Testing 7-Wire Strand for Prestressed Concrete— The State of the Art

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Special equipment and some experience in the details of its use are required to obtain the necessary degree of accuracy in testing 7-wire prestressed concrete strand.

ASTM A416 is the Standard Specification for Uncoated 7-Wire Stress-Relieved Steel Strand for Prestressed Concrete. The Supplement to ASTM A416 covers Low-Relaxation 7-Wire Strand.

AASHTO M203 is the same as ASTM A416.

Testing equipment and procedures are covered by Section VII of ASTM A370. Definitions of terms common to 7-wire strand and prestressed concrete are given at the end of this paper.

ASTM A416 addresses the following properties for stress-relieved strand:

Section 3.1 Strand — The requirement of "... a center wire *tightly* enclosed by six helically placed outer wires ..." means that the outer wires shall be neither overpreformed nor underpreformed. See comments near the end of "Modulus of Elasticity" and "Definitions."

Section 5 Materials and Manufacture — This section does not require action by the testing agency. Subsequent tests will show whether or not the requirements of Section 5 have been met.

Section 6.1 Breaking Strength — Minimum breaking strengths are tabulated in ASTM A416. Special problems in testing strand are discussed later in this paper under "Gripping a 7-Wire Strand."

Section 6.2 Yield Strength — If a load-elongation curve is plotted, the yield strength can be read directly from it. If not, the yield strength can be obtained by the test described in Section 6.2.2 using equipment of the type discussed under "Modulus of Elasticity."

Section 6.3 Elongation — In order to reach the required 3½ percent elongation, it is almost always necessary to use grips of the type described under "Gripping a 7-Wire Strand."

It is dangerous to leave sensitive extensometer equipment on the strand until a 3½ percent elongation has been reached. A premature failure due to a wire weld or a gripping problem could ruin the extensometer. Since strands generally have an elongation of 4½ percent or more, perfect accuracy is not required for this measurement. One type of device that can be used is shown in Fig. 8.

Section 6.4 — This section calls for a retest if the specimen fails in the grip without meeting the required ultimate strength and/or elongation. Some laboratories interpret this to mean that one retest is required and that the strand is rejected if the retest has a premature failure in the grip. Section 6.4 actually means that all tests which fail prematurely in the grips without meeting the required ultimate and elongation are invalid.

Section 7.2 — The requirement that the center wire be at least so much larger than any outside wire is very important. If a proper relation is not maintained, the outer wires can form a pipe around the center wire without bearing on it and the center wire will slip and not carry its share of the load.

Section 7.3 Permissible Variations in Diameter — These limitations were established many years ago in collaboration with the producers of strand anchors and gripping devices. A strand of a given nominal diameter meeting these tolerances should work in a grip specified for the same nominal diameter. Section 7.4 permits any size up to 0.75 in. diameter as a special case.

Section 8.3 — If one or more wires fly out of position when cut and cannot be replaced by hand, that wire is underpreformed. This condition may be spotty or for the full length of the package of strand. If the loose wires can be twisted back into place and held by taping at the end, the strand should have its normal properties except for a probable foot at the beginning of the load-elongation curve.

Section 8.4 — Oil and grease prevent proper bond to the concrete and an oily center wire will often slide through the outer wires and not carry its share of load. Many oils and greases become acidic with the passage of time and invite corrosion.

Light rust improves bond and is not detrimental in typical applications. A pit large enough to be seen without a magnifying glass is a stress raiser. A strand with a pitted wire can fail at 30,000 cycles of repeated load when a strand with no pits will carry 2,000,000 cycles without failure.

Synopsis

Presents the state-of-the-art of testing procedures for stress-relieved and low-relaxation 7-wire strand.

Specific information is given on material properties, gripping devices, determining the modulus of elasticity, testing equipment, and short-term relaxation test.

Definitions common to 7-wire strand and prestressed concrete are included.

Discussions of some of the testing methods are given together with suggested procedures.

ASTM A416 Supplement — Low-Relaxation Strand

The requirements for low-relaxation strand are the same as those for stress-relieved strand with the following two exceptions:

Table 1. Thin Line Splice for 270K Strand.

Strand size, in.	Catalog number	Color code	Spliced diameter, in.	Splice length, in.	Rated strength, lbs	Splice sets	Standard carton	
							Weight, lbs	Units, in.
3/8	TLS 1120	Yellow	0.615	52	23000	1@3, 2@4	55	25
7/16	TLS 1121	White	0.718	60	31000	1@3, 2@4	35	10
1/2	TLS 1122	Red	0.854	70	41300	2@3, 1@4	55	10

Section S5 Yield Strength — The yield strength must be at least 90 percent of the specified minimum breaking strength instead of the 85 percent required for stress-relieved strand.

Sections S2, S3, S4, and S6 — Low-relaxation strand must have a stress loss that does not exceed the specified amount when loaded to the specified load for the specified time under the specified conditions listed in these sections.

Very special equipment is required to conduct the relaxation test required by these sections. The strand being tested must be held at *exactly* constant length, and the load measuring device must read load changes that are very small in comparison with the total load on the strand.

Temperature must be constant at 68°F for the duration of the test. The special equipment required for this test is generally available only in the laboratories of fabricators of low-relaxation strand.

Since it is not practical to conduct long-term relaxation tests on every 20 tons of strand, as required by Section 9 for all other tests, Section S6.1 permits use of data from tests on similarly processed strand. Some fabricators of strand have had long-term tests in their laboratory witnessed and certified by representatives of a commercial testing laboratory.

A 30-minute relaxation test having the sole purpose of separating stress-relieved strand and low-relaxation strand is described under "Short-Term Relaxation Test."

GRIPPING A 7-WIRE STRAND

The configuration and metallurgical properties of a 7-wire strand are such that premature failure of the strand in the gripping devices occurs when the strand is tested using grips that are normally used for testing steel bars. A typical grip designed for a round steel bar will bear on only a small part of the outer surface of some of the outside wires.

The resulting load per tooth from the grip is excessive and the wires fail in shear at a load below their actual tensile capacity.

The problem is increased because the wire, with a strength in excess of 270,000 psi, is more notch sensitive than most steel bars. The occurrence of premature breaks has been so prevalent that ASTM A416 now includes Section 6.4 which makes the test invalid if failure occurs in a grip before the specified ultimate tensile strength and elongation are reached.

The true properties of a 7-wire strand can be measured only if an efficient gripping procedure is used. ASTM requirements are met if the specified minimum ultimate load and elongation are reached prior to failure. It is preferable to use equipment that will develop the full ultimate strength and elongation

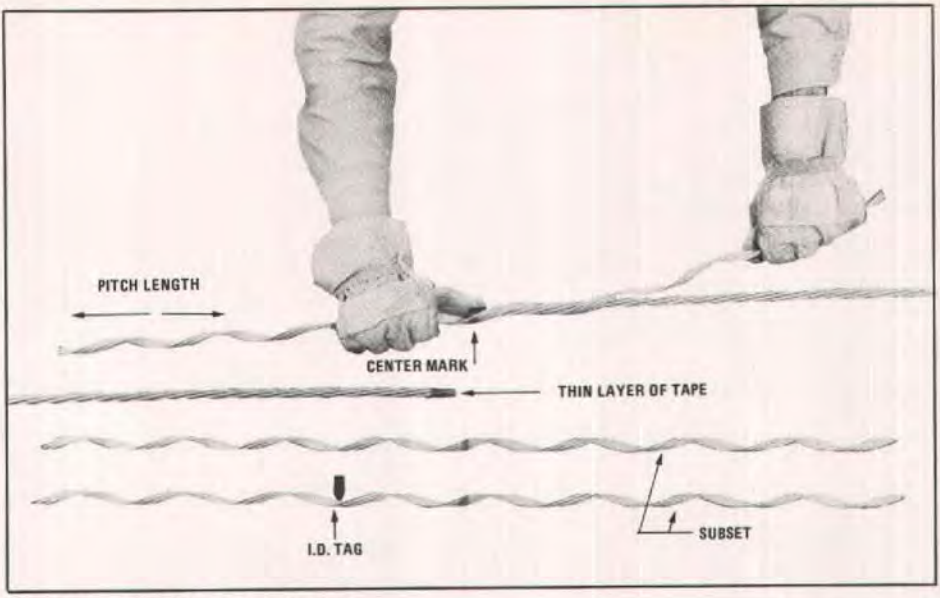


Fig. 1. Installing Thin Line Splice.

