108

STATE OF CALIFORNIA
TRANSPORTATION AGENCY
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS

BRIDGE DEPARTMENT

FRICTION LOSS IN POST-TENSIONED PRESTRESSING STEEL UNITS

By:
T. J. Bezouska

66-36

DNB

In Cooperation with
The U. S. Department of Commerce,
Bureau of Public Roads

September 1966

SSR 3-66

ClibPDF - www.fastio.com

STATE OF CALIFORNIA
TRANSPORTATION AGENCY
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS
BRIDGE DEPARTMENT

FRICTION LOSS IN POST-TENSIONED PRESTRESSING STEEL UNITS

Report prepared in the Design Section of the
Bridge Department by Thomas J. Bezouska

951102
624132
HPR-1(4) D0403

J. E. McMahon, Assistant State Highway Engineer - Bridges

J. C. WOMACK, State Highway Engineer

In Cooperation with
U. S. Department of Commerce
Bureau of Public Roads

September, 1966
SSR 3-66

ClibPDF - www.fastio.com

SYNOPSIS

In 1963, ten instrumented prestressing tendons were placed in a 360 foot long highway structure in Los Angeles, California. During the tensioning of these tendons, strain readings were obtained to determine the amount and distribution of friction loss.

Three different post-tensioning systems were used employing both bright and galvanized tendons and ducts.

Water soluble oil was used as a lubricant on four of the tendons in order to determine its effectiveness in reducing friction.

Friction coefficients found in the 1961 AASHO specifications were found to be acceptable for long, continuous structures of this type.

ClibPDF - www.fastio.com

INTRODUCTION

General Remarks

In the construction of prestressed concrete members, it is necessary to determine the losses between the jacking end and the point at which a certain prestressing force is required. In a long span continuous highway structure these losses may be in the order of 50% of the applied force. Because of their magnitude, it is necessary to calculate them accurately so that sufficient prestressing steel may be provided. When the tendon profile is known, some of the major variables affecting losses are the coefficients of friction for wobble and curvature, and the presence of grout leaks in the ducts, or other mechanical damage.

Over the years, various friction coefficients have been suggested for use in prestressed concrete. The ones currently used are those proposed by the ACI-ASCE Joint Committee 323 in 1958 and now incorporated in the 1961 edition of the AASHO specifications. These coefficients, and the formula $f_j=f_o na+ke$ have proved satisfactory for use in the relatively short

ClibPDF - www.fastio.com

spans normally used.

While the State of California has had more than ten years experience with simple span prestressed structures, it has had little experience with long span continuous prestressed structures. It is recognized that the care and precision with which the tendons are draped in the forms has a major effect on the losses that will be encountered. However, because of the many reversing parabolic curves comprising the path of a tendon in a continuous structure, it was felt that the actual friction loss would be different than that indicated by currently used friction coefficients. Little information on field measured friction losses in long span continuous prestressed structures can be found in the technical literature.

A freeway interchange that was to be built in West Los Angeles in 1963 provided an ideal opportunity to increase our knowledge of the magnitude and distribution of friction losses in long prestressed structures. The structure selected for instrumentation was a three span continuous box girder on a horizontal curve. This structure was a ramp from a larger reinforced concrete freeway structure. Due to the required span lengths, the ramp was to be prestressed.

ClibPDF - www.fastio.com

Ten extra tendons were added to this three span unit for this research project.

Objective

The primary purpose of the research was to measure the distribution of friction losses in various types of prestressing tendons in a long structure built on a horizontal curve. It was planned to make the experimental tendons representative of those normally used in structures of this type, and to evaluate the problems inherent in each of the systems.

Testing the effectiveness of water soluble oils as lubricants and evaluating the difficulty of their application were secondary objectives.

Notation

Unless otherwise stated in the test, the notation used is that found in the 1961 edition of the specifications of the Association of American State Highway Officials.

EXPERIMENTAL PROGRAM

Description of Structure

The ramp upon which the research was performed

ClibPDF - www.fastio.com

comprises a portion of the Exposition Boulevard Overhead, Bridge Number 53-704 OL, in West Los Angeles. The experimental portion is a three span continuous (90 foot - 180 foot - 90 foot) prestressed concrete box girder superstructure, 34 feet wide and 6 feet deep. The centerline is on a 600 foot horizontal radius curve for three-quarters of its length with the other quarter on a 461 foot radius.

The north end of the ramp rests on elastomeric pads at Bent #14. Bent #15 is a 6 foot round reinforced concrete column offset 5'-9-3/4" from the centerline of the roadway. To resist sidesway, the Bent #15 cap is connected to an adjacent abutment of the principal structure some 60 feet away. Bent #16 is a similar 6 foot column placed under the structure centerline. Abutment #17 consists of an end diaphragm supported on a single row of 16" diameter concrete piles. The columns of Bents #15 and #16 are hinged at the top. All bent caps and the abutment are placed radially with respect to the centerline of roadway. All the bent footings are of reinforced concrete and are supported on concrete piles.

Sufficient prestressing force was provided

ClibPDF - www.fastio.com

to take care of the normal design moment stresses. Ten additional tendons were provided. These were instrumented with electrical resistance strain gauges at various points. Upon completion of the tests, these tendons were stressed, anchored, and grouted. The addition of these tendons reduced the maximum deflection by 3 inches. In order to obtain as many different types of tendons as possible, the research tendons were specified as follows:

Girder No.	Tendon Number	Tendon Type	Sheath
1	1	40 wire BBRV, galvanized	Bright, thin wall tubing**
1	2	12-1/2" strand, Freyssinet	Galvanized flexhose
2	3	40 wire BBRV, galvanized	Galvanized flexhose
2	4	12-1/2" strand, Freyssinet	Bright flexhose
3	5	A unit of the type used by the Contractor***	Bright flexhose
3	6	A unit of the type used by the Contractor***	Galvanized flexhose
4	7	40 wire BBRV, bright	Bright flexhose
4	8	1-11/16" preformed wire strand*	Galvanized flexhose
5	9	40 wire BBRV, bright	Galvanized thin wall tubing**
5	10	1-11/16" preformed wire strand*	Bright flexhose

ClibPDF - www.fastio.com

* Strand and fittings shall be equal in all respects to Roebling galvanized prestressed concrete strand.

** Seamless steel tubing with rigid, mortar tight joints.

*** The Contractor elected to use the large Freyssinet tendons consisting of 12 strands of 1/2" diameter having an area of 0.153 square inches apiece and an ultimate strength of 270,000 psi.

For details of the strain gages and their installation, see Material and Research Department report entitled "Instrumentation Installation for Exposition Boulevard Overhead".

The physical properties of the various tendons were as follows:

Tendons No. 1 and 3 - 40-1/4" galvanized wires

A_s=0.04909x40=1.9636 in.^{2}

f'_s=220 ksi

E_s=27.5x10^{3}ksi

Tendons No. 7 and 9 - 40-1/4" bright wires

A_s=0.0409x40=1.9636 in.^{2}

f'_s=250 ksi

E_s=28.6x10^3 ksi

ClibPDF - www.fastio.com

Tendons No. 2, 4, 5 and 6 - 12-1/2" strand Freyssinet

A_s=0.153x12=1.836 in.^{2}

f'_s=270 ksi

D_s=27x10^3 (for entire strand - used in elongation calculation)

E_s=29x10^3 (for individual wire - used to convert strain readings to stress)

Tendons No. 8 and 10 - 1-11/16" Roebling Strand

A_s=1.73 in.^{2}

f'_s=203 ksi

E_s=27x10^3 ksi (for entire strand)

E_s=28x10^3 ksi (for individual wire)

Test Procedure

In general, there were two types of tests. In the first type, jacks applied increments of load to both ends of a tendon simultaneously. Strain gages mounted on the wires were read at each increment of load.

In the second type, jacks were secured to both ends, but only one jack applied the load while the other measured the force reaching it from the jacking end.

