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16. ABSTRACT

Our present design criteria and specifications for prestressed concrete do not specify how the prestress force is to be applied or retained. The ability of the anchorage to meet the constraining requirement of 95% of the guaranteed minimum ultimate of the prestressing steel is the only basic restriction on the hardware except that of demonstrating the adequacy thereof to distribute the prestressing force without distortion of any component.

A general outline of factors to be considered in determining system acceptance are attached. After a system has been properly tested and accepted for a given contract, the Materials and Research Department follows through with on-the-job technical assistance to the Bridge Department Resident Engineer to help assure that proper installations and stressing procedures are followed.

A conventional strain gage type load cell is used to assure that the design prestressing force is achieved with the basic stressing system. A second hydraulic pressure load cell is used to monitor prestress loading after jack calibration with the use of the primary load cell, thus minimizing the hazards involved in handling heavy load cells.

Some of the things to watch and check for are galling of the prestress steel, slipping of the swage or wedge, cracks or failure in the hardware or prestressing steel, adherence to all aspects of the approved system including the field procedure followed, and a double check on manufacturing quality control.

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FACTORS TO BE CONSIDERED IN THE INSPECTION OF POST-TENSIONED PRESTRESSED CONCRETE STRUCTURES

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April 1969

State of California
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Division of Highways
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TABLE OF CONTENTS

POST-TENSIONED PRESTRESSED CONCRETE

FIELD PROCEDURES

I. INTRODUCTION

Our present design criteria and specifications for prestressed concrete do not specify how the prestress force is to be applied or retained. The ability of the anchorage to meet the constraining requirement of 95% of the guaranteed minimum ultimate of the prestressing steel is the only basic restriction on the hardware except that of demonstrating the adequacy thereof to distribute the prestressing force without distortion of any component.

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Some of the things to watch and check for are galling of the prestress steel, slipping of the swage or wedge, cracks or failure in the hardware or prestressing steel, adherence to all aspects of the approved system including the field procedure followed, and a double check on manufacturing quality control.

As can be noted from a study of job plans and acceptance criteria, the contractor generally has a wide latitude in selecting the type,size, and number of tendons, and the type of anchorage. Even the type of prestressing steel is left open to certain alternatives. Seven-wire strand (250 and 270 ksi), ¼" wire, and rods have been used in our highway work. There are several accepted systems utilizing rods, wire, and strand. Rods and ¼" wire have almost disappeared from use in our highway work, due to inherent economic advantages in strand systems using friction wedges. Some economic advantages in the friction-wedge strand systems are: (1) the length of tendon is not critical, (2) the tendon is easily fabricated on the job, (3) higher strength steel (results in less steel than with rods or wire), (4) hardware is generally cheaper, and (5) ease of handling and trucking. Another outstanding advantage, both from the design and construction standpoint, is the use of rigid conduit which allows the seven-wire strand tendon to be placed just prior to stressing. This practically eliminates corrosion problems and, due to the increased rigidity, cuts down on duct wobble and resultant friction losses, thus making more efficient utilization of the prestressing steel.

II. PRESTRESSING SYSTEMS

There are currently four prestressing firms active in California highway work, all of which are now utilizing a version of the friction wedge anchored strand type system. These include the following:

V.S.L. Corporation (utilizing the Vorspann-System Losinger, also known as the Losinger Prestressing System

Western Concrete Structures, Inc. (Westrand System)

Post Tensioning Services (PTS), a subsidiary of Judson Steel and Stressteel Corp. - Rods Western Division utilizing the Stressteel Howlett or S/H System

Soulé Steel Corporation (utilizing the Freyssinet System)

A. V.S.L. Corporation System

In the V.S.L. system the strands are individually anchored by being passed through a tapered hole drilled in a steel anchor head and gripped with a pair of split wedges. These individually anchored strands are presently combined into units incorporating from 4 to 31 strands in each tendon. Overall configuration is similar to that shown in Figure 1.

A relatively long-stroke center-hole jack or ram is used to stress this system. The strands, after threading through the steel anchor head, are passed through the jack and each strand is gripped in a bearing (stressing head) plate with three-part strand-vise chucks. When full load is reached, the jack is released slowly allowing the permanent wedges to grip the strand and to seat in the tapered holes in the anchor head. The strand-vise chucks in the stressing head are then removed, permitting jack removal.

V.S.L. has 3 sizes of jacks to stress the various sizes of tendons and will require load cells as follows for jack calibration:

4 - 8 strand: (50 & 100 ton jack)	Since tendons this small are rarely used in bridge work, no load cells are being made for Bridge Department. Materials and Research Department will furnish assistance and/or equipment upon request, if the need arises.

9 - 12 strand: (200 ton jack) — Std. 400 Kip/4¼" I.D. load cell required ≃ 9" extra strand to accommodate load cell.

18 - 31 strand: (500 ton jack) — 1000 Kip/9" I.D. load cell requires ≃ 16" extra strand to accommodate load cell.

The 400 Kip/4-1/4" load cell is used without any alignment accessories and is held in place by hand until jack takes up load. Other than proper centering (by eyeball), there is no extra hardware needed or used to position the cell. The 1000 Kip/9" load cell, however, due to its weight, (≃ 192 lbs.) to center and hold it in position, it should be handled with a block and tackle whenever possible. Care should be taken so that the lip does not carry or transmit load. Both of these cells are mounted behind the jack (on the moving piston) and in front of the stressing head and the tension is read directly in kips on a digital strain gage indicator provided with the load cell.

Inspection Pointers:

Be sure to check to see that all wedges are in stressing head and anchor plate before starting.

On smaller tendons (up to 12 strand) it is recommended that elongation be measured from the bearing plate or another fixed point, while for larger tendons, the back of the jack or ram extension is generally more convenient. In addition, the strand extending behind the jack should be spray painted after initial loading seats the strand-vise chucks to provide a convenient check for possible slip of individual strands. On the V.S.L. system this is accomplished conveniently using the steel strand alignment fingers as a gage to provide an even paint line reference plane.

B. Westrand System-Western Concrete Structures

Western Concrete Structures' "Westrand System" is similar to V.S.L. in gripping and anchoring but the center hole jack or ram used for stressing is much different in that it is relatively short and bulky with no large center hole showing. The general configuration, however, is similar to that shown in Figure 1.

Western has chosen the relatively short jack configuration to accommodate its use in tight stressing spaces and for ease of handling. Furthermore, it is generally more economical to manufacture and is more easily adapted for automatic cycling to facilitate incremental stressing of long tendons. The jack, anchor block, stressing head, and wedges are assembled as one unit and are then fastened to the imbedded anchorage bearing plate to allow for convenient cycling without further handling of any components.

Western has developed this type of jack for stressing up to 22 strands. The development has just recently been completed on a 48-strand system similar in many ways to the 22-strand system.

The load cell for the Western 22-strand system must be bolted into place between the jack piston and the stressing head. A filler or strand guide must also be properly set and aligned to guide the strand through the load cell.

The load cell is rated at 750 kips with a 6.60" inside diameter clearance and is the same cell which is used on several other systems. However, in using the load cell with the Western system, a correction must be applied to the readings since there is a compressive load (preload) applied to the cell by the bolts holding it in place against the jack piston. This is the only instance on currently used systems where a correction is necessary when the load cell is properly used and calibrated. To simplify measurement of the preload correction, the load cell should be plugged into the strain indicator when final tightening of the connecting bolts is taking place. Thereby a desirable measured preload can be applied to the connecting bolts utilizing the strain indicator as a control. A 20 kip preload is recommended, the calculation of which is shown below:

5/8" bolt - 15" long with 2-1/2" of thread (stress area .226) plus 12-1/2" shank (stress area .307).

4 bolts   Divide into 20 Kips = 5 Kips/Bolt.

Using the formula for elastic deformation: $\delta = \frac{PL}{AE}$

δ bolts = δ load cell   Assuming E load cell = E bolts

$$\frac{P_1 L_1}{A_1 \not{E}} = \frac{P_2 L_2}{A_2 \not{E}}$$

Where: P_1, L_1, A_1 are Load, length and area of bolt

And: P_2, L_2, A_2 are Load, length and area of load cell

By proportion of 2-1/2" and 12-1/2" bolt increments, the Avg. stress area of each bolt is .295 sq. in. Stress area of load cell = 24.2 sq. in.

Assuming 5 kips preload in each bolt:

$$\frac{4 \times 5 \times 10^{3} \times 15}{4 \times 295 \times 10^{-3}} = \frac{P_2 \times 12}{24.2}$$

$$\text{Thus } P_2 = \frac{75 \times 10^{6} \times 24.2}{295 \times 12} = .508 \times 10^{6}$$

or for practical purposes 500 Kips.

Therefore, bolt preload effectively becomes zero when 500 kips are applied to the load cell or 20 kip preload is reduced at a rate of 4 kips/100,000 lb. applied to the tendon and load cell. Therefore the following corrections should be applied:

Jack Load as Read on Indicator		Correction	Actual Load on Tendon
20 kips	=	-20	0
100 kips	=	-16	84
200 kips	=	-12	188
300 kips	=	- 8	292
400 kips	=	- 4	396
500 kips	=	0	500

Equipment needed for calibration: (22 strands maximum)

Load cell 750 K/6.60" I.D. and Strain Gage Indicator

Hardware - Strand guide insert

4-15"-16" 5/8" Allen head bolt) Usually supplied by Western

4-short ≈ 2' long piece of strand for alignment of strand guide) Usually supplied by Western

Rope or strap support for the load cell to accommodate leveling jack - load cell assembly

Extra strand - 12" minimum.

Inspection Pointers:

Since the jack is fastened to the imbedded bearing plate the elongation can be measured from the back of the jack to a mark on the strand or the end of a strand. It is recommended that several strands be measured to assure a true representation of tendon elongation since the occasional malfunction of a wedge may permit slippage of an individual strand. The strand protruding behind the jack should be painted adjacent to the prestressing head after stressing wedges are seated by initial loading. This provides a convenient reference plane across all strands which will readily reveal strand slippage, if any. Slipping occurs occasionally when recycling the jack on tendons which require elongations that are greater than the available jacking stroke (6 inches).