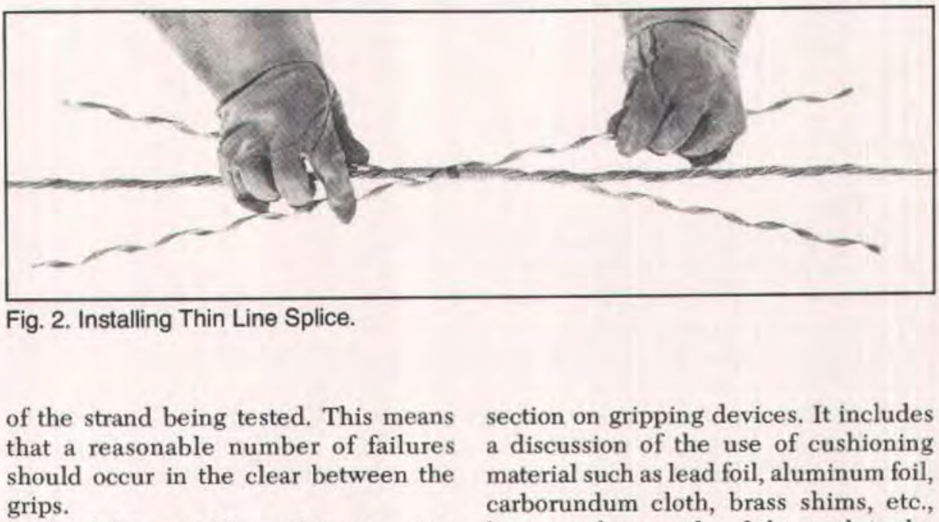


Fig. 2. Installing Thin Line Splice.

of the strand being tested. This means that a reasonable number of failures should occur in the clear between the grips.

All of the reusable wedge grips currently being used in casting yards cause shear failure of wires in the grip before the required ultimate load and/or elongation has been reached.

None of the post-tensioned anchors available will consistently reach the required 3.5 percent elongation before failure.

Section VII of ASTM A370 includes a section on gripping devices. It includes a discussion of the use of cushioning material such as lead foil, aluminum foil, carborundum cloth, brass shims, etc., between the strand and the teeth in the testing machine grip. These methods have been successful where special long jaws with fine teeth have been used.

Four methods of gripping strand which have given good results are discussed in the following paragraphs. The Sand Grip yields about 50 percent clear breaks. The PLP, the Tinius Olsen, and the aluminum insert method yield 90

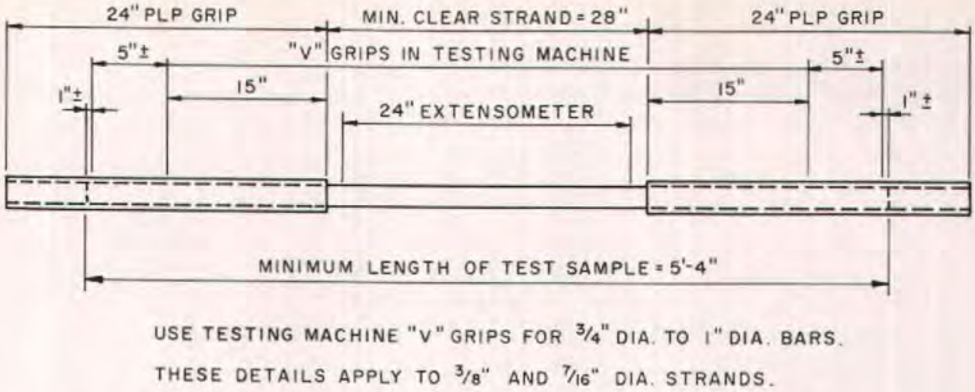


Fig. 3. Placement of Thin Line Splice on test specimen.

percent or better clear breaks.

Under "Specimen Preparation" ASTM A370 says "Wire slippage may be minimized by fusing together the cut ends of the specimen. . . . . ." ASTM A416 requires the center wire to be larger than the outer wires by a specified amount. This difference is required to make sure each outer wire bears on the center wire and grips it as there is no other means of applying and keeping tension in the center wire during its service life as a tendon.

If the wires are properly dimensioned and the wires are not lubricated, it should not be necessary to fuse the ends of the specimen. After all, the center wire of an unbonded post-tensioned strand is gripped only by the outer wires of the strand and the ends are often cut off with a carborundum wheel rather than with a torch.

The PLP Grip

The PLP Grip is made from devices for splicing 7-wire strand that are manufactured by the Preformed Line Products Company, P.O. Box 91129, Cleveland, Ohio 44101 and marketed as the Thin Line Splice by Spancrete Northeast Inc., 8 Cairn Street, Rochester, New York 14611.

Dimensions of the Thin Line Splice are shown in Table 1 and details in Figs. 1 and 2. The splice for ½-in. diameter 270 Grade strand is composed of two sets of three wires each plus one set of four wires and has an outside diameter of about ⅞ in. Each set of wires is helically preformed so that it will fit tightly around the strand for which it is designed.

The three or four wires in each set are cemented together and the inside surface of the set is coated with a grit which keeps the strand from slipping. When used to splice a ½-in. diameter 270 Grade strand, the TLS 1122 Thin Line Splice will develop the full ultimate strength and elongation of the strand.

Fig. 3 shows details of the assembly of a strand and PLP Grips in a testing machine. Best results are obtained using the longest strand "V" grips and finest teeth available. In the unlikely event that failure occurs at a grip because of coarse teeth or too short a grip, using a piece of 50 grit carborundum cloth between the jaws and the PLP Grip with the grit against the PLP Grip may correct the problem. Fig. 4 shows a PLP Grip and strand assembly in a testing machine and Fig. 5 shows the resulting clear break with pure tensile failures of the wires.

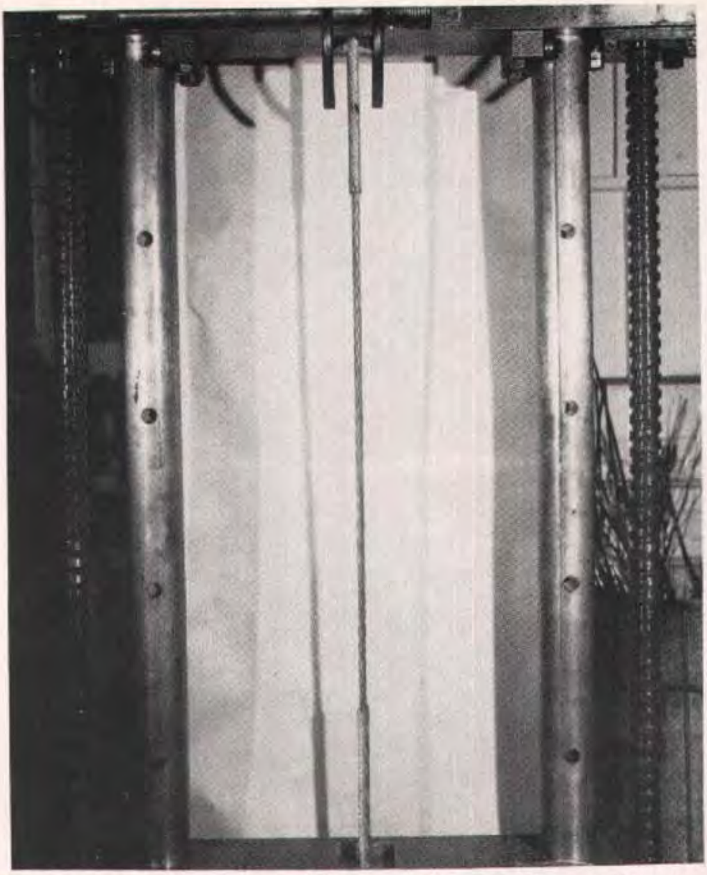


Fig. 4. Test assembly with Thin Line Splice in testing machine.

As shown in Table 1, the Thin Line Splice for ½-in. diameter 270 Grade strand is 70 in. plus or minus ¾ in. long. Using a carborundum disc, one such splice can be cut into three lengths to make three PLP Grips. When used for testing strand, PLP Grips have been removed and reused but the cost of the labor involved more or less offsets the saving achieved.

