applied with small, portable jacks that can be handled by one or two persons. The jacks contain a ratchet assembly that is used to advance the hex anchor nut when stressing the bar. The smaller size jack, although rates at 60 metric tons, has the capacity to stress the 1-1/4" (31.8 mm) bar to 75% ultimate. The larger jack, rated at 110 metric tons, is more rugged and is used for difficult conditions. (A metric ton equals 2204 lbs.)

Dywidag strand systems typically use 0.6" (15.24 mm) strand for 4 to 27 strand tendons. For box girders, DSI uses combinations of 9, 12, 15, 19 and 27 – 0.6" (15.24 mm) strands (see DSI Systems sheet).

Photo 32 – Stressing a DSI 27 Strand Tendon

Photo 33 – DSI Post-

Photo 34 – Close-up of DSI 1886 Kip Jack

Photo 35 – DSI Anchorages and Block-out

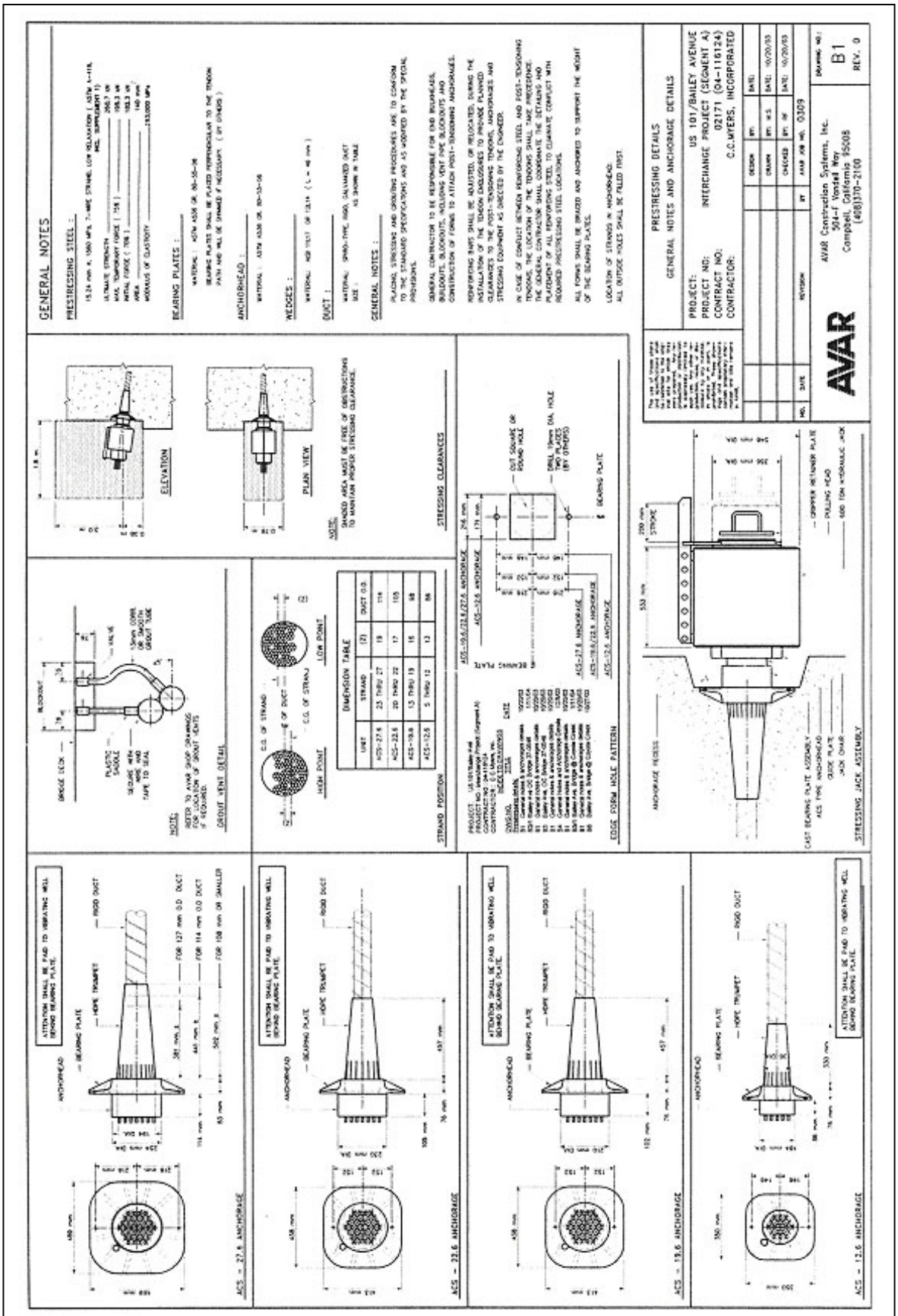


Figure 11 – AVAR Post-Tensioning Systems Used For Box-Girder Construction

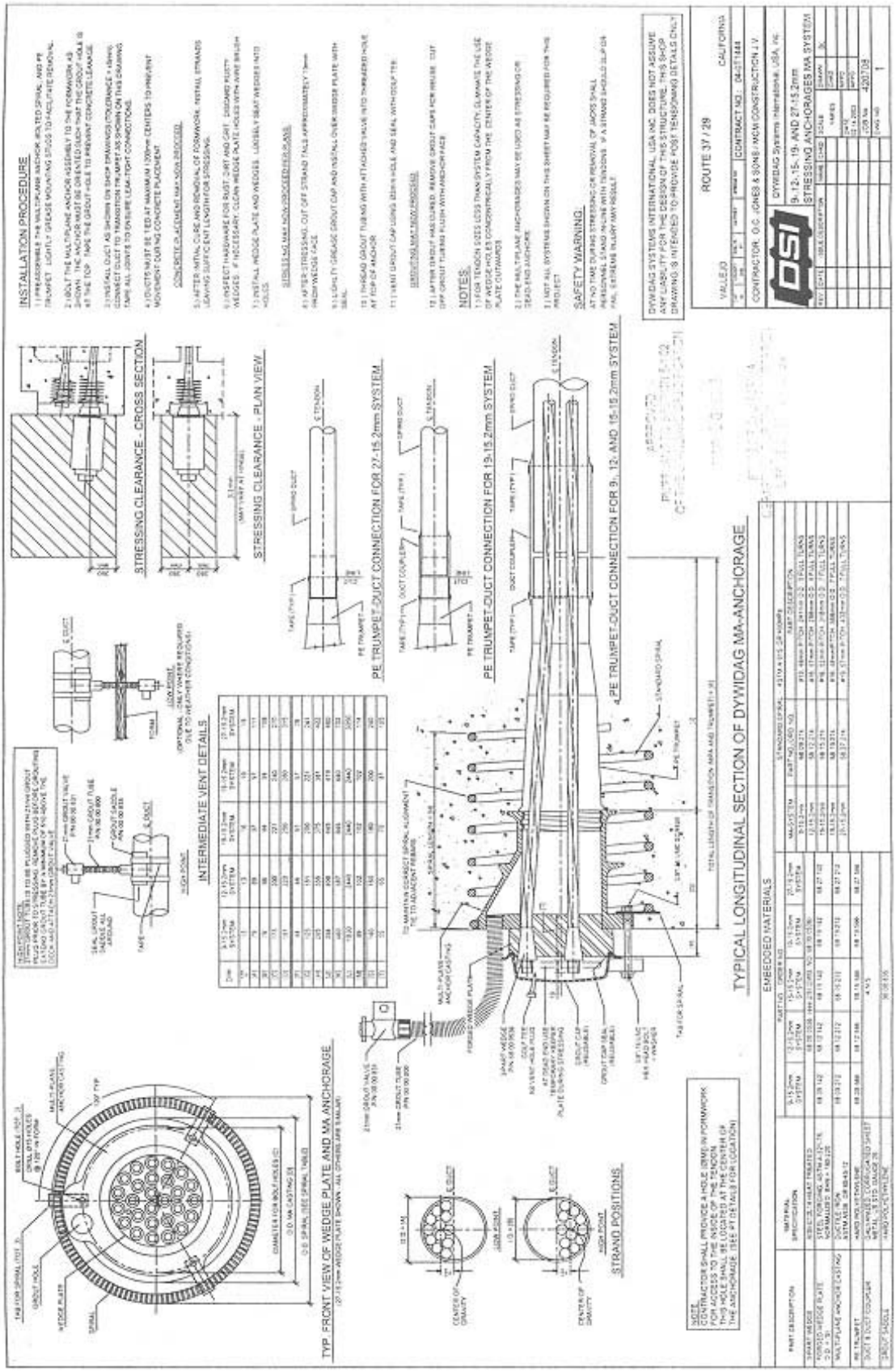


Figure 12 – DSI Post-Tensioning Systems Used for Box-Girder Construction

Stresstek System

Stresstek is not currently active on State projects, but is an approved system. Stresstek anchors individual ½" (12.70 mm) strands with a pair of split wedges at the anchor plate and three piece wedges in the pulling head. Individual strands are placed in a strand guide that is inserted into the center hole of the jack. A manually operated device, either mechanical or hydraulic, is used to initiate seating of the permanent wedges.

Anchorage systems presently used are capable of holding a maximum of 13, 19, or 31 ½" (12.70 mm) strands. Also approved are the Stresstek 0.6" (15.24 mm) strand systems using 4, 7, 13, or 19 strands maximum.

VSL System

As of the writing of this manual, VSL is not currently active in competing on State bridge projects. The VSL System uses individual ½" (12.70 mm) strands anchored with pairs of split wedges at the anchor plate and three part wedges at the pulling head. VSL presently uses anchorage systems capable of holding a maximum of 1, 4, 7, 12, 19, 24, 27, and 31 strands. The anchor set is determined by the head space between the anchor plate and jack. A 4 strand system utilizing 0.6" (15.24 mm) strand has also been approved for use on State projects.

VSL has also developed a flat duct system that makes use of 4 parallel 0.5" (12.70 mm) strands all in one plane. The duct is longitudinally seamed, 2" (50.8 mm) round galvanized drain pipe that has been flattened to a 2-3/4" (70 mm) x 7/8" (22.2 mm) section. A special cast steel anchorage unit splays the strands to a 5" (127 mm) width and seats conventional VSL wedges. A highly portable lightweight (60#) monostrand jack is used for stressing.

A short plastic tapered section transitions the flat duct to the flat steel anchorage. A steel tension ring is inserted at a smaller end to confine the lateral forces caused by the splayed ends.

This system is especially useful for stressing thin slabs transversely.

Western Concrete Structures System

Western Concrete Structures, Inc. is not currently active on State projects, but is an approved system. The Western Concrete System anchors individual ½" (12.70 mm) strands with pairs of split wedges at both the anchor plate and jack pulling head. Western uses a center hole jack with a strand guide permanently fixed in the center hole. A power seat is not available in this system to seat the wedges.

