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Change Letter – Revision No. 02 – February 28, 2014

The *Prestress Manual* is available on the Structure Construction (SC) Intranet site *Technical Manuals*: http://onramp.dot.ca.gov/hq/oscnet/sc_manuals/

Revisions

SECTION	REMOVE	DATED		SECTION	INSERT	DATED
ENTIRE MANUAL	PRESTRESS MANUAL	May 2005		ENTIRE MANUAL	PRESTRESS MANUAL	Revision No. 2 February 2014

Background
The State of California, Department of Transportation, Division of Engineering Services, *Prestress Manual*, A Guide for Field Inspection of Cast-in-Place Post-Tensioned Structures, January 2005, Revision 1, May 2005 has been updated. The revisions include:

- Updated specification references to the current 2010 Standard Specifications.
- Terms were updated to reflect the 2010 Standard Specifications. For example, *working drawings* is revised to *shop drawings*; and *approve* is revised to *authorize*.
- Intranet links/addresses to reference materials; such as the:
  - Authorized Products List.
  - Authorized Prestress Systems.
  - Prestress Jack Calibration – Gage Factor and Numerical Display.
- Instructions for the use of the Vishay P-3 Strain Indicator.
- Pictures, Figures, and Graphic revisions to make the manual copyright ready.
- Enhanced Safety Section with a link to the SC Code of Safe Practices.
- Updated the forms that are referenced in the manual.
- Updated the format of the manual to most of the standards introduced in the *Style Guide for Structure Construction Technical Manuals*.

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Deputy Division Chief
Division of Engineering Services
Structure Construction

STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF ENGINEERING SERVICES

PRESTRESS MANUAL

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

January 2005

Revision 2
February 2014

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TABLE OF CONTENTS

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INTRODUCTION

A large percentage of the bridges built in California are prestressed, post-tensioned bridges. As a Bridge Engineer[1] working for the Division of Engineering Services, Structure Construction, you should understand the construction principles relating to prestressed, post-tensioned bridge construction.

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

1. Check the Contractor's shop 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 *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 shop drawing review and during the prestressing operation. This manual, along with good communication between Structure Construction, 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.

[1] The title for a Bridge Engineer working for Structure Construction is the Structure Representative and the Assistant Structure Representative.

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Section 1: 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. In preparation, a pre-operation safety meeting should be held at the jobsite with the prime/subcontractor to discuss the following safety concerns:

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, alongside, 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,*[2] and to the Structure Construction, *Code of Safe Practices.*[3] Always be aware of the Contractor's operation and equipment during the stressing operation.
4. 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.
5. 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.
6. The cross slopes of bridge decks may require the Contractor to use additional rigging (i.e., cables, blocking the wheels) to secure the equipment from moving during jacking operations.
7. Have the Contractor confirm that there is sufficient counter balance (i.e., tank is full) for when the hydraulic jack is extended. The jack can weigh up to two tons and can easily cause all the equipment to topple over.

[2] Section 1721. http://www.dir.ca.gov/title8/1721.html.
[3] http://dschq.dot.ca.gov/OSCHQDownLoads/misc/Code%20of%20Safe%20Practices%207-7-08%20Updated%20Version.doc.

Photo 1-1 – Example of Failure During Prestress Operations.

Section 2: PRESTRESS SHOP DRAWINGS

The *Standard Specifications* (SS)[4] requires that the Contractor submit shop 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-authorized by Caltrans or obtain approval from METS for the systems that are proposed for use.

The prestress shop drawings are to be submitted by the Contractor to the Structure Design (SD) 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 Memo to Designers*, Section 11-1. All SD technical publications are available at http://www.dot.ca.gov/hq/esc/techpubs/.

The responsibility for checking the shop drawings is shared by the Designer and the Structure Representative. Shop drawings will 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 shop drawing review by Caltrans is 45 days for structures not involving railroads, and 60 days for structures involving railroads.[5]

The *Standard Specifications*, *Special Provisions*, contract plans, *Bridge Construction Records and Procedures Manual*, and the Resident Engineer's pending file should be carefully reviewed before and during the shop drawing review process. All dimensions, layouts, and calculations must 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.
7. Grouting Plan[6] (see Appendix C).

Bridge Memo to Designers, Section 11-1, defines the roles and responsibilities of the Prestressed Concrete Committee, Designer, and Structure Representative for post-tensioning shop drawing review. In addition, a checklist for reviewing shop drawings is included in this manual in Appendix C, *Inspection Checklist*.

[4] 2010 SS, Section 50-1.01C(3), *Shop Drawings.*
[5] 2010 SS, Section 50-1.01C(3), *Shop Drawings.*
[6] 07-19- 2013 Revised Standard Specifications (RSS), Section 50-1.01C(3), *Shop Drawings*.

It is important that all parties involved (Designer, Structure Representative, Assistant Structure Representative, Contractor, and prestressing subcontractor) are working from an *authorized* set of shop drawings.

It is possible that the Contractor will begin construction from an unauthorized set of shop drawings. The Contractor should be reminded (and noted in the daily report) that all work will be checked with an authorized set of shop drawings, any deficiencies require correction, and that concrete will not be placed until the corrections have been made.

At the completion of each structure on the contract, the Contractor must submit electronic copies of the as-built shop drawings[7] to the Structure Representative. Drawings shall be arranged in the order of numbers shown on the index. The Structure Representative shall review the drawings for accuracy and then forward the drawings, if complete, to Structures Design Documents Unit, 1801 30th Street, Mail Station 9-4/4I, Sacramento, CA 95816, as outlined in *Bridge Construction Memo* 2-12.1 of the *Bridge Construction Records and Procedures Manual*.[8]

[7] 2010 SS, Section 5-1.23B(2), *Shop Drawings*.
[8] http://dschq.dot.ca.gov/sc_manuals/construction_records_and_procedures_vol_I/2-12.1_BCM.pdf.

Section 3: PRESTRESSING DUCTS

The *Standard Specifications*[9] requires that the duct enclosures for prestressing steel must:

1. Be galvanized rigid ferrous metal.
2. Be fabricated with either welded or interlocked seams, except galvanizing of the welded seams is not required.
3. Be mortar tight.
4. Have sufficient strength to maintain their correct alignment during placing of concrete.
5. Have positive metallic connections at joints between sections that do not result in angle changes at the joints.
6. Have waterproof tape at the connections.
7. Have bends that are not crimped or flattened.
8. Have ferrous metal or polyolefin transition couplings connecting the ducts to anchorage system components. Ferrous metal transition couplings need not be galvanized.
9. Have an inside cross-sectional area of at least 2.5 times the net area of the prestressing steel for multi-strand tendons.
10. Have an inside diameter of at least 1/2 inch larger than the diameter of the bar.
11. Have an outside diameter not exceeding 50 percent of the girder web width.

Rigid duct is used to take advantage of the low tendon-to-duct friction inherent with rigid ducts. 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 authorized for use on State Highway structures 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 must be rejected if the damage is extensive. The placement of the ducts can be checked by using the "duct checker"[10] or with an engineer's rule

[9] 2010 SS, Section 50-1.02D, Ducts and 07-19-2013 RSS, Section 50-1.02D, *D*ucts..
[10] *Bridge Construction Records and Procedures Memo* (BCM) 145-7.0.

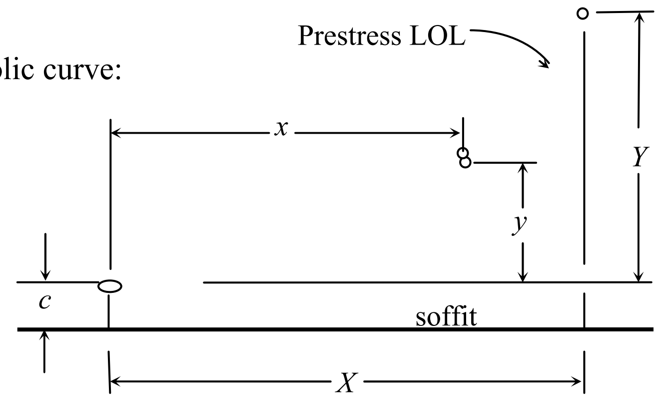
and level. Most tendon paths are parabolic and the distance from the soffit forms to the center of gravity (CG) of the path can be calculated as shown below:

Calculation of points along a parabolic curve:

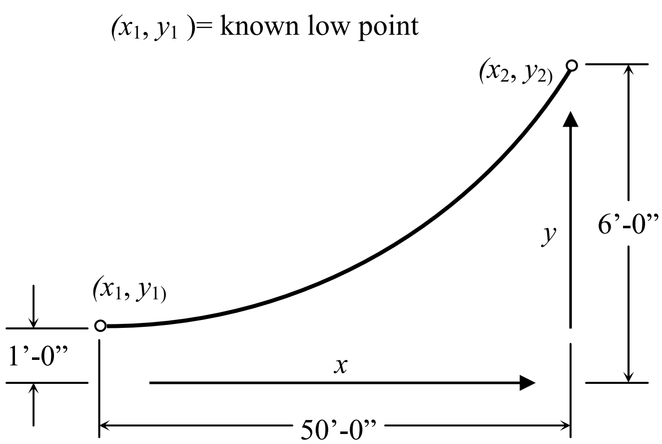
Where:

$$a = Y / X^2$$

$$y = ax^2 + c$$



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



GIVEN:

$x_1 = 0$

y_1 = 1'-0"

x_2 = 50'-0"

y_2 = 6'-0"

X=x2-x1 & Y=y2-y1

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

Solving for a: a = 5/2500

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. Waterproof tape must be used at all duct connections.[11]

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 supported vertically and horizontally during concrete placement at a spacing of at most four feet

[11] 2010 SS, Section 50-1.02D, *Ducts*.

intervals along the duct path, and is typically secured to the bar reinforcing steel using tie wire. Tie wire spacing intervals should be reduced if conditions warrant.

The Standard Specifications[12] requires vents for all ducts having a vertical duct profile change of six inches or more. Vents must:

1. Be at least 1/2-inch diameter standard pipe or suitable plastic pipe.
2. Be connected to ducts using metallic or plastic structural fasteners. Plastic components must not react with the concrete or enhance corrosion of the prestressing steel and must be free from water soluble chlorides.
3. Be mortar tight and taped as necessary.
4. Provide a means for injection of grout through the vents and for sealing the vents.
5. Be at the following locations:
    - Anchorage areas at both ends of the tendon.
    - Each high point.
    - Four feet upstream and downstream of each crest of a high point.
    - Each change in the cross section of duct.

The Contractor is required to protect the ducts from any water or debris entering them prior to the placement of the stressing steel. After installation, cover the duct ends to prevent water or debris from entering[13].

Before placing forms for deck slabs of box girder cells, the contractor is required to demonstrate:

- That any prestressing steel placed in the ducts is free and unbounded.
- That the ducts are unobstructed if no prestressing steel is in the ducts.[14]

If prestressing steel is installed after the concrete is placed, the contractor is required to demonstrate that the ducts are free of water and debris immediately before installation of prestressing steel.[15]

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.

Revisions to the *Standard Specifications*[16] will require the Contractor to pressure test each duct with compressed air after stressing and prior to grouting.[17]

[12] 2010 SS, Section 50-1.02E, *Vents* and 07-19-13 RSS, Section 50-1.03B(2)(d)(xi), *Vents.*
[13] 2010 SS, Section 50-1.03A(3), *Ducts*.
[14] 07-19-13 RSS, Section 50-1.01D(5), *Duct Demonstration of Post-Tensioned Members.*
[15] 07-19-13 RSS, Section 50-1.01D(5), *Duct Demonstration of Post-Tensioned Members.*
[16] 07-19-13 RSS, Section 50-1.01D(4), *Pressure Testing Ducts.*
[17] See Section 9, *Grouting Operation* and Appendix C, *Inspection Checklist*.

Photo 3-1 – Check of Tendon Profile.

Photo 3-2 – Smooth Duct Profile.

Photo 3-3 – 12 Ducts in One Girder at Midspan

Photo 3-4 – Part and Full Length Duct Profiles

Photo 3-5 – Transverse Ducts in Place.

Photo 3-6 – Transverse and Longitudinal Ducts

Section 4: PRESTRESSING STRANDS/BARS

The base material used to fabricate prestressing steel must conform to the requirements of ASTM A416 or A722, and the *Standard Specifications.*[18] The A416 designation covers the requirements for both 0.5″ (12.70 mm) and 0.6″ (15.24 mm) strands. The A722 designation gives requirements for high-strength steel bars. Figures 4-2, 4-3, and 4-4 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.

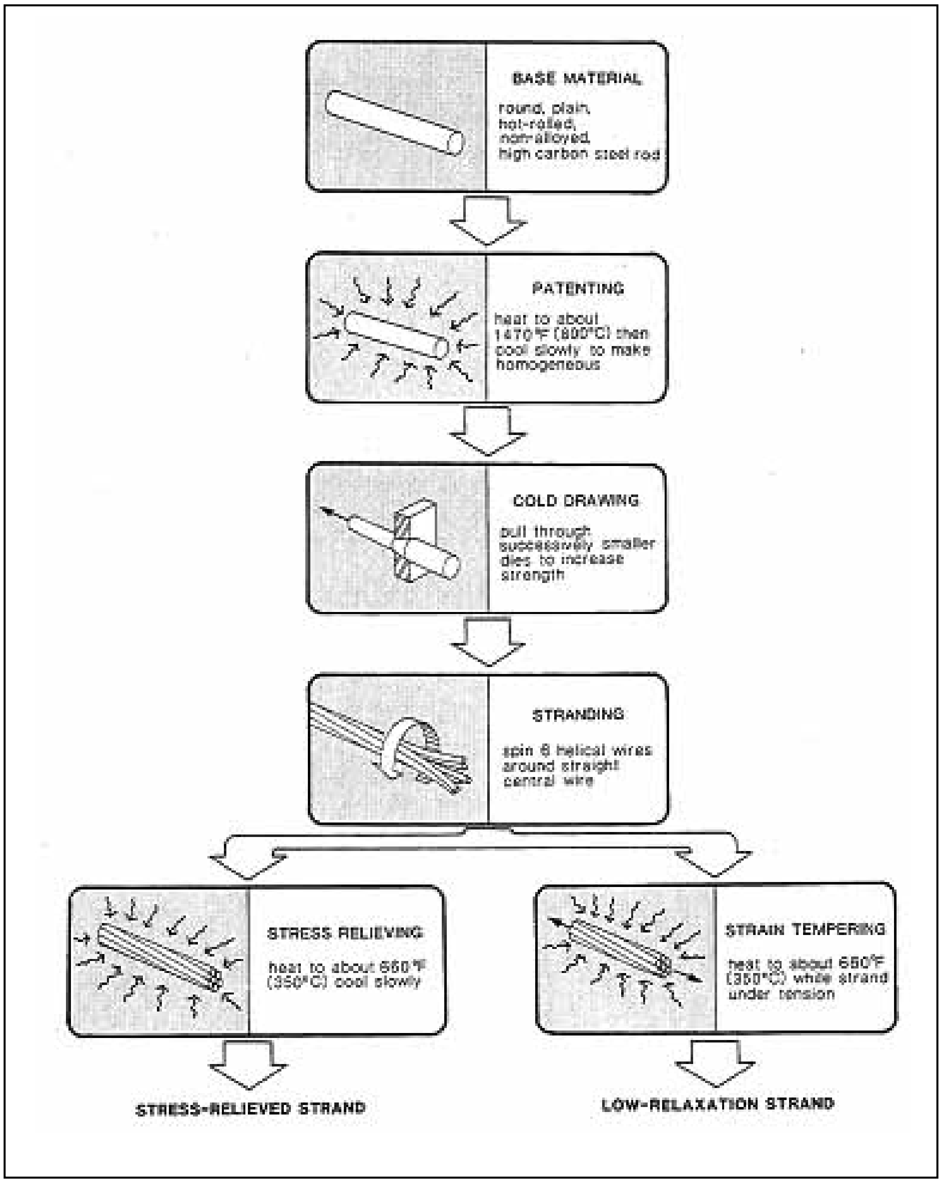


Figure 4-1 – Low-Lax Strand Manufacturing Process.

[18] 2010 SS, Section 50-1.02B, *Prestressing Steel.*

All strands are 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 4-1. 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*[19] allow the use of couplers for extending plain or deformed bars. The coupled unit must have a tensile strength of not less than the manufacturer's minimum guaranteed ultimate tensile strength of the bars.