ClibPDF - www.fastio.com

In both types of test, elongation, jack gages, load cells, and strain gages were read and recorded at each increment. Total loss from end to end of a tendon was measured by a load cell placed between the jacks and the tendon anchor plate. The distribution of this loss throughout the structure was measured by the mounted gages.

Tendons 5 and 6 were stressed from both ends and anchored on the first day of the tests. Strain gage readings were taken each morning and evening for the next eleven days.

After all tests were completed, the remaining eight tendons were stressed and anchored, and then all of the tendons were grouted.

After tendons Nos. 1, 7, 8 and 10 had been pulled at least three times they were lubricated with water soluble oil and tested at least twice more. It is interesting to note that a 55 gallon drum of oil was not enough to fill up one of these long ducts. Due to the fairly steep longitudinal grade of the bridge, the oil eventually ran through the ducts with the aid of gravity. It was not possible to pump the

ClibPDF - www.fastio.com

oil into the end of the duct under pressure because there was no feasible way of creating a tight seal. It would have been better to introduce the lubricant through the high point vents. Lubricating tendons is a messy business and should be avoided whenever possible. After testing the lubricated tendons, the oil was thoroughly flushed out with water before grouting.

EXPERIMENTAL RESULTS AND DISCUSSION

Freyssinet Tendons 5 and 6

The two Freyssi tendons in Girder No. 3 were stressed and anchored on the first day of the tests. Each morning and evening for the next eleven days all the active strain gages were read. See Table No. 1.

Although the exact stress at each of the gage points cannot be determined, the percent of stress loss for the eleven day period is believed to be reasonably accurate. In round numbers, the percent of stress loss at the middle of the end spans is about twice that at the center of the interior span. To put it another way, the point of greatest friction loss has

ClibPDF - www.fastio.com

the least stress loss due to creep and shrinkage.

There was no increment of stress loss in these two tendons that could be definitely attributed to the anchoring of the other eight research tendons.

It was very evident that the prestressing force varies as the structure expands and contracts due to daily temperature variations.

Other Freyssinet Tendons

Although strain gages were placed on wires of each of the four Freyssi tendons, it is not possible to convert the strain readings into actual stresses. Since the gages are mounted on helically wound wires, they are measuring an unknown component of the axially applied force.

Since Young's Modulus for the individual wires is about 29×10^3 ksi this value was used in calculating forces based on strain readings, although the apparent E_s for the seven wire strand is 27×10^3 ksi.

To obtain a more accurate measure of the stress in a helical strand it is necessary to calibrate

ClibPDF - www.fastio.com

the gage after it is mounted on the strand. This, of course, is virtually impossible to do on strands that are 360 feet long.

The Freyssi tendons were stressed with a jack having a 20 inch stroke. This allowed the total elongation to be applied without taking a second bite on the tendon. Elongations measured on the Freyssi tendons do not contain the accidental errors found in the other elongation measurements.

BBRV Tendons

These were of two types - galvanized and bright wires. At each of the gaging stations, strain gages were mounted on two different wires. Where both gages were operative, average values of the two strain readings were used in plotting the results.

At each end of a tendon, a 200 center hole jack with a 12 inch stroke was used. When the full travel of the jack has been reached, it was necessary to anchor off, retract the jack, and then resume pulling. During the anchoring off and regripping process, an error is introduced into the elongation measurement. The magnitude of this error is not known, but it may

ClibPDF - www.fastio.com

be in the order of 1/4 inch. Without specially built jacks, it is virtually impossible to obtain precise elongation measurements when stressing very long tendons. However, from a practical viewpoint, an accuracy of ± 1/4" in 12" is perfectly acceptable.

Roebling Tendons

The two Roebling Tendons showed the greatest loss of stress of all the tendons tested. This is thought to be the result of excessive grout leaks into the ducts, as well as local crushing of the ducts or of the stovepipe sections.

In all of the tests on the Roebling Tendons, it was noticed that the stress at any point appeared to increase with time during stressing. This may be because the relatively solid cable could only slide through constrictions in the duct with great difficulty - sliding on the zinc - whereas the other types of tendons could deform to fit the shape of the deformed duct. The Roebling Tendons were completely unaffected by the water soluble oil - there was no reduction in stress loss whatever.

ClibPDF - www.fastio.com

As in the case of the Freyssi strands, the strain gages on the wires do not measure the entire force, but only some component of it. The strain gage readings are useful only as an indication of the relative magnitude of the force distribution.

The same jacks were used to stress the Roebling Tendons as were used for the BBRV. The accuracy of the elongation measurements was affected by the same factors in both cases.

Thin Wall Tubing

The two tendons encased in thin wall tubing gave encouraging results.

Tendon No. 1, a galvanized BBRV tendon in bright thin wall tubing showed the smallest friction loss of all. When pulled from Abutment 17, the force remaining at Bent 14 was 78.8% as compared to a calculated value of 39.5%. When pulled from Bent 14, the remainder at Abutment 17 was 54.0%. After lubrication, these remainders were 86.2% and 55.6%, respectively.

Tendon No. 9, a bright BBRV in galvanized thin wall tubing, showed remainders of 29.5% and 50.0% as compared to a theoretical value of 41.4%.

ClibPDF - www.fastio.com

Comparison of the Three Systems

The Freyssinet Tendons were by far the easiest to stress and anchor. The jack is designed for the sole purpose of tensioning and anchoring this type of tendon. Since there is no prefabricated anchorage device attached to the ends of the tendon, there is unlimited length tolerance.

Because of the wedge type anchorage, there is a seating loss of about 3/4". This loss was quite consistent, and no further slip was observed at any time. In a long structure, this seating loss is dissipated by reversing friction before it reaches the point of maximum moment, and therefore, does not influence the designed prestressing force.

The BBRV Tendons showed no seating loss at all. The type used on this project was difficult to anchor because no provision has been made to center the anchor head in the pipe sleeve trumpet. During tensioning, the head would rub against the sleeve and burr the threads that engage the anchor nut. In addition, the jacks employed did not have sufficient stroke to obtain the required elongation in one pull.

ClibPDF - www.fastio.com

The tendons had to be stressed, anchored, and then restressed.

The plant-assembled end anchorages give the tendon a fixed length which reduces field length tolerances to a minimum. A too-long tendon requires shims under the anchor nut, and a too-short tendon requires a special "extender". Both of these expedients increase the cost of the system, although they do not impair its usefulness.

A few minor improvements in the details of the anchorage hardware, and a better engineered jacking assembly, would make this system equal to the Freyssinet in ease of stressing.

The Roebling tendons used a threaded stud two feet long that screwed into the center hole of the zinced-on end fitting. This stud was anchored with a nut after the tendon was stressed. The stud provided ample length tolerance and proved easy to use.

The excessive friction encountered could have been avoided by the use of a more rigid duct and is probably not indigenous to the system.

This type of tendon is more expensive than

ClibPDF - www.fastio.com

most others, but should be satisfactory when properly protected from grout leaks and crushed ducts.

CONCLUSIONS

1. The friction coefficients found in the 1961 edition of the AASHO specifications are applicable to this type of structure, with the possible exception of those for the case of galvanized steel in galvanized ducts; namely K=0.0010 and u=0.20, which are too optimistic.

2. In calculating the working stress in a tendon, AASHO recommends assuming a 25,000 psi loss between the initial and working stress. This value appears to be excessive where large friction losses have caused the initial stress to be significantly lower than 0.7f's.

3. It was quite apparent from the results obtained that there are many factors which exert a powerful influence on the distribution of the jacking force throughout the length of the tendon. When the tendon is carefully placed in the prescribed alignment, and when physical damage to the ducts is kept to a minimum, or eliminated, the measured friction losses can be considerably less than expected. For example,

ClibPDF - www.fastio.com

Tendon No. 7BBB showed a remainder of 44.5% at Abutment 17 and 68.3% at Bent 14 as compared with a calculated remainder of 31.3%. After overnight lubrication, these remainders increased to 59.3% and 84.8% respectively.