Anchorage systems presently approved are capable of holding a maximum of 1, 4, 12, 16, 20, 24, 28, and 48 strands.

c. Soil Anchors

The use of soil anchors as tie-backs, tie-downs, and soil nails for both temporary and permanent work has become increasingly common. Section 9 of the Trenching and Shoring Manual contains information on the design and analysis of these systems for temporary work. Specifications for installation and testing of permanent anchors are contained in the contract special provisions.

The following approved post-tensioning contractors perform tensioning on soil anchors only:

Case-Pacific

Case-Pacific utilized other approved systems.

Foundation Constructors

Foundation utilizes other systems.

Mahaffey Drilling

Mahaffey also utilizes other systems previously discussed.

Malcolm Drilling Co., Inc.

Malcolm also utilized other systems.

Pomeroy

Pomeroy utilizes other approved systems.

Schnabel Foundation

Although not on the METS active list, Schnabel is an approved contractor. They utilize the LANG system that is approved for 0.6" (15.24 mm) strands with an anchorage capable of a maximum of 6 strands.

Wagner Construction

Wagner also utilizes other approved systems.

Drill Tech Drilling and Shoring, Inc.

d. Girder Strengthening

Strengthening of bridge structures provides another use for post-tensioning systems. This work usually consists of pairs of single strand tendons or high strength bars, one on each side of the girder to be strengthened. These tendons are then tensioned simultaneously and later grouted. As with all previously described prestressing, only approved systems are to be used by approved contractors. Additional specifications will be found in the contract special provisions.

APPENDIX B – PRESSURE CELL

A pressure cell and transducer/strain indicator (see Photos 36 and 37) is a commercially made unit which accurately measures hydraulic pressure by converting changes in applied pressure into corresponding changes in output voltage. The pressure-sensing element consists of a cell fitted with strain gages. The strain gages are connected to form a balanced Wheatstone Bridge, which responds to pressure changes by proportional changes in resistance. The change in resistance is measured with a transducer/strain indicator. The indicator interprets the change in electrical resistance of the strain gage circuit in relation to the strain developed in the pressure cell.

Since the pressure in the hydraulic system is proportional to the force exerted by the jack, the readout can be calibrated to read directly in kips rather than resistance or strain. Although this system gives accurate measurements of hydraulic pressure, it must be calibrated with a load cell for any given jack and gage combination at least once a year. During calibration, the load cell is placed either behind or in front of the jack (see Figure 5) enabling readout of the actual force applied to the prestressing steel. Load cells are calibrated with the "National Bureau of Standards" load cell.

Readings should not be taken while the ram is retracting or in static condition as hysteresis will likely result in erroneous values. The calibration curves and pressure cell readings are only valid when the ram is extending.

Pressure gages are bourden tube-type with rack and pinion gear drive that accounts for part of the poor hysteresis curves. If there is any indication of damage to the gage, the stressing system should be checked with the pressure cell. If there is more than 3% difference between the pressure cell and the calibration chart, the jack and gage should be recalibrated. Usually the stressing contractor has the jacks calibrated with several gages as a backup. Also, if the jack has been overhauled (new packing, machine work, etc.), it must be recalibrated.

Instructions for the Use of the Pressure Cell: with Meter

1. Place the pressure cell into the hydraulic system near the contractor's gage.
2. Connect cell to indicator with 4 pin plug.
3. Turn toggle switch on.
4. Set controls (unless otherwise noted for particular jack).

Bridge	-	350 ohms
Readout switch	-	E
Sens	-	turn full clockwise
Polarity	-	F/B +

5. Close check valve on pressure cell.
6. Open pressure release valve (bleed) on pressure cell.
7. Turn numerical display to zero (0000).
8. Set meter to zero with balance meter.
9. Turn numerical display to a setting for the particular jack being used. (See pressure cell display setting chart).
10. While depressing (PC) switch set meter to zero with gage factor knob.
11. Reset numerical display to zero.
12. Check meter for return to zero. If needle does not return to zero, repeat above procedure of calibration (steps 7-12).
13. After calibration is complete, close pressure release valve.
14. Open check valve.
15. Numerical display indicated load in kips, e.g. 2130 = 213 kips or 213,000 lbs. If set-up requires Ex10, 213 = 213.
16. Recheck zero after each run until assured zero setting is stable. This requires closing check valve and opening pressure release valve with numerical display set at zero (0000).

Instructions for the Use of the Pressure Cell: with Digital Display

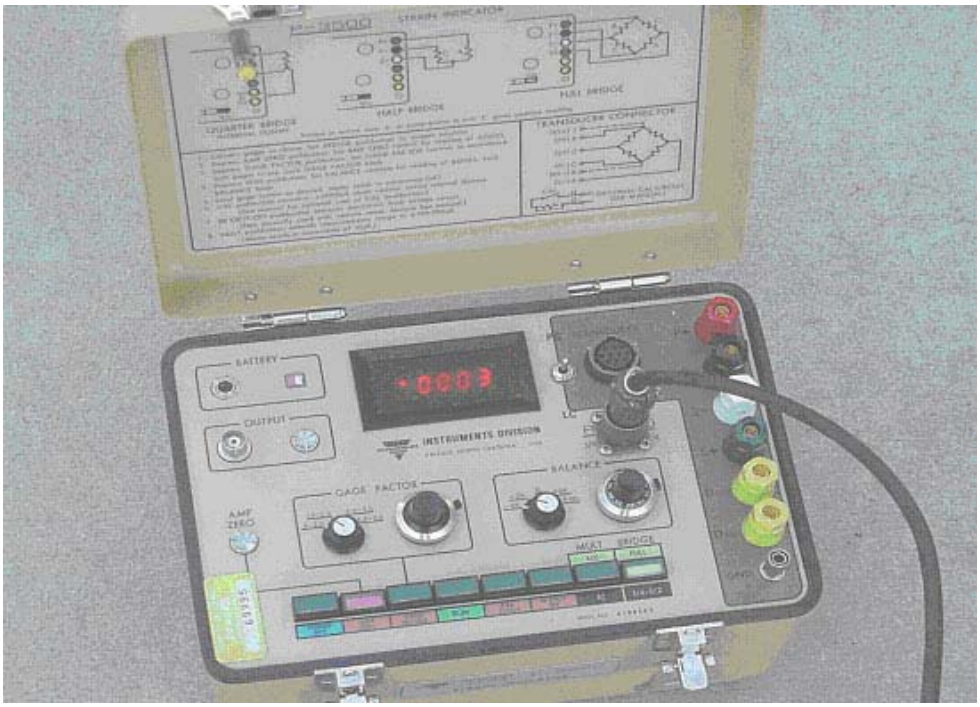


Photo 36 – Close-up of Model P-3500 Strain

1. Check pressure cell battery by pressing the "run" button (green on the bottom row) then check the battery indicator to make sure the needle is in the white area. If the needle is in the low white or orange area, it is time to change the battery. There is no charge cable for the pressure cell. Change the battery by closing the pressure cell top down, turn the unit over and unscrew the four screws on the bottom of the unit. Open the lip to the unit, lift the cell portion up from the cell box (the batteries are location on the bottom of the cell unit) change the 4 "D" batteries, put the cell portion back in the box and screw back the 4 screws on the bottom (See Figure 13a).

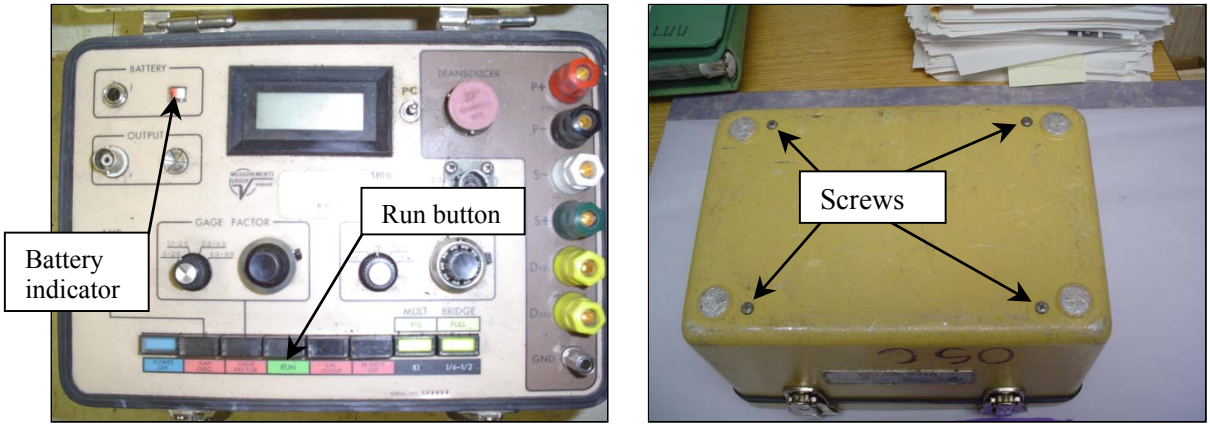


Figure 13a

2. Turn on unit by pressing the "run" button. Turn off unit once the battery is working properly.
3. Get Jack # and Gauge # (See Figure 13b) from the contractor, then obtain the gauge factor (GF) and the ND number from HQ's Active Prestress/Post Tensioning Jack Calibration Chart (you can get this from the OSC Webpage, under Field Resources, Prestress Calibration Charts).

