Joseph T. Ryerson & Son, Inc.

DIMENSIONAL INFORMATION AND TEST REPORTS
FOR 90- AND 170-WIRE SYSTEMS

TED M BROWN

[illegible]

1. "Dimensional data for tendons giving type, diameter of wire, number of wires and tendon diameter."

Two tendon sizes have been used in structures which have construction permits. They are 90 - 1/4" Ø wires and 170 - 1/4" Ø wires. The material submitted in support of Item 2 below shows the hardware systems used in conjunction with these tendons. The 90-wire tendon will form a bundle approximately 2-3/4" Ø, and a 3-3/4" ID sheath is recommended. The 170-wire tendon will form a bundle approximately 3-3/4" Ø, and a 4-1/2" ID sheath is recommended.

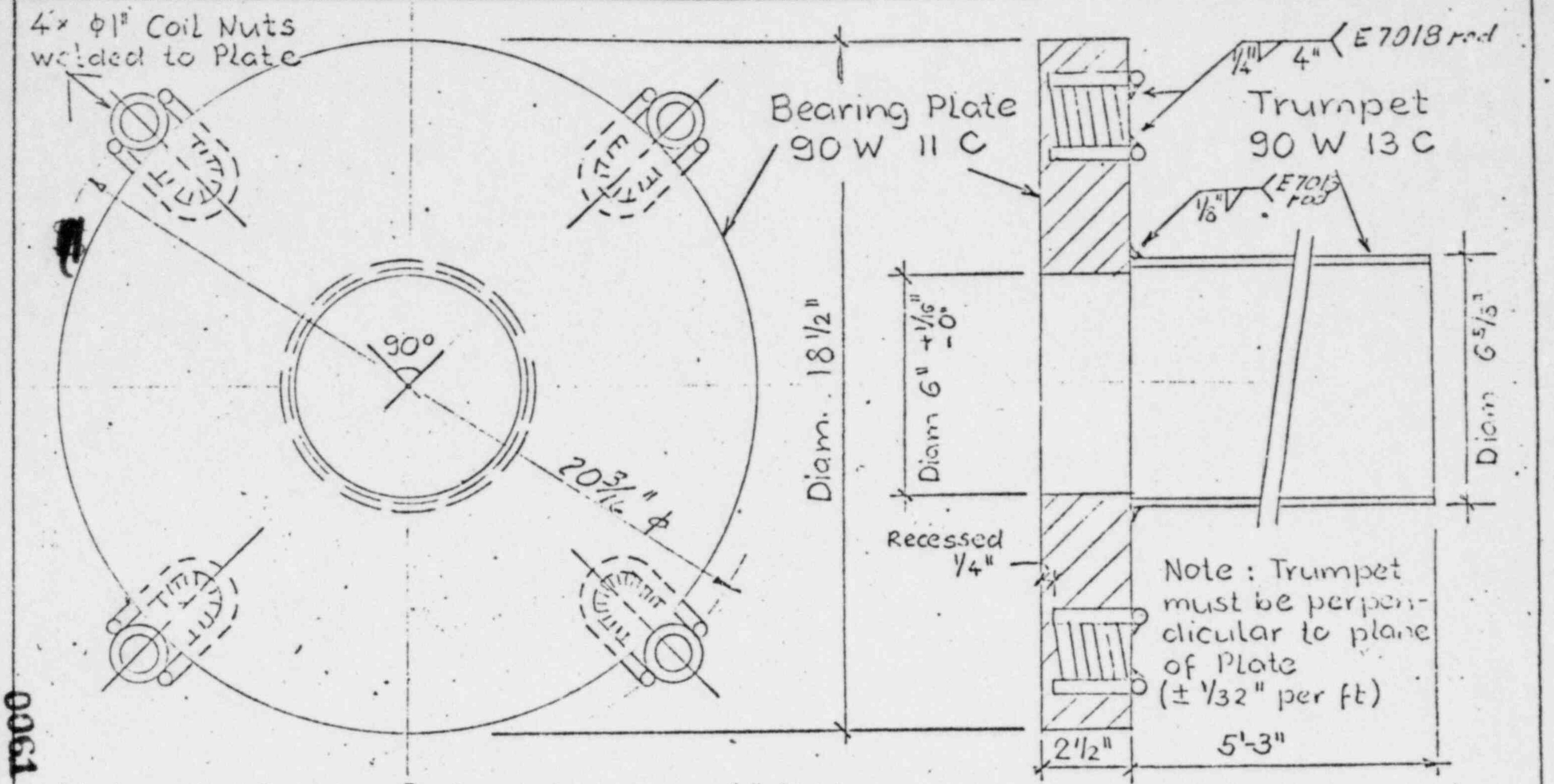
2. Detail information of tendon anchorage hardware, including "anchor diameter in inches" and "bearing plate size and thickness."