4. The over-all experience with the mounted strain gages was not very satisfactory. It is very difficult to mount the gages on the wires so that they can survive a strain of more than 5000 micro-inches. In an actual construction project such as this, it is virtually impossible to protect the instrumentation from the normal construction hazards. Ironworkers and laborers cannot be expected to exercise extreme care at all times, and one moment's carelessness can wipe out a gage installation.

Strain gages on 7 wire or Roebling strand do not measure the entire axially applied force. The difference between the measured strain and the total longitudinal strain is believed to be small because of the small size of the gages.

Although the force distribution, as indicated by the mounted gages, is not completely accurate, it does provide a useful measure of the friction losses at least as to order of magnitude.

ClibPDF - www.fastio.com

5. The use of load cells at both ends of a tendon permits the accurate measurement of the total friction loss. These load cells also provide an accurate calibration of the combined jack and pressure gage system under the actual conditions of use.

6. For both the BBRV and the Freyssinet tendons, lubrication appears to reduce the friction loss. It was not effective in the case of the two Roebling tendons. Although an effort was made to flush out the oil with water prior to grouting, it is believed that all was not removed. The bond value of the grouted, lubricated tendons is doubtful, and for this reason lubricating should be avoided as much as possible.

ClibPDF - www.fastio.com

RECOMMENDATIONS

1. Use k=0.0015 and u=0.25 for the combination of a galvanized tendon in a galvanized duct.

2. Do not attempt to use field mounted strain gages on prestressing tendons, except in special cases when they can be calibrated in place. Load cells at both ends of a tendon provide the surest way of measuring friction loss.

3. Verify the calibration of jacks and gages with load cells at the start of stressing, and whenever erratic results seem to indicate that something is wrong.

4. Avoid grout leaks caused by physical damage to the conduit since they have the greatest effect on the friction loss encountered in any tendon. The importance of careful placing and protection of conduits from damage cannot be overemphasized.

5. Develop a sturdier, less flexible type of conduit. This would greatly simplify future prestressed concrete construction because normal construction practices would cause less damage, and,

ClibPDF - www.fastio.com

therefore, fewer stressing and grouting problems.

6. Further tests should be performed with various types of thin-wall tubing. It is difficult to handle, and may be expensive, but the results with Tendon No. 1 were very good.

Acknowledgements

This investigation was made under the sponsorship of the Bureau of Public Roads.

The opinions, findings, and conclusions expressed in this publication are those of the author and not necessarily those of the Bureau of Public Roads.

The structure used in the investigation was designed by the Bridge Department of the California Division of Highways under the direction of J. E. McMahon.

All instrumentation was performed by personnel of the Materials and Research Department of the California Division of Highways under the direction of John L. Beaton.

ClibPDF - www.fastio.com

T E N D O N # 5

Date	BENT 15 Strain	BENT 15 Total Change	BENT 15 % Change	℄ SPAN 15 Strain	℄ SPAN 15 Total Change	℄ SPAN 15 % Change	BENT 16 Strain	BENT 16 Total Change	BENT 16 % Change
July 22	4280			4060			4105		
23	4245	-35	-0.9	4190	+130	+3.5	4060	-45	-1.2
24	4265	-15	-0.4	4100	+40	+1.0	4230	+125	+3.4
25	4270	-10	-0.3	4075	+15	+0.4	4130	_25	-0.7
26	4250	-30	-0.8	4085	+25	+0.6	4100	-5	-0.1
29	4220	-60	-1.6	4125	+65	_1.8	4010	-95	-2.6
30	4215	-65	-1.6	4020	-40	-1.1	3990	-115	-3.1
31	4270	-10	-0.2	4095	+35	+0.9	4020	-85	+2.3
Aug. 1	4200	-80	-2.1	3975	-85	-2.3	3985	-120	-3.2
2	4205	-75	-2.0	4015	-45	-1.3	3980	-125	-3.4

TIME DEPENDENT STRESS LOSS

ClibPDF - www.fastio.com

T E N D O N # 6

Date	BENT 15 Strain	BENT 15 Total Change	BENT 15 % Change	℄ SPAN 15 Strain	℄ SPAN 15 Total Change	℄ SPAN 15 % Change	BENT 16 Strain	BENT 16 Total Change	BENT 16 % Change
July 22	4730			4020			5450		
23	4675	-55	-1.5	4075	+55	+1.5	5285	-165	4.4
24	4685	-45	-1.2	4005	-15	-0.4	5315	-135	3.7
25	4525	-205	-5.6	4015	-5		5330	-120	3.2
26	4640	-90	-2.4	4010	-10	-0.3	5330	-120	3.3
29	4595	-135	-3.6	4035	+15	+0.4	5240	-210	5.7
30	4585	-145	-4.0	3940	-80	-2.2	5210	-240	6.5
31	4620	-110	-3.0	3980	-40	-1.0	5295	-155	4.2
Aug. 1	4545	-185	-5.0	3895	-125	-3.4	5275	-175	4.7
2	4545	-185	-5.0	3905	-115	-3.1	5255	-195	5.3

TIME DEPENDENT STRESS LOSS

ClibPDF - www.fastio.com

T E N D O N # 5

Date	AT BENT 15 AM	AT BENT 15 PM	AT SPAN 15 AM	AT SPAN 15 PM	AT BENT 16 AM	AT BENT 16 PM
July 22		4280		4060		4105
23	4085	4245	4015	4190	3950	4060
24	4085	4265	3990	4100	3895	4230
25	4065	4270	3980	4080	3920	4130
26	4070	4250	4025	4085	3940	4100
29	4080	4220	4045	4130	3890	4010
30	4060	4220	3975	4020	3910	3990
31	4040	4270	3915	4100	3885	4020
Aug. 1	4040	4200	3940	3975	3860	3985
2	4055	4205	3890	4015	3875	3980

STRAIN READINGS (in microinches)

AT VARIOUS TIMES

ClibPDF - www.fastio.com

PERCENT OF APPLIED LOAD

TENDON No.	TRIAL No.	TYPE	BENT 14	BENT 15	℄ SPAN 15	BENT 16	ABUT 17	COMMENTS
1	14	BGBTW	100	72.9		62.8	53.6	
1	28	BGBTW	"	65.4			46.5	Lubricated
1	29	BGBTW	"				55.6	Lubricated
2	6	FBG	"	61.0		48.6	39.7	
3	11	BGG	"	60.0	53.9	45.4	34.0	
3	12	BGG	"	60.2	53.8	44.9	33.9	
7	18	BBB	"	73.3	67.2	57.2	44.6	
7	30A	BBB	"	80.3	72.4	67.7	51.5	Lubricated
8	27	RGG	"	51.0		34.8	30.9	
8	32A	RGG	"	46.8		28.3	25.2	Lubricated
9	21	BBGTW	"	65.4		46.7	29.8	
10	24	RGB	"	59.6		46.7	29.8	
10	31	RGB	"	55.0		32.1	18.7	Lubricated

FORCE DISTRIBUTION

Pull From Bent 14

ClibPDF - www.fastio.com

PERCENT OF APPLIED LOAD

TENDON No.	TRIAL No.	TYPE	BENT 14	BENT 15	℄ SPAN 15	BENT 16	ABUT 17	COMMENTS
1	15	BGBTW	83.3	82.0		98.8	100	
1	28A	BGBTW	86.3	86.3			"	Lubricated
2	7	FBG	37.8	52.3		75.6	"	
3	10	BGG	50.4	56.5	69.0	74.8	"	
7	17	BBB	68.7	72.4	76.2	86.8	"	
7	30	BBB	85.0	85.4	85 4	90.0	"	Lubricated
8	26	RGG	34.6	37.5	46.6	54.6	"	
8	32	RGG	31.1	35.6	46.7	55.2	"	Lubricated
9	20	BBGTW	50.6	62.6		76.9	"	
10	23	RGB	30.4	34.2		99.3	"	
10	31A	RGB	27.3	29.5		62.9	"	Lubricated