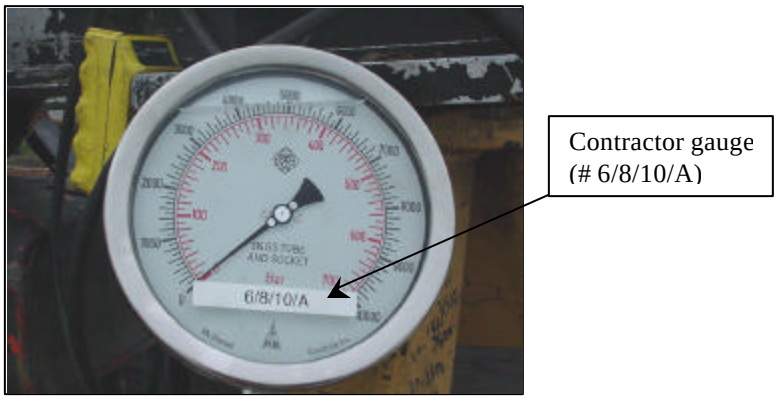


Figure 13b

4. Plug in cable at both ends (1 to pressure cell, 1 to "T" bar) – (See Figure 13c).

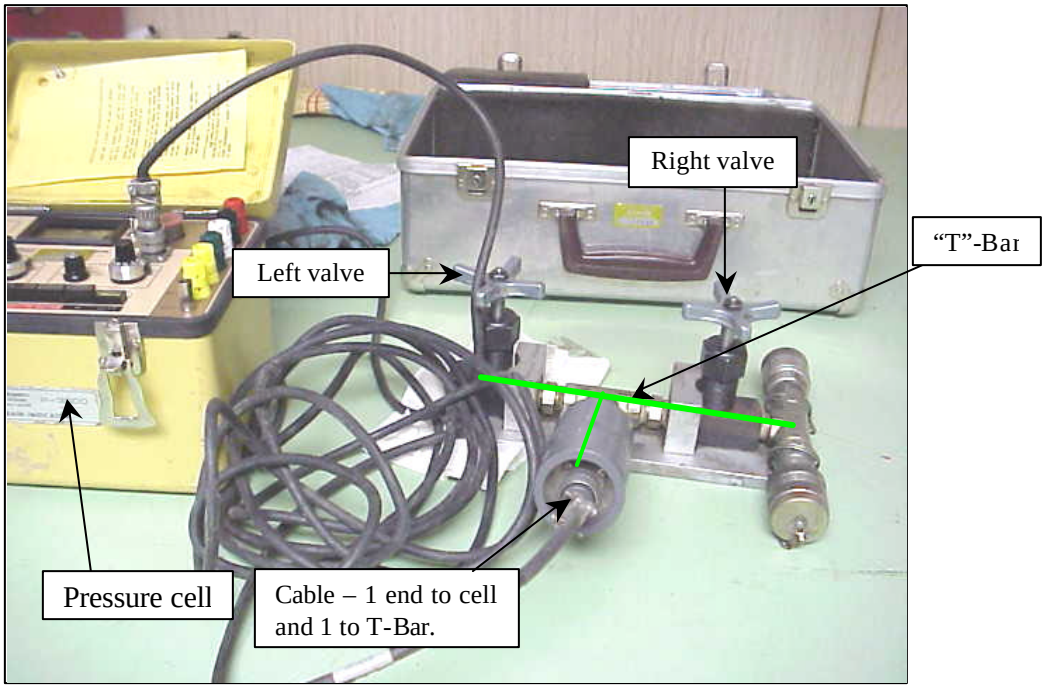


Figure 13c

5. Close the right valve and open the left valve on the "T" bar (See Figure 13c).
6. Push the "gauge factor" button; check gauge factor knob on the left of the gauge factor square to ensure the gauge factor range is properly set. Use the right knob in the same square to adjust to the correct gauge factor (GF) in the display LCD area. Keep in mind that this button has a locking switch, move switch counter clockwise to unlock before adjusting (Figure 13d).

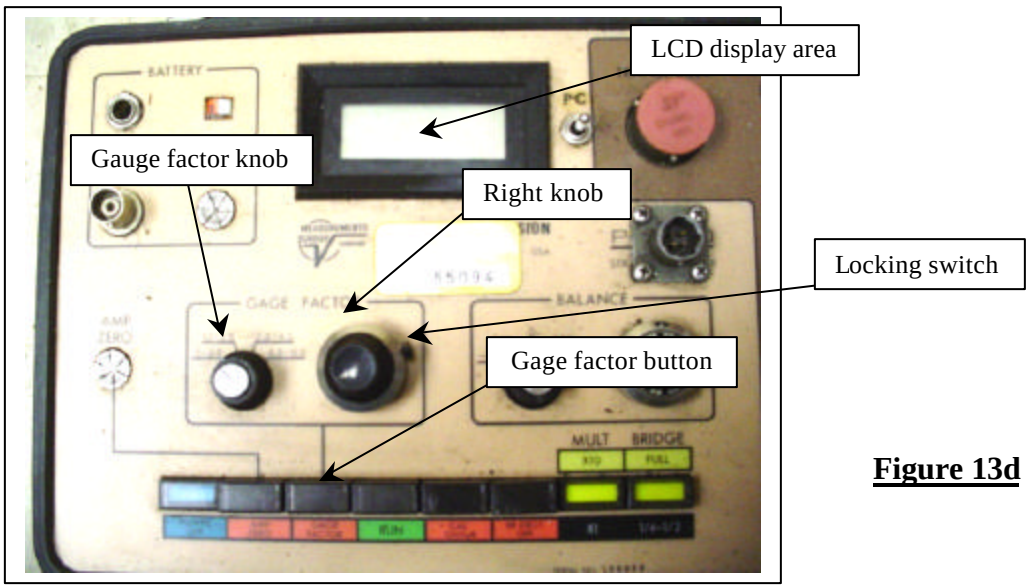


Figure 13d

7. Push the "run" button, use the knob on the right in the "balance square" to set the number in the LCD display to "0.000+/-" keeping in mind that this button also has a locking switch. Move the switch counter clockwise to unlock. After adjustment, move the switch to the lock position (clock wise) – (See Figure 13e).

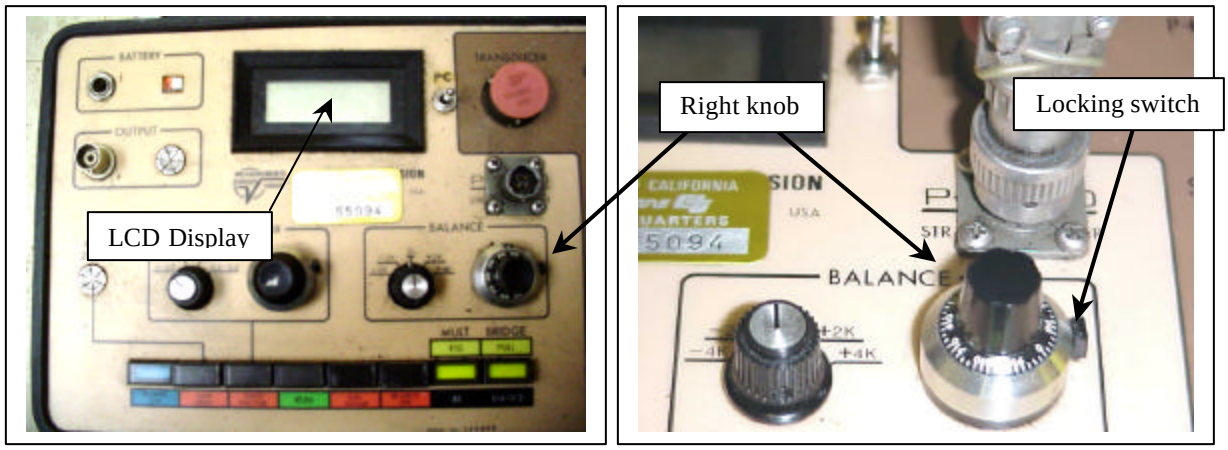


Figure 13e

8. Push a switch marked “PC” located to the right of the LCD display window upward and hold it in place. Check the display window for the ND # while holding the “PC” switch in place, if the ND # is not the same as the one shown on the calibration chart, then use the right knob in the “gauge factor” square to adjust it to the correct given ND#. Release the “PC” switch, the display should now read +/- 0.000. The unit is now ready.
9. Make sure the stressing contractor closes the left valve and open the right valve once the “T” Bar is connected to the contractor’s gauge (See Figure 13f).

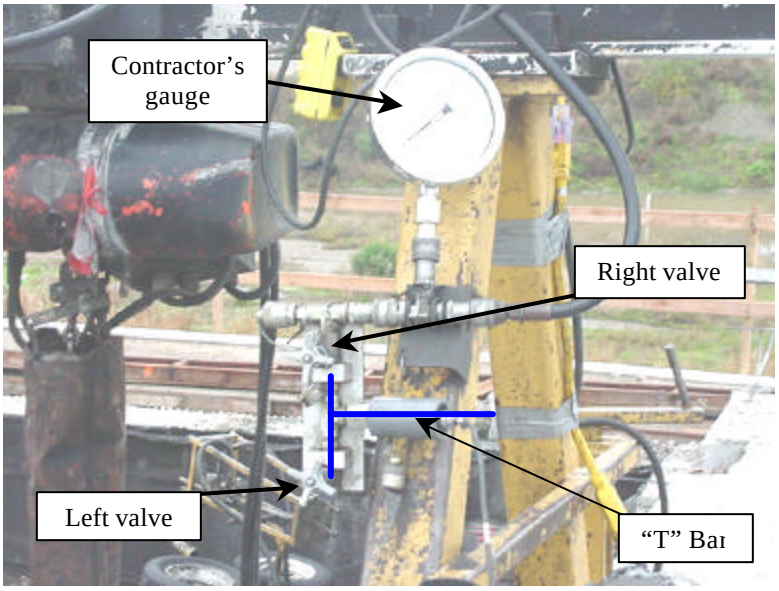


Figure 13f

Photo 37 – Model P-3500 Digital Display Strain Indicator

Check List for Malfunctioning Pressure Cell:

A. Cell indicator will not balance. Possible causes:
   1. "Low" battery
   2. Cell not properly plugged in
   3. Indicator not turned on
   4. Loose connections
   5. Severed or damaged lead wire
   6. Connections wet and/or muddy
   7. Cell wet and/or muddy
   8. Resistor is plugged in (older indicators only)
   9. Broken resistor
   10. Pressure applied to cell

B. Gage factor has large change. Possible Causes:
   1. Incorrect PC resistor setting
   2. Poor connection to cell
   3. Wire or cell damaged
   4. Cell is wet or damp
   5. Malfunction of indicator electronics

C. Needle jumping or erratic. Possible causes:
   1. Tendon friction in structure causing erratic load changes
   2. Static from motors or pumps – to alleviate, plug in ground wire
   3. A short or poor connection – connect white terminal to ground
   4. Hydraulic surge – keep gage connections away from pump
   5. Local Radio stations
   6. Contractor's generators

D. Needle sluggish or will hardly move. Possible causes:
   1. Pressure cell not plugged in
   2. Low battery
   3. Water on connections or cell
   4. Broken or damaged connection cable

If the malfunction cannot be solved in the field, consider the cell and/or indicator unsatisfactory for use.

Maintenance of the Pressure Cell:

1. Keep all components dry and clean. Do not oil or clean with solvents; wipe with a clean cloth.
2. Keep the battery charged, but do not over charge. (8 hrs max)
3. Remember that the pressure cell and readout box are delicate instruments and should be treated as such. Do not transport equipment in bed of truck.

APPENDIX C – INSPECTION CHECKLIST

Prior to Start of Field Work:

1. Remind the contractor of his responsibility to submit shop plans, calculation sheets, and notice of material sources in a timely manner.
2. Review of working drawings: The structure representative has an active role in the review of prestress working drawings. While *Bridge Memos to Designers*, Section 11-1 "Precast and/or Prestressed", defines the roles and responsibilities for working drawing review. Although the majority of the prestress shop drawing review responsibilities fall on the designer, the structure representative should review all aspects of the working drawings to fully understand the prestressing system to be constructed. In addition, the structure representative should be in contact with the designer throughout the entire review and approval process.
   a. Check tendon paths and contractor's corresponding calculations. Calculate ordinates at enough points to produce a smooth path.
   b. Compare physical layout of end anchorage details on shop plans with details shown on contract plans and B8-5 of the Standard Plans.
   c. Rough check length of tendons or bars as calculated by contractor.
   d. Review stressing sequence and locations of stressing operation shown on working drawings.
   e. If block-outs extend beyond the face of abutment, additional steel may be required. Also, special attention should be given to the support of the block-out concrete.
   f. Check for possible conflicts with ducts at columns, caps, abutments, and hinges, due to reinforcing steel, hinge restrainers, utilities and deck drains.
   g. Check to see if additional rebar or changes in concrete dimensions will be required to accommodate the contractor's system. Such details should be included on the shop plans.
   h. Skewed structures require additional investigation.
   i. Check elongation calculations.
   j. Concur with Structure Design on working drawings.
   k. Contractor should provide V.P.I. powder information.
3. Working drawings should be reviewed thoroughly, but also as quickly as possible. Contractually, in most cases, a six-week review period is provided in the special provisions, which includes extra time needed for re-submittals. Be sure to check the special provisions for your contract, and remind those involved in the review process of the time requirements.