C. Stressteel Howlett System (S/H) Post Tensioning Service

Post Tensioning Service, Corp., a subsidiary of Judson Steel and Stressteel Corp. - Rods Western Division, provides a friction wedge anchor system wherein the strands are anchored in units of three, by a three-piece wedge. The tri-strand units have been combined in groups of up to 8 with a maximum total of 24 strands. The general system is similar to that shown in Figure 1.

The S/H system utilizes a perforated strand guide (splay plate) to group the strands and align them so the three-piece wedge will grip properly. After the splay plate is put into place, the strands are passed through the large conical holes in the anchor block in groups of three and a three-part wedge (with a rubber O-ring holding the pieces together) is rammed into place with a piece of pipe.

An 18-inch stroke center hole jack with special front and rear attachments is used to stress this system. The front attachment is a small hand operated ram which partially seats the wedges after stressing to the desired force and elongation. This attachment is used to control the seating loss to a consistent value. A spacer block should be placed between the anchor block and the jack during stressing to keep the anchor block from moving back and constricting the wedges and galling the strand.

A split-ring type stressing gate is used to speed the stressing operation. This allows the tendons to be prepared for stressing by installing the stressing head prior to jack placement. The entire stressing head is then passed through the jack and the stressing gate is closed behind it. Although convenient for stressing this arrangement, along with the system's 18-inch stroke, makes the jack a two ton package that must be handled with a crane.

P.T.S. has 2 sizes of jacks now in operation:

9 - 12 strand: (200 ton jack)	750 K/6.60" I.D. Load Cell/Indicator 12" extra strand required.
12 - 24 strand: (400 ton jack)	800 K/7.5" I.D. Load Cell/Indicator 15" extra strand required.

The 9-12 strand jack and load cell arrangement is used and placed identically to V.S.L.'s 9-12 strand system, as discussed previously. When using the 750 K/6.60" I.D. load cell in its mid-range (approximately 400k) a slightly different indicator setting than that used at full range, should be used for increased accuracy.

The 12 - 24 strand jack and load cell requires an extra stressing head. The standard head has a slightly concave surface that mates with convex surface of the gates on the jack, thus to get a flat working surface the regular stressing anchor block is mated as per usual devoid of wedges. The load cell is then placed against the back of the stressing head. Then the second special stressing head with a protruding center for alignment is placed against the back of the cell and the three-part wedges are seated. Care should be taken to make sure that strand groups are not mixed or twisted between the anchor block and stressing head.

Inspection Pointers:

Elongation is measured best by measuring ram extension. Strand slippage with this system has been rare while stressing. However, unless someone is observing the wedge on the dead-end when stressing is done from one end only, it is a good idea to paint the strand to check for possible slippage. It should not be necessary, however, to paint strand on stressing end as the groups of three strands are usually taped together providing a convenient reference to check for strand slippage.

This system has had some delayed failures of wedge components from 1 to 48 hours after stressing. It is therefore advisable to check the strands and wedges for a few days after stressing. Any observations you have on this or any other problems encountered, or any other systems exhibiting field problems, should be passed on to the Laboratory. This type of background information is invaluable to further appraise the adequacy of current systems and often leads to improvements that are in the State's, as well as the Contractor's, best interests.

D. Freyssinet System - Soulé Steel Corporation

Although Freyssinet still falls in the loose classification of a friction wedge system, the large center male cone or plug which can wedge up to twelve strands at once in the female cone is significantly different than the single strand wedge systems of V.S.L. and Western as well as the tri-strand system used by P.T.S.

The Freyssinet system uses a specially designed jack that, with the aid of a spacer, bears on the female cone (see Figure 2). The individual strands are held for stressing against built-in lugs on the jack by means of individual friction wedge chucks rather than a separate stressing head as in the other systems

When the tendon is fully stressed, a second piston (built into the center of the jack) forces the male cone part way in. When the main piston is released, the strands pull the male cone further in, until all the strands are fully anchored by friction between the two cones. In seating, a stress loss occurs as the center cone and strands become seated, resulting in a strand movement which varies between ½" and 1", but is generally about 5/8" to 3/4". The loss of stress caused by this slippage is usually considered in the shop plans, and unless it is an inch or more it does not significantly affect the resultant working stress. On short tendons shimming under the female cone may be required to compensate for excessive seating losses, or to obtain required force on long tendons. This method is preferable to unseating male cones by recycling, as this can cause strand failure.

The load cell for this system is a 750 K/6.60" I.D.; however, just as with the P.T.S. system in the mid-load range, it must or should be adjusted to a slightly different value to keep proper accuracy.

Calibration of stressing hardware for this system is an operation in itself that is separate from an actual tendon stressing sequence, since the load cell must be placed behind the female anchor cone. The front alignment plate is first attached to the load cell and then is bolted to the anchorage bearing plate. Then the female cone is put on each end of the tendon behind the load cell without the male cone or wedge on either end. The jack is then placed on tendon per the usual stressing operation with all necessary hardware including front jack chair spacer as shown in the diagram of Freyssinet system (Figure 2).

The angle of the strand entering the female cone changes as the jack case extends (the ram is stationary with this system), thus increasing the friction of the strand on the jack case. The calibration is therefore more dependent on the jack case position than with any other system. In fact, if the load versus gage pressure is plotted on a large scale, as shown in Figure 8, the effect of this external friction will be quite evident as the curve is slightly S shaped. The effect of this external friction has been shown to be as high as 4½%. Therefore care should be taken to see that the ram (case) is in approximately the same position during calibration as it is in the actual stressing operation.

Since there is no stressing in progress during calibration, calibrating both ends simultaneously helps avoid unnecessary delay. It will not be possible to reach ultimate jacking load when the required elongation is greater than the jacking stroke length. In this case the gage pressure is obtained by plotting load vs. gage pressure and projecting the line. It is suggested that at least 3/4 of maximum jacking load be obtained and three points be used for this projection. You should never attempt to project to maximum from a point less than ½ the required jacking load.

Load Cell 750 K/6.60" I.D.

Hardware Front alignment attachment

Inspection Pointers:

Several strands should be measured to determine slippage which frequently occurs during regripping. The elongation is most conveniently determined from a mark placed where the strand passes out of the jack grooves and is exposed as noted in Figure 2. Calculated elongation should be checked before marking to make sure marks do not end up hidden in the stressing chucks when regripping occurs.