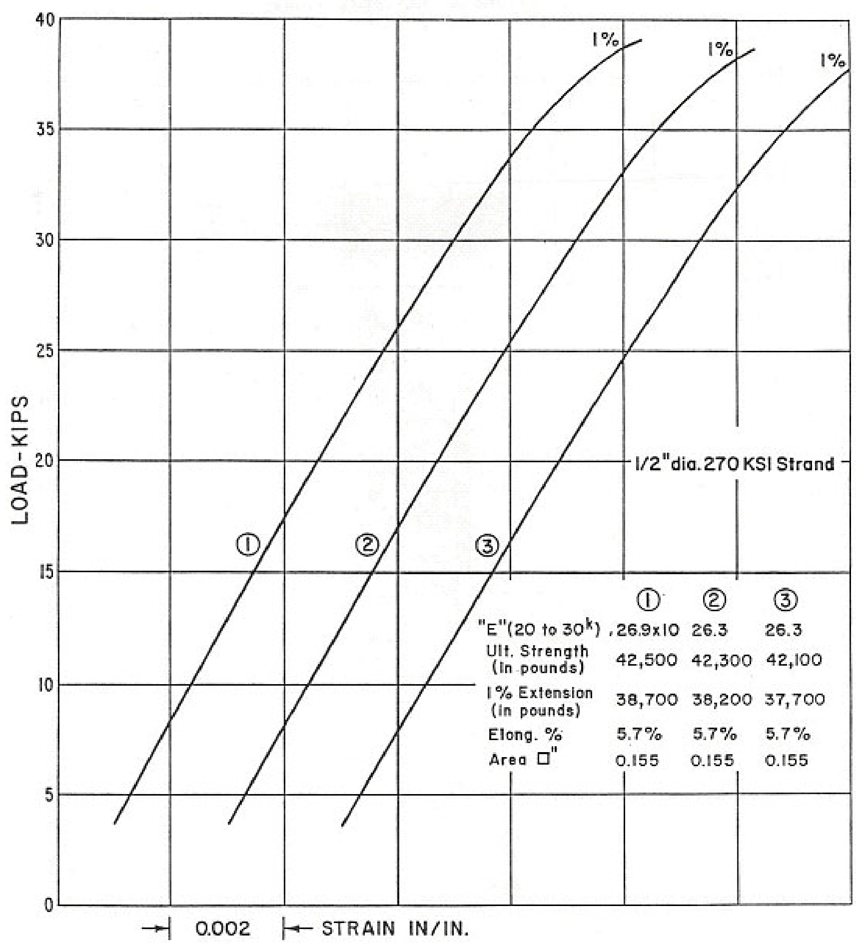


Figure 4-2 – Typical Stress-Strain Curve for 0.5 inch (12.70 mm) 270 ksi (1860 MPa) Strand

[19] 2010 SS, Section 50-1.02B, *Prestressing Steel.*

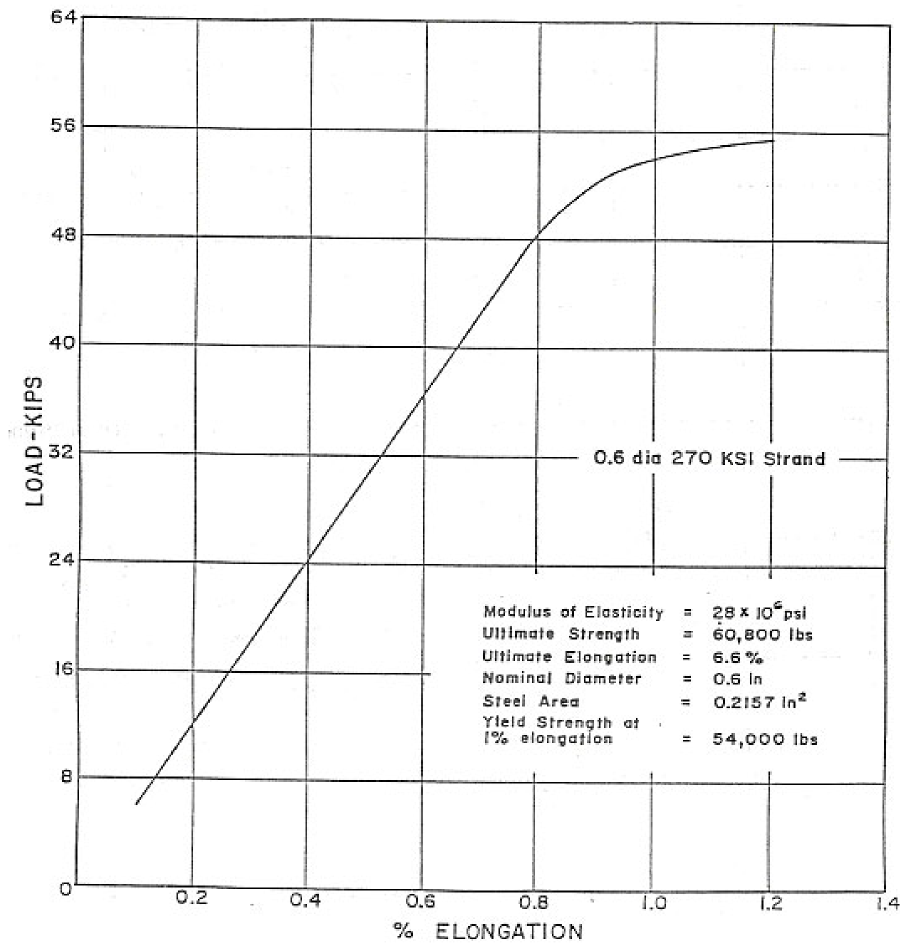


Figure 4-3 – Typical Stress-Strain Curve for 0.6 inch (15.24 mm) 270 ksi (1860 MPa) Strand.

The locations of couplers are subject to approval of the Engineer and must be shown on the Contractor's shop drawings. Effective packaging of prestressing steel is necessary to protect the material from physical damage and corrosion. The packaging 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 must 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 strands. The release tags attached to the individual packs will have the area (A), and the modulus of elasticity (E) of the strand, as determined by Materials Engineering and Testing Services (METS). 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.

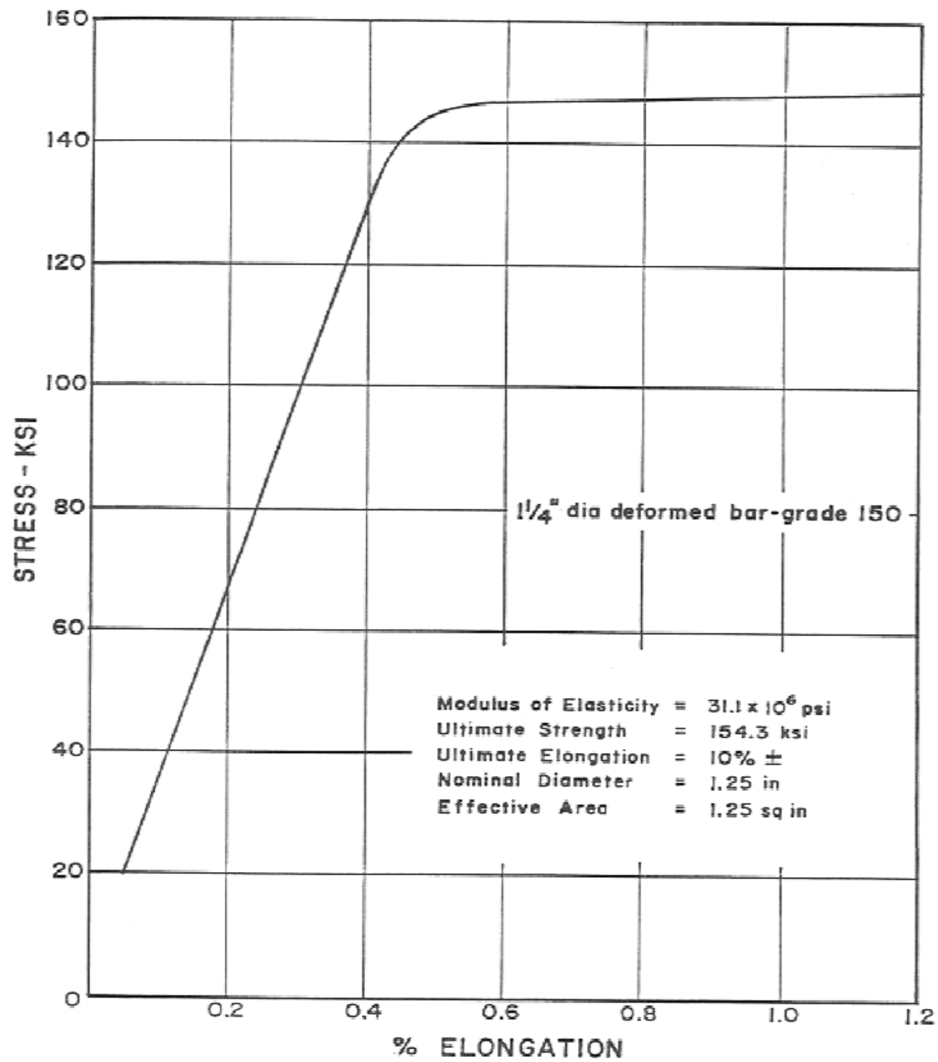


Figure 4-4 – Typical Stress-Strain Curve for 1 ¼ inch (32.0 mm) Grade 150 (1030 MPa) Deformed Bar.

The *Standard Specifications*[20] 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 must be rejected.

[20] 2010 SS, Section 50-1.02B, *Prestressing Steel.*

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 (BCE).

The prestressing steel must be checked for rust and other flaws, as described above, before it is pushed into ducts or while the tendons are being made up. 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. If the Contractor proposes arc welding, the circumstances and method must be reviewed and authorized by Structure Construction Headquarters (SC HQ) 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 is required if the stressing and grouting are not completed within 10 days. The Contractor must provide an authorized corrosion inhibitor that prevents rust or corrosion. Corrosion inhibitors must not have a deleterious effect on the steel, concrete, or bond strength of the steel to concrete.

Vapor Phase Inhibitors (VPI) are materials commonly used by contractors to protect prestressing strand. When properly applied, the powder volatizes (changes to a vapor), coating the metal surfaces to form an invisible film. Vapor Phase Inhibitors protect metal electrochemically.

The manufacturer’s recommendations should be used when applying the powder. The ducts must be reasonably dry. The powder is applied into the ducts by use of a floc gun. The application concentration for VPI Powder is typically 0.3-0.5oz/ft3 (300-500 g/m3) of enclosed space.

The Contractor must include provisions for placing VPI on the shop drawings. The provisions must include the manufacturer's technical data, application rate, and a Material Safety Data Sheet.

Contractors may propose the use of other types of corrosion inhibitors. On segmental construction either cast-in-place or precast, contractors will typically leave installed prestress tendons ungrouted for periods of time which exceed the standard specifications limit of 10 days. This is due to the risk of cross grouting into empty ducts which occur due to the sequential stressing sequences common to segmental bridge construction.

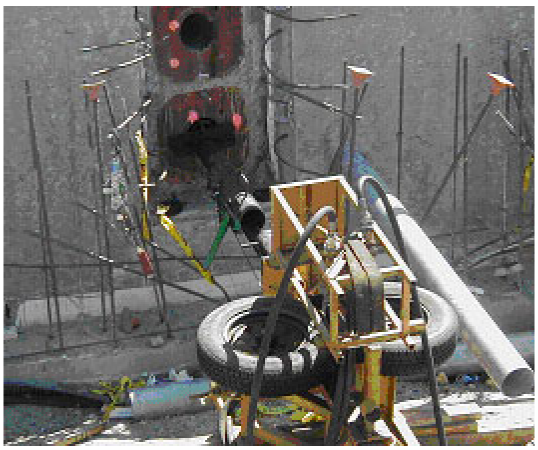


Photo 4-7 – Installation of Individual Strands by Pushing.

Photo 4-8 – Strand Packs on Bridge Deck.

Photo 4-9 – Dirt Free Prestressing Tendon.

Photo 4-10 – Tendon Installed with Pulling Cuff

Photo 4-11 – Tendon Pulling Machine.

Photo 4-12 – Cal-Wrapped Strand Packs.

Photo 4-13 – Strand, Wedge, and Anchor Head

Photo 4-14 – Sumiden Cold-drawing Process.

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Section 5: ANCHORAGE DEVICES

Authorized permanent type anchorage devices must be shown on the prestress shop drawings. The *Standard Specifications*[21] requires that the final unit compressive strength stress on the concrete behind the bearing plate must not exceed 3,300 psi (21 MPa). The bending stresses in the plates must 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 preauthorized by METS prior to their use on State contracts. The bearing plates must 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 shop drawing review and confirmed while the prestress blockouts are being formed.

The *Revised Standard Specifications*[22] require permanent grout caps.

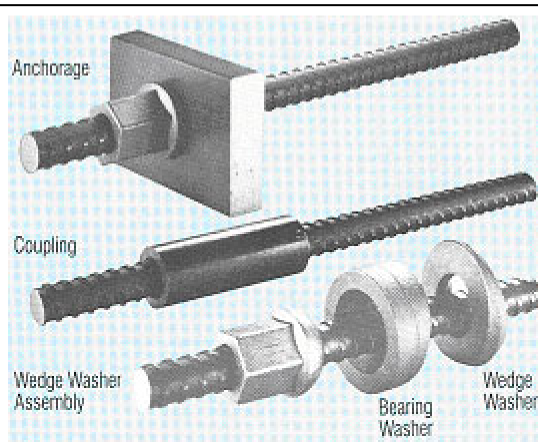

Photo 5-1 – AVAR Threadbar System.

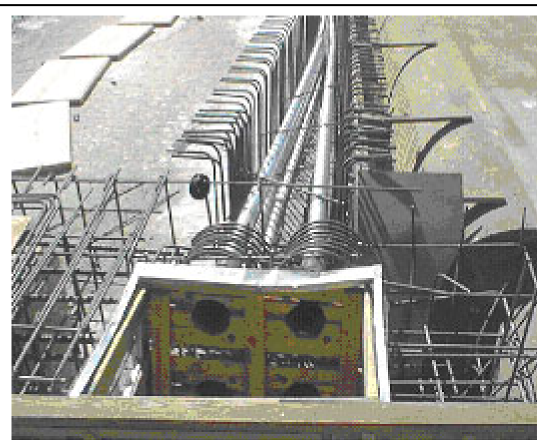

Photo 5-2 – Blockout for Anchorage Devices.

[21] 2010 SS, Section 50-1.03B(2)(c), *Anchorage and Distribution.*
[22] 07-19-13 RSS, Section 50-1.02F, *Permanent Grout Caps.*

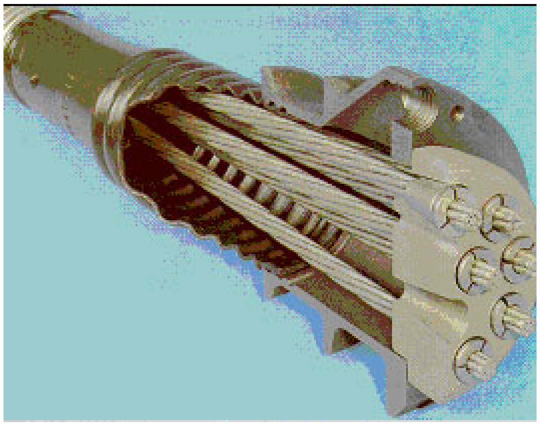

Photo 5-3 – DSI Multi-Plane Anchorage.

Photo 5-4 – Anchorage System Testing.

Section 6: 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 affect 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 affect 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 authorized 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 6-1 – Pulling Wedges Inserted into Jack

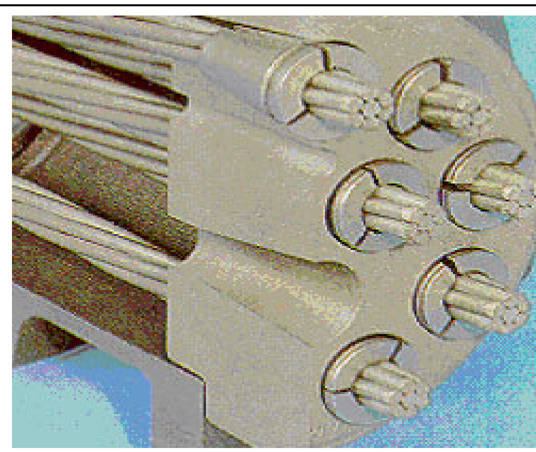

Photo 6-2 – Wedges in Anchor Head.

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Section 7: PRESTRESSING JACKS

Jacks used in typical post-tensioning systems are generally the center-hole variety (see Figure 7-1 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.

One 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.

The *Standard Specifications*[23] 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,

[23] 2010 SS, Section 50-1.01D(3), *Equipment and Calibration.*

must be calibrated by a private laboratory authorized 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 authorized stressing systems.