4. Make sure everyone concerned (Structures Design, structure representative, contractor, subcontractor) are working from the approved working drawings.

When Prestressing Materials Arrive at Jobsite:

1. See that material has been released and physically identified by METS (orange tags). Record the area (A) and Young's Modulus (E) of the strand from both the orange tags, and the fabricator's tags for each individual strand pack. Collect the orange release tag to coincide with the TL-29. Do not remove all of the release tags.
2. Check condition of packs.
3. Scan material to see that it is what contract and working drawings call for by number, size, length, etc.
4. Determine if required rust inhibitor agent (VPI, etc.) has been applied to prestressing steel – check for rust.
5. Check condition of ducts thoroughly.
6. Check storage site for adequate protection of materials.

Bearing Plates and Trumpets:

1. Check that block-outs are formed to correct slope/batter. Use alignment tool to check if bearing plates are perpendicular to the ducts.
2. Make certain anchor plates are the correct size.
3. Check that the trumpets are properly secured to the bearing plates.

Placement of Rigid Ducts:

1. Check adequacy of end anchorage formwork. Check the size of anchorage hardware. Plates should be fastened to the forms at the proper angle, grout tight, and secured.
2. Make sure each girder contains the correct number of ducts. And that the ducts are the same size as called for on the working drawings.
3. Check joints for adequate grade of waterproof tape. Be sure that there are adequate ties to hold ducts from floating during placement of PCC. Stagger joints to maintain proper profile.
4. Check final profile of rigid duct. Consider camber in forms when visually inspecting the tendon drape. The first 15 feet (4.6 m) from the end anchorage should also be given special

attention to eliminate severe angular changes. Correction may be required due to superelevation. Use duct check apparatus if required.

5. Check installation of intermediate grout vents if duct length is over 400 feet (122 m). These grout vents should be placed at the high point outside the limits of the bent cap.
6. Check that snap ties, tie bolts, etc., have not been placed through or just above or below ducts. Movement of ducts during stem pour can crush duct. Pass bullet through ducts to check for obstructions.
7. Make sure that all defects in ducts (breaks, crushed areas, etc.) have been repaired prior to concrete pour. Crushed ducts have caused problems in pulling strands and grouting.
8. Check reinforcing details. #4's (#13) at 12" (305 mm) O.C. at block-outs, 2-1/2" (60 mm) clearance for stirrups, 1'-6" (450 mm) behind bearing plates, duct ties, etc. Also consider any additional details shown on the working drawings.
9. Seal tendon openings to prevent water or debris from entering the duct.

<u>During Stem Pour:</u>

1. If possible, cover ducts with an inch of concrete in bent cap area but allow for cap rebar clearance.
2. Avoid rock pockets by proper vibration of concrete, particularly around anchor plates and low areas of the duct's path.
3. Avoid impact dumping on ducts and dropping vibrator directly on the ducts.
4. Check alignment to see that no unusual movement takes place during pour.

<u>After Stem Pour:</u>

1. Ducts shall be checked to see if they are free of obstructions clear of water and debris. The ends of the ducts shall be recovered after the ducts are checked.
2. Repair damaged ducts.
3. Check if ducts are in line with trumpets.

<u>During Deck Pour:</u>

1. See that vent pipes are not damaged during pour.
2. Sketch or mark location of vents.

3. Be sure sufficient concrete test cylinders are taken.

Fabrication and Placement of Tendons:

1. There should be an adequate area to pull the strands. The strands should be protected from contamination during fabrication. Pushing the strand is common practice that provides better protection for the strand.
2. When a complete tendon is fabricated on the ground, the strands must be clean dirt and debris before pulling the tendon through the duct. Stands must also be protected from scraping or wear when pulled over dunnage.
3. Contractor shall demonstrate that the ducts are free of water and debris. If water is encountered in the ducts, have the water removed.
4. Inspect the strands for rust.
5. Avoid unusual angle points when pulling the tendons into the ducts. Make use of rollers or pulleys.
6. Make sure tendons are installed in their proper locations.
7. Consider "rust free" period and possible need for corrosion inhibitor.

Prior to the Stressing Operation:

1. See that contractor has furnished the required calibration curves for specific jack/gage combinations.
2. Check out pressure cell. The battery should be charged for 8 hrs maximum prior to usage. While using pressure cell in the field, only turn on while monitoring the contractor's jack.
3. Get familiar with all the prestressing procedures, potential problems with the particular system being used, shop plans, and elongation calculations.
4. Set up prestressing tables to document a complete record of each tendon stressed. Have elongation calculated beforehand, using the material properties provided by the fabricator for the individual strand packs.
5. Check to see if the stressing is from one end, both ends, or simultaneously from both ends.
6. Make sure you have discussed the stressing sequence with the contractor.
7. Inspect the area around the anchorages for rock pockets. Large voids should be re-poured, while small voids should be dry-packed. Epoxy concrete or other specialty concrete mixes should not be used for repairs, whether before or after stressing.

8. Inspect the deck surface for excessive cracking, and repair areas not in compliance with the specifications.

During the Stressing Operation:

1. Direct the contractor to paint strands on both ends and check for slippage.
2. Plot at least one calibration curve per structure.
3. If elongation falls outside the acceptable limits, find out why.
4. If any anchorage hardware fails (even if the problem was corrected), call the area senior and the Headquarters Construction Office.
5. It is the practice of the Offices of Structures Construction to monitor the contractor's jacks at the start of each day, but not necessarily while stressing every tendon. The structure representative may require additional monitoring which shall override OSC practice.
6. If a strand breaks during the stressing operation, the designer and the Prestressed Concrete Committee should be contacted. Two or more strands breaking in the same tendon may indicate a problem at a particular location in the duct. This situation must be thoroughly reviewed and discussed with Structure Design and METS before additional work on the girder can be completed.

Grouting Operation:

1. Check for missing strands before placing grout caps.
2. Make sure the grouting equipment meets specifications and has adequate capacity for the job.
3. Make sure the cement is the correct type and protected from adverse conditions. The cement shall be supplied by an approved source and a Certificate of Compliance is required prior to placing the grout.
4. Use water/cement ratio not to exceed 5 gallons of water to one sack of cement.
5. Check the approved admixture list on the structures construction website under "Field Resources" to verify that proposed admixtures are acceptable. Contact METS for additional information on admixtures.
6. Check efflux time in accordance with test method.
7. Make sure there is continuous agitation of grout during grouting.
8. Monitor the grouting pressure. Pressure should gradually increase as the duct is filled. A sudden jump in pressure usually indicates blockage.

9. Close outlet valve before closing inlet valve.
10. Have standby flushing equipment as required.

Miscellaneous:

Most of the preceding inspection suggestions are also applicable to post-tensioned tie-backs, transverse deck stressing, and tie-down systems. However, there are a number of additional inspection items that are unique to these non box-girder applications. Inspection suggestions can be coordinated through the Headquarters Office of Structure Construction in Sacramento.

Early or partial post-tensioning of a structure due to project related issues such as a potential loss of falsework due to flooding must be considered on a job specific basis. In most cases, decisions must be made quickly, so it is important for both the designer and structure representative to work as fast as possible toward a solution.

APPENDIX D – POST-TENSIONING LOSSES AND ELONGATIONS

The following appendix contains all the necessary information and formulas for calculating prestress losses and elongations for prestressed, post-tensioned structures. Included are example calculations for a simple-span structure stressed from one end and for a continuous structure stressed from one end. Also included is an anchor set example calculation.

It should be understood that the formulas and calculations are approximate and the engineer should apply reasonable tolerances when comparing the actual field measured elongations with those that are theoretical.

Post-Tensioning Losses:

Post-tensioning of prestressed box girder bridges must consider stress losses that will occur. Listed below are seven causes of prestress losses:

1. Friction of the prestressing steel with the duct and loss due to misalignment of the duct.
2. Anchorage slip as the strand wedges seat at the bearing plate.
3. Elastic shortening of the concrete.
4. Creep of the concrete.
5. Shrinkage of the concrete.
6. Relaxation of the prestressing steel
7. The stressing sequence.

Items 3 to 7 above are losses that take effect after stressing is complete and in accordance with Section 50-1.08 “Prestressing”, of the standard specifications are assumed to be a total of 20 ksi (138 MPa) for low relaxation wire, 32 ksi (220 MPa) KSI for normal relaxation wire and 22 ksi (152 MPa) for bars.

Items 1 and 2 above are losses that occur during the stressing operation and can be calculated knowing the strand properties and the prestressing tendon path configuration. These are the losses that are of most concern to the structure representative.

Friction Loss:

The losses due to friction can be calculated using the following formula:

$$T_0 = T_x e^{(\mu\alpha + KL)} \qquad \text{(Equation 1)}$$

where:

T_o = Steel stress at the jacking end before seating.

T_x = Steel stress at any point x along tendon path.

e = Base of Naperian logarithms.

μ = Friction coefficient.

α = Total angular change of the prestressing steel profile (tendon path) in radians from the jacking end to a point x.

K = Wobble coefficient.

L = Length of prestressing steel from the jacking end to a point x.