Table 1 does not include a Thin Line Splice for 0.60-in. diameter strand. The cost of making one as a special item would probably be high.

Preformed Line Products Company makes dead end anchors for all sizes of strand. Their Number BG 2111 is for a ⅝-in. diameter galvanized strand. The straight portion of this is approximately 54 in. long and could be used to make two PLP Grips each about 27 in. long. There are no reports of testing with this but, unless the inside diameter is too large, it should work for 0.60-in. strand.

The Sand Grip

Details of a Sand Grip are shown in Fig. 6. These are U grips with no teeth in the gripping faces. In the area where the strand is gripped it is covered with a gritty mixture which prevents slippage. The grips are not patented and can be fabricated by any reasonably well equipped machine shop. Details can be obtained from major strand producers.

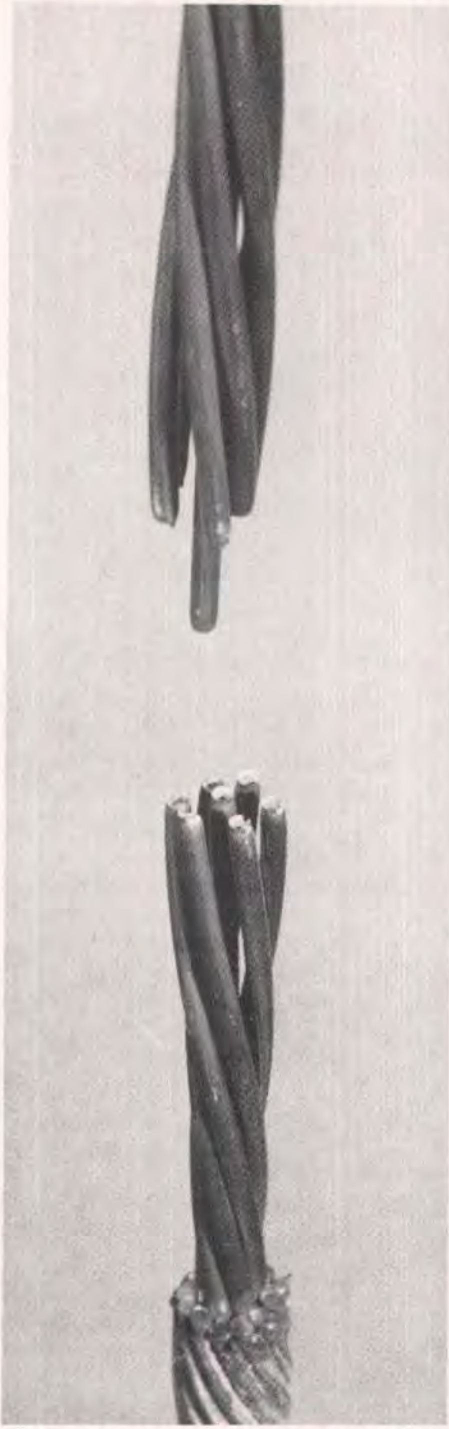


Fig. 5. Pure tension failure between Thin Line Splice grips.

Two types of grit have been used:

1. Ordinary sharp concrete sand screened to remove any oversize particles. The sand is mixed with enough SAE-10 or SAE-20 oil to make a cohesive but not wet mixture. If water is used in place of oil, the mixture will also function satisfactorily but it dries if allowed to stand and must be remixed.

2. 80 grit aluminum oxide and water. Use enough water to form a cohesive but not wet mix.

Sand Grip Testing Procedure:

(1) Install testing machine grips with flat file faces.

(2) Apply sand or grit mixture to entire surface of U grooves in Sand Grips.

(3) Install Sand Grips and strand in testing machine.

(4) Apply hydraulic pressure or other means to cause U grips to squeeze strand.

(5) Apply tension to strand.

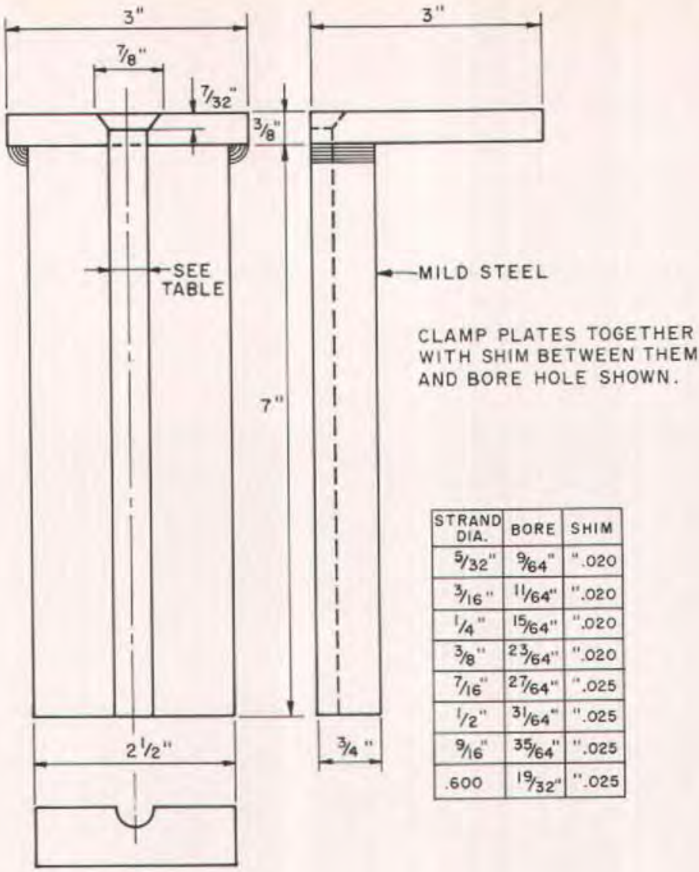
Note that a little of the grit mixture may fall from the grips during the test. Therefore, consider the need to protect any measuring devices attached to the strand.

The Tinius Olsen Grip

The Tinius Olsen Testing Machine Company, Inc., P.O. Box 429, Willow Grove, PA 19090 has developed and fabricates the SLS grip for testing 7-wire strand (see Figs. 7 and 16).

The SLS grips are toothless U grips that have a 10 in. length of contact with the strand. They are designed so that pressure on the strand is very light where it enters the grip and becomes heavier further into the grip after some of the tension has been transferred from the strand to the grip.

Since the gripping faces of the U are inclined to wear with the repeated use they get in a production laboratory, the U's are 10 in. long relatively small steel inserts that can be removed and replaced as necessary. Although the strand



STRAND DIA.	BORE	SHIM
5/32"	9/64"	".020
3/16"	11/64"	".020
1/4"	15/64"	".020
3/8"	23/64"	".020
7/16"	27/64"	".025
1/2"	31/64"	".025
9/16"	35/64"	".025
.600	19/32"	".025

Fig. 6. Details of Sand Grips.

may be gripped directly in the U's without any special preparation, it has been found that the number of clear breaks decreases as the grips wear and the use of aluminum oxide grit improves the performance of worn grips.

The Aluminum Insert

Aluminum insert angles have been used successfully in several ways. Two procedures have been used in machines that have tapered mechanical or wedge grips:

1. A thin layer of grease is applied to the ends of the test piece followed by the application of silicon carbide grit.

2. A mixture of epoxy compound with sand or grit is applied to the inner face of the aluminum insert.

A more recently installed procedure uses a machine with hydraulic grips which press the serrated teeth of the 90-deg V groove machine grips into the outer faces of the aluminum angle. The pressure also forces the strand configuration into the inner faces of the aluminum angles. With this procedure clear breaks are experienced all the time.

The testing machine being used to obtain these results is a 750 KN Avery

Denison 7155. The aluminum angles are 12 x 12 x 1.4 mm to 1.6 mm thick and ±120 mm long (½ x ½ x 0.055 in. to 0.063 x 4¾ in.). They are not reusable.

MODULUS OF ELASTICITY

ASTM A416 does not require a modulus of elasticity (MOE) test, but data on its load vs elongation properties are required almost every time a 7-wire strand is installed in a prestressed concrete member. Most specifications governing the fabrication of prestressed concrete members require the load indicated by the tensioning jack and the computed strand elongation to agree within 5 percent or work must be halted until that degree of agreement is achieved.