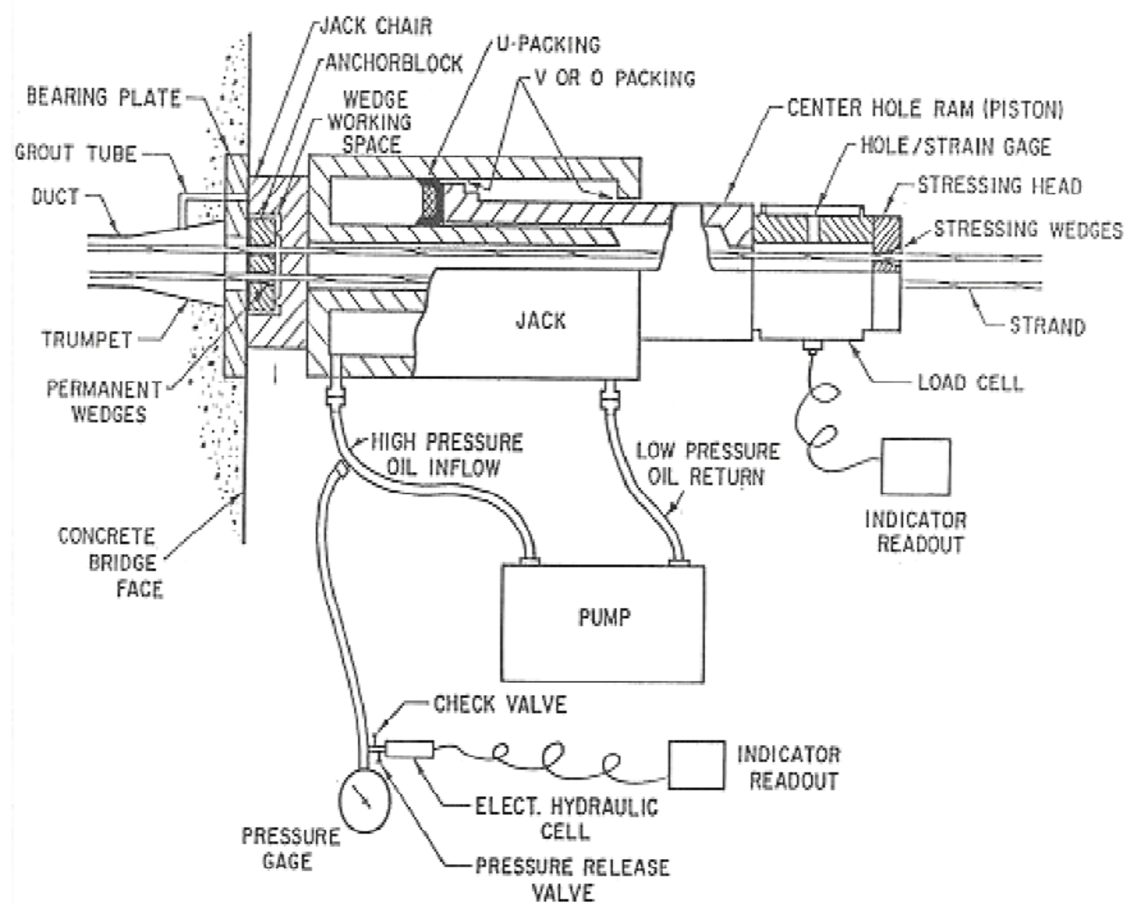

Figure 7-1 – Schematic of A Typical Post-Tensioning System.

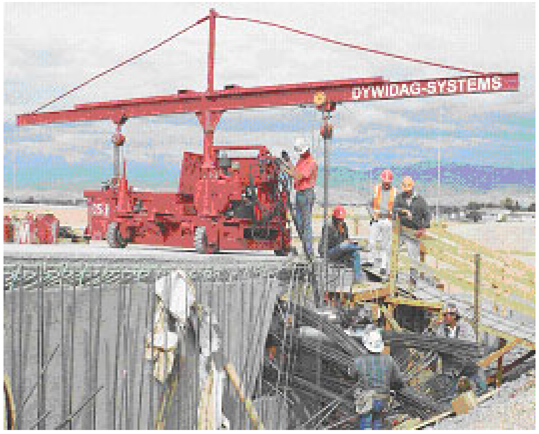

Photo 7-1 – DSI Post-Tensioning Operation.

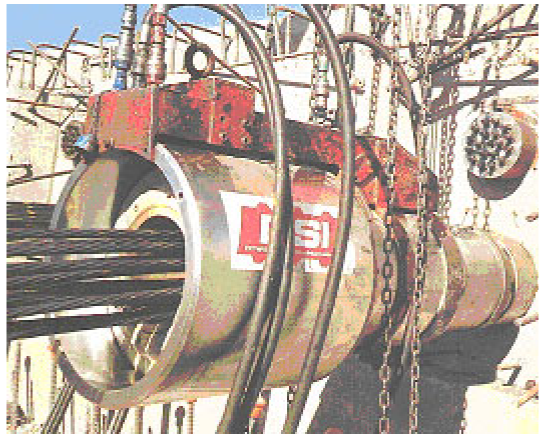

Photo 7-2 – High Capacity Prestressing Jack.

Photo 7-3 – High Strength Bar Stressing Operation.

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Section 8: 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. 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 shop 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 must 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. The current policy is to utilize the actual values for (E) and (A) provided by the strand fabricator on the individual strand packs to calculate elongations. Often packs of strand arrive with varying (E) and (A). In this case, it is best to separate the strand packs so that all strand in a given tendon are the same. 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. The *Standard Specifications*[24] 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.[25]

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

[24] 2010 SS, Section 50-1.01D(3), *Equipment and Calibration.*
[25] http://www.dot.ca.gov/hq/esc/approved_products_list/pdf/ps-pt_jack_calibration.pdf .

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. Field Inspection

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 shop drawings.

In order to minimize the possibility of undesirable construction stresses, the *Standard Specifications*[26] states, "Sequence the stressing of post-tensioned bridge girders such that no more than 1/2 of the prestressing force in any girder is applied before an equal force is stressed in the adjacent girders. The maximum temporary force variation between girders must not exceed the prestressing force of the largest tendon used in all girders. Do not apply an eccentric force about the centerline of the structure that exceeds 1/6 of the total prestressing force at any time during the prestressing."

Structure Design is responsible for checking for compliance to the requirements of Standard Plan B8-5. In addition, Structures Design will check the shop 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 authorized shop 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. *Bridge Memos to Designers,* 11-31, *Curved Post-Tensioned Bridges*, applies to girders with horizontal radii of 2,000 ft. or less.[27] The limits of, and details of these ducts ties and stirrup ties should be included in the contract plans. See Figure 8-1. If the duct ties are not shown in the plans or there is a question about installation, contact the designer.

[26] 2010 SS, Section 50-1.03B(2)(a), *General.*
[27] http://www.dot.ca.gov/hq/esc/techpubs/manual/bridgemanuals/bridge-memo-to-designer/page/Section%2011/11-31.pdf.

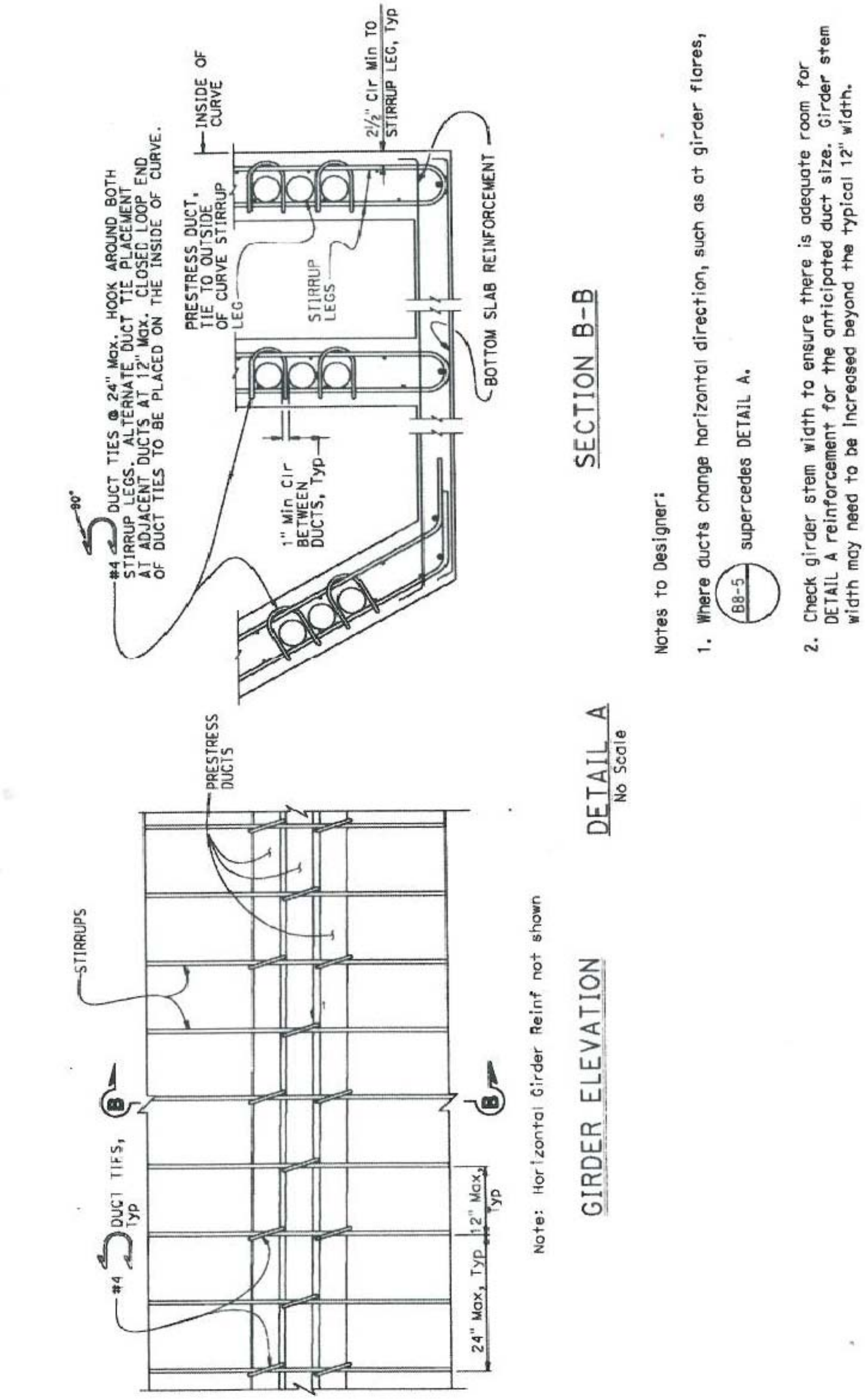


Figure 8-1 From Memo to Designers 11-31, *Curved Post-Tensioned Bridges* – October 2012, Figure 4.

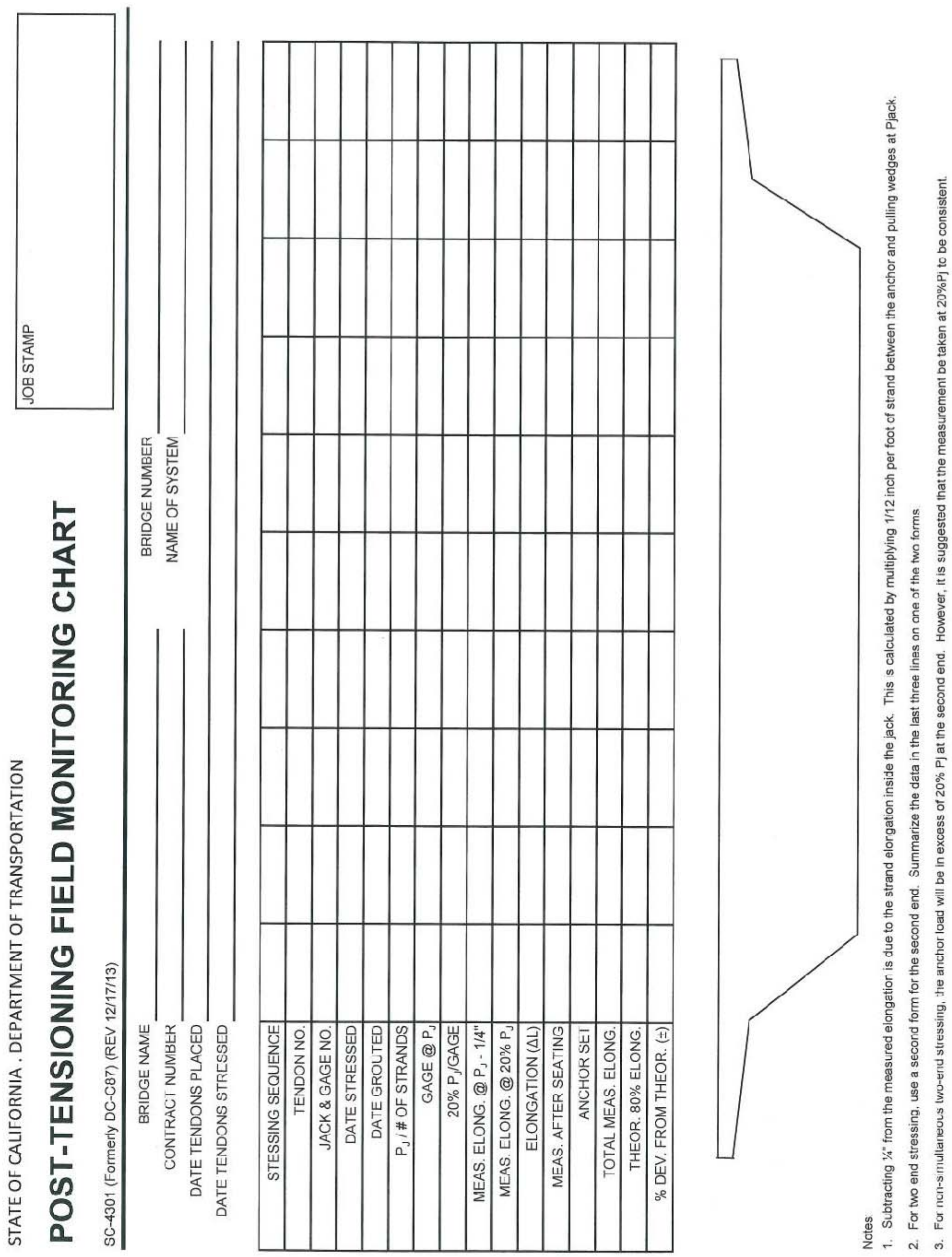
In order to efficiently monitor stressing operations, a record in chart form must be kept for each tendon stressed. Figure 8-2 shows form SC-4301 (formerly DS-C87) titled *Post-Tensioning Field Monitoring Chart.*[28] Note that some of the information shown can be entered prior to stressing. Remember, 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 strands 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 8-3, 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 must be made per structure of frame. The Structure Representative may require additional monitoring of the prestressing operation as needed. Figures 8-4 and 8-5 are examples of completed forms SC-4302 and SC-4202A[29] for recording the Contractor’s gage readings versus pressure cell readings. After completion, place these forms in the job files.

[28] http://onramp.dot.ca.gov/hq/oscnet/sc_manuals/crp/vol_1/crp016.htm.
[29] http://onramp.dot.ca.gov/hq/oscnet/sc_manuals/crp/vol_1/crp016.htm.



STATE OF CALIFORNIA . DEPARTMENT OF TRANSPORTATION

POST-TENSIONING FIELD MONITORING CHART

SC-4301 (Formerly DC-C87) (REV 12/17/13)

JOB STAMP

BRIDGE NAME ____________ BRIDGE NUMBER ____________

CONTRACT NUMBER ____________ NAME OF SYSTEM ____________

DATE TENDONS PLACED ____________

DATE TENDONS STRESSED ____________

STESSING SEQUENCE									
TENDON NO.									
JACK & GAGE NO.									
DATE STRESSED									
DATE GROUTED									
P_J / # OF STRANDS									
GAGE @ P_J									
20% P_J/GAGE									
MEAS. ELONG. @ P_J - 1/4"									
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 Pjack.
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 8-2 SC-4301 Post-Tensioning Field Monitoring Chart.

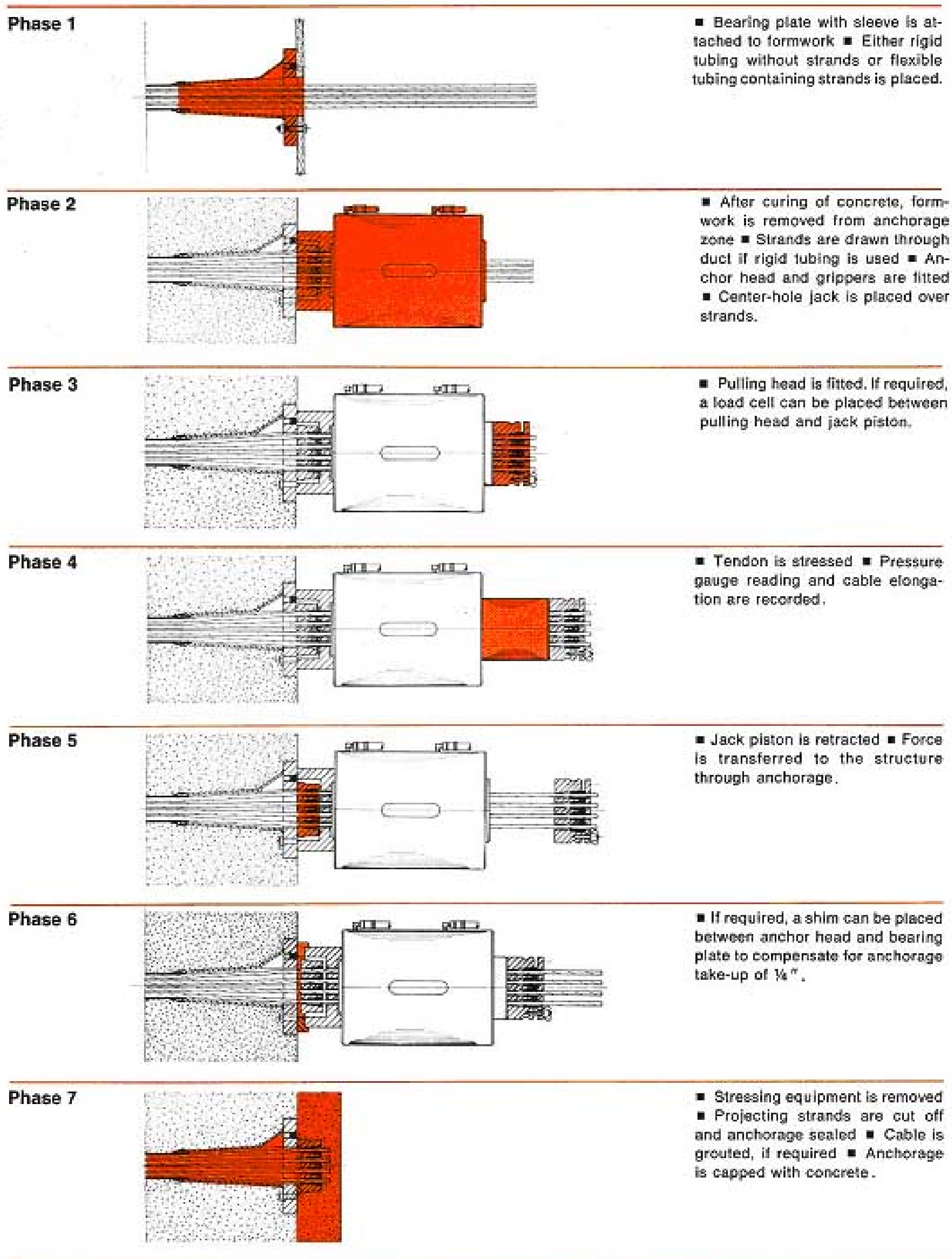


Figure 8-3 – The Complete Jacking Sequence.