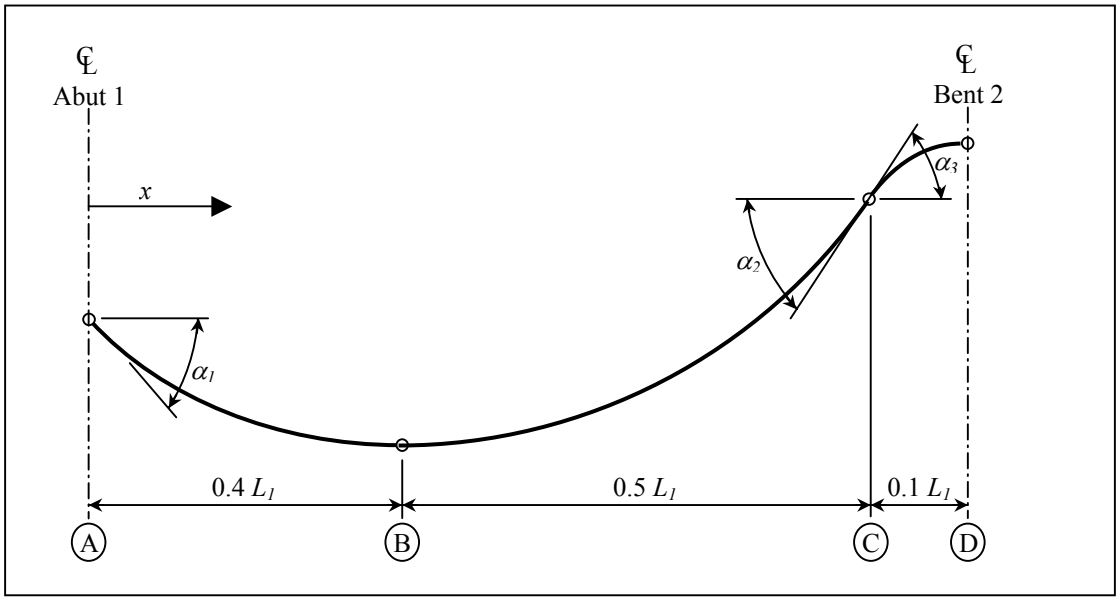
The equation $T_o = T_x e^{(\mu\alpha + KL)}$ has been found to overestimate field measurements of elongation for longer frames (greater than 600 feet, or 183 m). In order for Equation 1 to work effectively, values of friction and wobble coefficients for rigid and semi-rigid galvanized metal sheathing have become frame-length dependant, as shown in the following table:

Frame Length (feet)	Wobble Coefficient "K"	Friction Coefficient "μ"
0 - 600	0.0002	0.15
600 - 900	0.0002	0.20
900 - 1200	0.0002	0.25
> 1200	0.0002	See P/S Committee

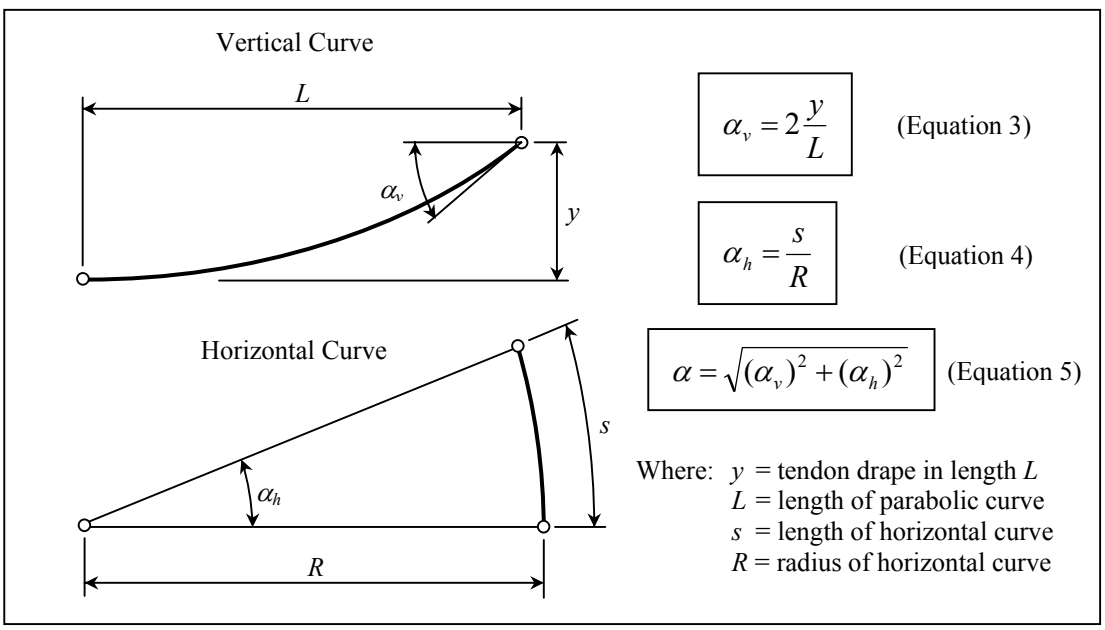
Section 50-1.07 of the Standard Specifications requires that the prestress ducts shall be rigid and galvanized. Frame length dependant friction and wobble coefficients should be shown in the prestressing notes on the contract plans.

The stress in the prestressing steel at any point x can be determined by manipulating Equation 1 as follows:

$$T_x = T_o e^{-(\mu\alpha + KL)} \qquad \text{(Equation 2)}$$



To determine the correction 'a' due to the vertical curvature of the tendon path and for any horizontal bridge curvature that does exist, the following formulas can be used.



$$\alpha_v = 2\frac{y}{L} \quad \text{(Equation 3)}$$

$$\alpha_h = \frac{s}{R} \quad \text{(Equation 4)}$$

$$\alpha = \sqrt{(\alpha_v)^2 + (\alpha_h)^2} \quad \text{(Equation 5)}$$

Where: y = tendon drape in length L
L = length of parabolic curve
s = length of horizontal curve
R = radius of horizontal curve

To determine the loss due to friction expressed as a fraction of the temporary jacking stress, use the following formula:

$$\frac{To - Tx}{To} = 1 - e^{-(\mu\alpha + KL)} \quad \text{(Equation 6)}$$

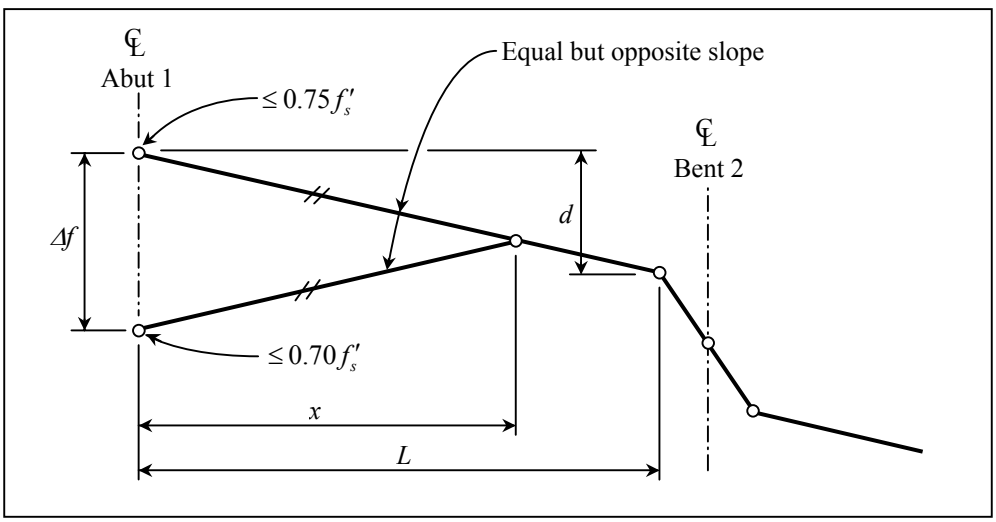
The loss that occurs due to the anchor set can be determined using the following approximate formulas:

$$\Delta f = \frac{2dx}{L} \qquad \text{(Equation 7)}$$

$$x = \sqrt{\frac{E(\Delta L)L}{d}} \qquad \text{(Equation 8)}$$

where:

	Δf	= change in stress due to anchor set
	d	= friction loss in length L
	x	= length influenced by anchor set
	L	= distance to a point where the loss is known
	ΔL	= anchor set (normally = 3/8”)
	E	= modulus of elasticity, assume 28 x 10 ksi



Section 50-1.08 of the Standard Specifications requires that the maximum temporary stress (jacking stress before anchor set) shall not exceed 75% of the specified minimum ultimate strength of the prestressing steel. In addition, the initial stress shall not exceed 70% of the specified tensile strength of the prestressing steel. This initial stress is just after anchor set but before any long term losses occur, such as concrete shrinkage, relaxation of prestress steel, etc.

Tendon Elongations:

As structure representative, it will be your responsibility to monitor the contractor's stressing operations. In addition to the use of a load cell to check prestress force as described earlier in this manual the strand elongations must be measured and compared with the calculated theoretical elongations.

The contractor will submit elongation calculations on the working drawings using assumed values for the modulus of elasticity (E) and the area of the strand (A). When the prestress strand is delivered to the jobsite, it should have an orange release tag with the actual E and A, as determined by METS, written on the back. If these values are not written on the back of this tag, then check the Category 41 file. The E and A should be on the TL-29. In addition, the actual (E) and (A) values determined by the manufacturer for the individual strand packs will also be provided by the contractor/supplier. The theoretical elongations should be recalculated using the manufacturer's E and A.

The elongation between two points where the stress varies linearly can be given by the following equation:

$$\boxed{\Delta = \frac{T_{avg} L}{E}} \qquad \text{(Equation 9)}$$

where: T_{avg} = average stress between two points = $(T_1 + T_2)/2$

E = modulus of elasticity

L = length between T_1 and T_2

For almost all field situations the elongations based on the numerical average of the end stresses will yield sufficiently accurate results.

Equation 9 above applies to one-end stressing. For two-end simultaneous stressing, the following derivation from Equation 9 can be used.

$$\boxed{\Delta = \frac{T_o(1+\otimes)(L_1 + L_2)}{2E}} \qquad \text{(Equation 10)}$$

where: $\otimes$ = is the theoretical point of no movement.

The above formulas can be expanded for the entire structure once the theoretical point of no movement or minimum stress is known or calculated. In a continuous structure stressed with two end stressing, the point of no movement in a cable occurs where the losses right of the point equal the losses

left of the same point. The force coefficient at that point is shown on the contract plans with the symbol, ⊗.

If the structure is stressed non-simultaneously, the elongations at the jacking end can be estimated using the assumption that the dead end stress T_e is given by the following formula:

$$T_e = T_0(2\otimes - 1) \qquad \text{(Equation 11)}$$

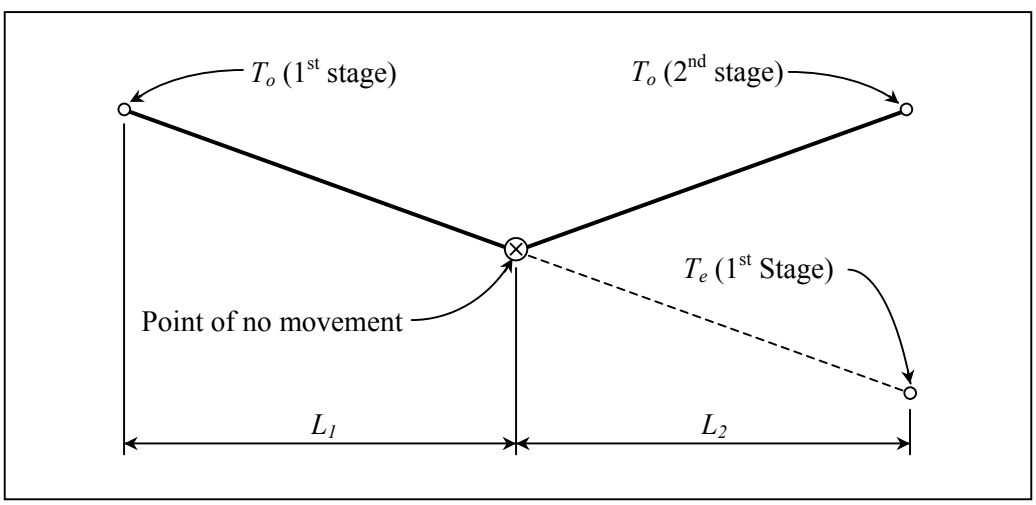
The first and second end elongations are:

$$\Delta_{1st} = \frac{T_0}{2E}\left[(1+\otimes)L_1 + (3\otimes - 1)L_2\right] \qquad \text{(Equation 12)}$$

And:

$$\Delta_{2nd} = \frac{T_0(1-\otimes)L_2}{E} \qquad \text{(Equation 13)}$$

Reasonably accurate elongation calculations can be made for a structure given the following stress diagram:



After obtaining the theoretical elongations, the measurable elongations are calculated. This is usually equal to 80% of the calculated elongation (using the actual E and A) from the first end and 100% from stressing the second end.