The 90-wire tendon system and components is shown on the following Ryerson drawings:

90W50C
90W50D
90W50E
90W1C
90W1E
90W2B
90W5
90W15
90WAC2
90WAC3
90WAC7

The 170-wire system is shown on the following WCS drawings:

100103
100104
100105
100106
1001~~07~~
14
100116
100117
100118
100119



Note : Trumpet must be perpendicular to plane of Plate (± 1/32" per ft)

Material: Bearing Plate HR A-36 2½" thick
Burned to shape

Trumpet: HREW Pipe φ6 5/8" .125 wall
Hacksaw cut to 5'-3" Length

Coil Nuts φ1", Special, see Drawing 90W-[illegible]

90 wire Trumplate (for Shop Buttonheaded End)

DRAWN BY A. Ws	DATE 2/6/6[illegible]
APPROVED BY	
DRAWING NO. 90 W 50 C	

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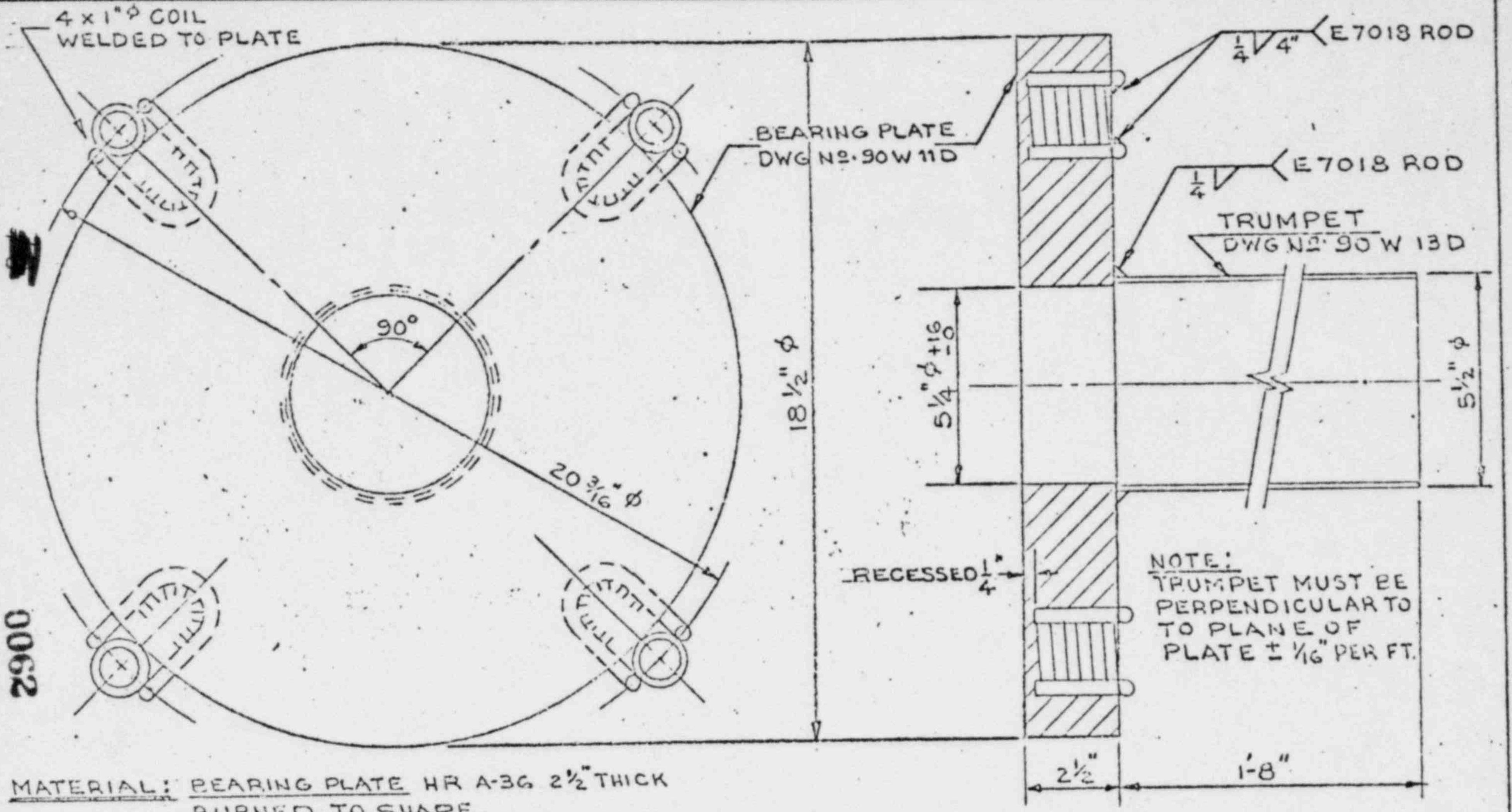
CENTRAL REINFORCING PRODUCTS
POST-TENSIONING SERVICE