FORCE DISTRIBUTION

Pull From Abut 17

ClibPDF - www.fastio.com

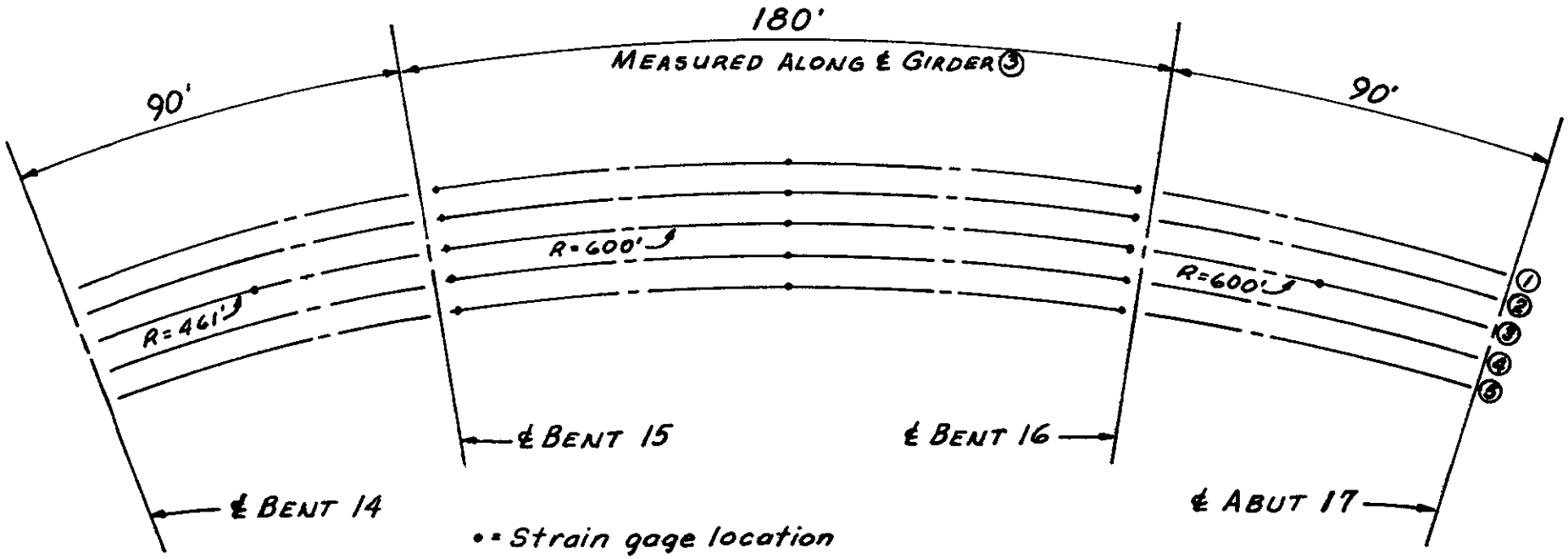
PERCENT OF APPLIED LOAD

TENDON No.	TRIAL No.	TYPE	BENT 14	BENT 15	℄ SPAN 15	℄ SPAN 15	BENT 16	ABUT 17	COMMENTS
1	13	BGBTW	100	74.1			89.2	100	
1	33	RGBTW	"	72.5				"	Lubricated
2	5	FBG	"	64.0			73.9	"	
2	8	FBG	"	62.3			74.9	"	
3	9	BGG	"	63.0	59.0	72.0	78.6	"	
4	3	FBB	"	56.4	50.5	51.6	73.3	"	
4	4	FBB	"	57.1	52.0	50.0	73.0	"	
4	4A	FBB	"	59.4	50.5	50.9	71.3	"	
5	1	FBB	"	70.2	59.1	57.6	57.9	"	
6	2	FBG	"	71.3	62.3	57.9		"	
7	16	BBB	"	73.2	77.6	78.9	90.3	"	
7	34	BBB	"	78.1			71.0	"	Lubricated
8	25	RGG	"	56.1	57.7	57.3	59.5	"	
8	32A	RGG	"	91.7		53.9	51.6	"	
9	19	BBGTW	"	68.4	69.0	77.0	83.0	"	
10	22	RGB	"	56.8	44.6	44.6	70.9	"	
10	31B	RGB	"	55.4			64.9	"	Lubricated