STATE OF CALIFORNIA.DEPARTMENT OF TRANSPORTATION

PRESTRESS CALIBRATION

MONITORING SHEET

SC-4302 (Formerly DS-C86) (REV 12/17/13)

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

DATE 1/30/2014

BRIDGE

NAME OF SYSTEM VSL

INSPECTOR(S) I. Girder, T. Beam, I. M. Lost

JACK NO. 6-10-43

GAGE NO. 6-10-43B

STRESSING FOREMAN

	(K)	X	(#STRANDS / TENDON)	=	(Pj)
FOR 1/2 " 270 KSI STRAND ABSOLUTE MAX...Pj 31^K X #STRANDS/TENDON =	31	X	48	=	1488
FOR 0.6" 270 KSI STRAND ABSOLUTE MAX.....Pj 44^K X #STRANDS/TENDON =	44	X		=	

CONTRACT REQUIRED....Pj

THEORETICAL MAX GAGE PRESSURE...Pj / RAM AREA = 1488 / 179.1 = 8.308

MAX GAGE PRESSURE FROM LATEST CONTRACTOR'S CALIBRATION 8750 psi

STRAIN GAGE INDICATOR CHC 13686

ELECTRO HYDRAULIC CELL NO. 18

NUMERICAL DISPLAY SETTING 1094

ACTUAL GAGE FACTOR 0.72

MEASURABLE ELONGATION = 8 TOTAL ELONGATION = 28.5"

GAGE READING	LOAD FROM INDICATOR	LOAD FROM CALIBRATION CHART			REMARKS
1680	297	300			20%
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"

BY ______________________
REPORTING PARTY

Figure 8-4

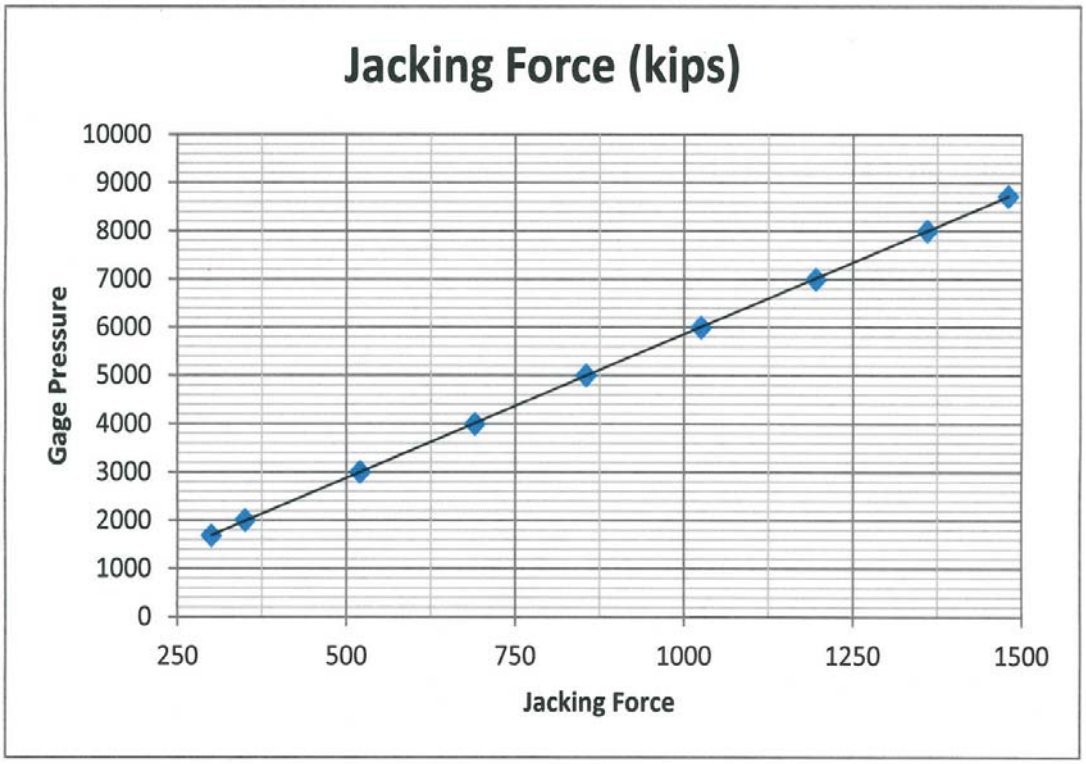


Figure 8-5 – Gage Pressure vs. Jacking Form (Form SC-4302A).

C. Overstressing of Prestressing Steel

Technically, prestressing strand develops 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 strands being of unequal length within a tendon, some of the 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 wires or strands in the tendon may be seriously overstressed. When steel, such as prestressing 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. The January 2005 edition revised the May 1992 edition of this manual, changing the friction coefficient (μ) 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 Post-tensioned Concrete 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 Post-Tensioned Concrete Committee.[30]

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.

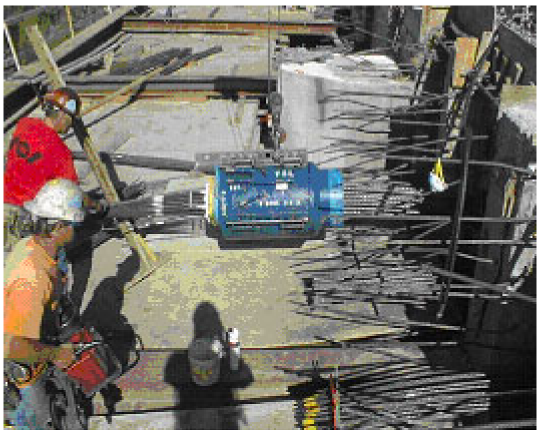


Photo 8-1 – Long Frame Stressing.

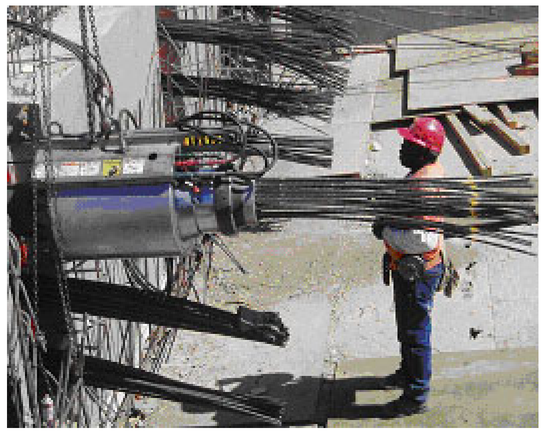


Photo 8-2 – Paint Marks Show 4 ft. Elongation.

[30] http://onramp.dot.ca.gov/hq/des/committees/posttensioned_concrete/.

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Section 9: 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 encased in well consolidated concrete, free of cracks.
2. Proper materials that have been authorized by METS.
3. Proper equipment in good working order.
4. Procedures that produce good results.

Revisions to the *Standard Specifications*[31] require the Contractor to pressure test each duct with compressed air after stressing and prior to grouting for post-tensioned concrete bridges. The Contractor is required to:

- Seal all inlets, outlets and grout caps.
- Open all inlets and outlets on adjacent ducts.
- Attach an air compressor to an inlet at one end of the duct with an attachment which includes a valve that separates the duct from the air source.
- Attach a pressure gage to the inlet at the end of the duct.
- Pressurize the duct to 50 psi.
- Lock off air source.
- Record the pressure loss after 1 minute.
- If there is a pressure loss exceeding 25 psi, repair the leaks with authorized methods and retest. Compressed air used to clear and test the ducts must be clean, dry and free of oil and contaminants.

Revisions to *Standard Specifications*[32] requires the Contractor to submit a daily grouting report for each day grouting is performed. The report must be submitted within 3 days after grouting. The report must be signed by the technician supervising the grouting activity. The report must include:

- Identification of each tendon.
- Date grouting occurred.
- Time the grouting started and ended.
- Date the prestressing steel was placed in the ducts.
- Date of stressing.
- Type of grout used.
- Injection end and grouting pressure.
- Actual and theoretical quantity of grout used to fill the duct.

[31] 2010 RSS, Section 50-1.01D(4) *Pressure Testing Ducts.*
[32] 07-19-2013 RSS, Section 50-1.01C (5), *Grout.*

- Ratio of actual and theoretical grout quantity.
- Records of air, grout, and structure surface temperatures during grouting.
- Summary of tests performed and results.
    - Except submit compressive strength and chloride ion test results within 48 hours of test completion.
- Names of personnel performing the grouting activity.
- A summary of the problems encountered and corrective actions taken.
- A summary of void investigations and repairs made.

Revisions to the *Standard Specifications*[33] require the use of permanent grout caps. Permanent grout caps for anchorage systems of post tensioned tendons must:

- Be glass-fiber-reinforced plastic with antioxidant additives meeting ASTM D 1693.
- Condition C where the environmental stress-cracking failure time must be a least 192 hours.
- Must completely cover and seal the wedge plate or anchorage head and all exposed metal parts of the anchorage against the bearing plate using neoprene O-ring seals.
- Have a grout vent.

Grout consists of cement conforming to the *Standard Specifications*[34] 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 authorized admixture is optional, but must be authorized by the Engineer.[35] 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 authorized admixtures, should be checked in accordance with California Test No. 541.[36] 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:

- Loss of water in the equipment due to poor seals, hose connections, etc.
- Hot weather conditions.
- Insufficient mixing time.

[33] 2010 RSS, Section 50-1.02F, *Permanent Grout Caps.*
[34] 2010 SS, Section 90-1.02B(2), *Cement*
[35] 2010 SS 50-1.02C, *Grout.*
[36] Appendix F.

- 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 in cement and trouble are synonymous.

Equipment used for grouting is generally at the option of the Contractor. Refer to *Standard Specifications*[37] for grouting equipment requirements. The specifications require equipment capable of grouting at least to a pressure of 100 psi (700 MPa), and a pressure gage having a full-scale reading of not more than 300 psi (2000 MPa). Also a screen with 0.07″ 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 9-1 – Large Scale Grouting Operation.

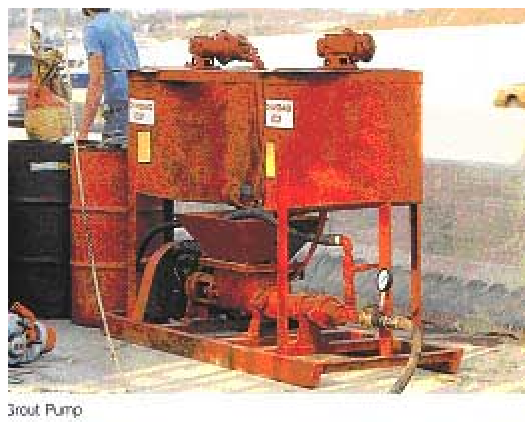


Photo 9-2 – DSI Grout Pump.

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 with water prior to grouting is no longer allowed. Flushing with water as a remedial action for blockages is no longer permitted. The grouting plan will have to address procedures for handling blockages[38].

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.

[37] 2010 SS, Sections 50-1.03B(2)(d)(i), *General* and 5-1.03B(2)(d)(vi), *Grouting Equipment.*
[38] 07-19-2013 RSS, Section 50-1.01C(3)12, *Shop Drawings.*

Blowing air through the ducts after stressing are a means of discovering blockages[39]. 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 blowing with air.

Upon grouting a tendon, it is necessary to ensure the outlet valve is closed before the inlet valve is closed. 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. 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.

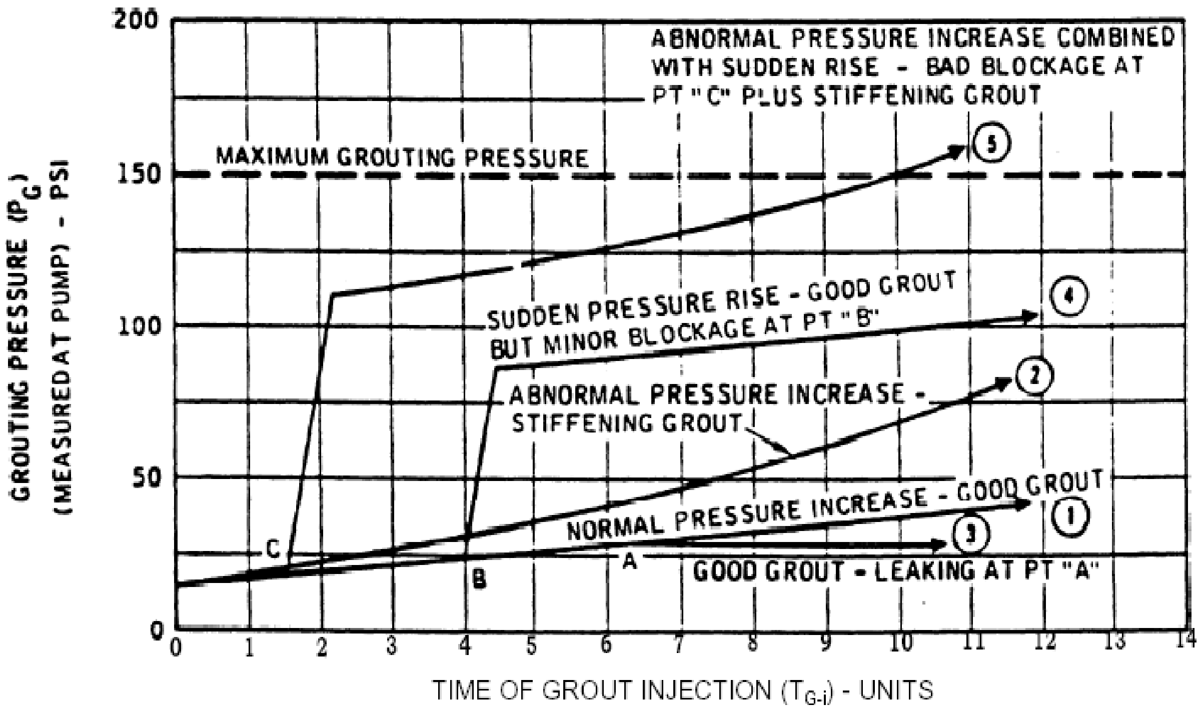
Care should be taken with the wasted grout. Avoid running grout into pervious backfill, traffic, structural or highway drainage, etc. Discuss with the Contractor prior to beginning the grouting operation how the wasted grout and spillage will be cleaned up, and define the location of disposal. The grouting operation, cleanup and disposal, must be in accordance with the authorized 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 dependent on two constants; the duct void volume and the pumping rate, as shown in Figure 9-1. 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.[40] A grout that "flash sets" in the duct will still exhibit increasing pressure, but at a greater rate.[41] A relatively constant pressure[42] 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.[43] 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, and the blockage repaired. An excessive blockage, possibly combined with

[39] 07-19-2013 RSS, Section 50-1.01D(4), *Pressure Testing Ducts.*
[40] Figure 9-1, Curve 1.
[41] Figure 9-1, Curve 2.
[42] Figure 9-1, Curve 3.
[43] Figure 9-1, Curve 4.

stiffening grout, would show up as a large increase in pressure.[44] 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:

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

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 9-1 – Pressure vs Rate of Grout Injection.

[44] Figure 9-1, Curve 5.

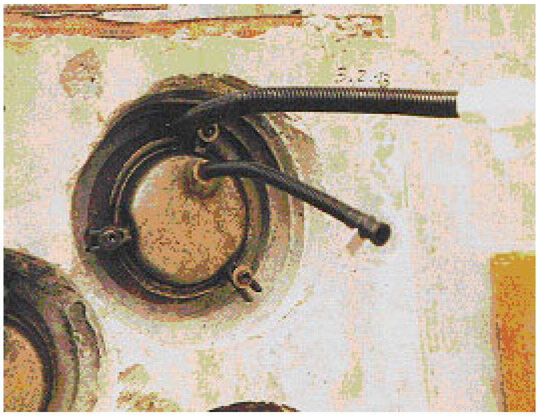


Photo 9-3 – Grout Cap and Tubes in Place.