FOR INSPECTION AND QUALITY CONTROL TEST REPORTS FOR NUCLEAR CONTAINMENT VESSEL WORK SEE CHAPTER II OF RYERSON PROCEDURE MANUAL.



NOTE:
TRUMPET MUST BE PERPENDICULAR TO TO PLANE OF PLATE ± 1/16" PER FT.

MATERIAL: BEARING PLATE HR A-36 2½" THICK
BURNED TO SHAPE.
TRUMPET HREW TUBING 5½" ϕ x .125" WALL
HACKSAW CUT TO 1'-8" LENGTH
COIL NUTS 1" ϕ, SPECIAL, SEE DWG 90 W AC7

90 WIRE TRUMPLATE (FOR FIELD BUTTON HEADING END)

DRAWN BY AWS/ELS

DATE 2-6-69

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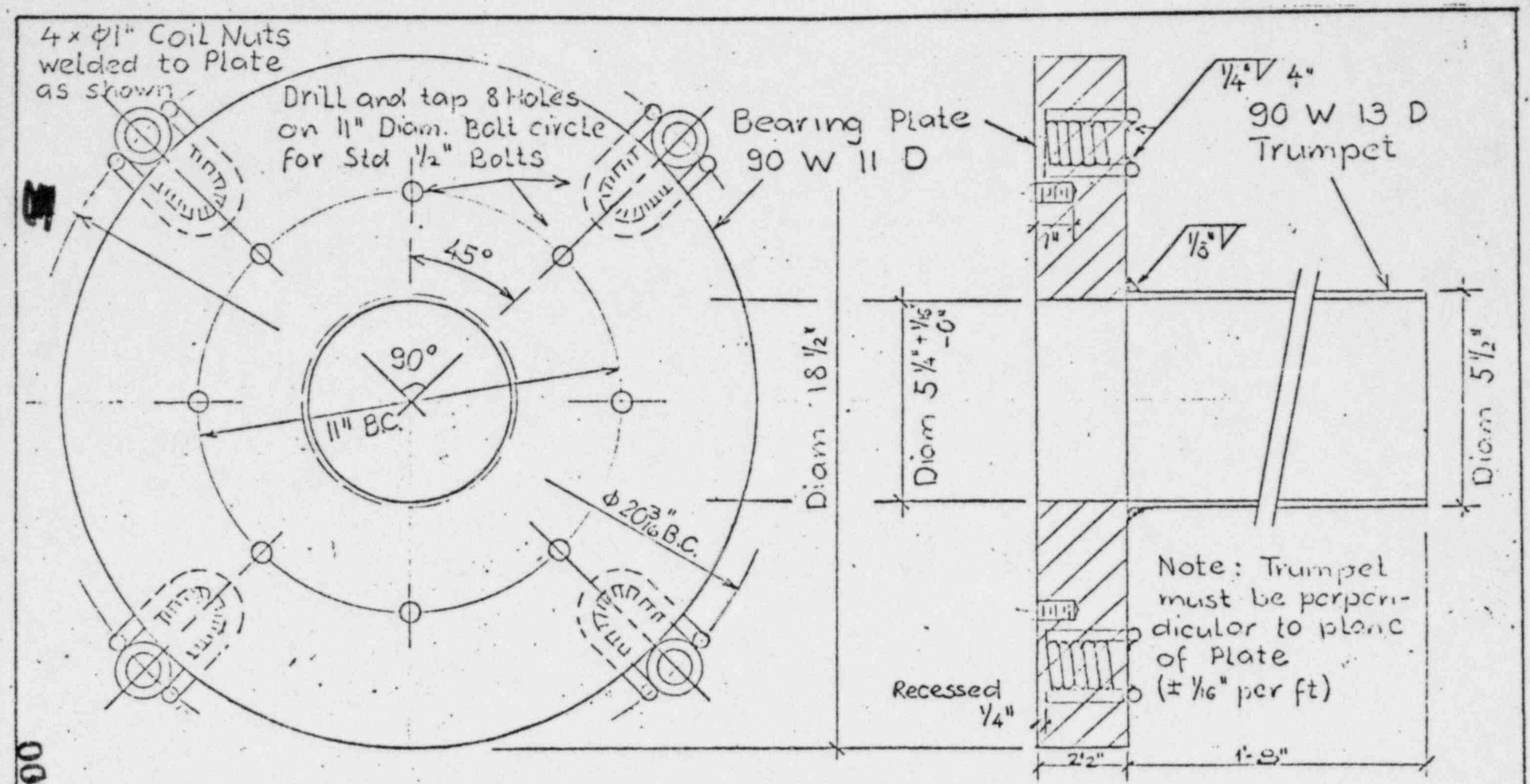
DRAWING NO. 90 W 50D

FOR INSPECTION & QUALITY CONTROL REPORTS (FOR NUCLEAR CONTAINMENT VESSEL WORK)



Material: Bearing Plate HR A-36 2½" thick
Burned to shape
Trumpet HREW Tubing φ 5½" × .125" wall
Hacksaw cut to 1'-8" length.
Coil Nuts φ1", Special, see Drawing 90W-AC 7

90 wire Trumplate (For Field Buttonheading End)

DRAWN BY A.W.
DATE 7/4/[illegible]