Although a possible error of 5 percent in initial tension may seem rather large from the designer's viewpoint, it re-

Fig. 7. Tinius Olsen SLS Grips, new liners for grips and strand that broke in clear between grips.

quires a considerable degree of accuracy at the job site and in the laboratory. Several things, including variations in piston friction and gage accuracy, can cause an error in the hydraulic jack's measurement of load in the strand. If this amounts to 2.5 percent of the load, then the measured elongation must be within 2.5 percent of the computed elongation.

Extremely good laboratory equipment and procedures are needed if the MOE established in the laboratory is to always be within 2.5 percent of the actual MOE of the strand being tensioned at the job site. As indicated in the following discussion, strand fabricating tolerances are such that the actual MOE of two lengths of strand fabricated on the same equipment to the same specification can differ by as much as 2.4 percent. In addition, it is difficult to attach a strain gage to a member composed of seven individual wires so that it will measure the MOE with complete accuracy across a relatively small gage length.

In order to reduce the effect of shop tolerances to a minimum, some strand fabricators furnish a typical curve which is the average of the last 30 to 50 tests on the specific size and grade being furnished. If the MOE test of the strand being shipped is within 2.5 percent of the typical, it is within the accuracy that can be expected and is considered adequate. Tensioning to the typical curve eliminates the large differences that can come from testing a strand that happens to have a maximum MOE and then getting a strand with a minimum MOE at the job site.

ASTM A416 requires a minimum yield strength of 85 percent of the ultimate for stress-relieved and 90 percent of ultimate for low-relaxation strand. This is defined as the load at which the strand reaches 1.0 percent elongation and the straight line MOE *does not* extend to these values. The load-elongation curve furnished by the strand fabricator should be consulted for tensions within 10 percent of the specified yield strength.

The MOE of a strand is affected by the total area of the seven wires and, to a lesser degree, by the pitch or lay of the six outside wires.

ASTM A416 permits a pitch of anything from 12 to 16 diameters but requires that whatever pitch is used be constant for the full length of the strand. A strand with a long pitch has a larger MOE than a strand with a short pitch.

ASTM A416 gives a nominal area for each strand but permits a considerable tolerance with respect to actual area as long as the specified minimum ultimate load is met. Because of different rod properties and wire drawing procedures, there is a very appreciable difference between the actual area of the strand with the smallest area on the market in the United States and that of the strand with the largest area.

When wire is drawn for a prestressed concrete strand, the shop practice of the strand manufacturer will specify a diameter, but it must also permit some degree of tolerance. The wires of a ½-in. diameter strand have a diameter of about 0.167 in. The minimum reasonable tolerance is ±0.001 in. This variation in diameter of 0.001 in. represents a change in area, and MOE, of 1.2 percent.

The diameter of the hole in the last die of the wire drawing operation determines the diameter of the finished wire. Since the diameter of this hole increases with wear as wire is drawn through it, it is standard practice to start a new die with a hole slightly under size and continue to use the die until the hole is producing wire that meets the maximum permissible oversize tolerance. The result is a deliberately created variation in area, and MOE, of ±1.2 percent from the nominal.

It is essential that a standard procedure for computing MOE be established and adhered to. A complete series of tests on a strand includes measuring the diameter of each wire to be sure that the required difference between center and outside wires is met. Some laboratories compute the actual strand area from these diameters and use this area in conjunction with the load-elongation curve to compute MOE. Other laboratories use the nominal area from ASTM A416 in conjunction with the load-elongation curve to compute MOE.

In a number of instances, an excessive discrepancy between jack load reading and computed elongation has caused a work stoppage finally traced to an error in MOE. The laboratory reported a MOE which they computed using actual area. The field engineer, not knowing this, used the laboratory's MOE and the nominal area of the strand with a resultant error in computed elongation.

In order to eliminate the type of error illustrated in the previous paragraph, it is strongly recommended that the area used in its computation be given at the same time the MOE of a strand is given.

Although the MOE of most 7-wire stress-relieved and low-relaxation strands is a little above 28,500,000 psi, it is common practice for the design engineer to use 28,000,000 psi and the nominal area of the strand for structural design calculations. The 28,000,000 psi value should not be used when computing the elongation required to pull the strand to specified tension at the job site.

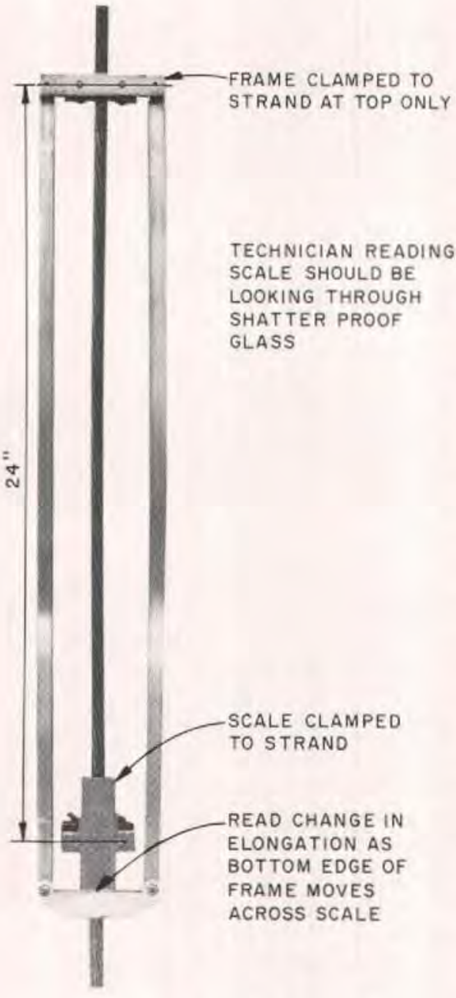


Fig. 8. Device for measuring total elongation in 24 in. at failure.

Testing Equipment and Procedure

ASTM E111 covers standard details of testing for Young's modulus or MOE. The chief difference between conducting a load-elongation or stress-strain test on a 7-wire strand and on a single wire or a steel bar is that of attaching the extensometer to the six outside wires of the strand so that it does not slip or rotate and so that any effect of bending as load is applied is cancelled out.

Experience has shown that the extensometers which are normally attached to wires or steel bars for making autographic curves, generally do not perform properly when attached to a 7-wire strand. One laboratory reports improved results when masking tape is placed on the strand at the points where the gage points contact the strand.

A procedure which gives excellent results using parts that can be fabricated by a good machine shop is the Double Dial method devised by Howard J.

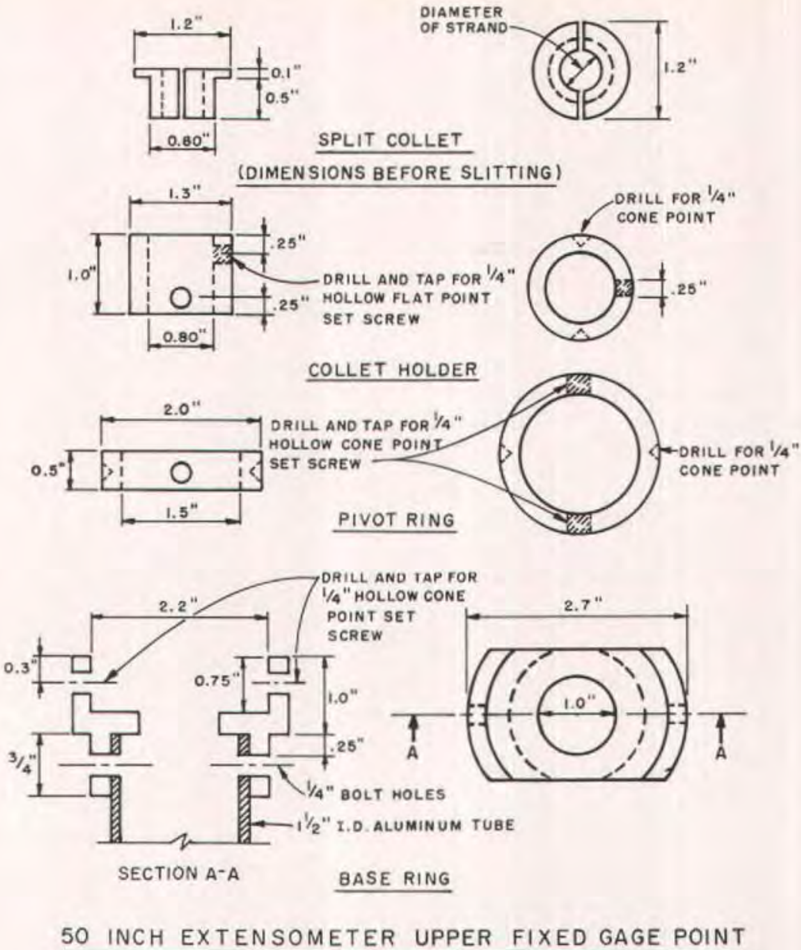


Fig. 9. Details of extensometer for Double Dial method of measuring elongation.