Photo 9-4 – Grout Vents.

APPENDIX A – PRESTRESSING SYSTEMS

A. New System Proposals

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

All prestressing systems that are proposed for use in the State of California must 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 must be bound or stapled together with a title page indicating the name or names of the systems being submitted. The individual numbered sections must 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. Presently Used Systems

The following is a summary of the State authorized prestress systems. The summary is considered complete and includes both systems used in bridges and as ground 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 authorized for State use. Both METS in Sacramento and the Division of Engineering Services Prestressed Concrete Committee have current files for all authorized systems. Check the Structure Construction web site for a current list of those contractors with currently authorized systems.

AVAR Construction Systems, Inc.[45]

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.

[45] In January 2012, Schwager Davis Inc., purchased AVAR’s Construction Post-tensioning Division. Schwager Davis Inc. now owns Avar’s prestress jacks, equipment and approved systems.

Photo A-1 – AVAR.

Photo A-2 – 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. Its use, including a broad application as a rock anchor, has greatly expanded in this country since its introduction in the 1970's. 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 authorized 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 rated at 60 metric tons,[46] 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.

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).

[46] A metric ton equals 2204 lbs.

Photo A-3 – Close-up of DSI 1886 Kip Jack.

Photo A-4 – DSI Anchorages and Block-out.

Photo A-5 – Stressing a DSI 27 Strand Tendon.

Photo A-6 – DSI Post-Tension.

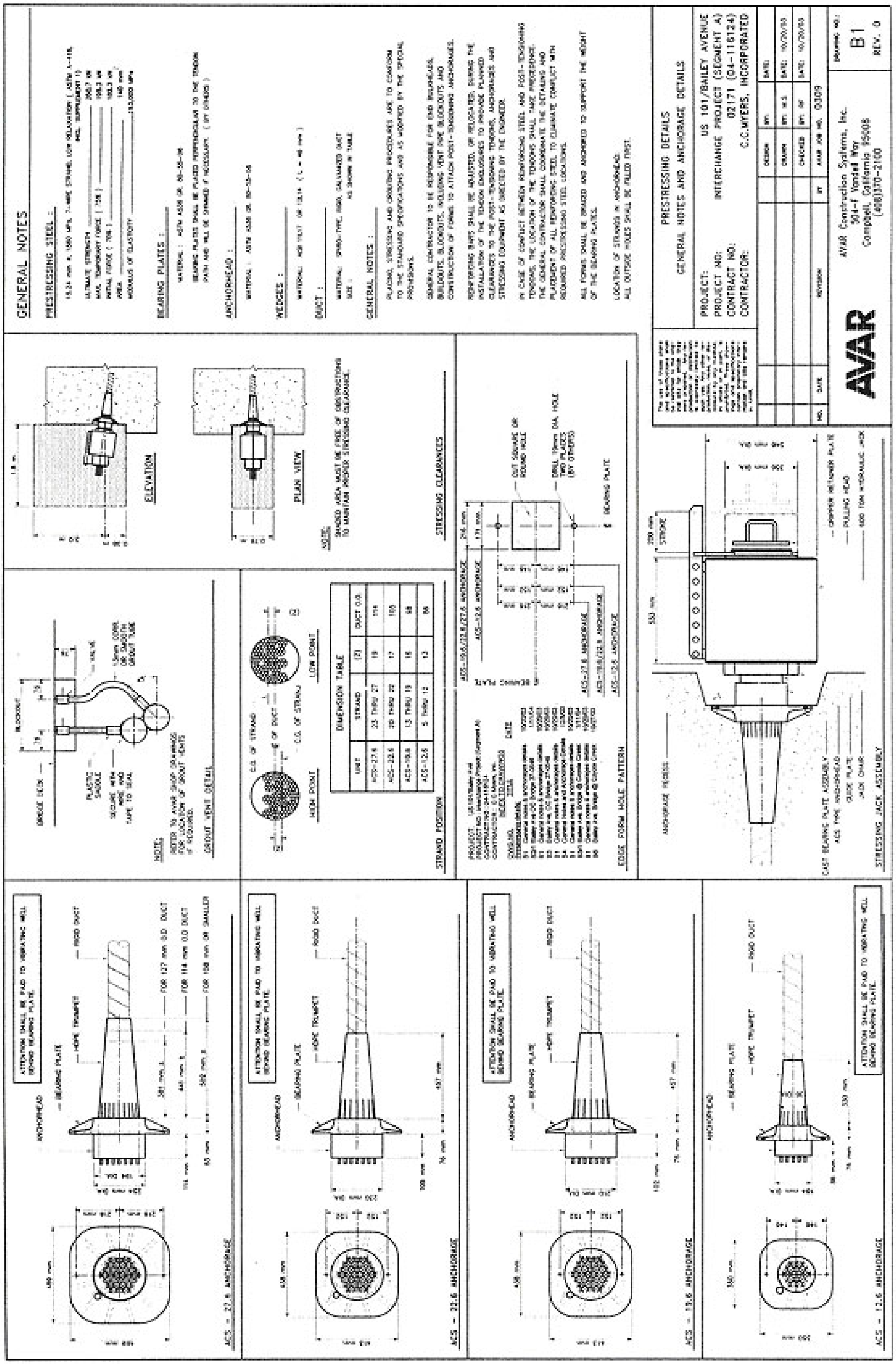


Figure A-1 – AVAR Post-Tensioning Systems Used For Box-Girder Construction.

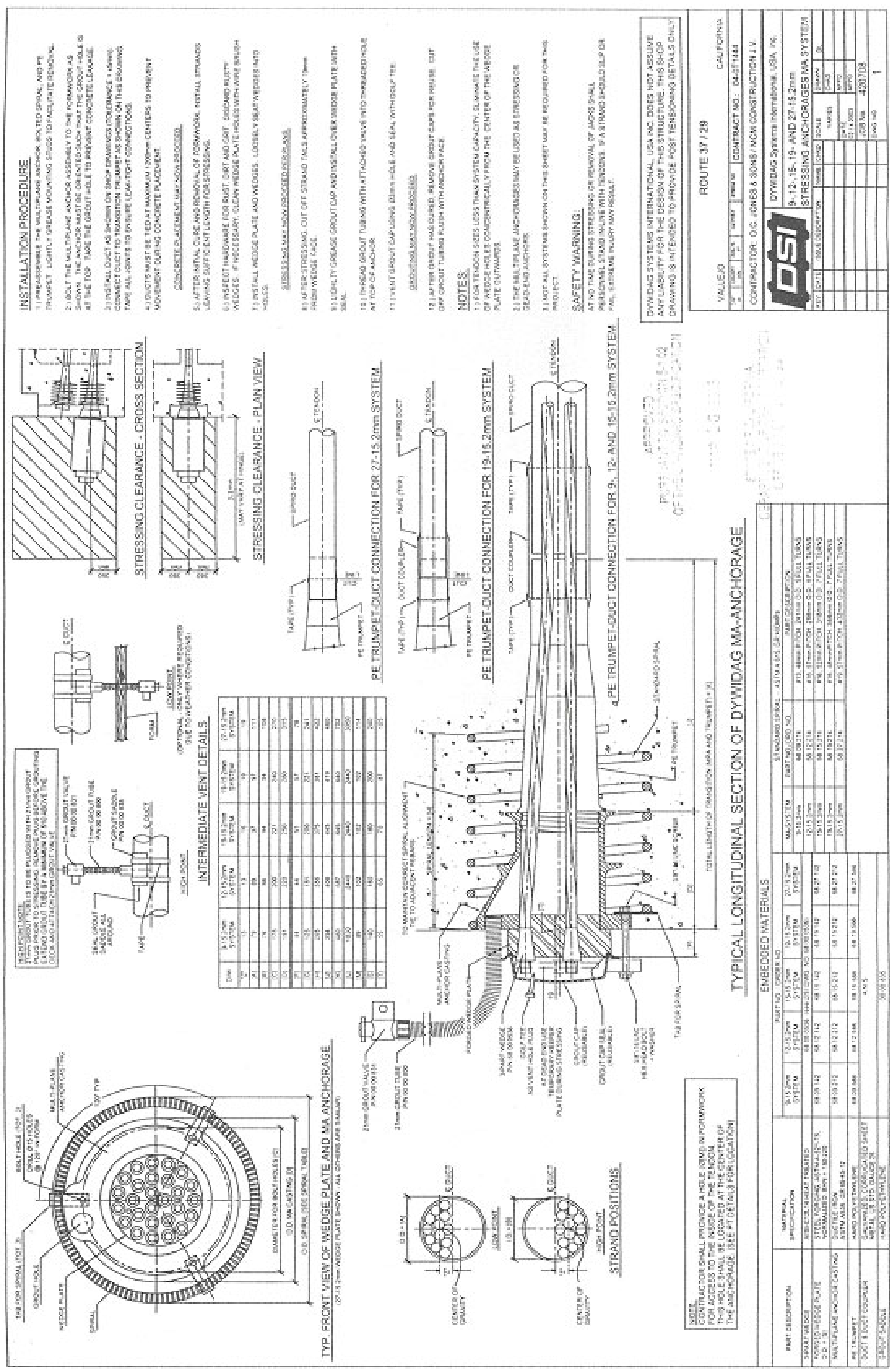


Figure A-2 – DSI Post-Tensioning Systems Used for Box-Girder Construction.

Stresstek System
Stresstek is not currently active on State projects, but is an authorized 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 authorized are the Stresstek 0.6″ (15.24 mm) strand systems using 4, 7, 13, or 19 strands maximum.

Western Concrete Structures System
Western Concrete Structures, Inc. is not currently active on State projects, but is an authorized 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 authorized are capable of holding a maximum of 1, 4, 12, 16, 20, 24, 28, and 48 strands.

C. Ground Anchors and Soil Nails

The use of ground 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 *Standard Specifications*[47].

The following authorized post-tensioning contractors perform tensioning on ground anchors only. Visit the METS link to obtain the current authorized list. Scroll down to *Concrete Anchorage Devices.*[48]

Case-Pacific
  Case-Pacific utilizes other authorized systems.
Foundation Constructors
  Foundation utilizes other systems.
Mahaffey Drilling
  Mahaffey also utilizes other systems previously discussed.
Malcolm Drilling Co., Inc.
  Malcolm also utilizes other systems.
Pomeroy
  Pomeroy utilizes other authorized systems.
Schnabel Foundation

47 2010 SS 50-1.03B(2)(c), *Anchorages and Distribution.*
48 http://www.dot.ca.gov/hq/esc/approved_products_list/.

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

Wagner Construction

Wagner also utilizes other authorized 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 authorized systems are to be used by authorized contractors. Additional specifications will be found in the contract special provisions.

APPENDIX B – STRAIN INDICATOR - PRESSURE CELL

A pressure cell and transducer/strain indicator (see photos B-1 and B-2) 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 7-1) enabling readout of the actual force applied to the prestressing steel. Load cells are calibrated with the "National Bureau of Standards" load cell.

If the Caltrans pressure cell needs to be recalibrated, coordinate with SC HQ Equipment Coordinator. The SCHQ Equipment Coordinator will be in contact with the Structure Representative and METS during this process.

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 P3500 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 Ex 10, 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 P3500 Pressure Cell: with Digital Display

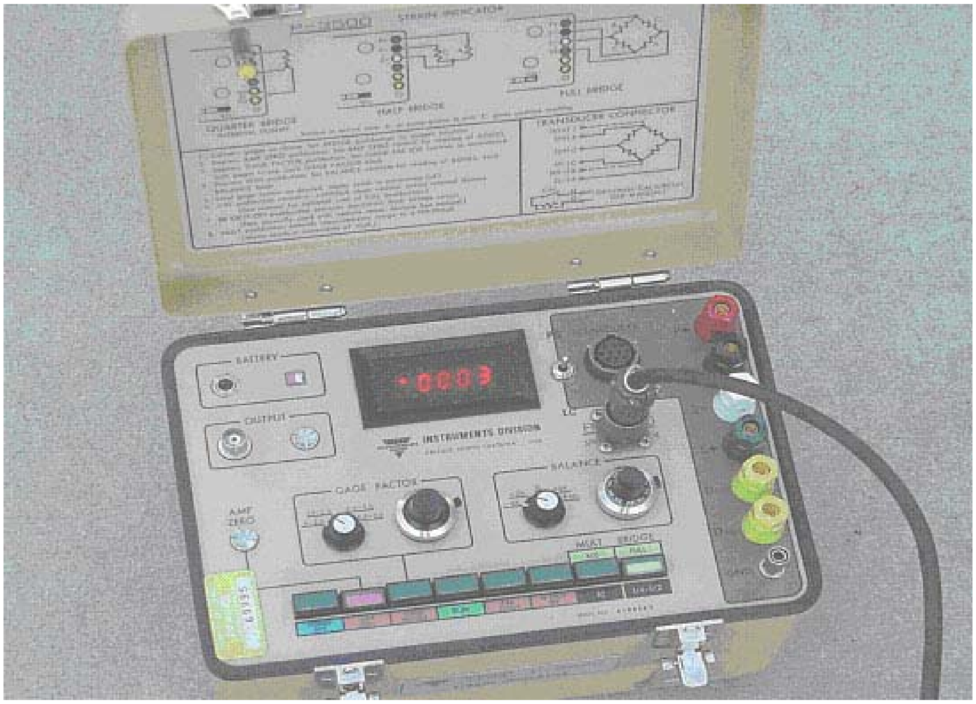


Photo B-1 – Close-up of Model P-3500 Strain.

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 located 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 B-2).

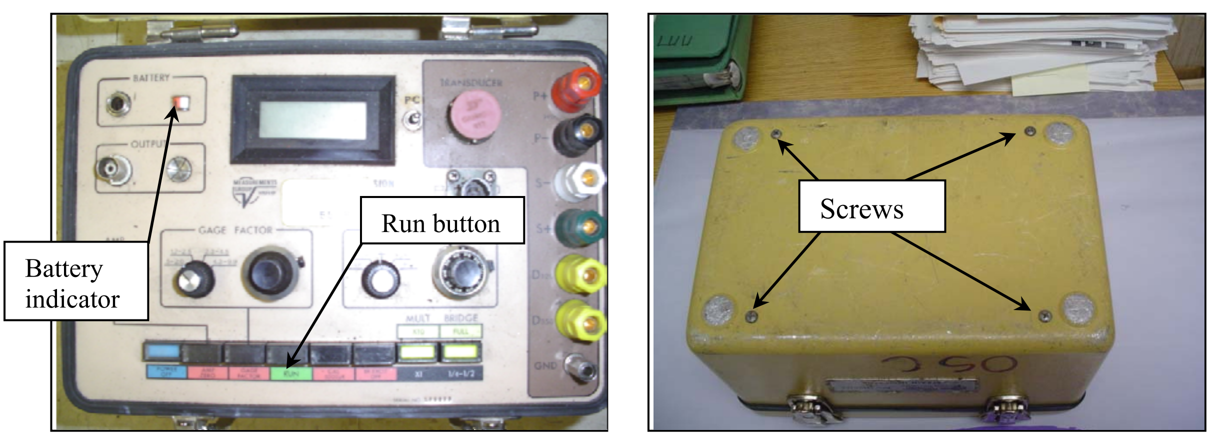


Figure B-2.

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 B-3) 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 SC Webpage, under Field Resources, Prestress Calibration Charts).

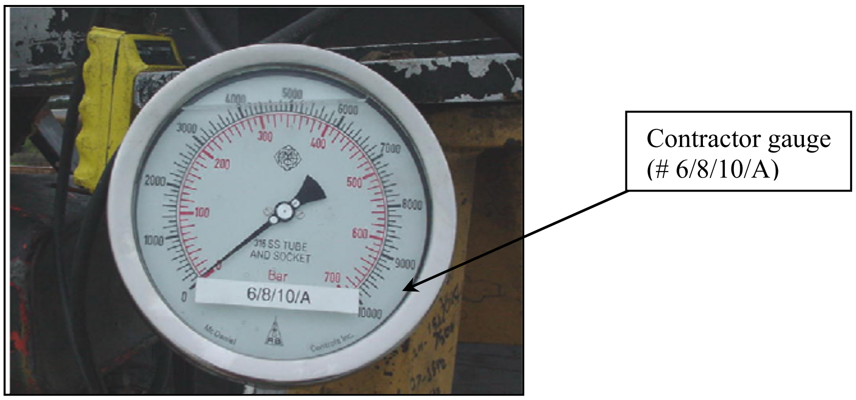


Figure B-3.