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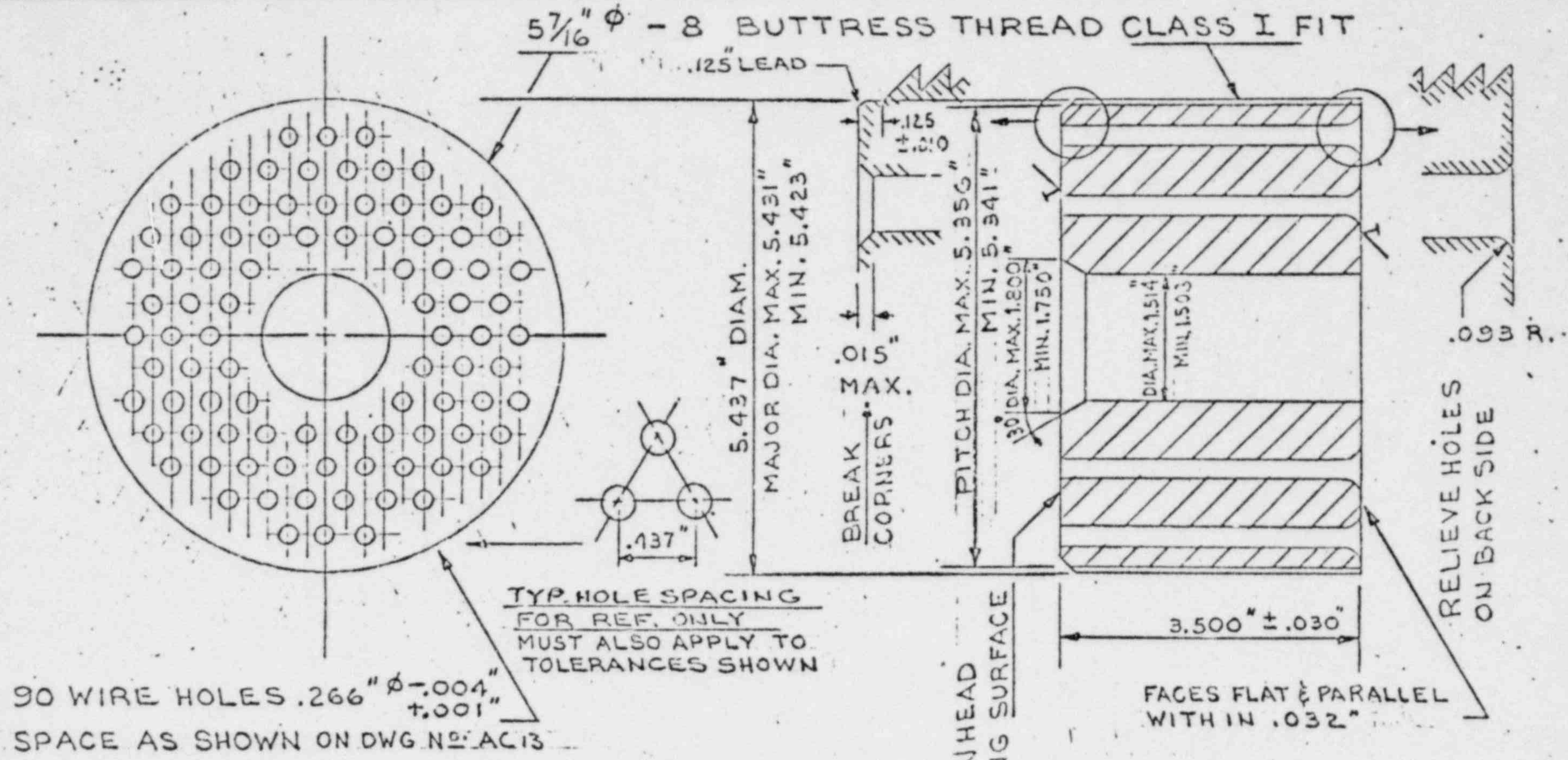
APPROVED BY [illegible]