TYPICAL POST TENSIONING SYSTEM

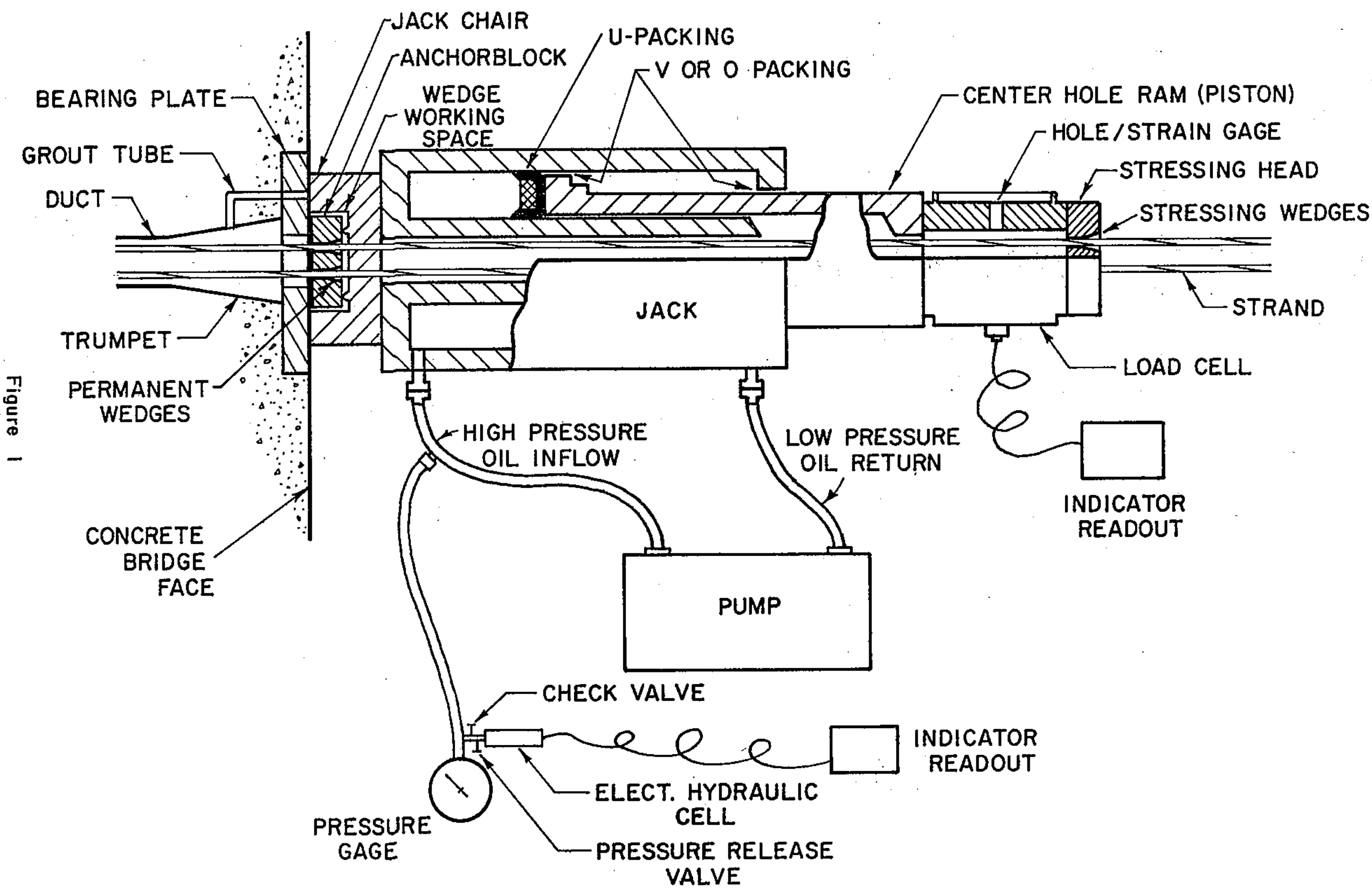

Figure 1

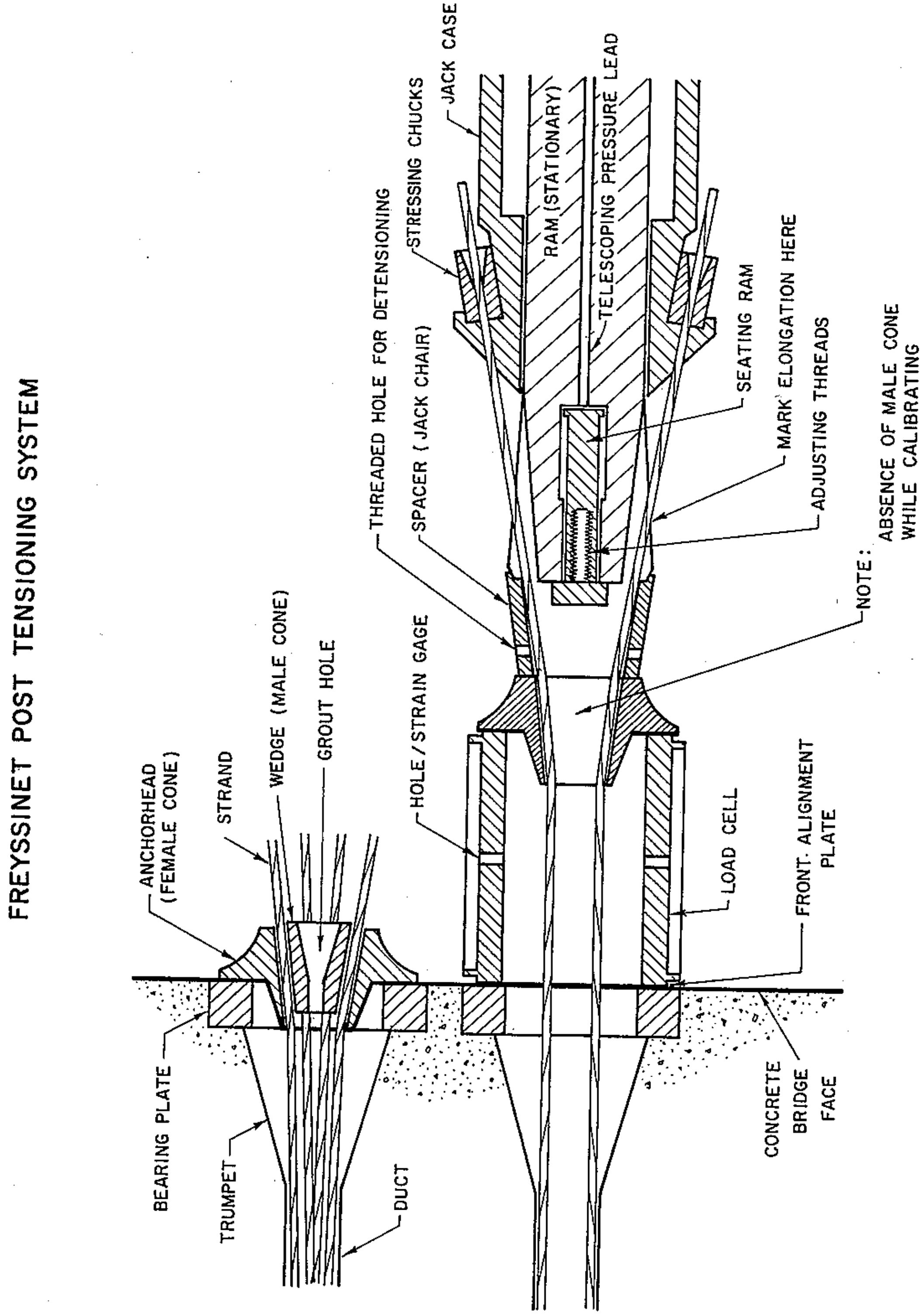
FREYSSINET POST TENSIONING SYSTEM
JACK CASE
TELESCOPING PRESSURE LEAD
RAM (STATIONARY)
STRESSING CHUCKS
THREADED HOLE FOR DETENSIONING
SPACER (JACK CHAIR)
SEATING RAM
MARK ELONGATION HERE
ADJUSTING THREADS
NOTE:
ABSENCE OF MALE CONE
WHILE CALIBRATING
HOLE / STRAIN GAGE
LOAD CELL
FRONT ALIGNMENT
PLATE
CONCRETE
BRIDGE
FACE
ANCHORHEAD
(FEMALE CONE)
STRAND
WEDGE (MALE CONE)
GROUT HOLE
BEARING PLATE
TRUMPET
DUCT

Figure 2

III. CHUCKS AND WEDGES

All the friction wedges have teeth or small serrations which make small notches on the material being gripped. The size of these teeth range from very coarse in appearance, as on P.T.S. wedges to those that are hardly descernable, as on the male Freyssinet cone. The wedge angle, type of steel, type of heat treatment, constraining case, and general configuration all affect the efficiency of a wedge system. The efficiency of a wedge is a measure of its ability to develop the potential ultimate strength of the material being gripped.

The permanent wedges of all the systems now approved are capable of developing a minimum of 95% of the ultimate strength of the steel strand they are gripping. However, some of the wedges used for stressing purposes only, especially the 3 part varieties, are only capable of attaining about 82% of ultimate of the strand. On 270 ksi ½" strand this equals about 34 kips/strand.

The care in use, cleanliness, lubrication, surface condition, and finish also significantly affect the efficiency of wedge systems. All of the manufacturers have quality control procedures which should catch obvious manufacturing defects. The on-the-job care varies widely with the prestressing crew and is often left to fend for itself. Therefore it is very important that we are alert to any improper materials or practices that might affect the finished product.

A. Permanent Anchor Wedges:

V.S.L.

V.S.L. uses a 2-part wedge for each strand with a saw slot in each of the two parts. This slot allows the wedge to conform better to the strand and acts as a weakened plane which controls cracking thus occasionally the two-part wedges becomes a four-part wedge. This is expected and is of no consequence.

S/H (P.T.S.)

The P.T.S. system uses a three-part wedge which grips three strands at once. It consists of right, left, and center (key wedge or piece) parts. The right and center parts combine to grip one strand so do the left and center, but to grip the third strand, all three parts work together. Thus the wedges are dependent on each other and must work as a unit. The right and left parts are match marked and are not interchangeable but can be interchanged with matching parts from different units.

It is necessary to stress this system in three strand increments. It is possible, however, to insert a dummy (a small short noncontinuous piece) strand in one or two positions in the three-part system and make the wedges function. This procedure should not be allowed as a standard practice as there has been no qualification test covering this arrangement. There is no assurance that it could meet the 95% constraining requirements.

The key wedge on the P.T.S. system is fractured (sheared due to the lay of the strand) occasionally. Thus bears scrutinizing as there has been only limited testing as to its affect. If this happens in the pulling head wedges they should be discarded.

Freysinnet (Soulé Steel)

The Freysinnet permanent wedge system is capable of constraining from 6 to 12 strands at once. There has not been or should not be any cracking or distortions of either the male wedge or female cone. It is also noteworthy that only the round 12 grooved steel male wedge and the circular female cone are capable of meeting the qualification requirements. Do not allow any other material besides steel for the male wedge (aluminum and concrete have been tried on other similar systems) or any configuration besides circular for the female cone (square ones have not developed the required 95% in testing).

Westrand (Western)

Westrand wedges appear to be identical to the V.S.L. wedge minus the slot. The reason for this is that the Westrand jacking system is based on a short stroke cycling procedure and it would not function properly if one of the wedges were to fracture during this operation.

The Westrand and V.S.L. wedges are made from the same type of steel and have a very similar heat treatment.

B. Stressing Wedges and Chucks:

All stressing wedges and chucks should be cleaned, lubed, and replaced when necessary. Some companies use the pulling chucks once or twice then insert them into the permanent anchorage. This is an economy measure which, when properly controlled, is acceptable.

This means that care should be taken to cull out damaged pieces and to properly clean, lube, and reassemble before insertion into the permanent anchor.

It should be noted that although C.C.L. and Supreme wedges are both used in stressing heads and are a three-part, almost identical wedge and appear interchangeable, they are not interchangeable.

Workmen often beat on the case of Supreme grips, which for safety's sake, should be discouraged, as the hardened steel case could fracture and fail (fly apart) while stressing. If the Supreme grips are properly lubed and cared for, a light tap is all that is necessary to release them.

Lubrication

Proper lubrication of chucks and wedges can be attained with several materials and methods. One company uses relatively costly teflon in a liquid suspension while another system (Freysinnet) neither utilizes nor requires lubrication on the permanent anchorage but does require lubrication on the Supreme chucks used for stressing only.

Current Lubrication Generally Used

Company	Anchor	Stressing Head
V.S.L.	Light machine oil	Graphite or molybdenumdisulfide. (spray, power or cream)
Western	Teflon(liquid)	Teflon
P.T.S.	Molybdenumdisulfide (cream)	Same
Freysinnet (Soulé Steel)	Nothing	Paraffin or Graphite

The method recommended by the Materials and Research Department for lubrication for reusable chucks not subjected to steam (as in precast prestressing plants) is to coat the wedge with a paraffin type material or oil and apply molybdenumdisulfide in powder form. Moly-disulfide is recommended because it is the best known lubrication availabe for high pressure loading.