FORCE DISTRIBUTION

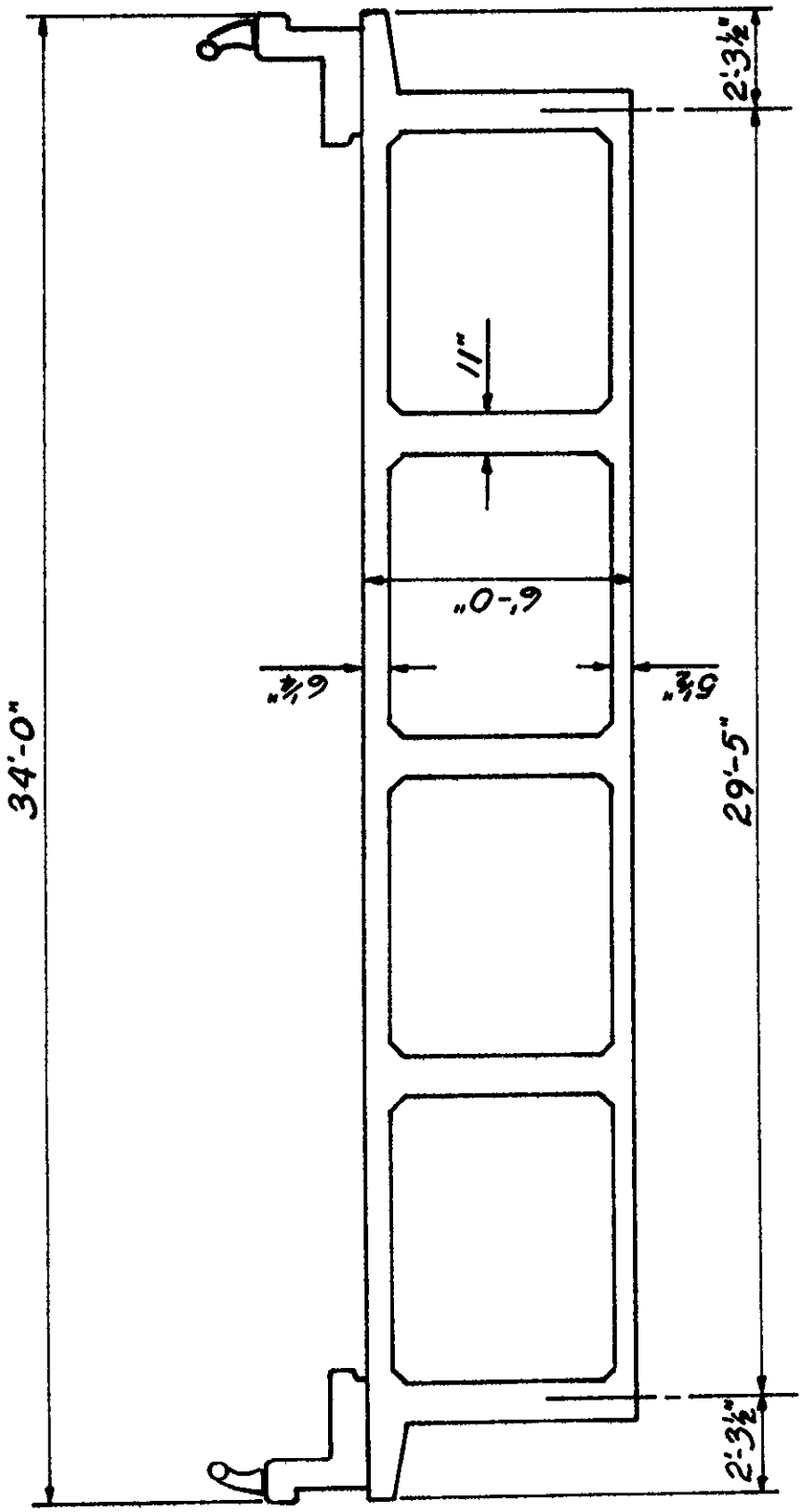
Pull From Both Ends

ClibPDF - www.fastio.com



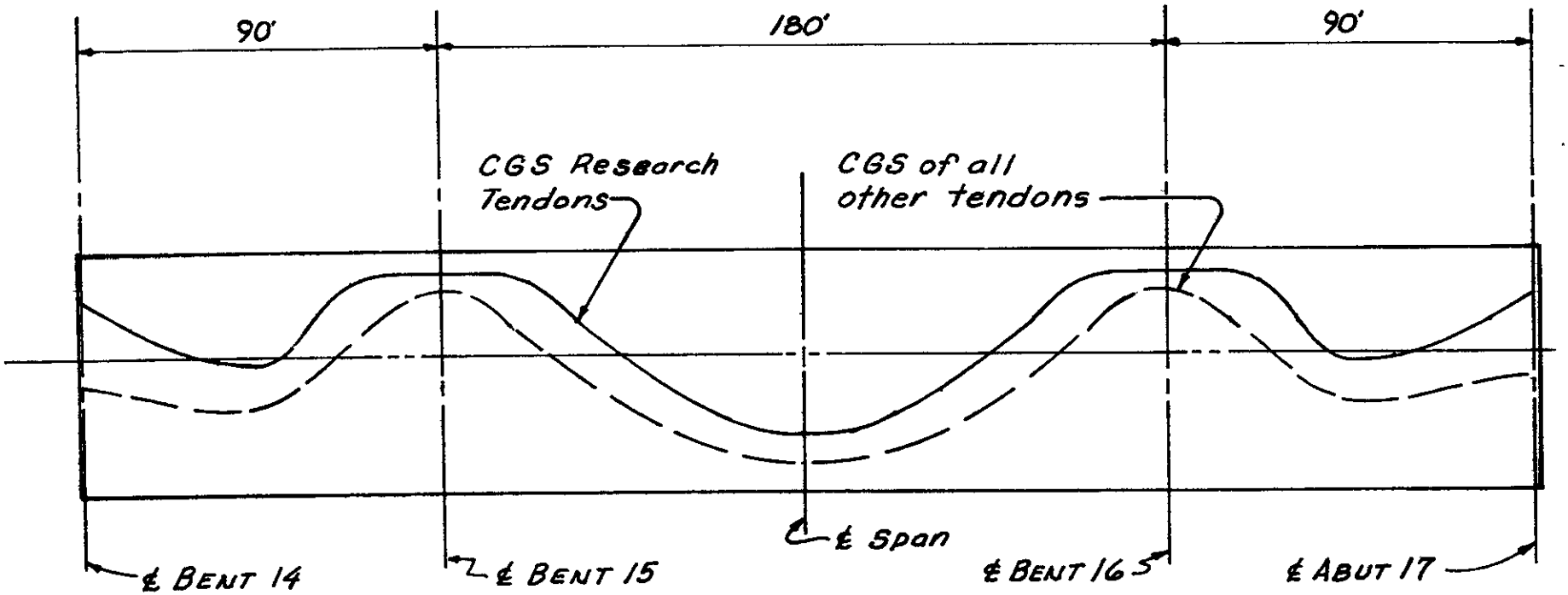
SCHEMATIC PLAN VIEW

ClibPDF - www.fastio.com