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

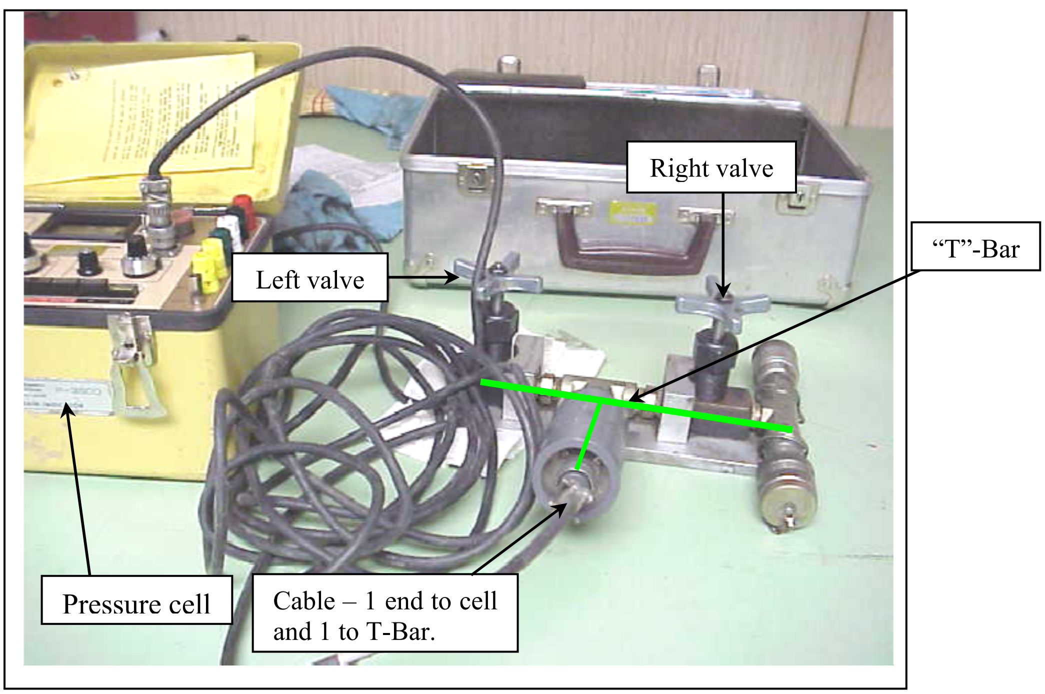


Figure B-4.

5. Close the right valve and open the left valve on the "T" bar (See Figure B-4).

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 B-5).

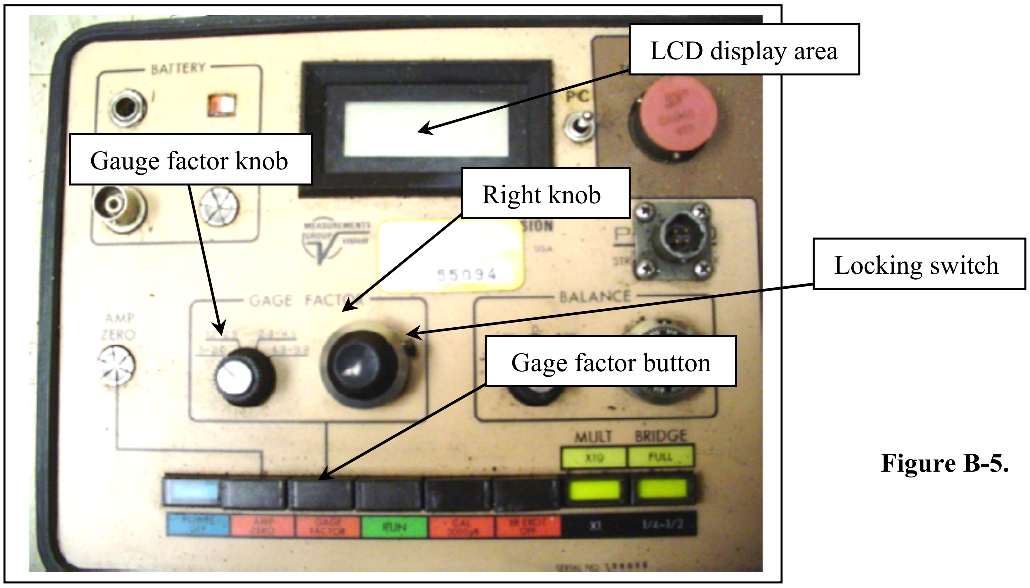


Figure B-5.

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 (clockwise) (Figure B-6).

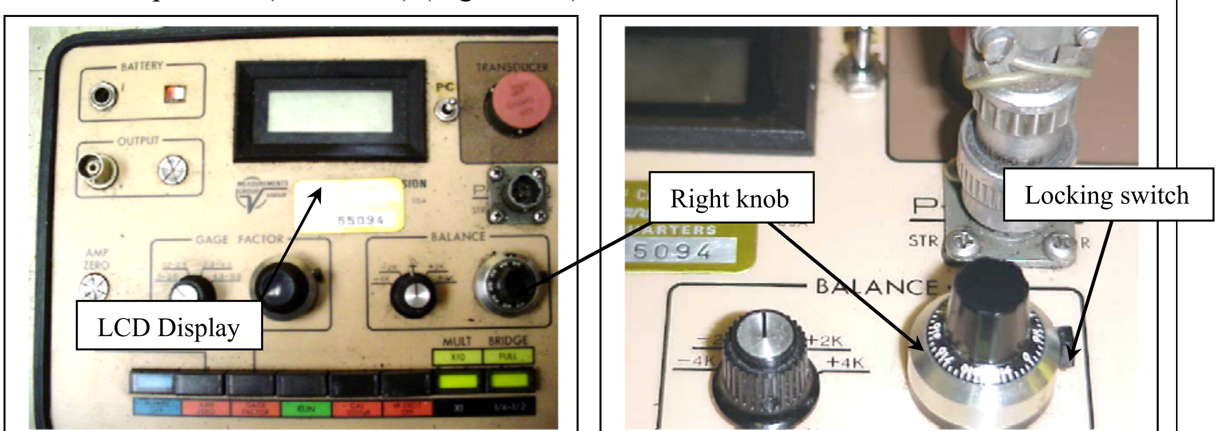


Figure B-6.

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 B-7).

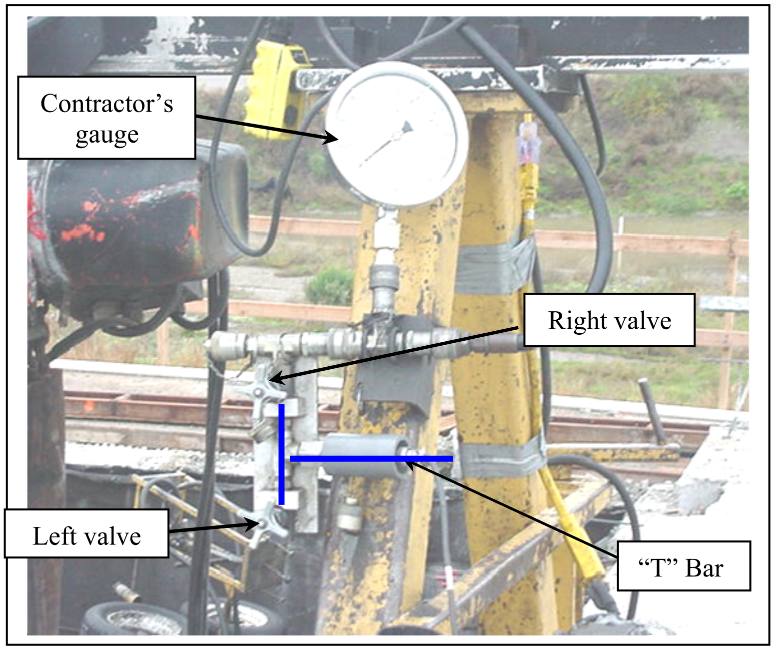


Figure B-7.

Photo B-2 – Model P-3500 Digital Display Strain Indicator.

Instruction for the Vishay P-3 Strain Indicator

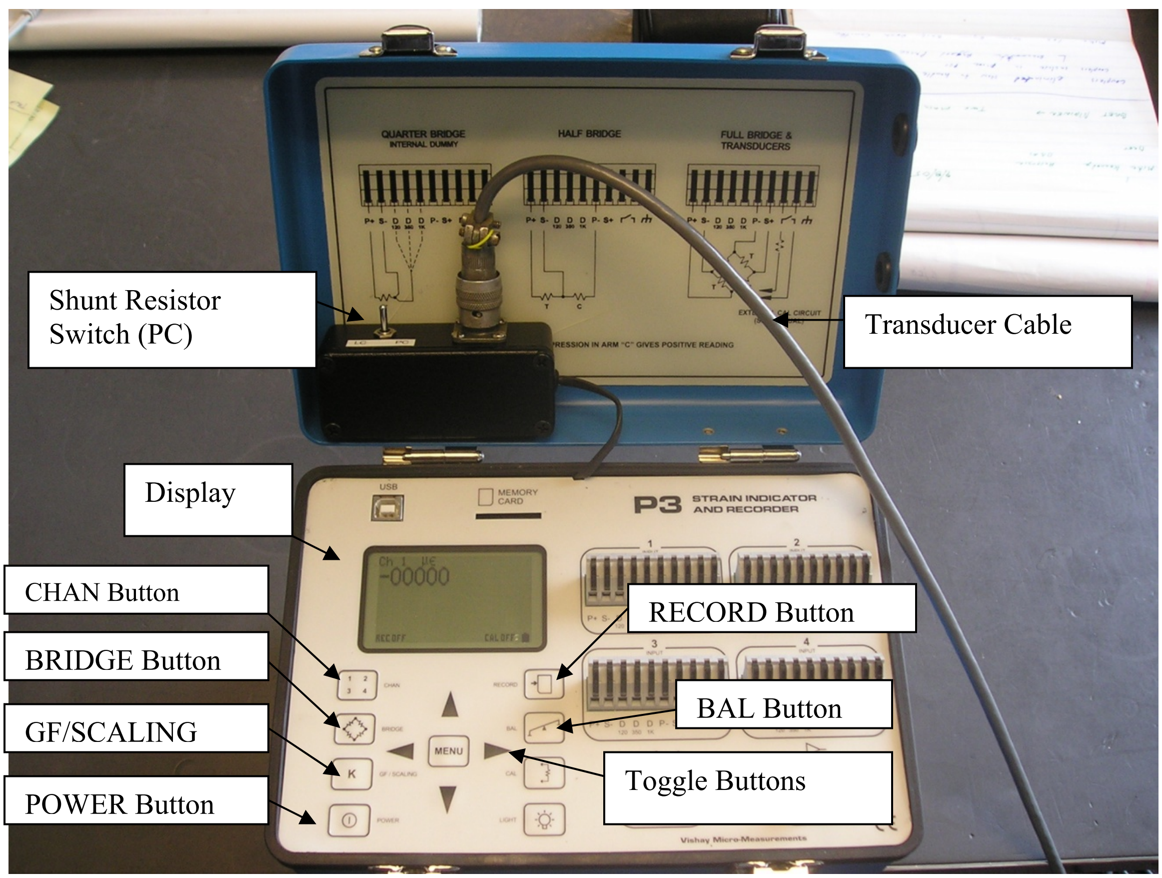
The Vishay P-3 Strain Indicator is a replacement model for the P3500. The P-3 has an all-digital interface, and operates very similarly to the P3500. Compared to the P3500, the P-3 has many more options and features. However, for post tensioning monitoring only the basic of these features are utilized. Below is a quick start guide for the P-3.

Step 1. Pressure Cell Hook-Up.

Have the Contractor hook up the pressure cell into the hydraulic system close to the gage. Install the transducer cable as shown below (small end to the P-3, other end to the pressure transducer).

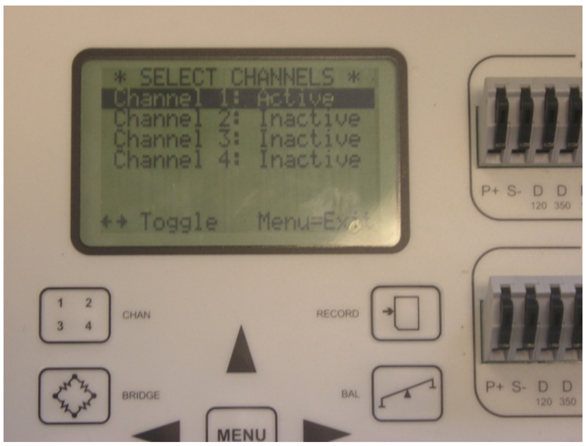
Step 2. Power On

Turn the P-3 unit on by pressing the "Power" button. The unit should beep and briefly display model information. The battery symbol is shown in the lower right corner.

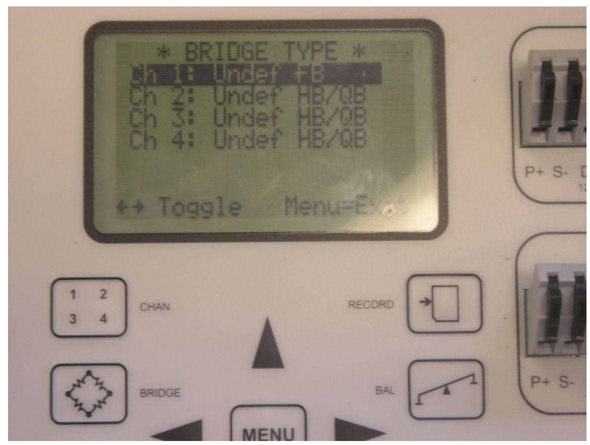


Step 3. Verifying Channel and Bridge Settings

Verify the "Channel" and "Bridge" settings are correct. These settings should not be changed from the values listed below. Press the "CHAN" button. The display should read, "Channel 1: Active". All other channels should read "Inactive". Press the "MENU" button to return to the display. Press the "Bridge" button and verify that Channel 1 is set to "undef FB" (Full Bridge). Press the "MENU" to return to the display. As stated above, these settings should always remain the same and should not be changed. If these settings have been changed, use the toggle buttons to restore them to the correct values. See pictures below.



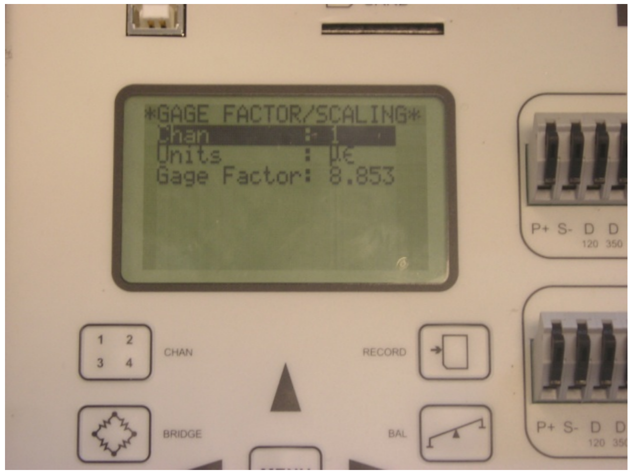
Channel Setting



Bridge Setting

Step 4. Setting Gage Factor

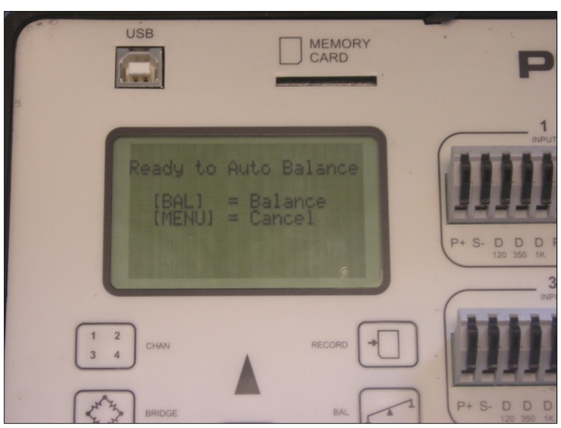
Press the "GF/SCALING" button. Verify that the Channel is set to "1" and the Units are set to $\mu\varepsilon$ (microstrain). Note these values should never be changed. If these settings have been changed, use the toggle buttons to restore them to the correct values. Set the GF (gage factor) to the value found in the Department's Prestress Calibration Chart using the toggle buttons. The GF is unique to the stressing jack being used. Once the GF is set, return to the display screen by pressing the "MENU" button.

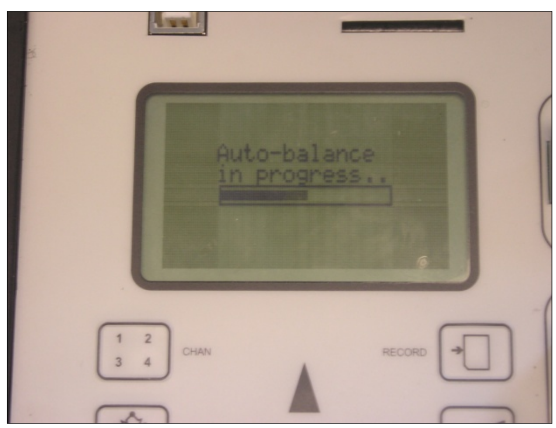


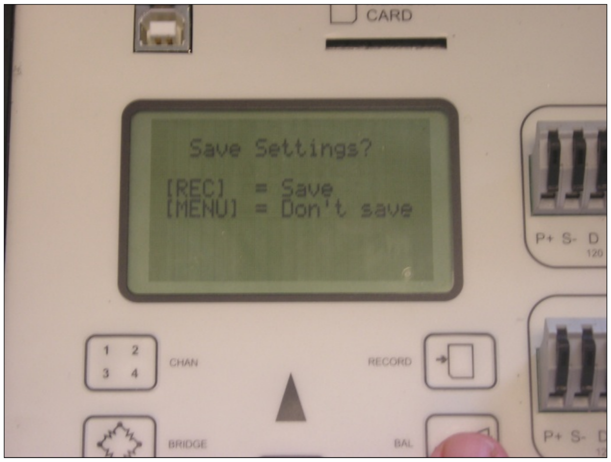
Gage Factor Setting.