IV. HYDRAULIC JACKING SYSTEMS

With few exceptions all the jacks used in prestressing are of the center hole variety. This type of jack has more wearing surfaces and packing than a conventional jack of the same size, coupled with the general necessity for a long stroke, increases the variability potential of the applied force (see cut away of typical system, Figure 1).

An article in the Portland Cement Association Journal lists a number of factors that may affect accuracy and efficiency of hydraulic systems as follows:

1. Use of unfiltered oil.
2. Exposure to dust or grit.
3. Eccentric loading.
4. Type of packing.
5. Configuration of packing.
6. Ram positions.
7. Oil temperature control.
8. Flow control valves.
9. Load holder valves.
10. Ram and packing maintenance.
11. Piston motion (ram travel and position).
12. Read-out equipment.

Therefore considerable care and effort in fabrication and maintenance is necessary to attain desirable accuracy and consistency. Special care is also required to calibrate the equipment.

One of the things that should not be done with hydraulic jacking equipment is to take pressure or load readings while retracting the ram as hysteresis will likely result in erroneous values. Another phenomenon occurs when the ram is fully extended (bottomed out) and the hydraulic pressure is dissipated against the jack case. This is of no consequence provided it does not damage the jack or gage and the resultant reading is not mistaken as an indication of the actual tendon stress.

The gages are all bourden tube type with rack and pinion gear drive which accounts for part of the poor hysteresis curves of hydraulic measuring systems. These gages can be adjusted; however, the adjustment is a delicate matter as it can be nonlinear or linear and should not be attempted in the field.

Fittings and valves cause a lot of day to day problems. Frequently they either do not work properly or leak. The fittings are equipped with spring loaded self-closing ball valves which occasionally will not open when mated together. If this occurs on any fitting except the ones in the gage line the system usually will not work and will cause the gage to show large readings very quickly when starting the hydraulic pump. However, if it occurs in the gage line everything will work except the gage. Valves and fittings that leak or will not hold the load should be replaced.

There is a definite relationship between applied force, ram area and gage pressure; however, it is not direct due to friction losses both mechanical and hydraulic. A better more direct relation can be found by establishing a "ram factor" or effective ram area that can multiplied by the gage pressure to determine the applied force. Effective ram area can be established by dividing a known load (determined by use of a load cell) by the gage reading thus coming up with an imaginary ram area. This imaginary or effective ram area should always be smaller than the actual ram area due to the friction losses.

The installation of new packing is about the only corrective measure, apart from general overhaul, that improves jack efficiency. This factor is favorable since it reduces the probability of overstressing a tendon. However, care must be taken to avoid switching of gages without recalibration of the system, as serious over or understressing could result.

V. PRESTRESSING STEEL

A. Strand Specifications and Manufacture:

Uncoated ½" 270 ksi 7-wire stress-relieved strand, as presently used on California bridge projects, conforms to ASTM A-416 and Section 50 of our Standard Specifications.

Strand is made of high carbon steel with a dry drawn finish and is stranded in such a manner as to have the center wire, which is larger (.003" min. for ½") than outside wires, enclosed tightly by six helically placed outer wires with a uniform pitch of not less than 12 and not more than 16 times the nominal diameter of the strand.

There are no joints or strand splices allowed in strand used for our bridge work. Splicing (butt welding) of individual wires of the strand is allowed every 150 ft. of finished strand. However, most manufacturers do not make a practice of splicing this often even though it is permitted in the specifications.

The slight deep bluish (tempered colored) appearance of the strand comes from stress-relieving continuous heat treatment which is necessary to produce the prescribed mechanical properties.

The mechanical properties are outlined in both ASTM A-416 and our Standard Specifications. The main reason for this duplication is that until January 1969 ASTM did not cover 270 ksi material.

The yield strength of strand is specified (in paragraph 10 of ASTM A-416) to be "measured by the 1 percent extension under load method", which "shall be not less than 85 percent of the specified minimum breaking strength". Specifying yield strength by the offset method (% extension) is common on materials which do not have a clearly defined yield point as indicated in typical stress strain curves.

The specified yield as given in ASTM for strand is well past the proportional limit of the strand, as illustrated in Figure 3. If a straight edge is laid on the typical stress strain curves of 270 ksi strand, it will be noted that the proportional limit occurs at approximately 31 kips or 75% of the guaranteed minimum ultimate strength. Thus any loading beyond that point may result in over stressing the material into a range of unknown creep and resultant stress loss. The following critique on overstressing of prestress steel and its accompanying stress strain diagram should emphasize the point.

B. Overstressing of Prestressing Steel:

Why do the Standard Specifications state "The maximum temporary tensile stress (jacking stress) in prestressing steel shall not exceed 75% of the specified minimum ultimate tensile strength of the prestressing steel"?

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

The three stress strain curves shown in Figure 4 are of ¼" cold-drawn, stress-relieved prestressing wire removed from a tendon that had been stressed to 83% of the minimum ultimate strength of the wire.

Note the great difference in the stress strain relationship between sample #1 and sample #2 and #3, keeping in mind that all 3 samples came from the same tendon. The apparent unpredictability of physical properties of wire stressed above the proportional limit is the main reason that the Standard Specifications do not permit stressing beyond 75% of the specified minimum ultimate strength of the prestressing steel.

Due to inevitable weaving of wires or strands within a tendon resulting in unequal lengths, some of the wires or strand will very likely be stressed to their yield strength, even when the tendon is not stressed over 75% of ultimate. Therefore, when the jacking forces exceed the 75% limitation, some of the wires or strand in the tendon may be seriously overstressed. This condition is demonstrated by the stress-strain curve for sample #1 in Figure 4.

When steel such as prestressing wire or strand is stressed beyond its elastic limit or yield strength, some of its physical characteristics change. The most significant to us are the modulus of elasticity and creep rate. If we have changed these properties by overstressing, the significance of elongation measurements is questionable.

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

Initial Jacking Force	Initial Percent of Ultimate	Residual Stress @ 72 Hours	Percent Stress Losses @ 72 Hours
34 kips	82.3	26 kips	23.5
28 kips	67.8	27 kips	3.6

This example indicates that a 10% overstress may result in a significant increase in the reduction of prestressing force due to the change in creep properties of a given strand.

In view of the above factors, if we are to obtain the structural quality and obtain the conditions intended in the structural design, we must be assured that prestressing operations are carefully and adequately controlled.