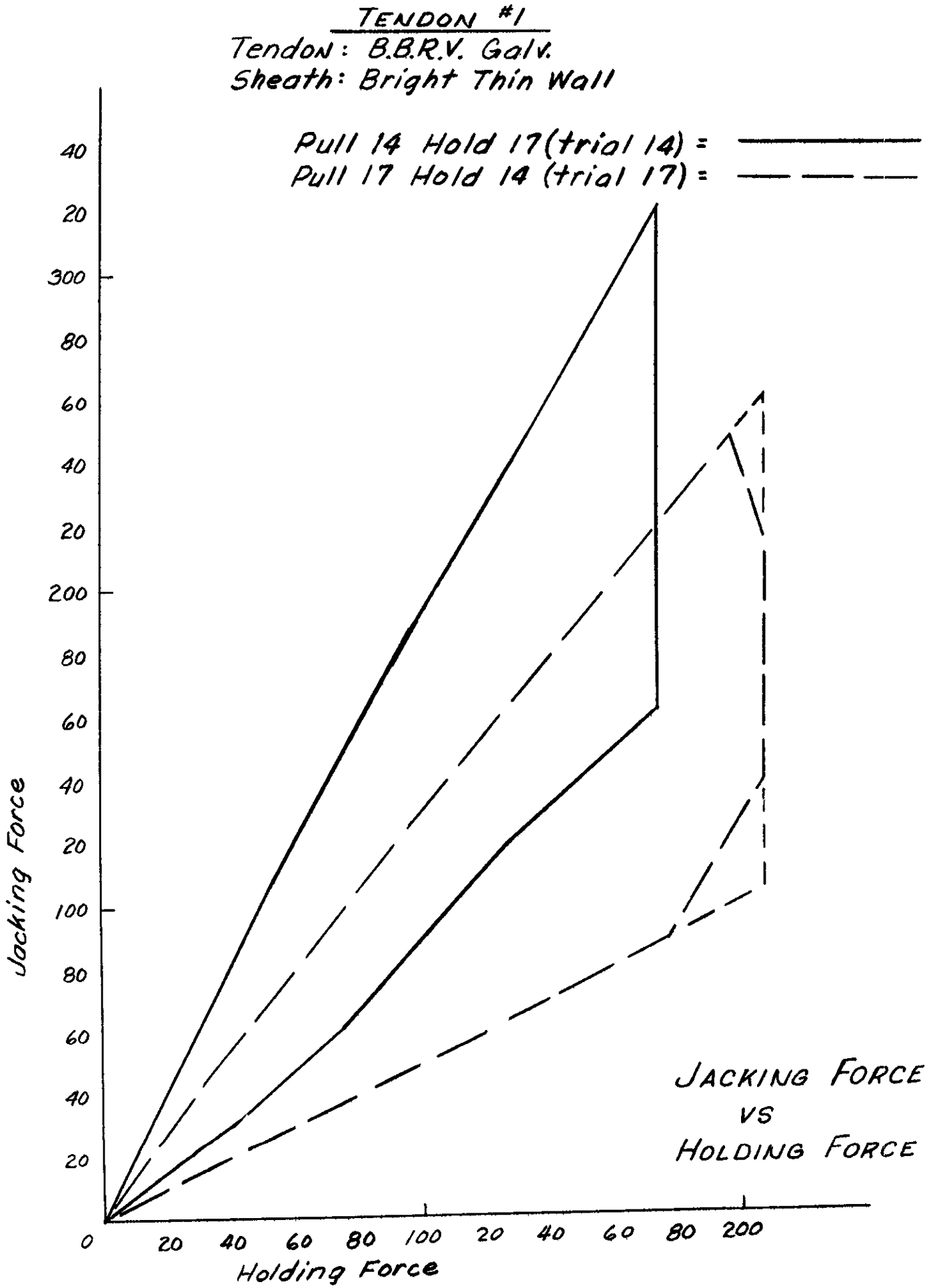
TYPICAL SECTION

ClibPDF - www.fastio.com



SCHEMATIC DIAGRAM OF TENDONS

ClibPDF - www.fastio.com

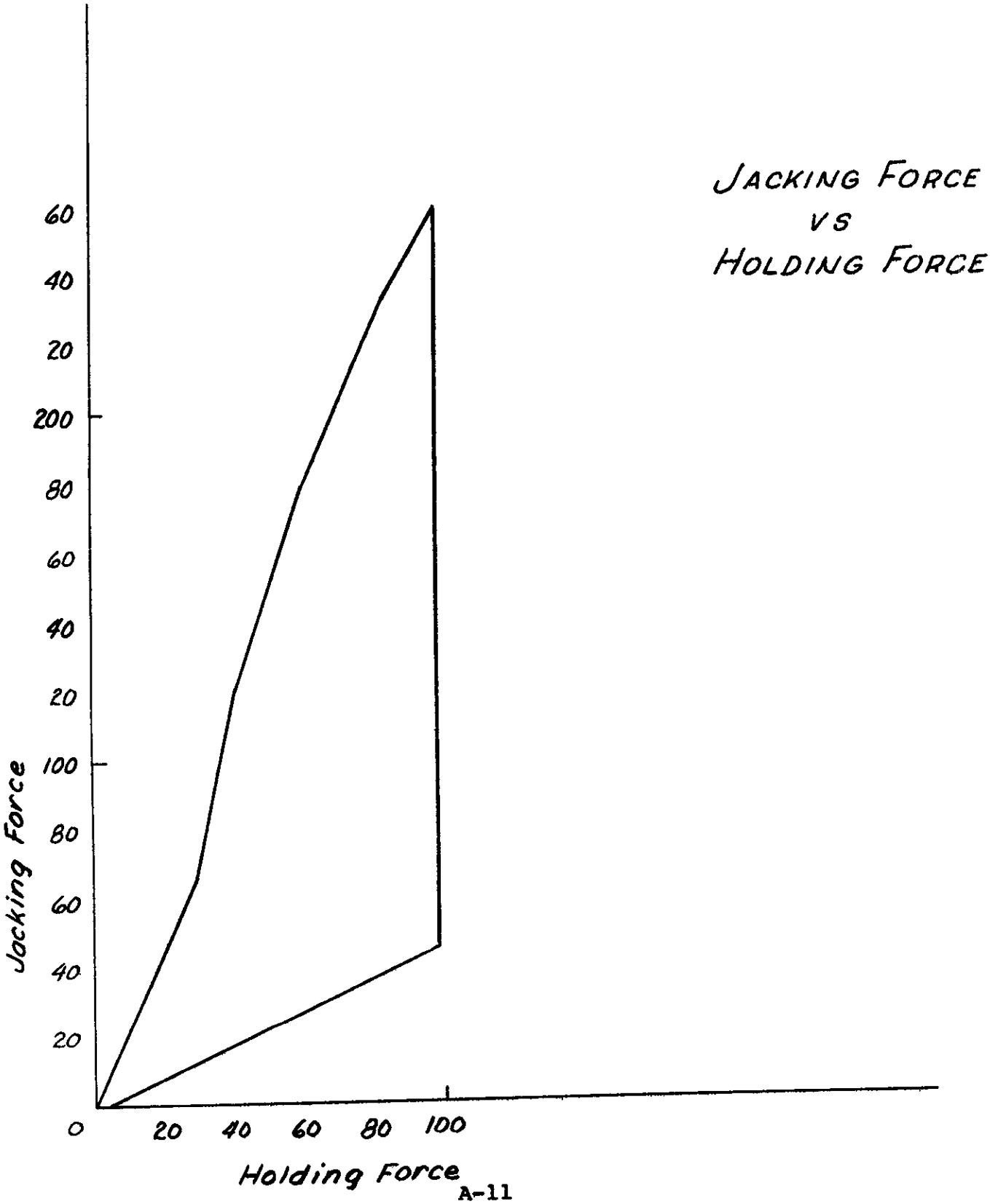