Godfrey who is now a consultant in Pennington, New Jersey. The following discussion and illustrations have been furnished by Mr. Godfrey.

THE 50-IN. EXTENSOMETER FOR PRESTRESSED CONCRETE STRAND

The 50-in. extensometer consists of an aluminum tube somewhat less than 50 in. in length. A flexible fitting is attached to the upper end of the tube so that the extensometer will hang vertically. The flexible fitting is fastened to the strand by split collets which have an internal diameter equal to the strand diameter.

The dimensions of the collets shown in Fig. 9 are those of the solid sleeve before slitting with a milling cutter. The cut allows the two halves of the split collet to be pressed against the strand by means of the ¼ in. hollow flat point setscrew which is held in a 1.3 in. outside diameter (OD) steel ring.

The 1.3 in. OD ring is pivoted inside a

2 in. OD steel ring by ¼ in. hollow cone point setscrews.

The 2.0 in. OD ring is pivoted in a 2.7 in. OD steel bracket which is attached to the top end of the aluminum tube. The pivot axis of the 2.0 in. OD ring is at 90 deg to the pivot axis of the 2.7 in. OD bracket. Only a limited amount of motion is required of the upper fitting because the extensometer is not attached to the strand until an initial load has been applied. However, the available movement allows the extensometer to adjust for any further straightening of the strand during testing.

The various parts of the upper flexible fitting are shown in Fig. 9 and a photograph of the assembled fitting is presented in Fig. 9a. The dimensions have been estimated and may be revised as required.

The parts for the lower gage point fitting are shown in Fig. 10 and consist of a 6 in. OD aluminum disc and two steel bars which are machined to hold the split collets. One of the steel bars is permanently fastened to the bottom of the aluminum disc and the second bar is attached to the permanent bar after the strand is under an initial load.

Fig. 9a. Top clamp for Double Dial method.

Before placing the strand in the testing machine grips, it is threaded through the aluminum tube and the top fitting without the collets in place. The top end of the strand is then fixed in the testing machine grips, after which the lower gage point fitting is threaded on to the strand. The bottom end of the strand is then placed in the testing machine grips and the initial load applied.

The split collets are then placed in the upper fitting and attached to the strand by means of the setscrew. The lower fitting is then attached to the strand by a second set of collets held in the two bar clamp under the aluminum disc. The 50-in. gage length is measured by a steel tape from the top edge of the upper collets to the top edge of the lower collets.

The dial gages reading to 0.001 in. should then be attached to the lower end of the aluminum tube by an adjustable aluminum clamp as shown in Fig. 11. The aluminum clamp should be so designed that the dial stems are equidistant from the centerline of the strand and are on the same axis through the center of the strand. Under these conditions any rotation of the aluminum disc or tube, or any change in the level of the disc during testing will not result in an incorrect measurement of the elongation.

In order to eliminate excessive lateral movement of the bottom end of the aluminum tube due to accidental contact, a slit cork stopper should be inserted into the lower end of the tube. Before slitting, a hole should be drilled on the vertical axis of the cork stopper slightly larger than the diameter of the strand. A view of the stopper in place is shown in Fig. 11. This guide system

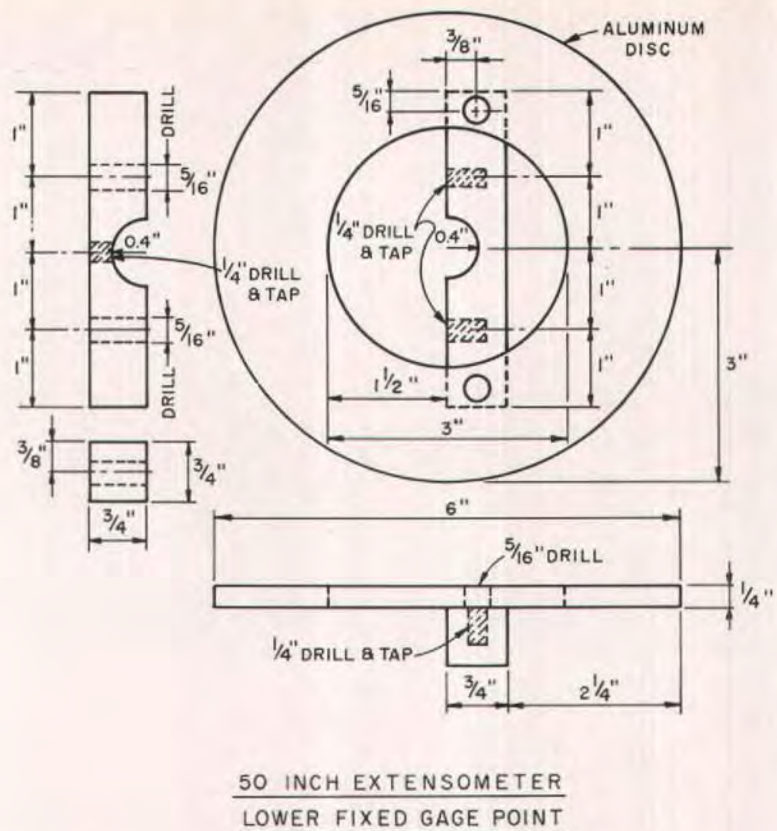


Fig. 10. Details of extensometer for Double Dial method of measuring elongation.

does not result in any friction between the strand and the stopper.

Either 1 in. or 2 in. travel dial gages may be used for measuring the elongation of the strand as the load is applied. The full range of 1 in. travel dial gages is equivalent to an elongation of 2.0 percent. In general, load-elongation tests are discontinued when the elongation has exceeded 1.0 percent which is the extension for determining the yield strength according to ASTM A421.

The 50-in. extensometer is not designed to be left on the strand when fracture takes place so it is necessary to remove the extensometer before testing the strand to failure. A view of the extensometer attached to a test specimen is presented in Fig. 12 and a typical load-elongation curve is shown in Fig. 13.

Curves produced by the Double Dial method and a testing machine with a load scale that permits the reading increments to be determined with accuracy have given very good results. If it is not possible to get a 50-in. gage length in a machine, the equipment can be designed for a shorter length but some accuracy will be sacrificed.

The Double Dial test is run at a constant speed. As each increment of load is reached the machine operator calls "Mark" and the two assistants reading the dials record the dial readings at that instant. At the conclusion of the test, a

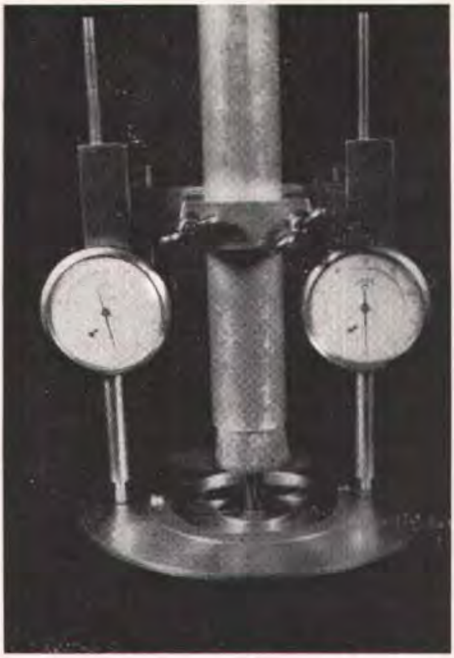


Fig. 11. Dial gages and base plate for Double Dial method.