TYPICAL STRESS - STRAIN CURVE

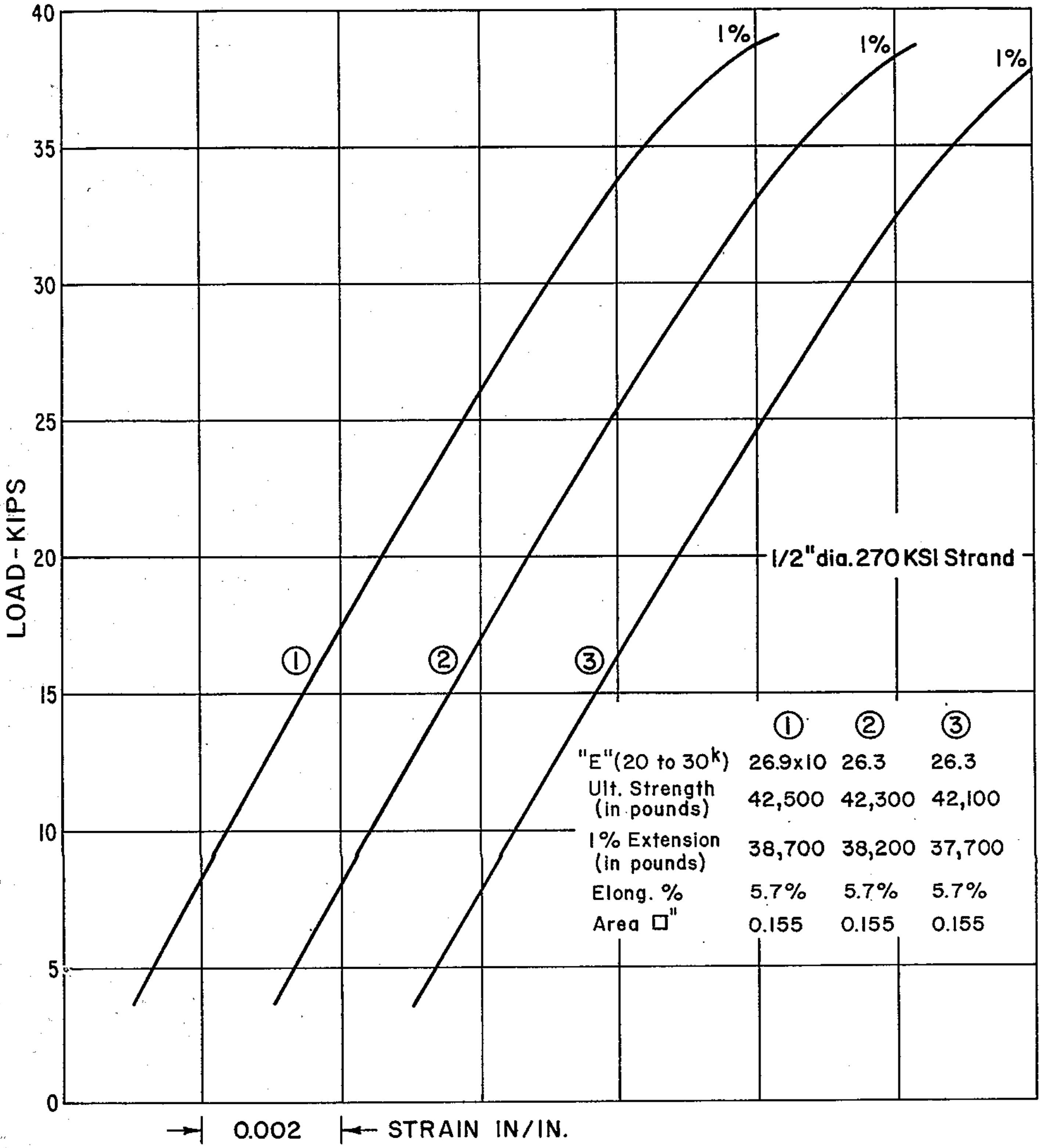

Figure 3

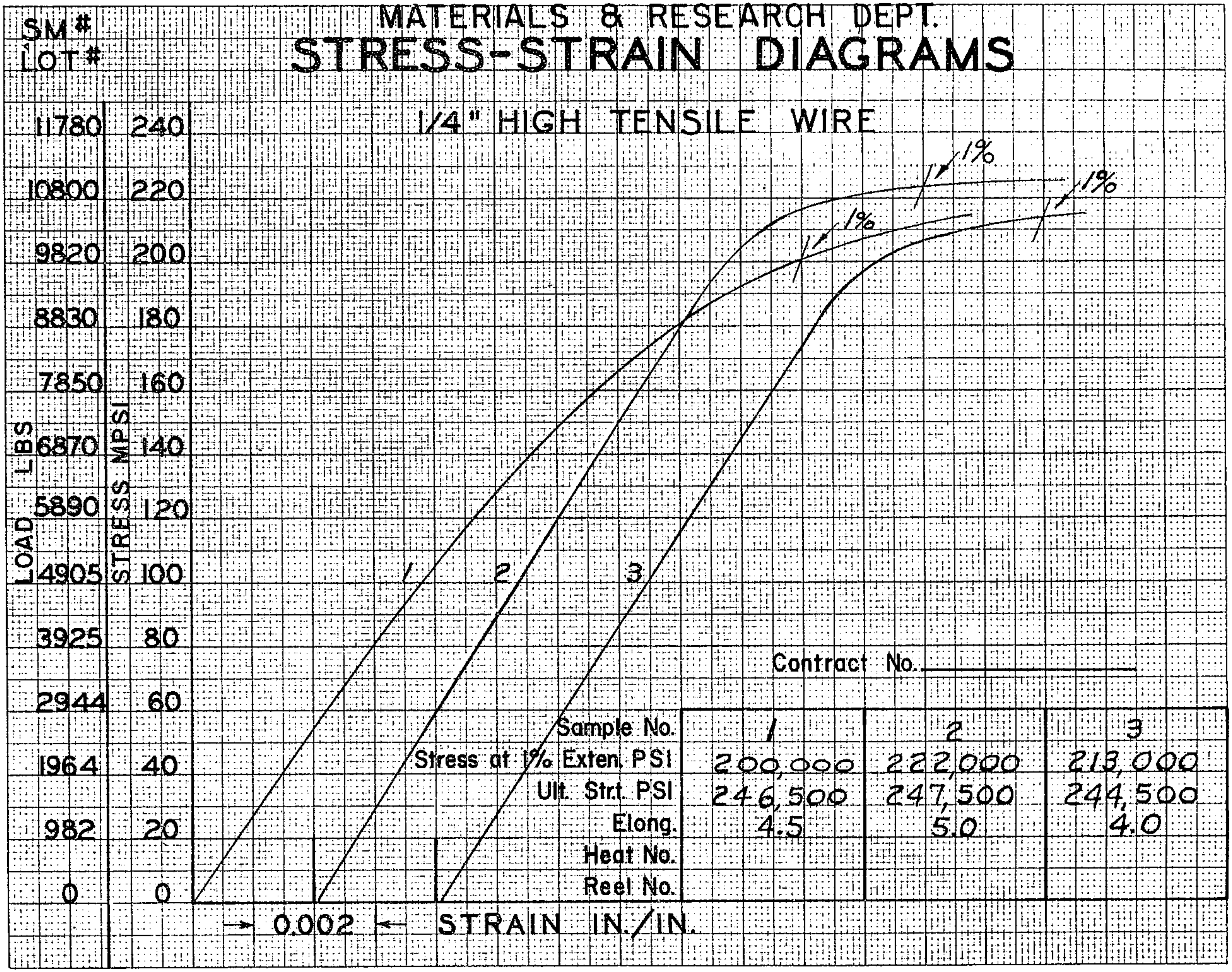
SM #
LOT #
MATERIALS & RESEARCH DEPT.
STRESS-STRAIN DIAGRAMS
1/4" HIGH TENSILE WIRE
LOAD LBS
STRESS MPSI
11780 240
10800 220
9820 200
8830 180
7850 160
6870 140
5890 120
4905 100
3925 80
2944 60
1964 40
982 20
0 0
1%
1%
1%
1
2
3
Contract No.
Sample No. 1 2 3
Stress at 1% Exten. PSI 200,000 222,000 213,000
Ult. Strt. PSI 246,500 247,500 244,500
Elong. 4.5 5.0 4.0
Heat No.
Reel No.
→ 0.002 ← STRAIN IN./IN.

Figure 4

CREEP LOSS VS. MAXIMUM LOAD
1/2" DIA. 270 KSI STRAND

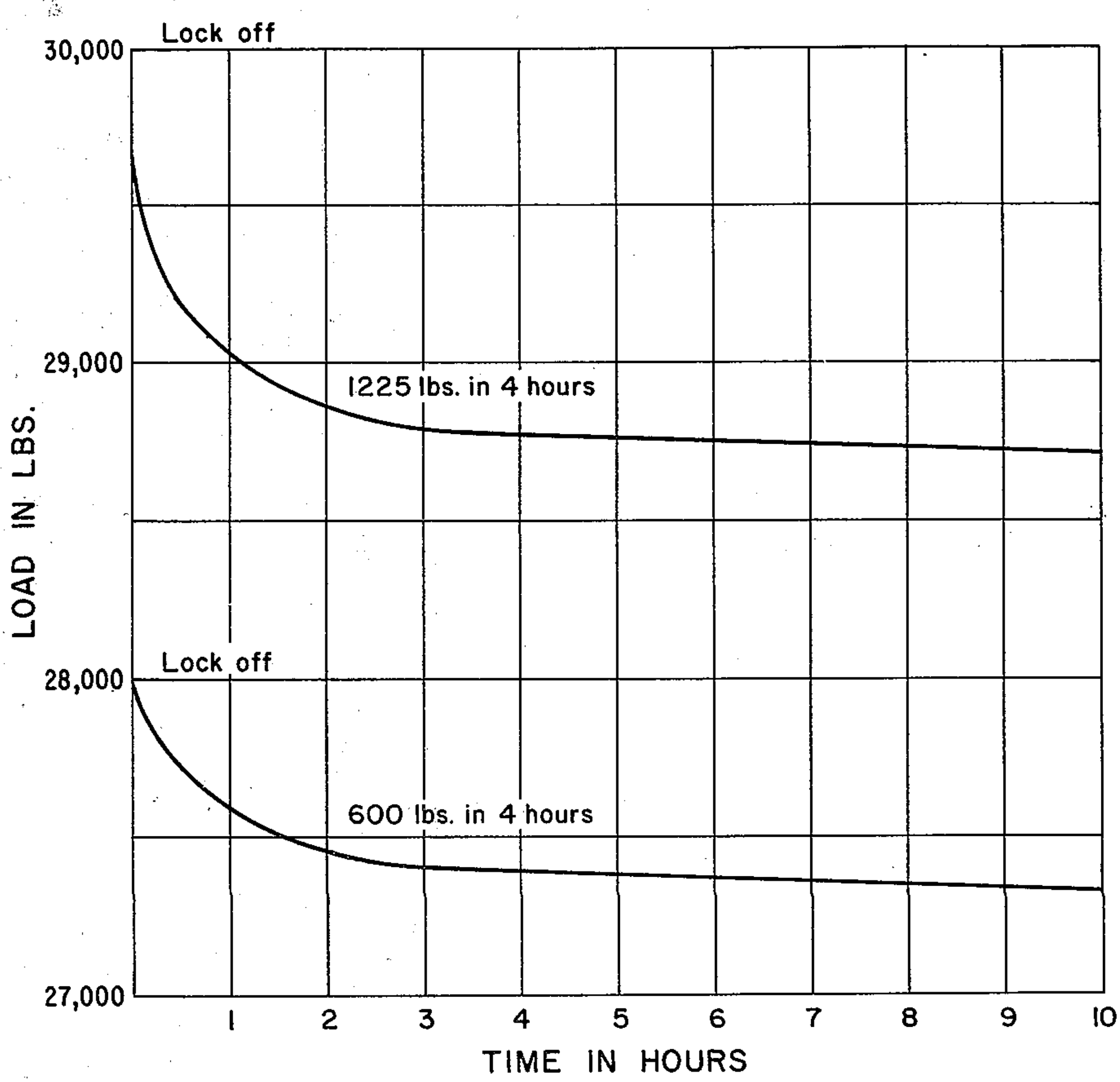

Figure 5

VI. QUALITY CONTROL UTILIZING LOAD CELLS

A. Electro-Mechanical Type Cell

The load cell is a electro-mechanical load measuring device utilizing a Wheatstone bridge and galvanometer with a calibrated variable resistor to interpret the load. The load sensing portion of this apparatus is made up of a thick walled steel cylinder with extremely fine (0.001" diameter) loops of wire (referred to as SR-4 strain gages) integrally attached. As load is applied to the ends of the cylinder, the strain is translated to the gages which changes their cross-sectional area. This change in cross-sectional area causes a change in electrical resistance which is read on the sophisticated computer like galvanometer referred to as a strain indicator or readout. In our case the readout is set up to read directly in kips, rather than resistance change or strain.

Although the principal of a load cell is simple, the techniques used to apply the principal accurately and efficently becomes quite complicated. Our research and experience, revealed that glueing the strain gages to the surface of the cylinder did not yield the accuracy and ruggedness desired for field use.