In most cases, the use of the ⊗ term as shown on the plans will yield acceptable results. Error is introduced because the calculations are based on a straight-line stress variation and the term is usually an average of tendons and does not account for tendon path length variations.

Checking the tendon length on the working drawings can be a tedious task, and doesn't warrant accuracy to the ¼ inch. In fact, since elongation varies linearly with tendon length, a tendon length can be off by 1% and not make a significant difference in elongation calculations. For example, if the theoretical elongation for a 300 foot long frame is 24 inches, then a 1% or 3 foot discrepancy in computing the tendon length results in only a 0.24 or ¼ inch difference in elongation.

APPENDIX E – EXAMPLE CALCULATIONS

Example 1 – Continuous Two Span CIP Box-Girder Stressed from One End:

Information given on contract plans:

- 270 ksi low relaxation prestressing strand
- E = 28,000 ksi
- F_{jack} = 202.5 ksi

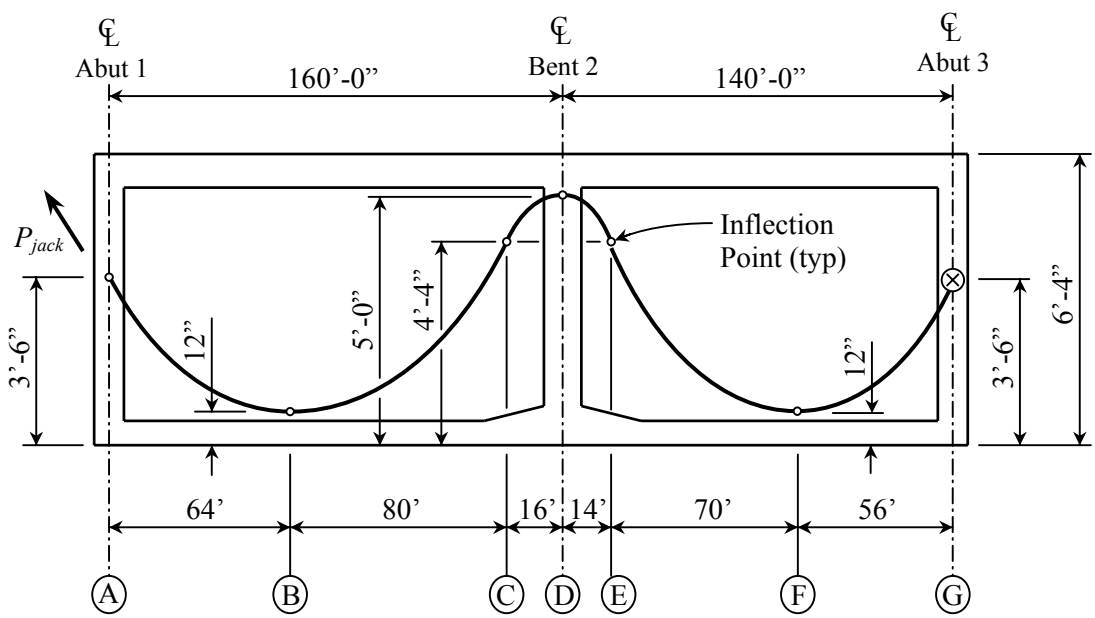


Figure 1 - Prestressing Cable Path

The equation for stress in the prestressing steel at a distance x from the jacking end of the frame is:

$$T_x = T_o e^{-(\mu\alpha + KL)} \qquad \text{(Equation 2)}$$

Where: μ = 0.15 for frame lengths < 600 feet

K = 0.0002

μ = cumulative angle change at point of interest x from jacking end

L = distance to point of interest x from jacking end.

Find the measurable elongation for the prestressing path in Figure 1:

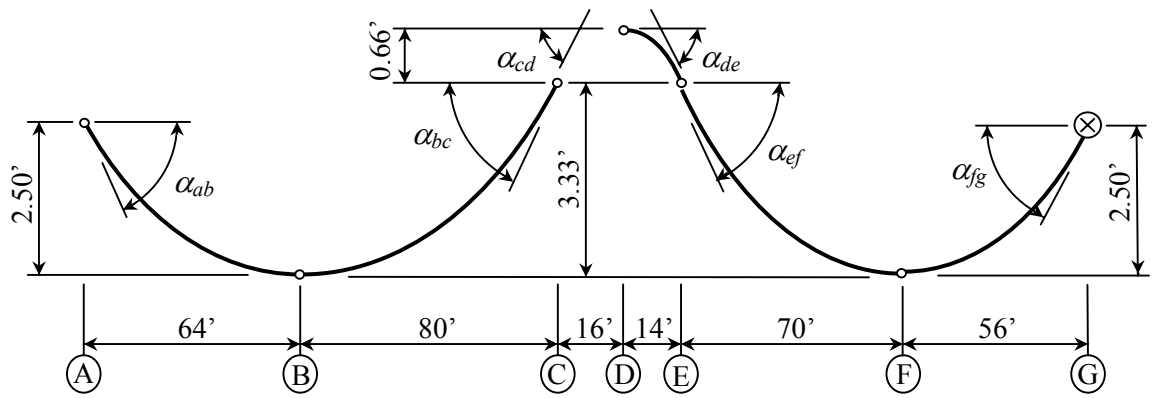


Figure 2 – Vertical Angle Change

Step 1: Tendon elongations during the stressing operation are a function of both the average stress in the strands, and the length of the tendon. The stress in the strands varies along the tendon path due to angular friction between the tendon and the inside surface of the duct. Since there is no horizontal curvature given in this exercise, the angle changes are based on the vertical tendon profile only.

Vertical Angle Change Calculations			
Segment	y (feet)	L (feet)	$\alpha = 2(y/L)$ (radians)
AB	2.500	64	0.0781
BC	3.333	80	0.0833
CD	0.666	16	0.0833
DE	0.666	14	0.0952
EF	3.333	70	0.0952
FG	2.500	56	0.0893

Step 2: Now that the vertical angle change within each parabolic segment has been calculated, it is time to compute the initial friction coefficients. These coefficients represent a decimal percentage of the jacking stress at the end of each parabolic segment. Based on the results in the following table, there is a slightly more than 87 percent of P_{jack} in the strands at the dead end.

Initial Friction Coefficient Calculations								
Segment	Friction μ	$\alpha = 2(y/L)$ (radians)	$\Sigma\ \alpha$ (radians)	Wobble K	L (feet)	$\Sigma\ L$ (feet)	$(\mu\Sigma\alpha+K\Sigma L)$	$e^{-(\mu\Sigma\alpha+K\Sigma L)}$
AB	0.15	0.0781	0.0781	0.0002	64	64	0.0245	0.976
BC	0.15	0.0833	0.1614	0.0002	80	144	0.0530	0.948
CD	0.15	0.0833	0.2447	0.0002	16	160	0.0687	0.934
DE	0.15	0.0952	0.3399	0.0002	14	174	0.0858	0.918
EF	0.15	0.0952	0.4351	0.0002	70	244	0.1141	0.892
FG	0.15	0.0893	0.5244	0.0002	56	300	0.1387	0.870

Step 3: With the initial friction coefficients in hand, it is now possible to compute the average stress in the strands in each segment. Knowing the stress distribution along the entire length of the frame, and assuming a Young's modulus for prestressing steel of E = 28,000 ksi, the tendon elongation can be calculated using the following equation:

$$\Delta = \frac{T_{avg}L}{E}$$

Elongation Calculations							
Segment	$e^{-(\mu\alpha+KL)}$	T_o (ksi)	$T_x=T_o e^{-(\mu\alpha+KL)}$ (ksi)	T_{avg} (ksi)	L (feet)	L (in)	$\Delta_x=T_{avg}L/E$ (in)
AB	0.976	202.5	197.6	200.1	64	768	5.49
BC	0.948	202.5	192.0	194.8	80	960	6.68
CD	0.934	202.5	189.1	190.6	16	192	1.31
DE	0.918	202.5	185.9	187.5	14	168	1.13
EF	0.892	202.5	180.6	183.3	70	840	5.50
FG	0.870	202.5	176.2	178.4	56	672	4.28
				Total Elongation			24.39

Please note that the length of the strand in the jack was not considered in the calculations. The total elongation calculated above must be reduced by 20 percent to account for take-up and reorienting of prestressing strand at the beginning of the stressing operation. The measurable elongation, $\Delta_{80\%}$, for this example problem is shown below:

$$\Delta_{80\%} = 0.80\Delta_{100\%} = 0.80\ x\ 24.39 = 19.51 \qquad \boxed{\Delta_{80\%} = 19.51 \text{ in.}}$$

Example 2 – Anchor Set Calculation:

The contract plans usually identify an anchor set length of $^3/_8$ inch (10 mm). This length represents the distance the strand slips back into the anchor head during the seating process. Using the results from Example 1, what is the change in stress at the jacking end of the frame, and how far into the frame does anchor set loss affect the stress in the tendon?