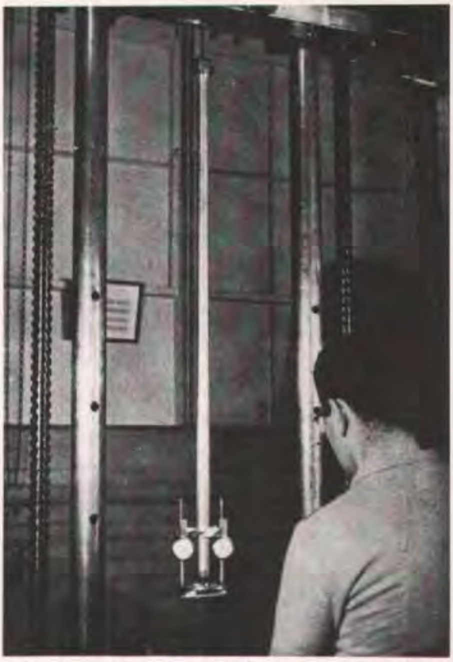


Fig. 12. 50-in. Double Dial extensometer in use.

curve is plotted using the load increments and the average of the two dial readings. Experience has shown that this method gives more consistent and accurate results than any other method that requires attaching the gage points to the strand.

Experience has shown that the extensometers which are normally attached to wires or steel bars for making autographic curves do not perform properly when attached to a 7-wire strand. After a considerable development effort Tinius Olsen Testing Machine Company, Inc., succeeded in developing and now markets an extensometer that can be attached to a strand to produce good and consistent autographic curves (see Figs. 14, 15, and 16). Fig. 17 shows a curve made with Olsen equipment.

The Wallace No-Contact Extensometer eliminates the problem of slippage of the contact points by using optical reading devices which do not touch the strand. There are several models from which to choose and they can be used on all types of specimens in addition to strand. Users report good results.

In the United States, Wallace Extensometers are available through:

Testing Machines Inc.
400 Bayview Avenue
Amityville, New York 11701
(516) 842-5400

In 1984, for an extensometer suitable for use with 7-wire strand, Testing Machines Inc. quoted a price of $16,565.00 plus freight and installation.

Since the test for yield strength begins with a 10 percent load on the strand, some laboratories begin their load-elongation curve at this point and then project it downward to zero load as a projection of the line from 10 percent upward. If the strand is overpreformed, the bottom part of the curve is not a straight line and this procedure fails to detect the condition. When load is first

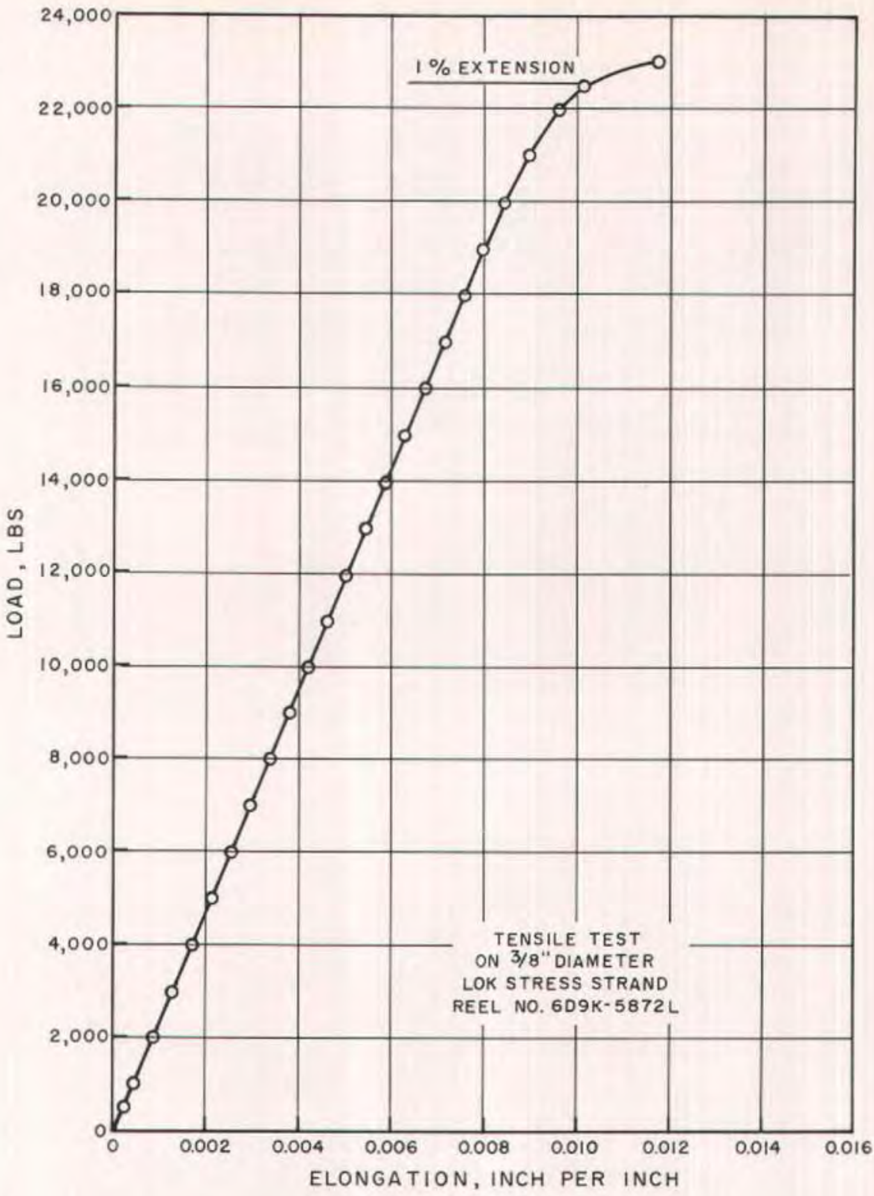


Fig. 13. Load-elongation curve plotted by Double Dial method.

applied to an overpreformed strand, a small increase in load causes a large increase in elongation creating a nearly flat line called a foot at the beginning of the curve. As the outer wires pull down against the center wire, the slope of the curve increases until the wires are all tight and the remaining curve is a straight line to the point where yielding begins.

In almost all tendon installations, both pretensioned and post-tensioned, each

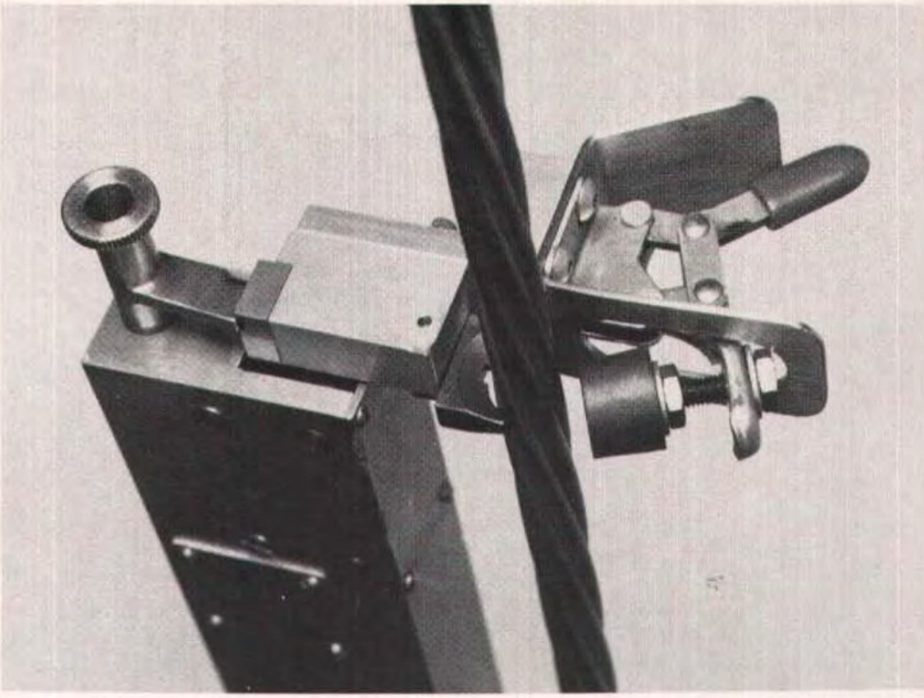


Fig. 14. Gage point on Tinius Olsen extensometer prior to clamping.