Presently our basic design consists of a steel cylinder with 4 holes drilled through the cylinder wall. The holes are circumferentially spaced 90 degrees apart at mid-height of the cylinder. A strain gage is glued to the internal surface of each hole. Drilling the 4 holes in the cylinder wall creates a localized stress riser (concentration) around the hole area. This arrangement has proved to be far superior to the old method (glueing the gages to cylinder surface) by increasing the sensitivity, accuracy, and ruggedness of our load cells.

The four strain gages are wired in such a manner that they yield one average reading. To assure the four gages will not receive a disproportionate share of the load (a load that would cause the hole to permanently distort or break the bond of the strain gage would be a disproportionate share) the height of the cell is about 1.3 times the outside working diameter. The stress area at full load capacity is subjected to 25,000 - 30,000 psi. Thus, the systems which require large center holes require extremely heavy load cells. Presently we have cells weighing up to 190 lbs.

B. Electro-Hydraulic Type Cell

The electro-hydraulic load cell is a commercially made unit which accurately measures hydraulic pressure through a cell fitted with a strain gage. Although this system will give an accurate measure of hydraulic pressure, it must first be calibrated with an electro-mechanical load cell on any given jack and gage combination. Thereafter provided changes in conditions of equipment and combinations thereof do not occur, it may be used as a monitoring device, in lieu of the more cumbersome electro-mechanical type load cell.

C. Load Cell Set-Up Procedure

To set up a load cell for use the following count down must be followed: (Refer to Figure 6)

After making sure the connections are dry and clean:

1. Connect cell and indicator (plug in 4-pin connector).

2. Turn toggle switch to ON position.

3. Controls should be set at:

   Bridge - 120 ohm
   Sens. - Full clockwise
   Polarity - F B +
   (These knobs may be preset and locked or removed from indicator)

   Readout - switch UE (unless otherwise noted on calibration for jack)

4. Turn numerical display to zero (00000). Note: This indicator reading x 100 equals the load in lbs., unless otherwise noted.

5. Bring meter needle to zero position with balance knob. On electro-hydraulic cell open pressure release valve so that there will be no pressure on cell while doing Step 5.

6. Either (a) plug calibration resistor into green and white terminals making sure resistor matches load cell being used. Turn numerical display knob till the value indicated for that cell is showing. Bring meter needle to zero this time by adjusting gage factor dial. Remove resistor and check zero, it may have shifted; if it has, continue repeating the above procedure until both zero and resistor readings are at the required values (usually twice is sufficient); (b) or: When no resistor is used set gage factor to given value and recheck zero.

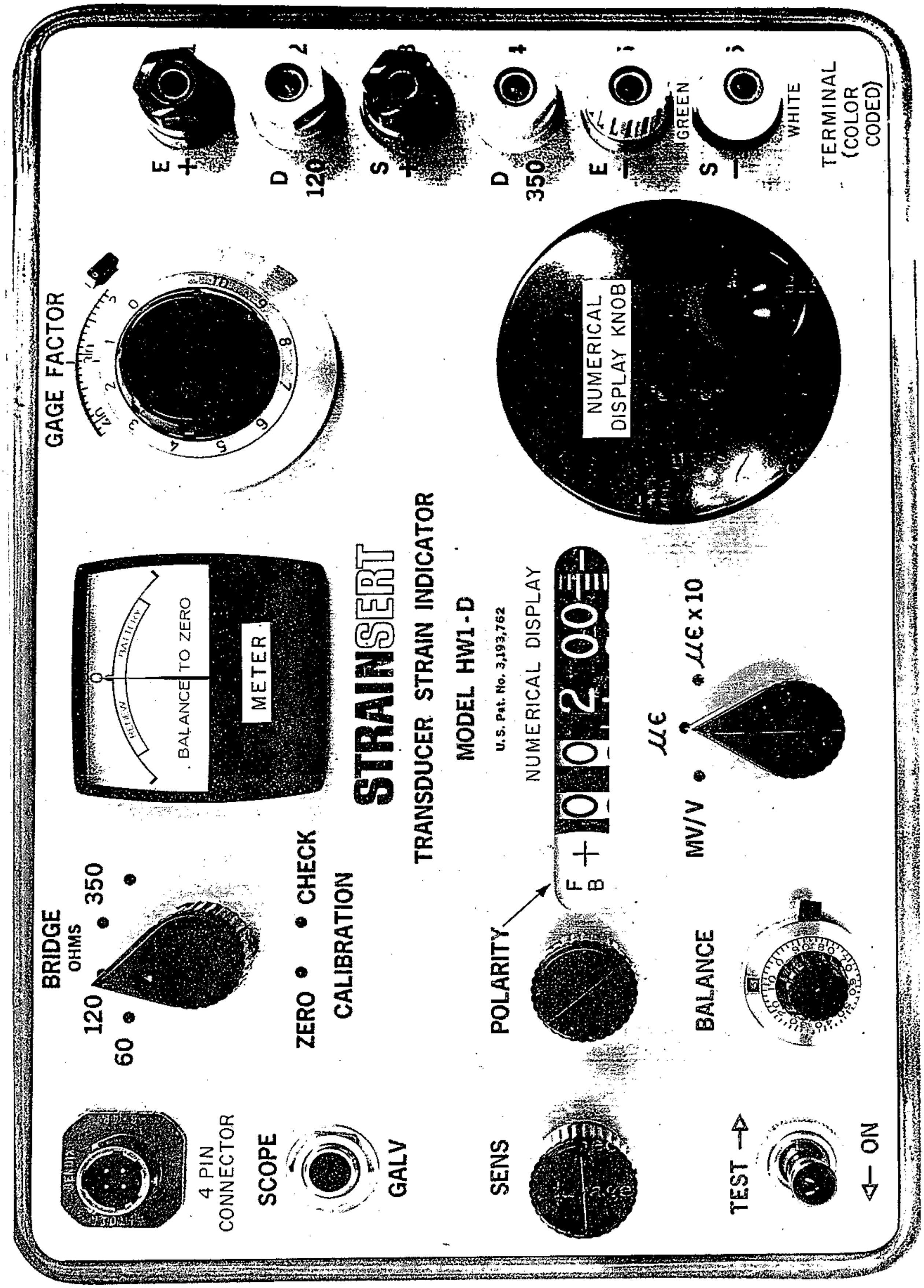
STRAINSERT
TRANSDUCER STRAIN INDICATOR
MODEL HW1-D
U.S. Pat. No. 3,193,762
NUMERICAL DISPLAY
METER
BALANCE TO ZERO
GAGE FACTOR
NUMERICAL DISPLAY KNOB
BRIDGE
OHMS
60
120
350
ZERO
CHECK
CALIBRATION
POLARITY
F
B
BALANCE
MV/V
με
με x 10
4 PIN CONNECTOR
SCOPE
GALV
SENS
TEST
ON
E +
D 120
S +
D 350
E −
S −
GREEN
WHITE
TERMINAL (COLOR CODED)

Figure 6

7. Insert load cell into system.

8. Re-zero before each run.

An outline of the above procedure is in the lid of all the indicators.

Although the gage factor on any particular indicator is capable of being set very accurately by eye (extrapolating of course) a properly selected resistor not only improves the accuracy but allows checking of the range and temperature drift even under load. The use of the resistor is essentially a field calibration of the load cell and indicator as it is electronically equivalent to applying a fixed load to the load cell.

D. Load Cell Malfunction Check List

1. Apparent Malfunction: Cell indicator will not balance

Possible Causes:

(1) "Test" battery.

(2) Cell plugged in?

(3) Indicator turned on?

(4) Loose connections?

(5) Severed or damaged lead wire?

(6) Connections wet and/or muddy?

(7) Cell wet and/or muddy?

(8) Make sure resistor is not plugged in.

(9) Make sure resistor is not broken.

(10) Make sure there is no load on cell.

2. Apparent Malfunction: Gage factor has large change

Possible Causes:

(1) Although wires are interchangeable, check correct wire?

(2) Correct resistor, or resistor setting?

(3) Correct cell?

(4) Connection to cell?

(5) Wire or cell damaged?

(6) Cell - wet or damp?

3. <u>Apparent Malfunction: Needle jumping or erratic</u>

Possible Causes:

(1) Tendon friction in structure causing erratic load changes.

(2) Static from motors or pumps in immediate vicinity - usually plugging in of ground wire will overcome this.

(3) A short or poor connection in calibration system - if it is not obvious or simple, send in for repair.

(4) On electro-hydraulic cell flicking or erratic needle may be caused by hydraulic surge. To alleviate this, make sure that gage and cell hook-up are coming off the jack and not the pump. Generally you should keep the gage connections away from the pump.

4. <u>Apparent Malfunction: Needle sluggish or will hardly move</u>

Possible Causes:

(1) Cell plugged in?

(2) "Test" battery.

(3) System set-up properly?

(4) Spots where potential increase in resistance might occur.

a. Water on connections or cell.

b. Broken or damaged wire.

If none of the suggested checks prove to be fruitful in overcoming the apparent malfunction, consider the cell and/or indicator to be unsatisfactory for use. One and/or the other is either out of calibration or needs maintenance and should be returned to the Materials and Research Department for repairs. If available, you should change indicator and/or load cell before proceeding with further calibration.

E. Load Cell System Care

1. Keep all components dry and clean. Do not oil or clean with solvents; wipe with clean cloth.

2. Keep the battery charged.

3. Avoid rough handling.

4. Avoid eccentric loading.

5. Always be sure to have uniform bearing on both ends of the cell.

6. Do not carry load cell or indicator in trunk, on car seat or where it might be damaged by impact. It is generally preferable to place it on the vehicle floor.

7. When left over night on a bridge tendon, put cap in place and cover with waterproof canvas. Plastic sheeting creates condensation which is likely to create electrical as well as corrosion problems.

8. Remember that the load cell and indicator are delicate inspection instruments and should be treated as such. As one of the surveying instrument companies says on their equipment, "HANDLE LIKE EGGS".