Given:

- E = 28,000 ksi
- $\Delta L = {}^3/_8$ in.
- Friction loss in length L = 202.5 ksi – 192.0 ksi = 10.5 ksi = d

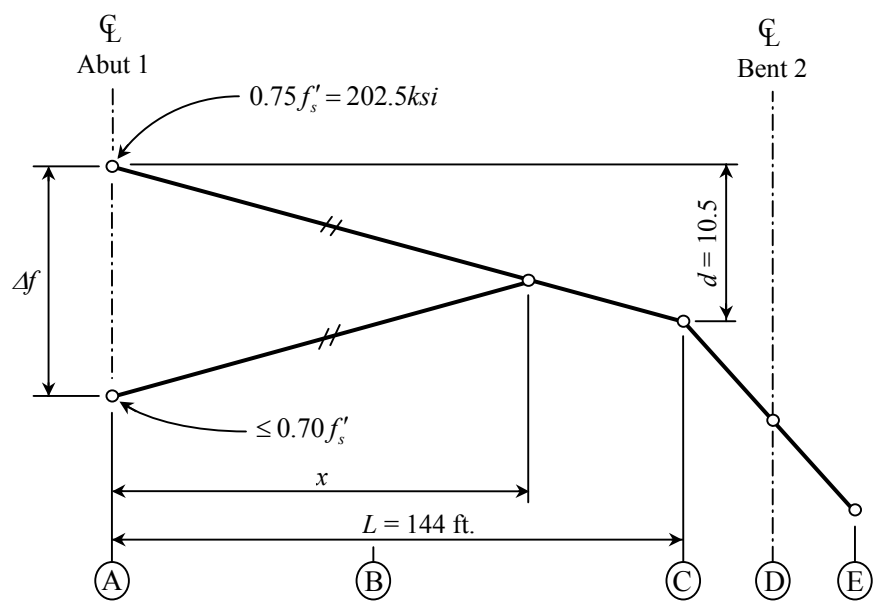


Figure 3 – Anchor Set Loss Diagram

$$\sqrt{\frac{E(\Delta L)L}{d}} = \sqrt{\frac{(28{,}000ksi)(0.375in)(144ft)}{(10.5ksi)(12in/ft)}} = 109.5ft$$

$$\Delta f = \frac{2dx}{L} = \frac{(2)(10.5ksi)(109.5ft)}{144ft} = 15.97ksi$$

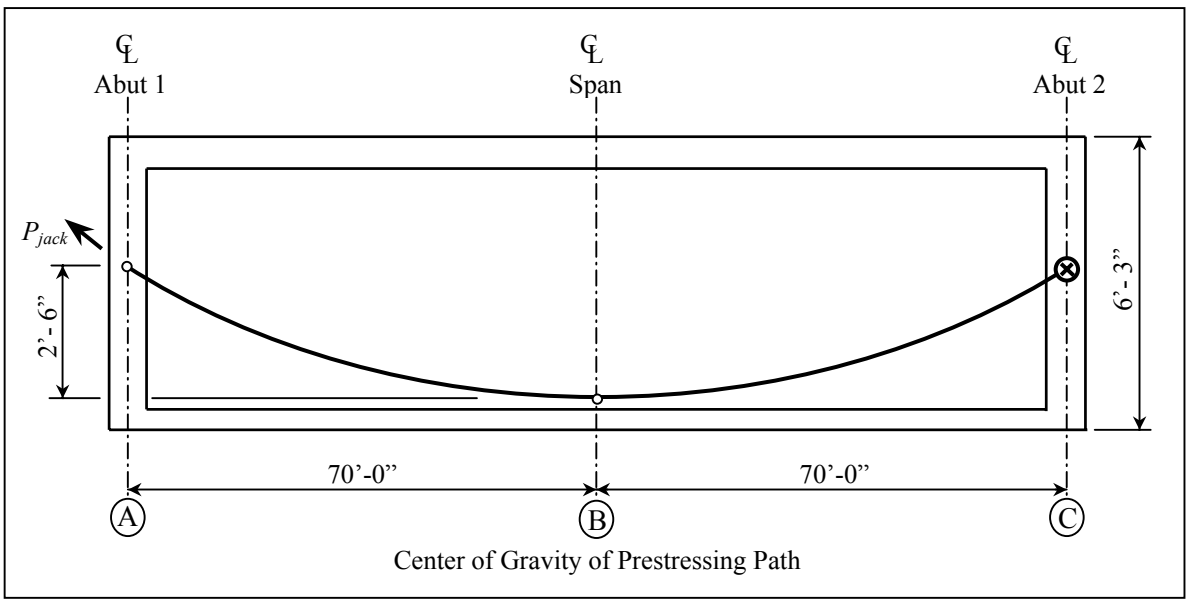
The stress at the anchorage after seating must be less than $0.70f'_s$:

{202.5 ksi – 15.97 ksi = 186.53 ksi} < {$0.70f'_s$ = 0.70 (270 ksi) = 189 ksi} ∴ OK

Example 3 – Simple Span Box Girder Stressed from One End:

Given:

- 140 ft long simply supported CIP P/S Box Girder = L
- 270 ksi Low Relaxation strand
- P_{jack} = 12,600 kips
- Area of 0.5 inch diameter strand = 0.153 in^2
- Anchor set length = 0.375 in = ΔL
- One end stressing
- $\mu = 0.15$, $K = 0.0002$



Find:

1. How many 0.5 inch diameter strands are required?
2. Find the initial and final stress distribution in the prestressing steel.
3. Find the final working force at the centerline of the span.
4. Find the theoretical and measurable elongation.

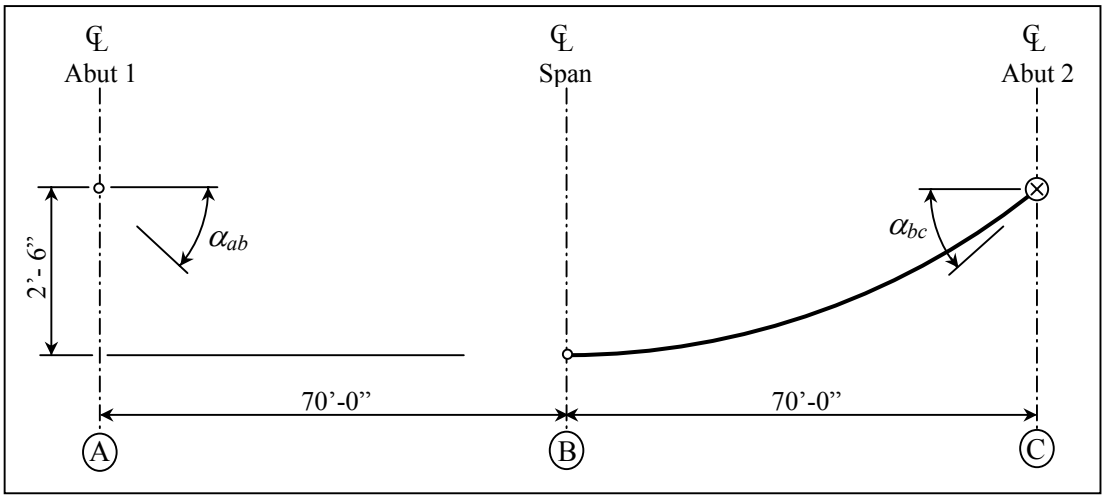
Part 1: Number of strands required -

$0.75 f'_s$ = The jacking stress on the contract plans = 0.75 (270 ksi) = 202.5 ksi

$A_{p/s} = P_{jack} / f_{jack}$ = 12,600 kips / 202.5 ksi = 62.22 in^2

$n_{p/s}$ = number of strands = $A_{p/s} / A_{strand}$ = 62.22 in^2 / 0.153 in^2 = 407 strands

Part 2: Initial and Final Stresses in Prestressing Steel -



Stress at dead end:

$\alpha_{ab} = \alpha_{bc} = 2y/L = 2\ (2.5)\ /\ 70 = \underline{0.0714}$

At dead end, $\alpha_{ac} = 2\ (0.0714) = \underline{0.1428}$

$T_x = T_o e^{-(\mu\alpha + KL)}$

At dead end, $T_c = 202.5\ e^{-[(0.15)(0.1428)+(0.0002)(140)]} = 202.5\ e^{-0.0494} = \underline{192.73\ \text{ksi}}$

Effect of anchor set:

$$= \sqrt{\frac{E(\Delta L)L}{d}} = \sqrt{\frac{(28{,}000ksi)(0.375in)(140ft)}{(9.77ksi)(12in/ft)}} = 112ft$$

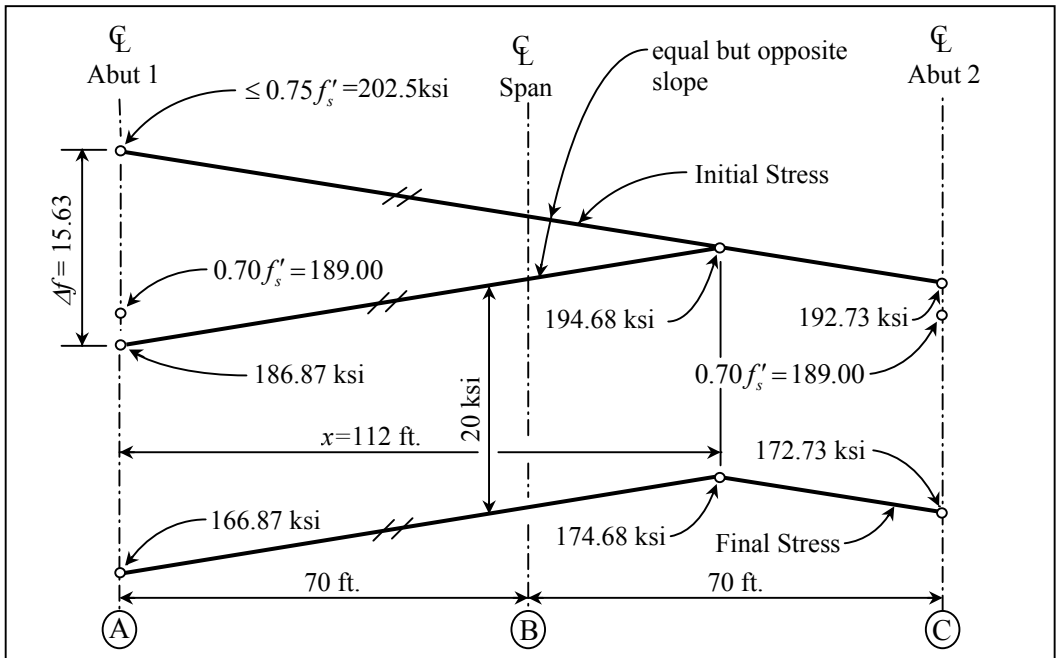
$$\Delta f = \frac{2dx}{L} = \frac{(2)(9.77ksi)(112ft)}{140ft} = 15.63ksi$$

Stress at jacking end:

$T_a = f_{jack} - \Delta f = 202.5\ \text{ksi} - 15.63\ \text{ksi} = \underline{186.87\ \text{ksi}}$

$\{T_a = 186.87\ \text{ksi}\} \leq \{0.70 f'_s = 0.70\ (270\ \text{ksi}) = 189\ \text{ksi}) \quad \therefore \quad \text{OK}$