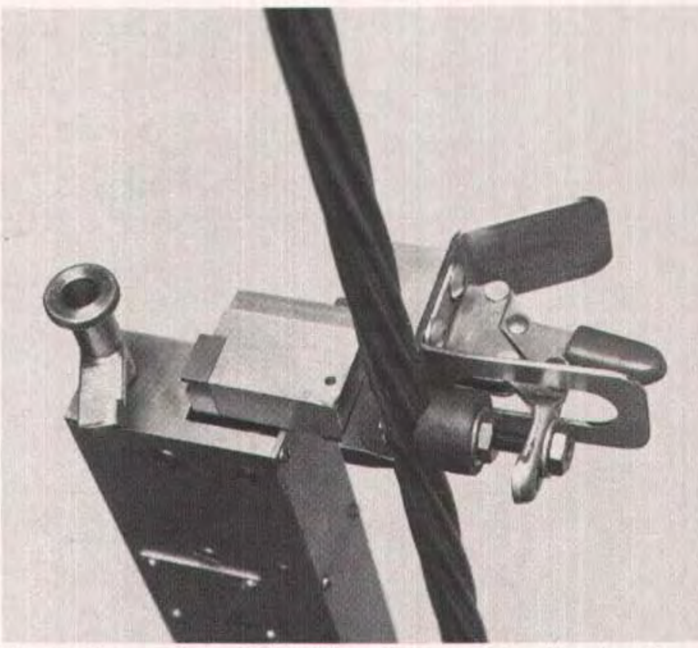


Fig. 15. Gage point on Tinius Olsen extensometer after clamping.

strand is pulled to a tension of 1000 lbs or more before elongation measurements are begun. Since this load will pull down all but very severely overpreformed outside wires, failure to detect the foot when plotting the load-elongation curve is not critical. It should be noted that the low-relaxation process eliminates both the overpreformed and underpreformed condition as a result of the permanent stretching of the wires.

Under "Specimen Preparation" ASTM A370 states "Wire slippage may be minimized by fusing together the cut ends of the specimen . . ." ASTM A416 requires the center wire to be larger than the outer wires by a specified amount. This difference is required to make sure each outer wire bears on the center wire and grips it as there is no other means of applying and keeping tension on the center wire during its service life as a tendon. If the wires are properly dimensioned and are not lubricated it should not be necessary to fuse the ends of the specimen.

If the center wire slips during testing of an unfused strand, the cause should be investigated. It could be oily wires, undersize center wire or over or underpreforming. The author does not approve of fusing the cut ends of the specimen. If one of the wires is in any way out of place at the time of fusing, the resultant load-elongation curve will be inaccurate.

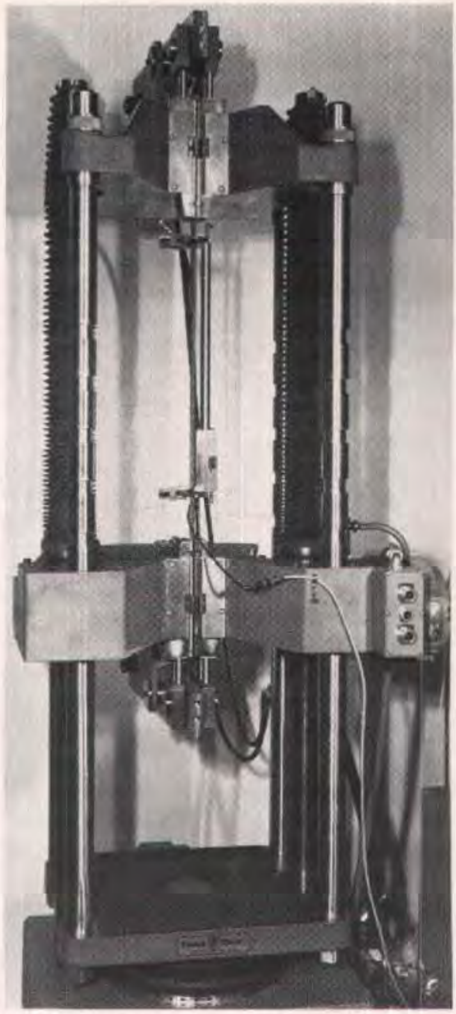


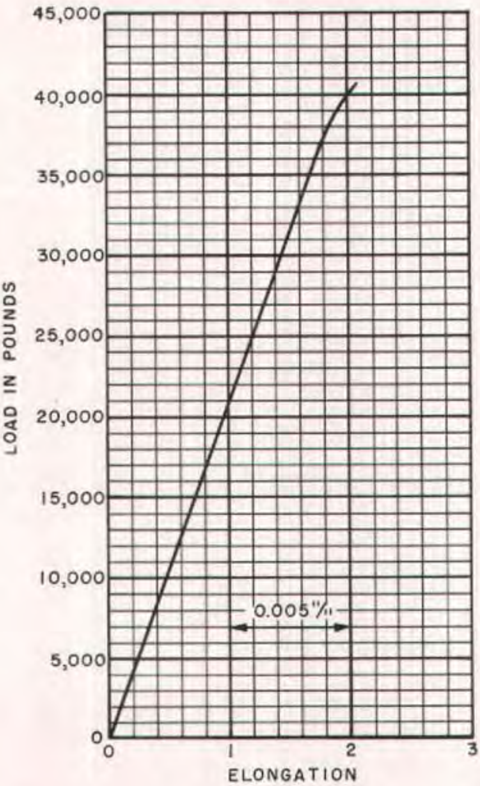
Fig. 16. Tinius Olsen testing machine with SLS grips and extensometer for strand in place.

SHORT-TERM RELAXATION TEST

The purpose of the 30-minute short-term relaxation test is to determine whether the sample of 7-wire strand being tested is of stress-relieved grade (SR) or low-relaxation grade (LR). It is not intended to provide data that could be used to project long-term losses under service life conditions.

Since the difference in relaxation losses between SR and LR strand, measured as a percent of initial tension, increases as the initial tension is increased, the short-term test is conducted at a high initial tension (80 percent of GUTS) to create as large a difference as possible during the short term of the test.

In the 1000 hour relaxation test required by ASTM A416, the specimen is loaded to a prescribed tension and then held at constant length for the duration of the test. Loss due to relaxation is the difference in load in the tendon between the start of the test and its conclusion. The degree of accuracy with which the constant length must be maintained and with which the small changes in a large tensile force must be measured require special equipment that is not available in otherwise fully equipped testing laboratories. For example, each of the relaxation units in the laboratory of one strand producer uses a double dial extensometer with a 192-in. gage length and dial gages that read to 0.001 in.



TEST NO. : 1234 DATE: 11-19-84
SIZE & GRADE: ½" DIA. LOW-RELAXATION
COIL NO: 54321

BREAKING LOAD IN POUNDS : 43,300
1.0 % EXTENSION IN POUNDS : 40,250
ULTIMATE ELONGATION IN 24": 4.17 %

ELONGATION IN 10 FEET
AT 30,970 POUNDS = 0.870"

ELONGATION IN INCHES PER
INCH AT 30,970 POUNDS = 0.00725

Fig. 17. Load-elongation curve made with Tinius Olsen extensometer.

Basic Principles of Short-Term Test

The purpose of this test is to determine within a reasonable degree of accuracy the loss due to relaxation of a strand loaded to a high tension for a short period of time.

It will be necessary to record with considerable accuracy the:

1. Change in tension in the specimen.
2. Change in length of the portion being measured by the extensometer.
3. Change in temperature.

Also, it will be necessary to adjust the results accordingly. Let the:

Effective change in load = P_E

Measured change in load = P_M

Change in load due to the measured change in length = P_L

The effective change in load is:

$$P_E = \pm P_M + P_L \quad (1)$$

and the percentage of loss, P, is:

$$P = (P_E/P_I)\,100 \quad (2)$$

where P_I = initial tension.