Step 5. Balancing

Make sure the Pressure Cell is connected to the Contractor's hydraulic system. Check the cable connections on the P-3 and the pressure transducer. Close the valve closest to the hydraulic hose connection. Open the other valve. (This is done to assure no hydraulic pressure exists at the transducer). Press the "BAL" button on the P-3. Press it again to start the auto-balance. When the auto-balance program is completed you will be prompted to press the "RECORD" button to save the settings. The unit should now read 00000 and is ready for use.







Balancing.

Step 6. Check the Set-Up by Verifying the Numeric Display (N.D.)

To verify if the P-3 is operating correctly, a calibration shunt resistor is applied to the full bridge circuit. The resistor is applied by toggling the switch next to the cable connection to the position marked "PC". After Steps 1 through 5 have been completed, toggle the shunt resistor switch to "PC". The display should read a value close (within 2%) of the Numeric Display (N.D.) listed in the Department's Prestress Calibration Chart for the jack that is being used. If a greater discrepancy is found, check all connections and repeat Steps 1 through 6. If a large discrepancy is still noted, do not use. Arrange for the equipment to be serviced. Contact the SC Equipment Manager at 916-227-7777.

Step 7. Proceed with Stressing Operation and Taking Readings

Similar to the P3500, the P-3 will read in units of kips. No decimal point will be shown. The last digit on the right will be tenths of a kip. For example a display reading of 07586 equals 758.6 kips.

Check List for Malfunctioning Pressure Cell:

1. Cell indicator will not balance. Possible causes:
    a. “Low” battery.
    b. Cell not properly plugged in.
    c. Indicator not turned on.
    d. Loose connections.
    e. Severed or damaged lead wire.
    f. Connections wet and/or muddy.
    g. Cell wet and/or muddy.
    h. Resistor is plugged in (older indicators only).
    i. Broken resistor.
    j. Pressure applied to cell.

2. Gage factor has large change. Possible causes:
   a. Incorrect PC resistor setting.
   b. Poor connection to cell.
   c. Wire or cell damaged.
   d. Cell is wet or damp.
   e. Malfunction of indicator electronics.

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

4. Needle sluggish or will hardly move. Possible causes:
   a. Pressure cell not plugged in.
   b. Low battery.
   c. Water on connections or cell.
   d. 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 shop drawings: The Structure Representative has an active role in the review of prestress shop drawings. The *Bridge Memo to Designers*, Section 11-1 *Precast and/or Prestressed*, defines the roles and responsibilities for shop 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 shop 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 the 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 shop 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 shop drawings.
   k. Contractor should provide V.P.I. powder information.
   l. Check grouting plan. Plan must include the information required by Section50-1.101C(3):
      1) Detailed grouting sequence.
      2) Type.
      3) Quality and brand of materials to be used.
      4) Type of equipment to be used including provisions for backup equipment.
      5) Types and location for grout inlets.
      6) Outlets and vents.
      7) Methods to clean ducts before grouting.
      8) Methods to control the rate of flow within the ducts.
      9) Theoretical grout volume calculations for each duct.
      10) Duct repair procedures due to an air pressure test failure.

11) Mixing and pumping procedures.
12) Direction of grouting.
13) Sequence of use of inlets and outlets.
14) Procedure for secondary grouting.
15) Names of people who will perform grouting activities including their relevant experience and certifications.

3. Shop drawings should be reviewed thoroughly, but also as quickly as possible. In most cases *Standard Specifications*[49] mandate a 60 day review time for railroad bridges and 45 days for other structures. 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 authorized shop drawings.

When Prestressing Materials Arrive at Jobsite:

1. See that material has been released and physically identified by METS TL-0624, *Inspection Release Tag.* (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 shop 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 the 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 the same size as called for on the shop drawings.

[49] 2010 SS, Section 50-1.01C(3) *Shop 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[50].
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 shop drawings.
9. Seal tendon openings to prevent water or debris from entering the duct.

During Stem Pour:

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.

After Stem Pour:

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

During Deck Pour:

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.

[50] 07-19-2013 RSS, Section 50-1.03B(2)(d)(xi), *Vents.*

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 cleaned of dirt and debris before pulling the tendon through the duct. Strands must also be protected from scraping or wear when pulled over dunnage.
3. Contractor must 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 the Contractor has furnished the required calibration curves for specific jack/gage combinations. Make sure that this is listed on METS' authorized jack calibration list.[51]
2. Check out pressure cell. The battery should be charged for 8 hrs maximum prior to usage. While using the pressure cell in the field, only turn it 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, from 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.

[51] http://www.dot.ca.gov/hq/esc/approved_products_list/pdf/ps-pt_jack_calibration.pdf

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 SC HQ office.[52]
5. It is the practice of Structure 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 overrides SC practice.
6. If a strand breaks during the stressing operation, the Designer and the Post-tensioned Concrete Technical 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. Witness pressure testing for the ducts as required by the *Standard Specifications.*[53]
3. Make sure the grouting equipment meets specifications and has adequate capacity for the job.
4. Make sure the cement is the correct type and protected from adverse conditions. The cement must be supplied by an authorized source and a Certificate of Compliance is required prior to placing the grout.
5. Use water/cement ratio not to exceed 5 gallons of water to one sack of cement.
6. Check the authorized admixture list on the SC website under "Field Resources" to verify that proposed admixtures are acceptable. Contact METS for additional information on admixtures.
7. Check efflux time in accordance with test method.
8. Make sure there is continuous agitation of grout during grouting.
9. Monitor the grouting pressure. Pressure should gradually increase as the duct is filled. A sudden jump in pressure usually indicates blockage.
10. Close outlet valve before closing inlet valve.
11. Verify the Contractor is collecting the data needed for the required daily grouting report to be submitted within 3 days of grouting per the *Standard Specifications.*[54]

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 SC HQ in Sacramento.

[52] (916) 227-7777.
[53] 2010 SS, Section 50-1.01D(4), *Pressure Testing Ducts.*
[54] 2010 SS, Section 50-1.01C(5), *Duct Demonstration of Post-Tensioned Members*.

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 are assumed to be a total of:

- 20 ksi (138 MPa) for low relaxation wire.
- 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:

$$T_0 = T_x e^{(\mu\alpha + KL)}$$ **(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:

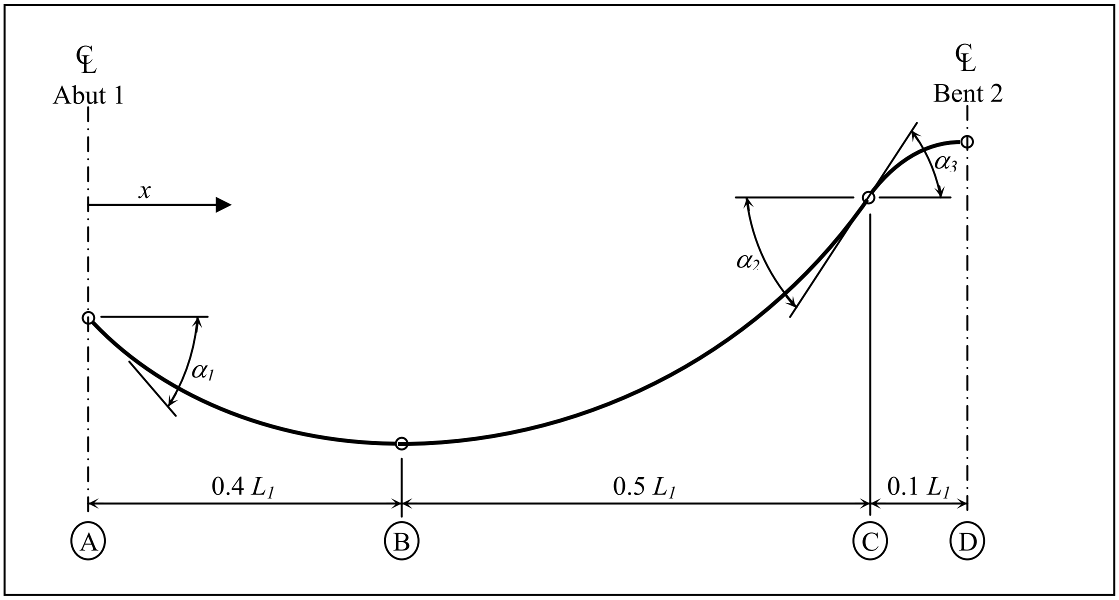
Frame Length (feet)	Wobble Coefficient "K"	Friction Coefficient "μ"
0 - 600	0.0002	0.15
600 - 900	0.0002	0.20
900 - 1200	0.0002	0.25
> 1200	0.0002	See Post-tensioned Technical Committee

The *Standard Specification*[55]*s* requires that the prestress ducts must be rigid and galvanized. Frame length dependant friction and wobble coefficients should be shown in the prestressing notes on the contract plans.

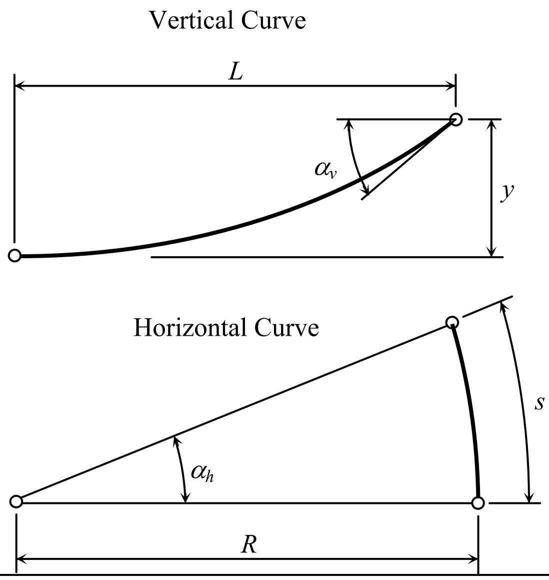
The stress in the prestressing steel at any point "*x*" can be determined by manipulating Equation 1 as follows:

[55] 2010 SS, Section 50-1.02D, *Ducts.*

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



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



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

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

$$\alpha = \sqrt{(\alpha_v)^2 + (\alpha_h)^2}$$ **(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:

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

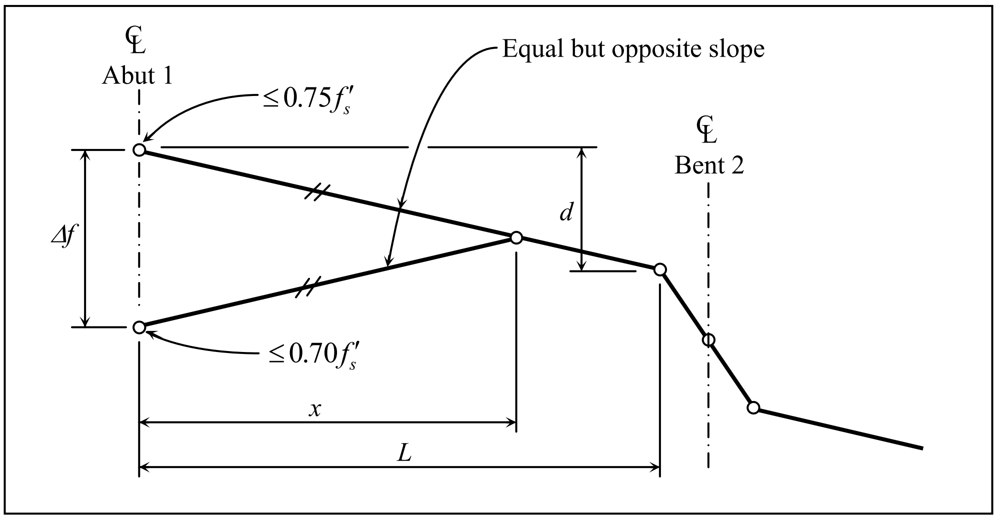
The loss that occurs due to the anchor set can be determined using the following approximate formulas:

$$\Delta f = \frac{2dx}{L}$$ **(Equation 7.)**

$$x = \sqrt{\frac{E(\Delta L)L}{d}}$$ **(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



The *Standard Specifications*[56] requires that the maximum temporary tensile strength (jacking stress before anchor set) must not exceed 75% of the specified minimum ultimate 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.

[56] 2010 SS, Section 50-1.03B(2)(a), *General.*

Tendon Elongations:

Structure Representatives are responsible for monitoring 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 shop 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:

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

(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.

$$\Delta = \frac{T_o(1 + \otimes)(L_1 + L_2)}{2E}$$

(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:

$$T_e = T_0(2\otimes - 1) \quad \textbf{(Equation 11.)}$$

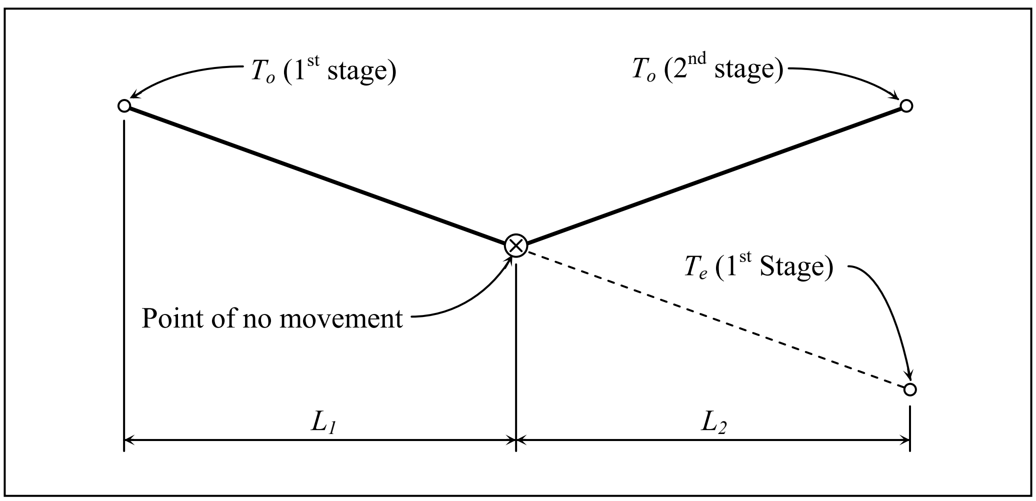
The first and second end elongations are:

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

And:

$$\Delta_{2nd} = \frac{T_0(1-\otimes)L_2}{E} \quad \textbf{(Equation 13.)}$$

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 shop 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.
- P_{jack} = 202.5 ksi.

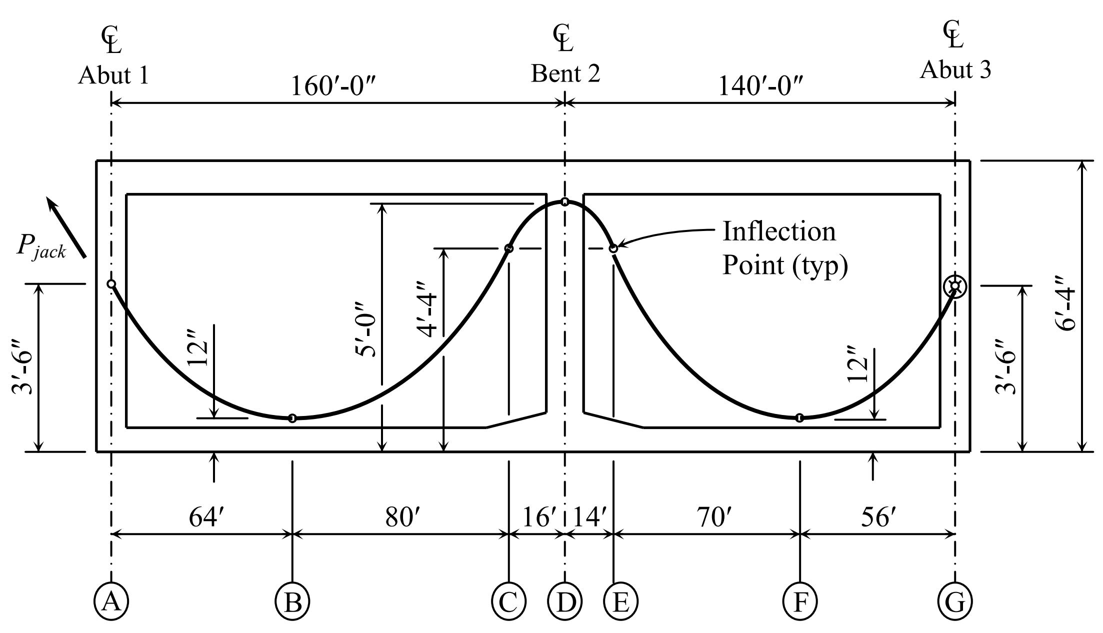


Figure 1 - Prestressing Cable Path.