Assume long term losses = 20 ksi



Initial and Final Stress Distribution in Prestressing

Part 3: Final working force at the centerline of Span –

$$\frac{f_b - 166.87}{70} = \frac{174.68 - 166.87}{112}$$

$$f_b - 166.87 = \frac{70(7.81)}{112}$$

$$f_b = 4.88 + 166.87 = 171.75 \quad ksi$$

Part 4: Theoretical and measurable elongation –

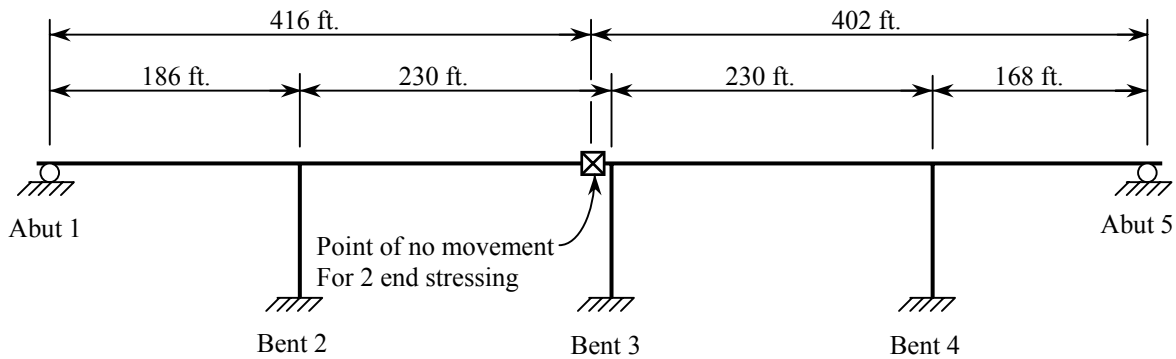
$$\Delta_{100\%} = \frac{\left[(202.5 + 192.73)ksi/2\right]\ (140ft)(12in/ft)}{28{,}000ksi} = 11.86 \quad in.$$

$$\Delta_{80\%} = 0.80\ \ (11.86in) = 9.49 \quad in.$$

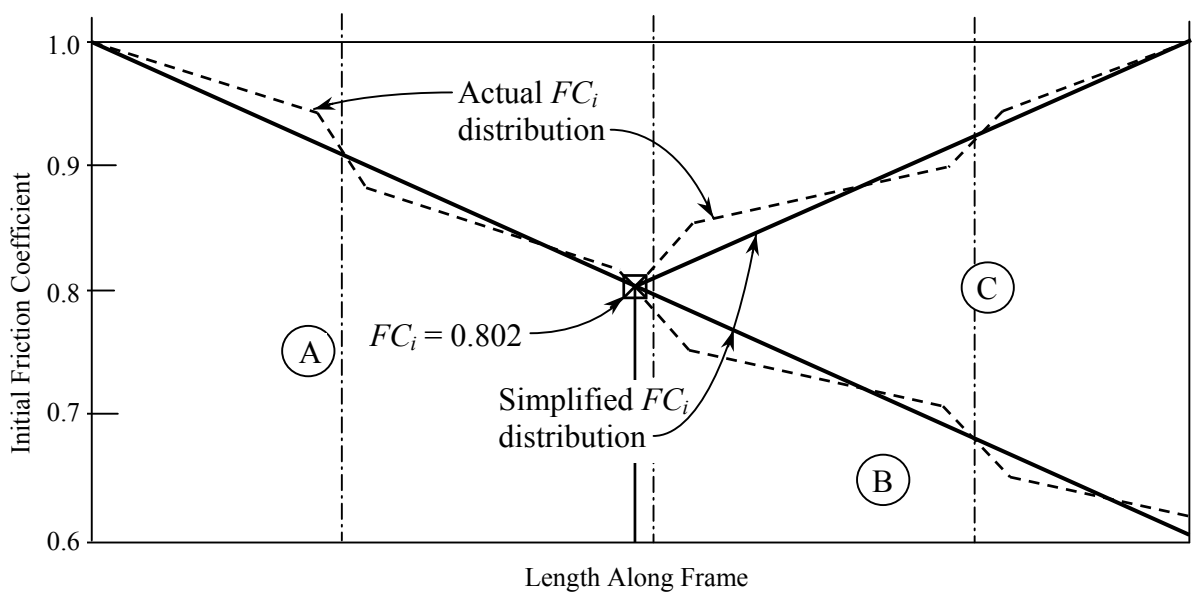
Example 4 – Continuous Four Span CIP Box-Girder Stressed from Both Ends:

Given:

- 818 ft long continuous 4 span CIP P/S box girder frame
- Two end stressing, with first stage jacked from left end
- 270 ksi Low Relaxation strand
- Jacking stress = 202.5 ksi
- Area of 0.5 inch diameter strand = 0.153 in^2
- The initial force coefficient (FC_i) at the point of no movement = 0.802
- $\mu = 0.20$, $K = 0.0002$ (informational only)



Frame Description



Initial Force Coefficient Diagram

Find: 1. What is the total theoretical (expected) 1st stage elongation?

2. What is the measurable 1st stage elongation?

3. What is the theoretical (expected) 2nd stage elongation?

Part 1: Total theoretical (expected) 1st stage elongation:

When calculating the first stage elongation, it is common practice to break the force coefficient diagram into two parts, identified as areas A and B in the above diagram. The equation for calculating tendon elongations is shown as follows:

$$\boxed{\Delta = \frac{PL}{AE}}$$

When jacking to 202.5 *ksi*, and using a strand nominal area of 0.153 in^2 the jacking force per strand is calculated below:

$$P_{strand} = (202.5\ ksi)(0.153) = \underline{30.98\ kips/strand}$$

When calculating Δ_A, it is important to include the length of tendon within the jack. The strand movement will be measured relative to the end of the ram, which generally results in 2½ to 3 feet of extra of strand within the length of the jack.

$$\Delta_A = \frac{(30.98\ kips)(1+0.802)}{2} x \frac{(416ft + 3ft)(12)}{(0.153\ in^2)(28{,}500\ ksi)} = (27.91)(1.153) = \underline{32.2\ inches}$$

In order to find the first stage elongation for area B, it is necessary to extrapolate the FC_i out to the dead end of the first stage post tensioning:

$$FCi_{dead} = 1 - [(2)(1-0.802)] = \underline{0.604}$$

$$\Delta_B = \frac{(30.98\ kips)(0.802+0.604)}{2} x \frac{(402ft)(12)}{(0.153\ in^2)(28{,}500\ ksi)} = (21.78)(1.106) = \underline{24.1\ inches}$$

$$\Delta_{A+B} = \Delta_{1st\ stage\ theo} = 32.2 + 24.1 = \underline{56.3\ inches}$$

Part 2: Measurable 1st stage elongation:

The total theoretical elongation does not have direct practical application because it does not take into account slack or strand reorientation in the tendon. The measurable elongation is determined to be

80% of the theoretical, as strands are marked with paint after being stressed to 20% of P_{jack}. In this case, after stressing the tendon to 20% of P_{jack}, the remaining 80% stressing should yield an elongation of…

$$\Delta_{1st\ stage\ meas} = (0.80)\Delta_{1st\ stage\ theo} = (0.80)(56.3\ \ inches) = \underline{45.0\ \ inches}$$

<u>Part 3</u>: Theoretical (expected) 2nd stage elongation:

Once the first stage stressing operation is complete, and the engineer is satisfied with the physical measurements obtained, the second stage stressing operation can begin. Theoretical 2nd stage elongations must be calculated before stressing, to serve as a tool to guarantee that the proper amount of P/S force is being delivered to the structure. The second stage elongation equates to Area C in the force coefficient diagram. Again, the length of the tendon within the jack must be included in the calculation.

$$\Delta_C = \Delta_{2nd\ stage\ theo} = \frac{(30.98\ \ kips)(1-0.604)}{2} x \frac{(402\,ft + 3\,ft)(12)}{(0.153\ \ in^2)(28{,}500\ \ ksi)} = (6.13)(1.115) = \underline{6.8\ \ inches}$$

APPENDIX F – CALIFORNIA TEST # 541 (FLOW CONE METHOD)

California Test 541

STATE OF CALIFORNIA—BUSINESS, TRANSPORTATION AND HOUSING AGENCY

February 2000

DEPARTMENT OF TRANSPORTATION
ENGINEERING SERVICE CENTER
Transportation Laboratory
5900 Folsom Blvd.
Sacramento, California 95819-4612

METHOD OF TEST FOR FLOW OF GROUT MIXTURES (FLOW CONE METHOD)

CAUTION: Prior to handling test materials, performing equipment setups, and/or conducting this method, testers are required to read "**SAFETY AND HEALTH**" in Section G of this method. It is the responsibility of the user of this method to consult and use departmental safety and health practices and determine the applicability of regulatory limitations before any testing is performed.

A. SCOPE

The procedure to be used for determining the flow of grout mixtures is described in this test method.

B. APPARATUS

1. Flow cone and supporting ring conforming to the dimensions indicated in Figure 1.
2. Stop watch having a least reading of not more than 0.1 s.
3. Rubber stoppers, size 00.
4. Sample container of 4 L minimum capacity.
5. Suitable stand for supporting ring. A 19 L paint bucket may be used. See Figure 2.

C. SAMPLE

The test sample shall be approximately 4000 mL of grout.

D. DETERMINATION OF EFFLUX TIME

1. Dampen flow cone and allow any excess water to drain. Place the cone in the supporting ring and insert the rubber stopper.
2. Level the cone, then pour the grout from the sample container into the cone until the grout surface is level with the bottom of the three holes in the side of the cone.
3. Remove the stopper and start the stopwatch simultaneously.
4. Stop the stopwatch at the first break or change in the continuous flow of grout from the discharge tube. Record the indicated time of efflux to the nearest 0.1 s.
5. Dispose of the grout sample and rinse the equipment.

E. DETERMINATION OF EFFLUX AFTER QUIESCENCE

1. Fill cone with grout, as previously described, using remainder of 4000 mL sample.
2. Allow grout to rest in cone for 20 min ± 15 s from the instant the cone is filled to the time the efflux time is to be measured. After the 20-min quiescent period, determine efflux time as described previously in Section "D."

3. Record efflux time of the grout to the nearest 0.1 s.

F. PRECAUTIONS

The cone must be placed in a location that is free from vibration.

The cone must be kept clean from cement buildup, especially in or near the orifice and nozzle.

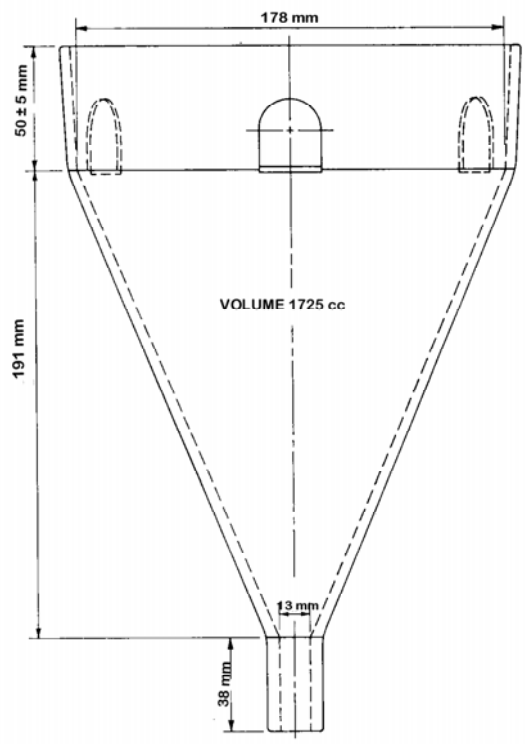


Figure 1
GROUT FLOW CONE

G. SAFETY AND HEALTH

Prior to handling, testing or disposing of any waste materials, testers are required to read: Part A (Section 5.0), Part B (Sections: 5.0, 6.0 and 10.0) and Part C (Section 1.0) of Caltrans Laboratory Safety Manual. Users of this method do so at their own risk.

End of Text (California Test 541 contains 2 pages)

Figure 2
GROUT EQUIPMENT