The change in load due to change in length resulting from slippage in the grips is:

$$P_L = (A\,E\,L_1)/L \quad (3)$$

in which

A = cross section area of strand (in.^{2})

E = modulus of elasticity of strand

L = gage length of extensometer

L_1 = change in extensometer reading

It is not feasible to adjust the reading for an appreciable change in air temperature because the effect on the strand

and other items of small mass will not be the same as the effect on the testing machine and other items of large mass. A maximum permissible temperature change, say ±3°F, should be established and maintained. The specimen being tested as well as the environment of the testing machine must be maintained within the limited temperature range for a considerable period of time prior to the start of the test as well as for the duration of the test.

Procedure for Short-Term Relaxation Test

1. Make sure that strand, testing machine, extensometer, etc., have been in the same constant temperature environment long enough for all parts of all items to reach the same temperature.

2. It is not permitted to perform plastic bending or straightening on the sample to be tested for relaxation behavior.

3. Place strand in testing machine and load to approximately 5 percent of specified minimum ultimate strength. Use gripping devices with an efficiency that will provide a comfortable factor of safety above the load to be applied and that will not allow the strand to slip during the period of the relaxation test. Slippage and/or seating of wedges during the application of P_I is not detrimental to the test.

4. Attach extensometer to strand using a long gage length, preferably 24 in. or more.

5. Load at a uniform rate to P_I. Loading time should take not less than 3 minutes and not more than 5 minutes and should be approximately the same for all tests.

6. Maintain the load at P_I for 1 minute. During this period make any desirable adjustments to extensometer equipment such as setting dial gages to zero, etc.

7. At end of 1 minute hold, read and record extensometer reading, load in strand and temperature.

8. Maintain length constant for 30 minutes.

9. At end of 30 minutes read and record extensometer reading, load in strand and temperature.

10. Compute percentage of loss using foregoing Eqs.(1), (2), and (3).

Notes on Short-Term Test

It must be remembered that the function of the 30-minute test is solely to determine whether or not the strand being tested is the low-relaxation grade. Test data used to make any sort of prediction with regard to long-term losses must be made in equipment capable of making the 1000-hour test and should be of at least 100 hours duration.

The P_I used in the short-term test should be 80 percent of the GUTS of the specimen being tested.

Since the change in load being recorded is a very small percentage of the total load in the strand, it is important that the machine being used be able to record small load increments with accuracy.

Maintaining a constant length for the 30-minute duration of the test is of extreme importance. This means preventing movement of the head of the testing machine. By the time the specimen has been loaded to P_I and held at that load for 1 minute, all seating of gripping wedges or slippage within the grips should have taken place.

The old style mechanical testing machine is best suited for this purpose; as long as the driving gears are not operated, the head remains motionless and the operator simply balances the beam to weigh the load as relaxation takes place. Depending on their design, hydraulic testing machines can hold a constant length with anything from a fair to a very poor degree of accuracy.

Theoretically the results obtained using Eqs. (1), (2), and (3) should be the same whether the value of P_L is relatively small and the value of P_M is relatively large or the reverse is true. The data from some tests suggest that the re-

Metric (SI) Conversion Factors

1 ft = 0.305 m
1 in. = 25.4 mm
1 in.^{2} = 645.2 mm^2
1 lb = 4.448 N
1 ksi = 6.895 MPa
1 psi = 0.006895 MPa
1°C = (5/9) (°F − 32)

sults are appreciably more accurate when P_L is small indicating a very small or zero change in length during the test.

Accuracy in measuring any change in length is imperative. The maximum allowable relaxation for the 30-minute period will be small; probably not more than 1.5 percent of initial tension. For an extensometer with a gage length of 24 in., an error of 0.003 in. in measurement of change in length represents ¼ of 1 percent of the initial tension or about 17 percent of the total allowable loss.

This could easily result in the rejection of a specimen that actually had acceptable properties. An accuracy of 0.005 percent in measuring length is recommended. Comments on the design and use of extensometers are presented under the heading of "Modulus of Elasticity."

If a mechanical machine is used and the gears are not engaged during the 30-minute test, there should be no motion of the head and an extensometer may not be needed.

When a testing machine is used that may have even the slightest adjustment of the head position during the test, the accuracy of the extensometer is critical and the 50-in. Double Dial system is recommended. Experience with other types, even those that give good results when plotting load-elongation curves, has not been satisfactory. This may be because of a slight hysteresis at the clamps when the direction of motion is reversed or just stopped. There is no hysteresis in the spring loaded dial gages of the Double Dial system.

Several factors must be considered in establishing the maximum allowable loss for the 30-minute test:

1. Temperature

The 1000-hour test specified by ASTM is conducted at a constant temperature of 68°F ± 3.5°F. Test data show that a low-relaxation strand will have more relaxation at 78°F than at 68°F.

2. Consistency of Test Results

(A) Although 1000-hour tests show reasonably good agreement at 1000 hours, the spread between different tests is greater for the points plotted early in the test.

(B) The load and length measuring devices being used for this test by a commercial laboratory may be less accurate than the equipment used by a strand producer for the 1000-hour test.

3. Relaxation Properties of Strand

(A) Tests run on 1000-hour equipment, at 68°F at a tension of 80 percent of minimum specified ultimate show a 30-minute relaxation of 0.50 percent for low-relaxation strand and 2.6 percent for stress-relieved strand. There was no tension on the stress-relieved strands during the stress-relieving process.

(B) Some strand fabricators make stress-relieved and low-relaxation strand on the same equipment. Thus, there may be some tension on the stress-relieved strand during the stress-relieving process. The resulting product may have relaxation properties better than those of stress-relieved but not as good as those of low-relaxation strand.

It is suggested that low-relaxation strand subjected to the foregoing 30-minute test be required to show a relaxation loss of not more than 1.20 percent of the initial tension with an adjustment for test temperatures over 72°F. If the initial 30-minute test exceeds 1.20 percent, two additional tests should be made of strand from the same pack and both tests must be equal to or less than 1.20 percent for acceptance.

It is further suggested that any laboratory planning to conduct 30-minute tests obtain a length of low-relaxation strand with known relaxation properties and conduct several trial runs to make sure that its equipment and procedure produce correct results.

DEFINITIONS

Wire — A wire of the type used in 7-wire strand is a single, round, high tensile strength, high carbon steel unit of considerable length.

7-Wire Strand — A 7-wire strand is composed of six wires wrapped helically around a center wire.

Cable — A cable is a tension carrying tendon composed of two or more parallel 7-wire strands (or wires) installed together and functioning as one unit.

Nominal Area — The nominal area of a strand as shown in ASTM A416 Table 1 is the theoretical cross-sectional area computed by dividing the minimum specified ultimate strength by the unit strength of the grade specified. Thus, the nominal area of a ½-in. diameter 270 Grade strand is 41,300/270,000 = 0.153 sq in. Since the diameter tolerances specified in Section 7.3 of ASTM A416 are the only items which limit actual area, the actual area of the strand supplied may differ appreciably from the nominal area.

Pitch or Lay — The pitch, specified in Section 3.1 of ASTM A416, is the distance along the strand in which an outside wire makes one complete turn around the center wire.

Underpreformed — During the standing operation the outside wires are preformed so they will fit snugly around the center wire. If the amount of preforming is insufficient they do not remain in place when the strand is cut. A strand that fails to meet the requirement of ASTM A416 Section 8.3 is underpreformed.

Overpreformed — If the outside wires are too heavily preformed they do not fly open when the strand is cut, but there is open space between some of the outside wires and the center wire. This causes an undesirable foot on the bottom of the load-elongation curve as discussed under "Modulus of Elasticity."

Stress-Relieved — When a 7-wire strand emerges from the stranding machine which twists the six outer wires around the center wire, all of the wires have high internal stresses as a result of the wire drawing and stranding process. This is called a "green" strand. The green strand is passed through a heating device which raises its temperature to about 725°F for a few seconds before it is water cooled. While it is at the elevated temperature its yield strength is appreciably reduced, the high internal stresses cause local yielding and the stress-relieved strand emerges with far less internal stress than was present in the green strand.

Low-Relaxation — Low-relaxation strand is made from the same green strand as stress-relieved and subjected to the same stress-relieving elevated temperature. While at the elevated temperature, it is tensioned to a high stress which causes a permanent elongation of approximately 1 percent. The resulting strand has very little remaining capacity for creep or relaxation. The 1.0 percent elongation also eliminates any overpreformed or underpreformed condition.

ACKNOWLEDGMENT

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