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

$$T_x = T_o e^{-(\mu\alpha + KL)}$$ **(Equation 1)**

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:

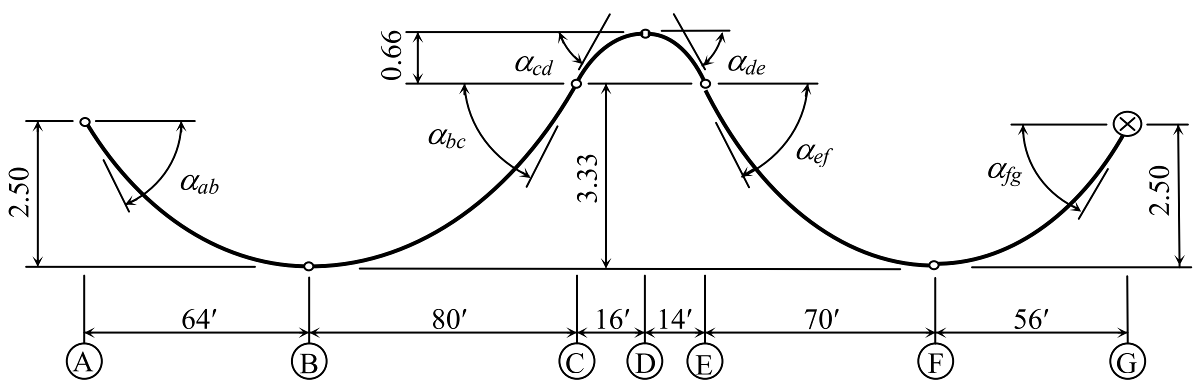


Figure 2 – Vertical Angle Change.

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 vary 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 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)	$\Delta_x = T_{avg}L/\mathrm{E}$ (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

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:

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

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

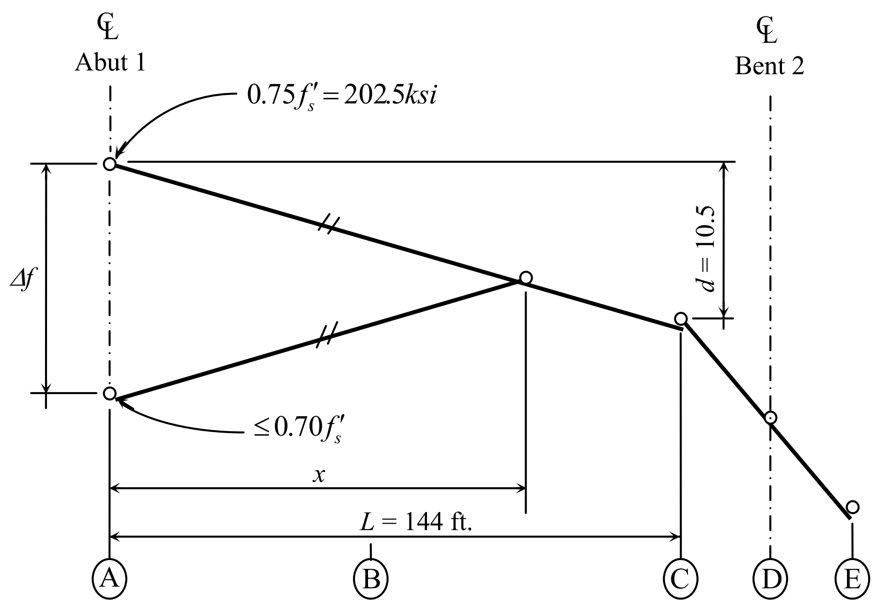


Figure 3 – Anchor Set Loss Diagram

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

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

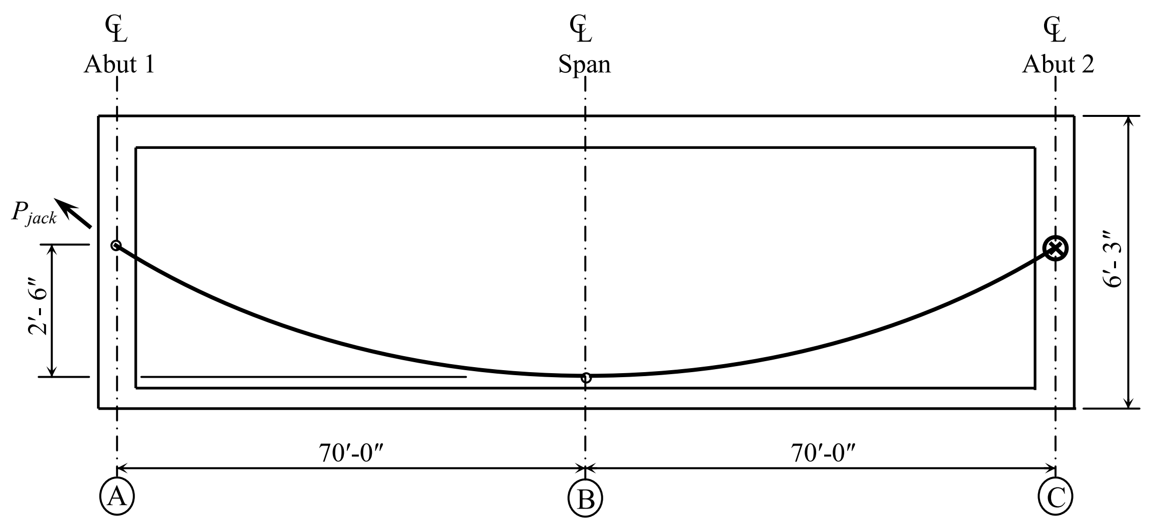
The stress at the anchorage after seating must be less than $0.70 f'_s$:

{202.5 ksi – 15.97 ksi = 186.53 ksi} < {$0.70 f'_s$ = 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.
- $\mu = 0.15$, $K = 0.0002$



Center of Gravity of Prestressing Path

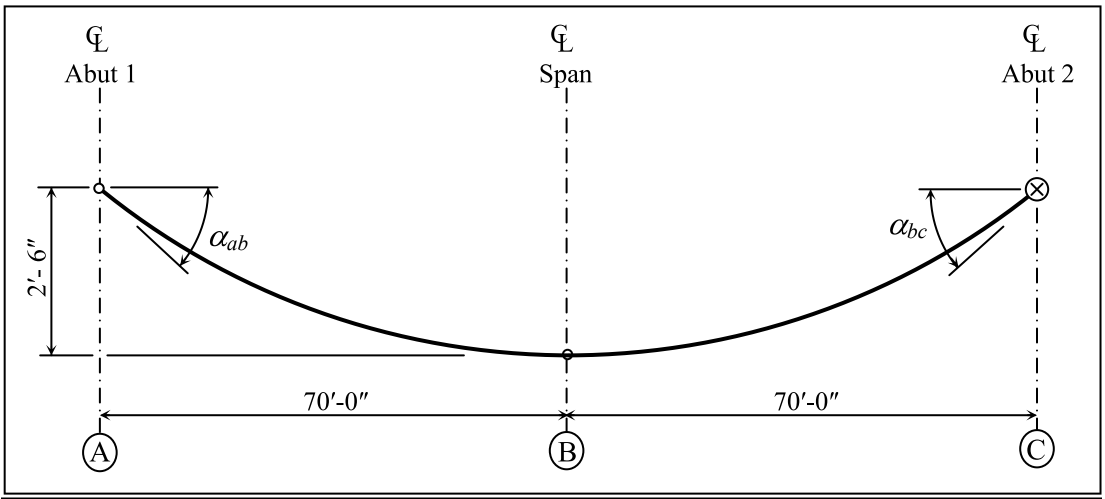
Find:

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 = <u>0.0714</u>

At dead end, α_{ac} = 2 (0.0714) = <u>0.1428</u>

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

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

Effect of anchor set:

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

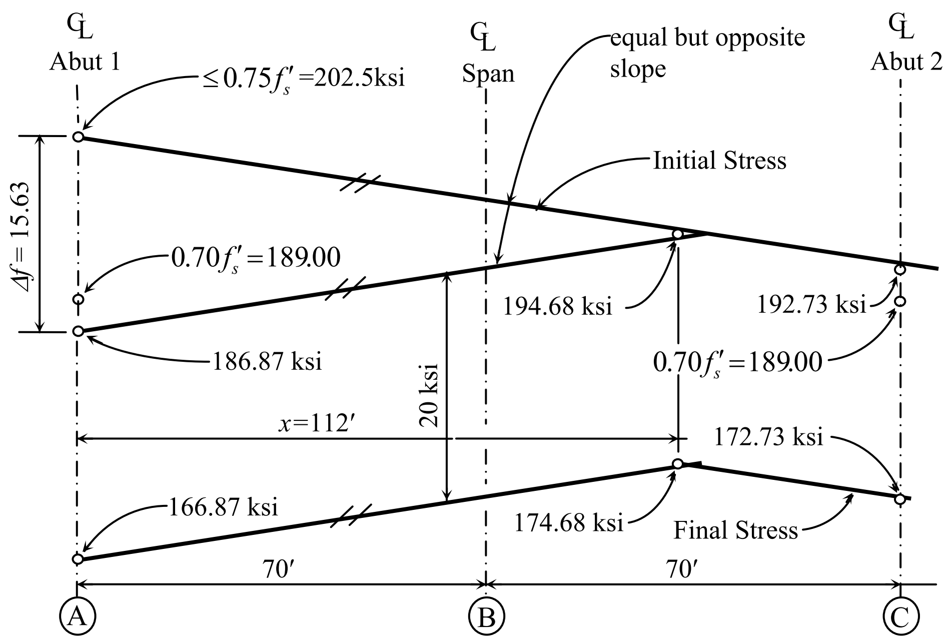
$$\Delta f = \frac{2dx}{L} = \frac{(2)(9.77 ksi)(112 ft)}{140 ft} = 15.63 ksi$$

Stress at jacking end:

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

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

Assume long term losses = 20 ksi



Initial and Final Stress Distribution in Prestressing Steel.

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.

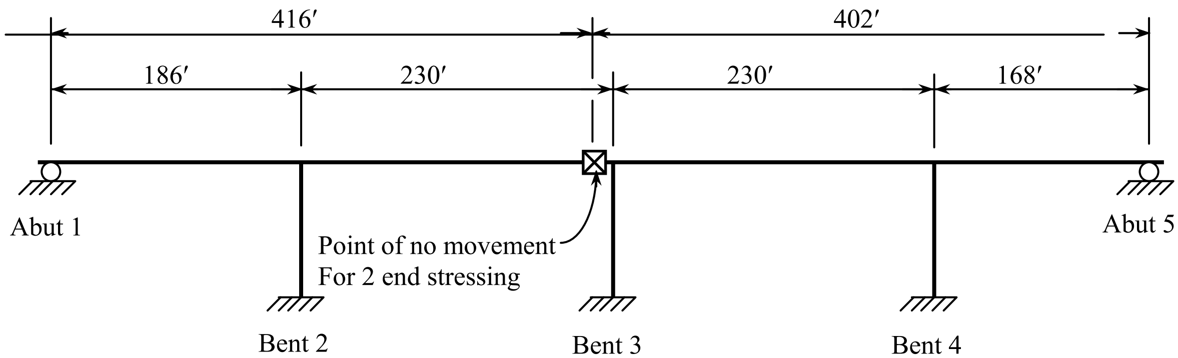
$$\Delta_{100\%} = \frac{[(202.5 + 192.73)ksi/2]\ \ (140\,ft)(12in/ft)}{28{,}000ksi} = 11.86 \quad in.$$

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

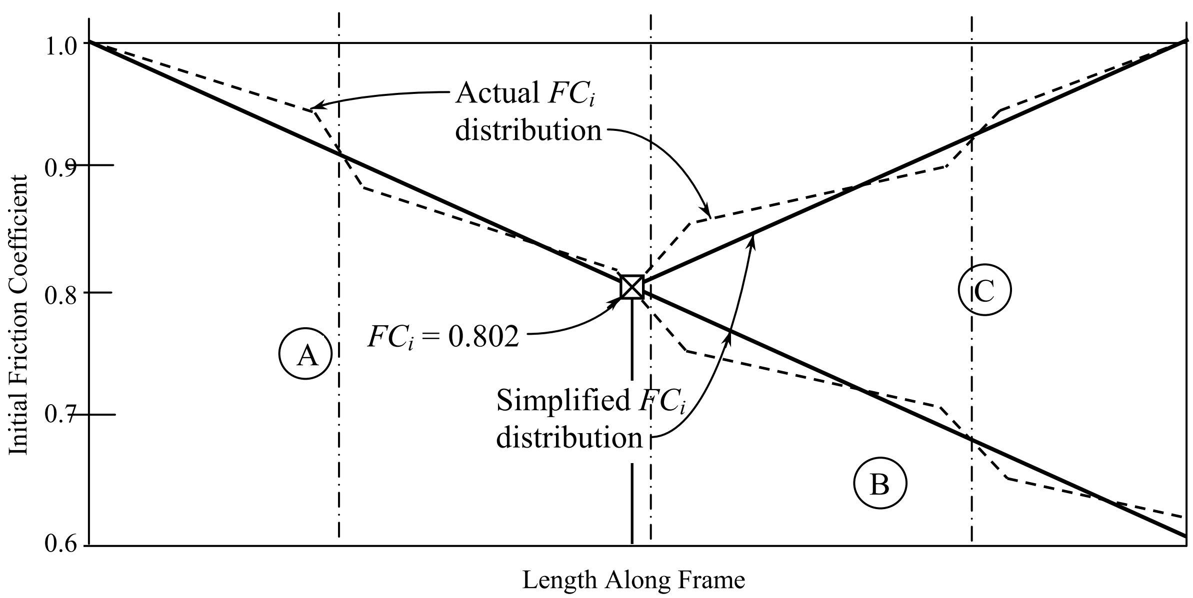
Example 4 – Continuous Four Span CIP Box-Girder Stressed from Both Ends

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

1. What is the measurable 1st stage elongation?
2. 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:

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

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:

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

Part 3: 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.

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

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

STATE OF CALIFORNIA—BUSINESS, TRANSPORTATION AND HOUSING AGENCY

California Test 541
November 2010

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

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

A. SCOPE

This test method contains the procedure to be used for determining the flow of grout mixtures.

B. REFERENCES

ASTM C 939 – Standard Test Method for Flow of Grout for Preplaced-Aggregate Concrete (Flow Cone Method)

C. APPARATUS

1. Flow cone and supporting ring conforming to the dimensions indicated in Figure 1.
2. Stopwatch having a least reading of not more than 0.1 s.
3. Rubber stoppers, size 00.
4. Sample container – 4 qt minimum capacity (a 6 in. × 12 in. concrete mold is adequate).
5. Suitable stand for supporting ring. A 5-gal paint bucket may be used. See Figure 2.

D. CALIBRATION

Before the first use of the flow cone, and periodically thereafter, check the calibration of the cone as follows:

1. Mount the flow cone firmly, free of vibration, and with the top vertical. Close the outlet of the discharge tube with a finger or stopper. Fill the cone with 1725 mL ± 5 mL of water. Ensure that the water surface is at, but not overflowing, the indicators at the top of the Caltrans cone. For the ASTM cone, adjust the point gage to indicate the level of the water surface.
2. After ensuring the accuracy of the volume measurement, refill the cone with water and simultaneously remove the finger or stopper and begin the stopwatch. Stop the watch at the first break in the continuous flow of water.
3. The cone is calibrated if the volume of the cone is 1725 mL ± 5 mL and the efflux time is 8.0 s ± 0.2 s.

E. SAMPLE

The test sample must be approximately 1 gal of grout.

California Test 541
November 2010

F. 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 (Caltrans cone) or makes contact with the point gage (ASTM 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.

G. DETERMINATION OF EFFLUX AFTER QUIESCENCE

1. Fill cone with grout, as previously described, using remainder of 1 gal 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 F.3 and F.4 above.

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

4. Dispose of the grout sample and clean the equipment.

H. 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.

The presence of solid particles retained on the No. 8 sieve or lumps of unmixed material in the grout may interfere with grout discharge and result in a false consistency.

I. HEALTH AND SAFETY

It is the responsibility of the user of this test method to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. Prior to handling, testing or disposing of any materials, testers must be knowledgeable about safe laboratory practices, hazards and exposure, chemical procurement and storage, and personal protective apparel and equipment.

Caltrans Laboratory Safety Manual is available at:

http://www.dot.ca.gov/hq/esc/ctms/pdf/lab_safety_manual.pdf

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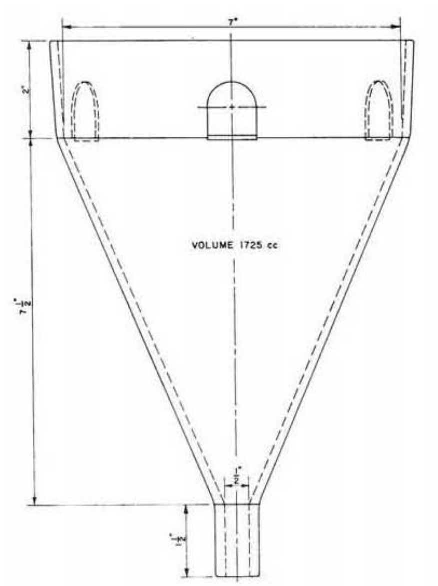
(California Test 541 contains 3 Pages)

California Test 541
November 2010



d

(Optional - From ASTM C939)

Figure 1: GROUT FLOW CONE

Figure 2: GROUT EQUIPMENT

Photo F-1 – Testing Efflux Time of Grout.

The *Standard Specifications*[57] specifies that the Department tests efflux time of grout under *California Test 541*.

[57] 2010 SS, Section 50-1.01D(2), *Quality Assurance Testing*