ClibPDF - www.fastio.com

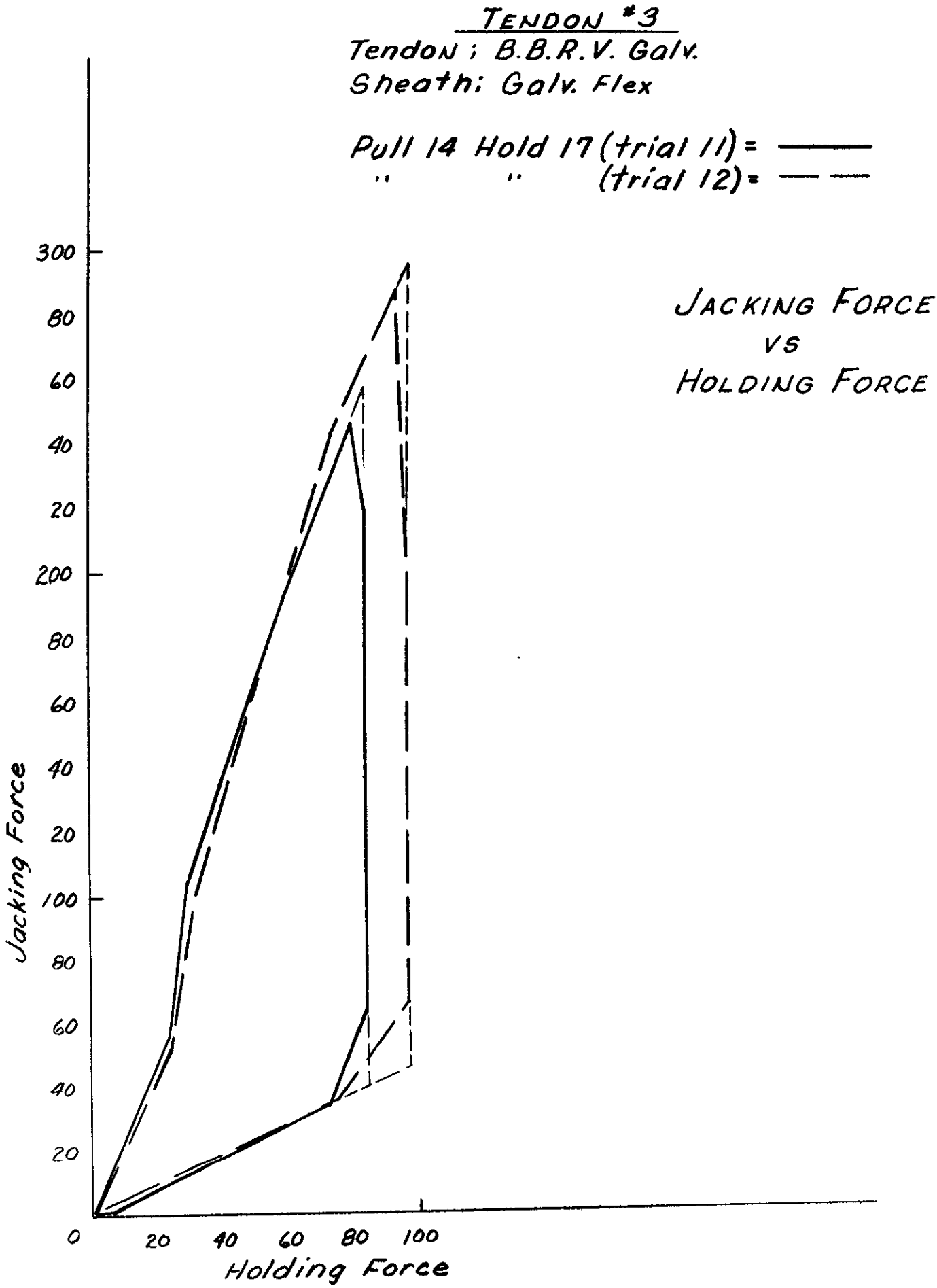
TENDON #2

Tendon: Freyssinet
Sheath; Galv. Flex

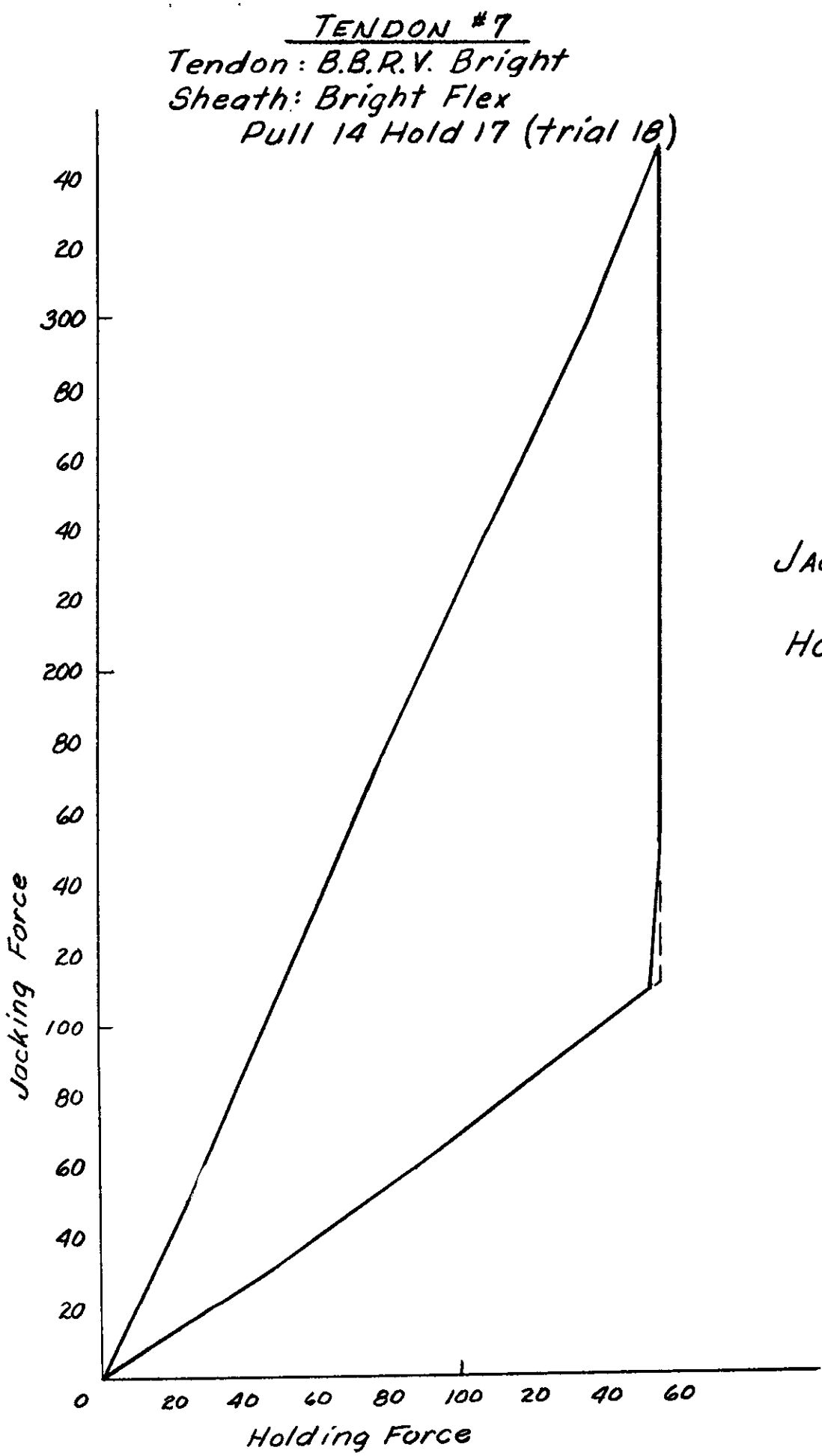
Pull 17 Hold 14 (trial 7)