VII. CALIBRATION

A. Electro-Mechanical Load Cells

The calibration of load cells should be done only by trained laboratory personnel with the proper equipment. Briefly, an electro-mechanical load cell is calibrated in a loading frame where it is loaded simultaneously in series with National Bureau of Standards calibrated load cells or in a testing machine which has a certified load measuring accuracy within $\pm$ .05 of the true load. The former method is preferred. When the desired maximum load is attained by either method, the indicator is set up to read directly in kips by adjusting the gage factor knob. The zero is then rechecked, and if satisfactory the cell is subjected to multiple incremental loadings to assure accuracy throughout its operating range.

B. Prestressing Jacks

Jacks are calibrated with electro-mechanical load cells and checked thereafter by monitoring with calibrated electro-hydraulic cells. Following are a number of general steps that should be followed and some information that should be obtained to assure proper use of either or both types of load cells:

1. Become familiar with the name and type of system being used.

2. Study the prestressing contractor's working drawings.

3. Verify the number of strands in each tendon by count and compare to working drawings.

4. Calculate or look up (on working drawings) maximum corresponding jacking force. In no case for ½" 270 ksi strand should this force exceed 75% of 41,300 lb/strand which equals about 31 kips. (Number of strands X 31 kips = absolute max. jacking force)

5. Record the jack number and ram area, as indicated on the jack.

6. Divide max. jacking force by ram area. This equals the theoretical gage pressure (theoretical because gage error and friction are ignored).

7. Look up max. gage pressure used on latest calibration for the same size tendon.

8. Compare results of Steps 6 and 7. Max. gage pressure from calibration will generally be slightly higher by 1 - 5%.

9. Set up indicator and load cell (see Set-up Procedure).

   a. Check to see if correct cell has been selected.

   b. Double check setting on indicator gage factor, etc.

   c. Make sure there is no load when zeroing cells (open pressure release valve on electro-hydraulic cell).

   NOTE: If different size tendons are used and/or jack is changed, repeat 1 through 9.

10. Place cell in system.

    a. Standard load cell (see discussion of particular system).

    b. Electro-hydraulic cell is hooked in next to gage.

11. Jack to 10% of jacking force.

    a. Mark elongation and record measurement (for detail see discussion of particular system).

    b. For stressing from one end only also measure how far dead end wedges are protruding and record.

12. Proceed to 50% of total required jacking force, as determined by gage pressure.

    a. Stop jacking.

    b. Recheck gage, should be at ½ of total anticipated reading.

    c. Check read out, should be ½ of total load.

    d. Elongation should be approximately 4/9 of measurable elongation, since elongation zero measurement started at 10% of total load.

13. Finish jacking to max. (usually 75% of specified ultimate).

    a. Control stopping by whichever checking method achieves anticipated maximum first (think).

    b. If remaining checks are reasonably close, take choice of which to use as the main control, giving credence in the following order:

        (1) Load cell (std. or electro-hydraulic).

        (2) Gage pressure

        (3) Elongation

14. Measure elongation; if desired load has been achieved, do not jack any further, even if elongation is short; anchor tendon.

    a. Measure seating loss.

    b. If stressing one end only, subtract seating loss of dead end wedges from measured elongation.

    c. Also correct seating loss (on jacking end) for length of strand inside jack.

15. Recheck zero on load cell.

The difference between the product of the gage pressure times the piston area and the force indicated by the standard load cell is the friction in the jacking system. In order to properly evaluate friction in a jacking system, it must be done in a way representative of its actual use. Generally this can be achieved easiest on the structure or in some cases a testing bed. It is impossible to develop or evaluate this friction in a testing machine.

A typical testing machine calibration of a jack and gage combination will start at zero and be practically the same as ram area X gage pressure for whatever load anticipated. However, a calibration taking into account friction will not project to zero unless there are compensating factors such as variable internal and/or external friction (as in Freyssinet) or the gage is nonlinear. Thus a plot of a proper calibration will always show some pressure on the gage with zero load as shown in typical plots (Figures 7 and 8).

When calibrating a jack, you should read and record even gage pressure values along with simultaneous load cell readings. This information, when plotted, readily reveals the relationship between gage reading and actual jacking force. At least two and preferably three runs should be made before plotting the final calibration curve.

The plotted curve is not only useful for extrapolation in case it is necessary to adjust the load but it serves as a check on validity of the calibration. The plot should generally be a straight line which, when projected, should not pass through zero but should show some gage pressure without load. In order to establish uniformity, always plot the load on the horizontal axis and the gage pressure on the vertical axis.

C. Electro-Hydraulic Load Cells

Although electronic integrity of electro-hydraulic cells can be easily and quickly checked in the laboratory with a pressure meter calibrator, it is necessary to perform the calibration with the jacking system in order to compensate for the actual friction of the particular jacking system.

Proper calibration of an electro-hydraulic cell must be done simultaneously with a standard load cell on the tendon to determine actual load applied. General instructions for use of load cells and electro-hydraulic load cells and load cell setup procedure must be followed for both cells with the following deviations:

In addition to regular instructions listed under "B. Prestresing Jacks", Step 12:

e. While holding load (at 50% as determined by standard load cell) set numerical display knob on electro-hydraulic cell indicator to read same as numerical display on the standard load cell indicator.

f. Bring meter needle to zero by adjusting gage factor dial.

g. While still holding same load:

  (1) Close check valve of electro-hydraulic cell.

  (2) Open pressure release valve on electro-hydraulic cell.

(3) Re-zero electro-hydraulic cell by dialing numerical display knob to 00000 and bringing meter needle to zero position with balance knob.

(4) Close pressure release valve and open check valve.

(5) Dial numerical display knob to whatever is showing on the standard load cell indicator.

(6) Adjust meter needle to zero again, if necessary, with gage factor knob. Procedure may have to be repeated to insure accurate gage factor adjustment.

After resumption of jacking, pace and compare indicated loads at selected intervals throughout the loading to assure proper calibration. When the total jacking force is reached (B. Prestressing Jacks, Step 13) and there is more than several kips difference between readings, hold the jacking load and repeat Steps 12 e through 12 g above. Follow this procedure on several tendons; make adjustments, if necessary, until calibration is satisfactory.

Record the following:

1. Indicator and cell number (both cells)

2. Gage factor (both cells)

3. Date

4. Job (contract number)

5. Jack and system

6. Gage

7. Any other pertinent data.

VIII. TENDON ELONGATION

Calculate anticipated elongation using the modulus of elasticity (E) shown on M & R Lab release for actual material used in the tendons. The elongation shown on the shop plans is based on an assumed E which may not be correct for the material on the particular contract. A shortcut method is to multiply the shop plan elongation by the ratio of the assumed E to the measured E. Always use the load cell or jack gage pressure reading to measure force in preference to elongation. Then compare measured elongation with calculated elongation. As a rule of thumb, if the deviation exceeds plus three or minus seven percent, the operation should be discontinued until the cause of the apparent discrepancy is determined. This criteria is based on experience only and is not a specification tolerance and must be used with discretion. In general, the total elongation should agree with the calculated value within three percent plus or minus.

IX. SAFETY

Prestressing is a hazardous operation, if safety practices are not followed consistenly. Terrific forces are involved and if anything breaks, parts are going to fly. The direction the parts fly is generally where the tendon is pointed, so stay away from behind the jack or a dead-end anchorage during stressing.

Occasionally wedges will also pop out sideways when they are not squarely set so this is another area to avoid. Always keep fingers away from moving parts of the jack; the operator cannot watch you and his work too. Although this is the contractor's operation and responsibility, any obviously unsafe condition should be brought to the Resident Engineer's attention.

X. ACKNOWLEDGEMENTS

Other contributors to the foregoing included:

W. H. Ames and W. E. Faist of the Materials and Research Department.

T. J. Bezouska and D. Pinski of the Bridge Department.

JACK CALIBRATION
TYPICAL SYSTEM

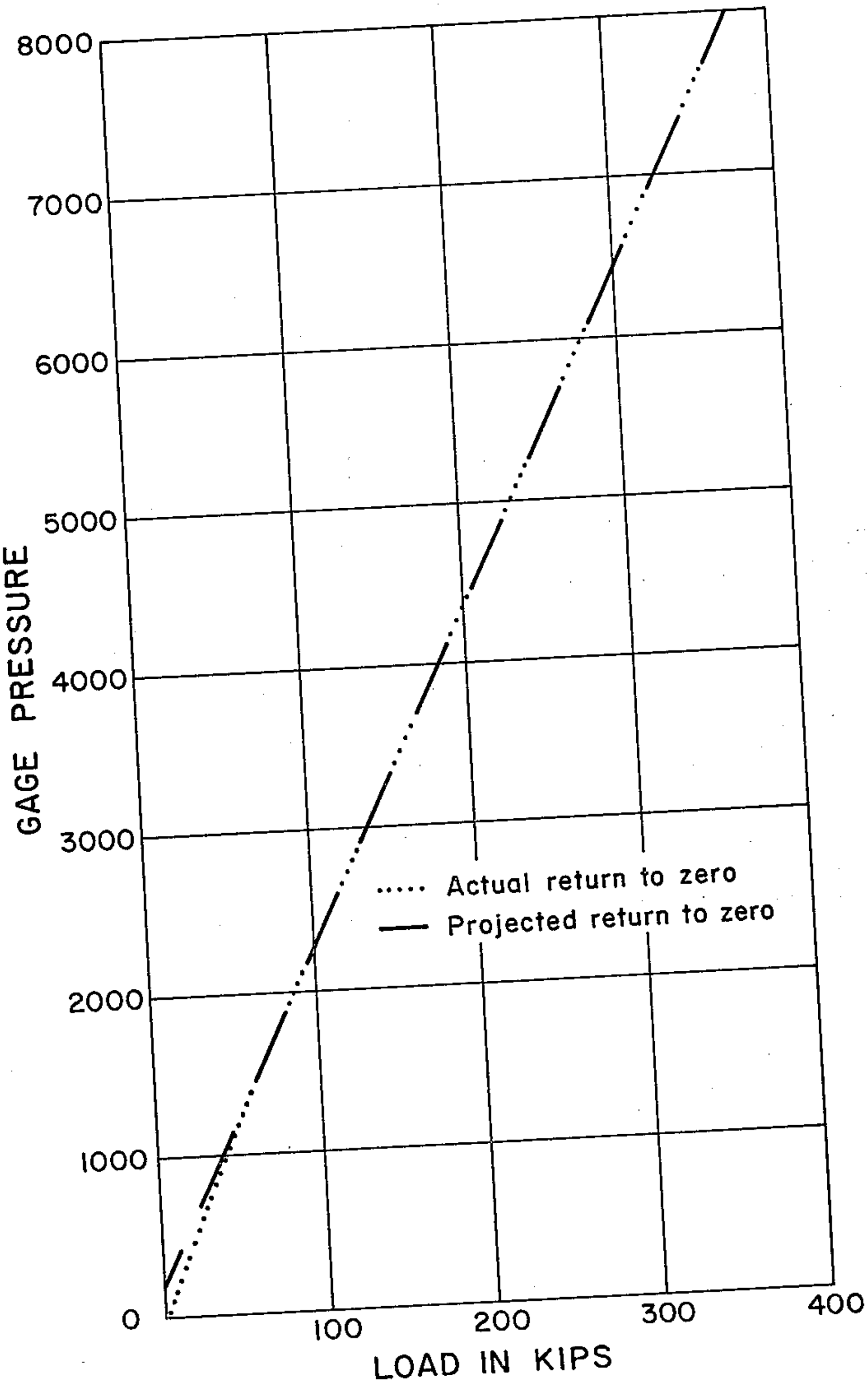

Figure 7

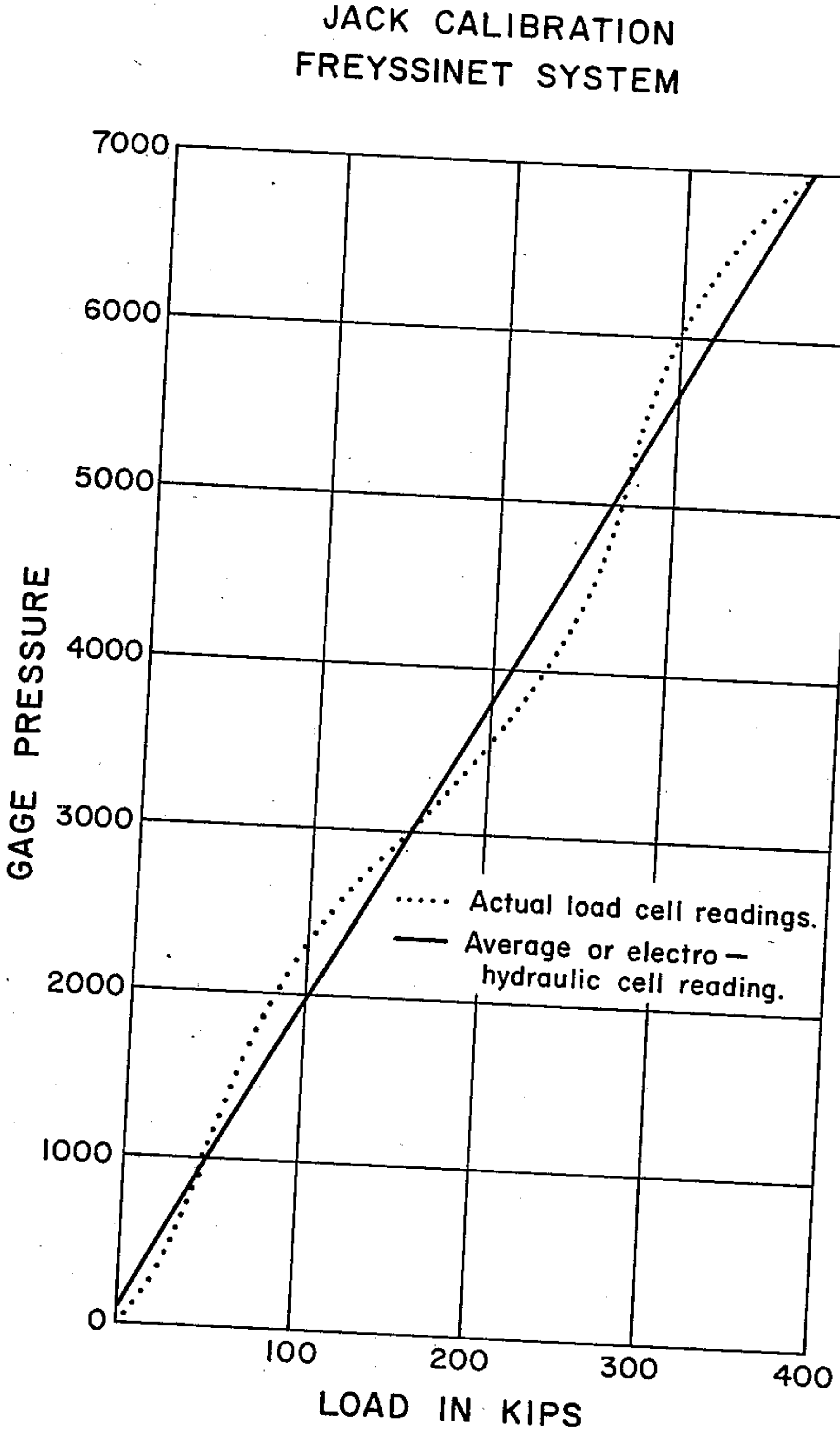
JACK CALIBRATION
FREYSSINET SYSTEM
GAGE PRESSURE
7000
6000
5000
4000
3000
2000
1000
0
100
200
300
400
LOAD IN KIPS
Actual load cell readings.
Average or electro-hydraulic cell reading.

Figure 8

APPENDIX I

plication, and shall be worked into any voids in the prestressing tendons.

50-1.06 Anchorages and Distribution.—All post-tensioned prestressing steel shall be secured at the ends by means of approved permanent type anchoring devices.

All anchorage devices for post-tensioning shall hold the prestressing steel at a load producing a stress of not less than 95 percent of the guaranteed minimum tensile strength of the prestressing steel, when tested in accordance with Test Method No. Calif. 641.

When headed wires are used, the outside edge of any hole for prestressing wire through a stressing washer or through an unthreaded bearing ring or plate shall not be less than ¼ inch from the root of the thread of the washer or from the edge of the ring or plate.

The load from the anchoring device shall be distributed to the concrete by means of approved devices that will effectively distribute the load to the concrete.

Such approved devices shall conform to the following requirements:

(1) The final unit compressive stress on the concrete directly underneath the plate or assembly shall not exceed 3,000 pounds per square inch.

(2) Bending stresses in the plates or assemblies induced by the pull of the prestressing steel shall not exceed the yield point of the material or cause visible distortion in the anchorage plate when 100 percent of the ultimate load is applied as determined by the Engineer.

(3) Materials and workmanship shall conform to the requirements in Section 55, "Steel Structures."

Should the Contractor elect to furnish anchoring devices of a type which are sufficiently large and which are used in conjunction with a steel grillage embedded in the concrete that effectively distributes the compressive stresses to the concrete, the steel distribution plates or assemblies may be omitted.

Where the end of a post-tensioned assembly will not be covered by concrete, the anchoring devices shall be recessed so that the ends of the prestressing steel and all parts of the anchoring devices will be at least 2 inches inside of the end surface of the members, unless a greater embedment is shown on the plans. Following post-tensioning, the recesses shall be filled with grout, and finished flush. The grout shall conform to the requirements in Section 51-1.135, "Grout," and shall consist of one part cement and 2 parts sand.

50-1.07 Ducts.—Duct enclosures for prestressing steel shall be ferrous metal, mortar-tight, and accurately placed at the locations shown on the plans or approved by the Engineer.

All ducts or anchorage assemblies shall be provided with pipes or other suitable connections for the injection of grout after prestressing.

Ducts for prestressing steel when bars are used shall have a minimum inside diameter ⅜ inch larger than the diameter of the bars to be used.

INFORMATION REQUIRED PRIOR TO ACCEPTANCE OF NEW POST-TENSIONING SYSTEMS

1. Prestressing systems proposed: What type of prestressing steel is to be used, and what is the proposed ultimate strength per tendon? What is the minimum guaranteed ultimate strength of the tendon? What is the percent elongation at ultimate load?

2. What is the prior history of the system, including specific details of projects where used?

3. Complete records of tests proving the system; method of test, tendon length, hardware, etc.

4. Specific instructions concerning stressing methods to be used by contractor performing work. Are methods for shimming explained? What are details of seating losses? What is the expected seating loss? On short tendons, explain shimming methods to be used by the contractor?

5. Complete quality control procedures you require of your suppliers or subcontractors. Have you run tests on maximum allowable tolerances of your anchorage material?

6. Complete specifications on your anchorages and materials.

7. Testing Criteria: How do you propose to test the system?

8. Has the proposed anchorage always developed your stated ultimate tendon strength without failure or visible distortion in the anchorage? What steps have been taken to determine the cause of deviations that you have experienced, what specifically caused these failures, and what corrective steps were taken? What deviations can contribute to failure of your system?

9. If partial tendon failure occurs during stressing, what corrective measures are proposed? What are your procedures for tendon detensioning and replacement if the need should arise?

10. What are your recommendations to the contractor for protecting the tendons against physical damage and corrosion during fabrication and construction? Give complete information on grouting procedures and equipment to be used.

11. When your system is in use, will qualified technical assistance be provided in the field for the contractor building the structure?

12. Complete detailed drawings of your anchorage system, jacking system, duct and grouting details, will be required. These will be honored as strictly confidential as will all your submittals.

Prior to final acceptance, a formal written prequalification manual, covering all of the above points as applicable to your system, will be required.