ClibPDF - www.fastio.com



ClibPDF - www.fastio.com



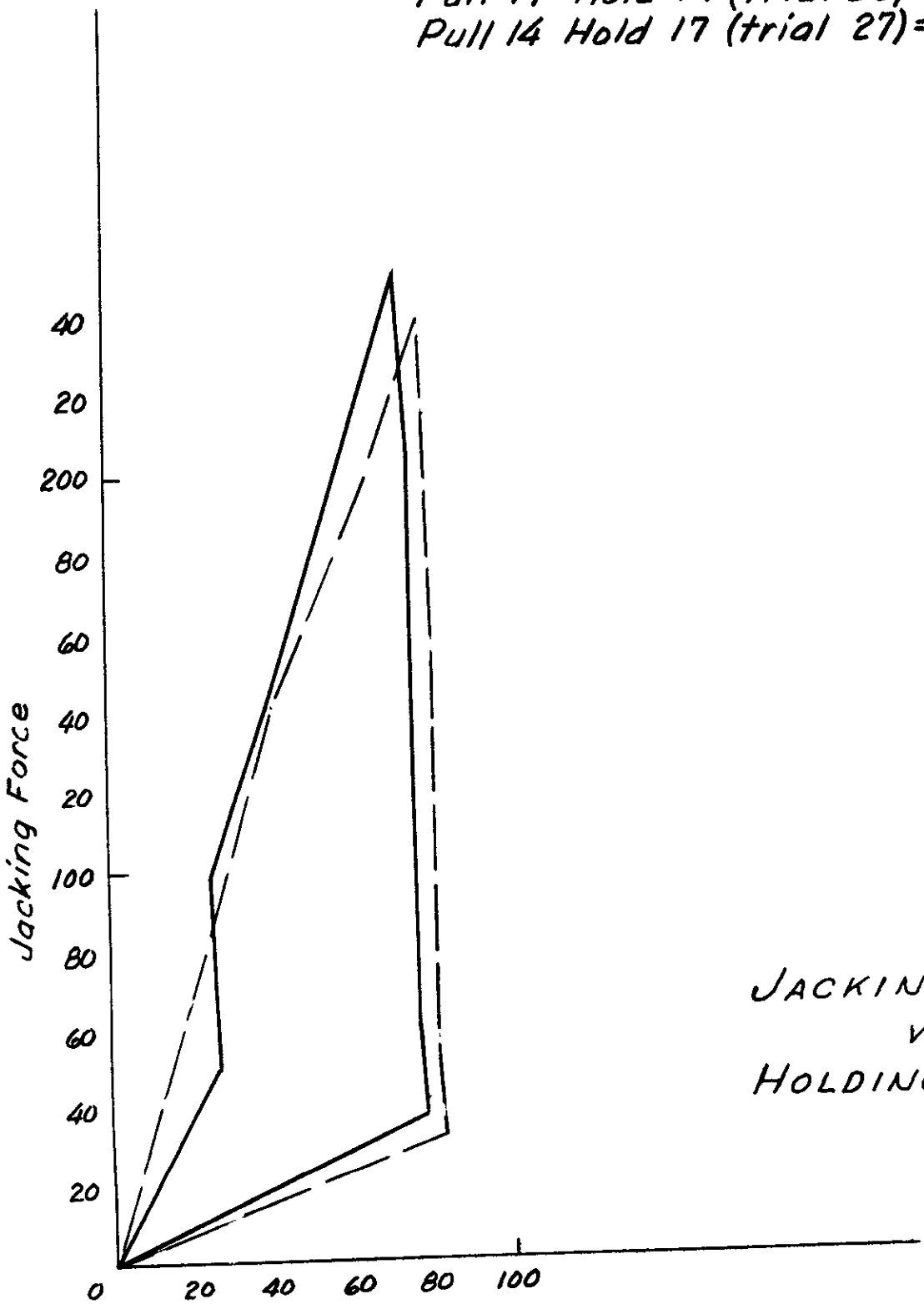
JACKING FORCE
VS
HOLDING FORCE

ClibPDF - www.fastio.com

TENDON #8

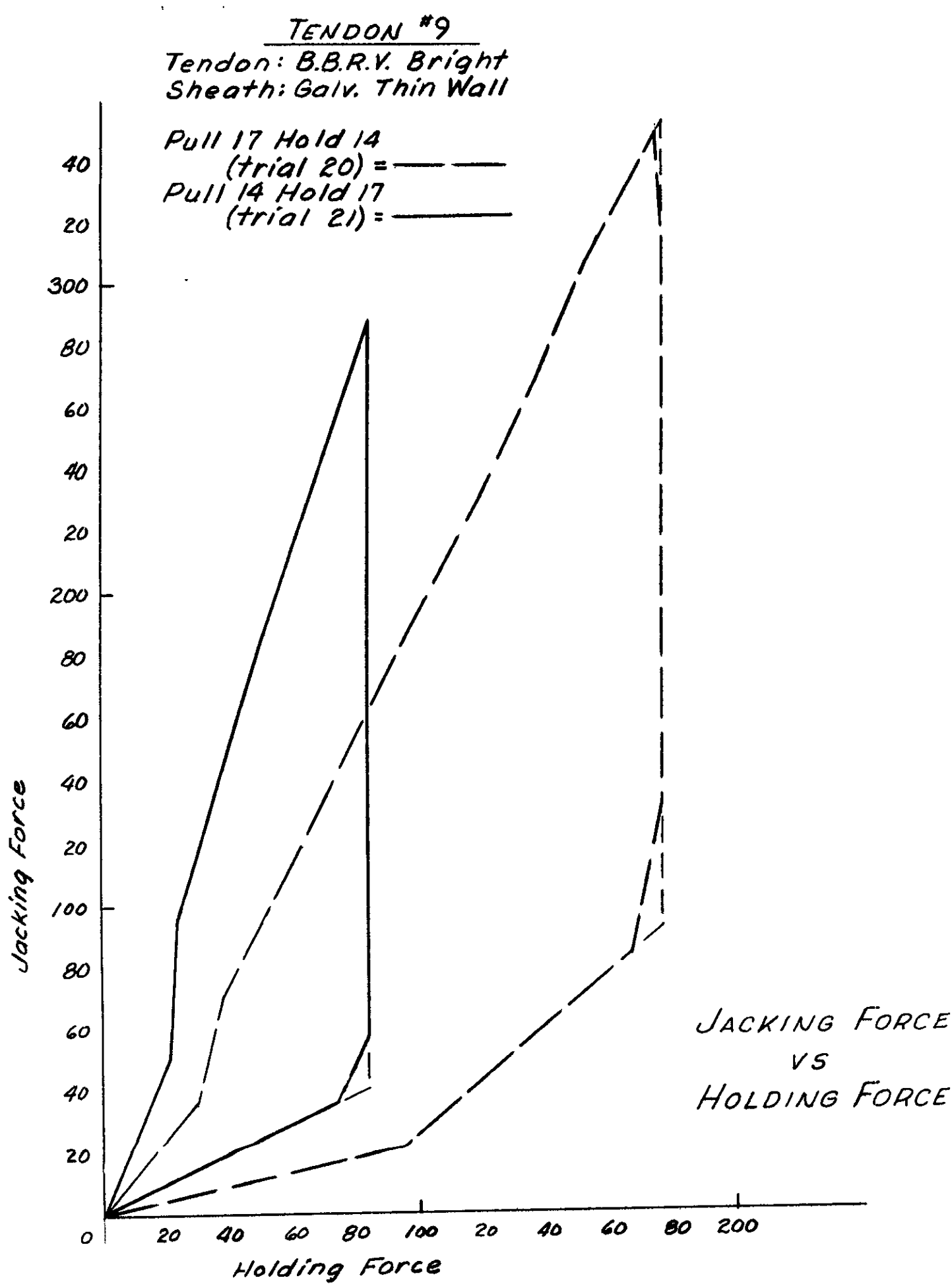
Tendon : Roebling
Sheath : Galv. Flex

Pull 17 Hold 14 (trial 26) = — — —
Pull 14 Hold 17 (trial 27) = ———



JACKING FORCE
VS
HOLDING FORCE

ClibPDF - www.fastio.com

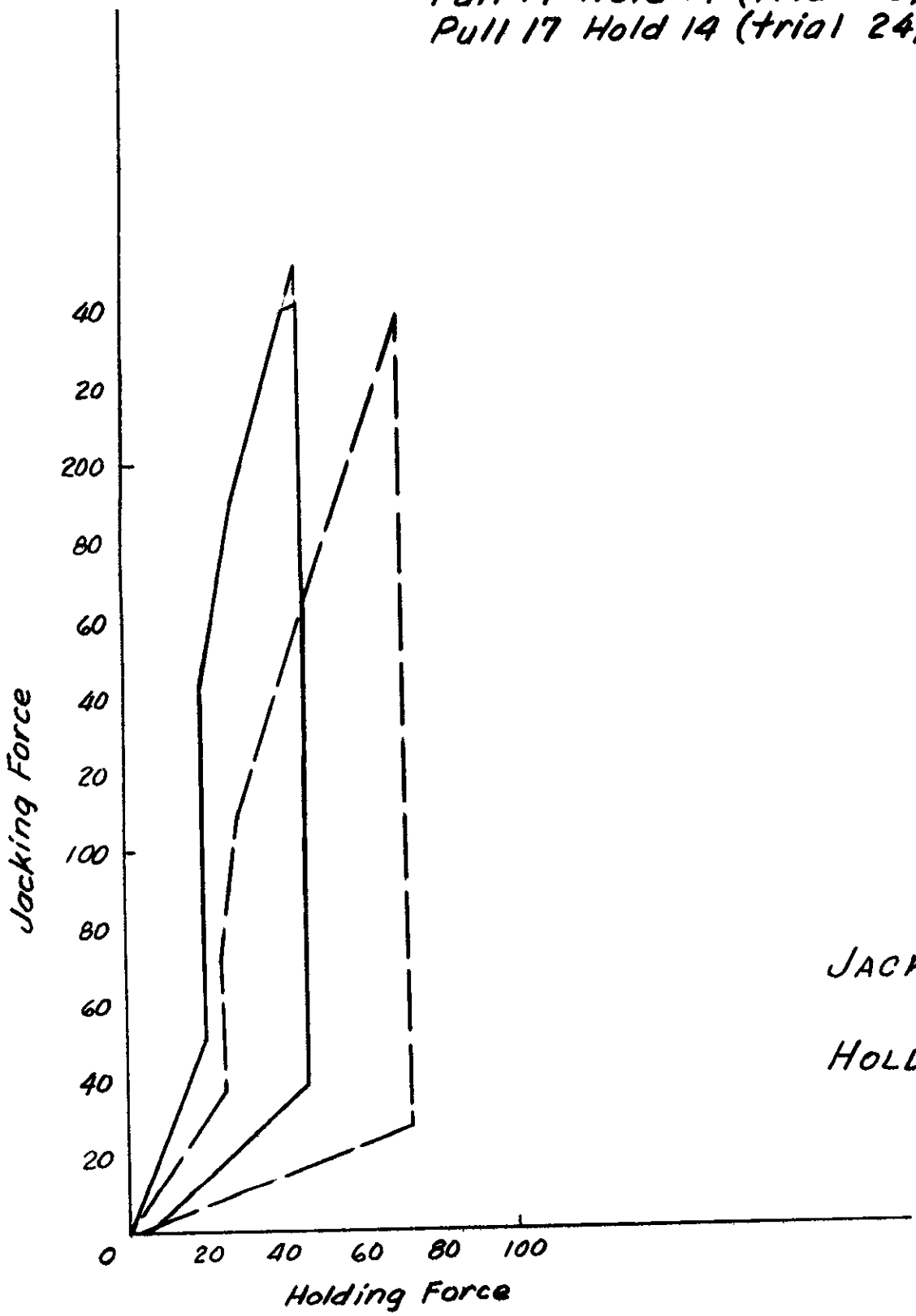


ClibPDF - www.fastio.com

TENDON #10

Tendon: Roebling
Sheath: Bright Flex

Pull 14 Hold 17 (trial 23) = ————
Pull 17 Hold 14 (trial 24) = — —



JACKING FORCE
VS
HOLDING FORCE

ClibPDF - www.fastio.com