DRAWING NO. 90 W 50 E

FOR INSPECTION & QUALITY CONTROL TEST REPORTS FOR NUCLEAR VESSEL WORK SEE CHAPTER II OF



TOLERANCES
DIMENSIONAL ±.010"
ANGULAR ± 2.0°
FINISH .125 WHERE NOTED ✓

HEAT TREAT, OIL QUENCH AND TEMPER
TO ROCKWELL C29 TO C33 AT B.H. BEARING SURFACE

MATERIAL: HR C1141 5 3/4" Φ BAR, HACKSAW CUT TO 3 5/8" $^{+1/16"}_{-0"}$ LENGTH

DRAWN BY ELS
DATE 1-17-68

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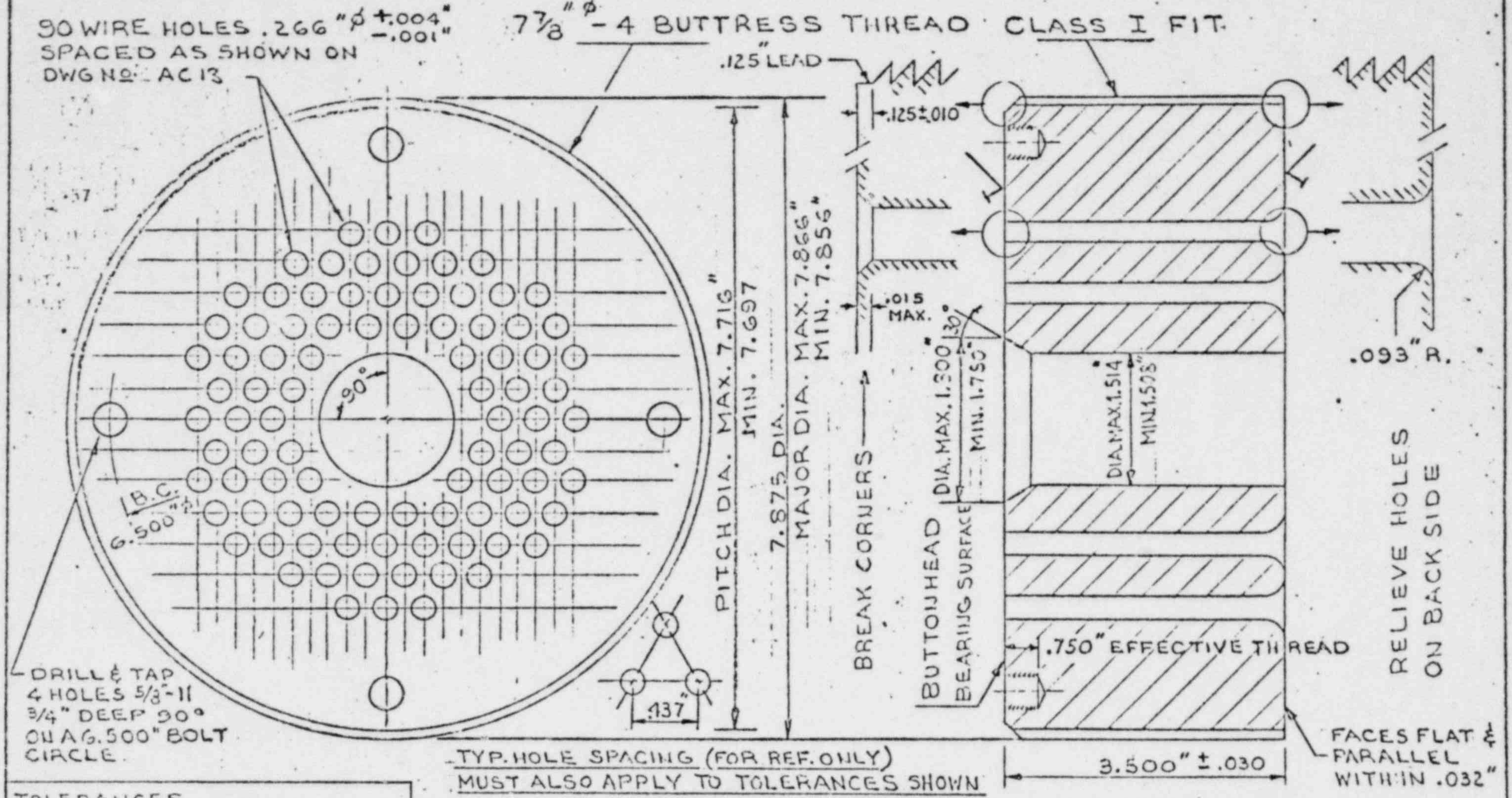
DRAWING NO. 90 W 1C

FORM 734.136-1 NOV 67

FOR: INSPECTION & QUALITY CONTROL-TEST REPORTS (FOR NUCLEAR VESSEL WORK)



TOLERANCES
DIMENSIONAL ±.010"
ANGULAR ± 2.0°
FINISH .125 WHERE NOTED ✓

HEAT TREAT OIL QUENCH & TEMPER TO ROCKWELL C29 TO C33 AT B.H. BEARING SURFACE

MATERIAL: HR C1141 8¼"ϕ BAR, HACKSAW CUT TO 3⅝" +1/16" -0" LENGTH

DRAWN BY ELS	DATE 1-17-68
REVISED 2/24/69	
APPROVED BY	
DRAWING NO. 90W1E	

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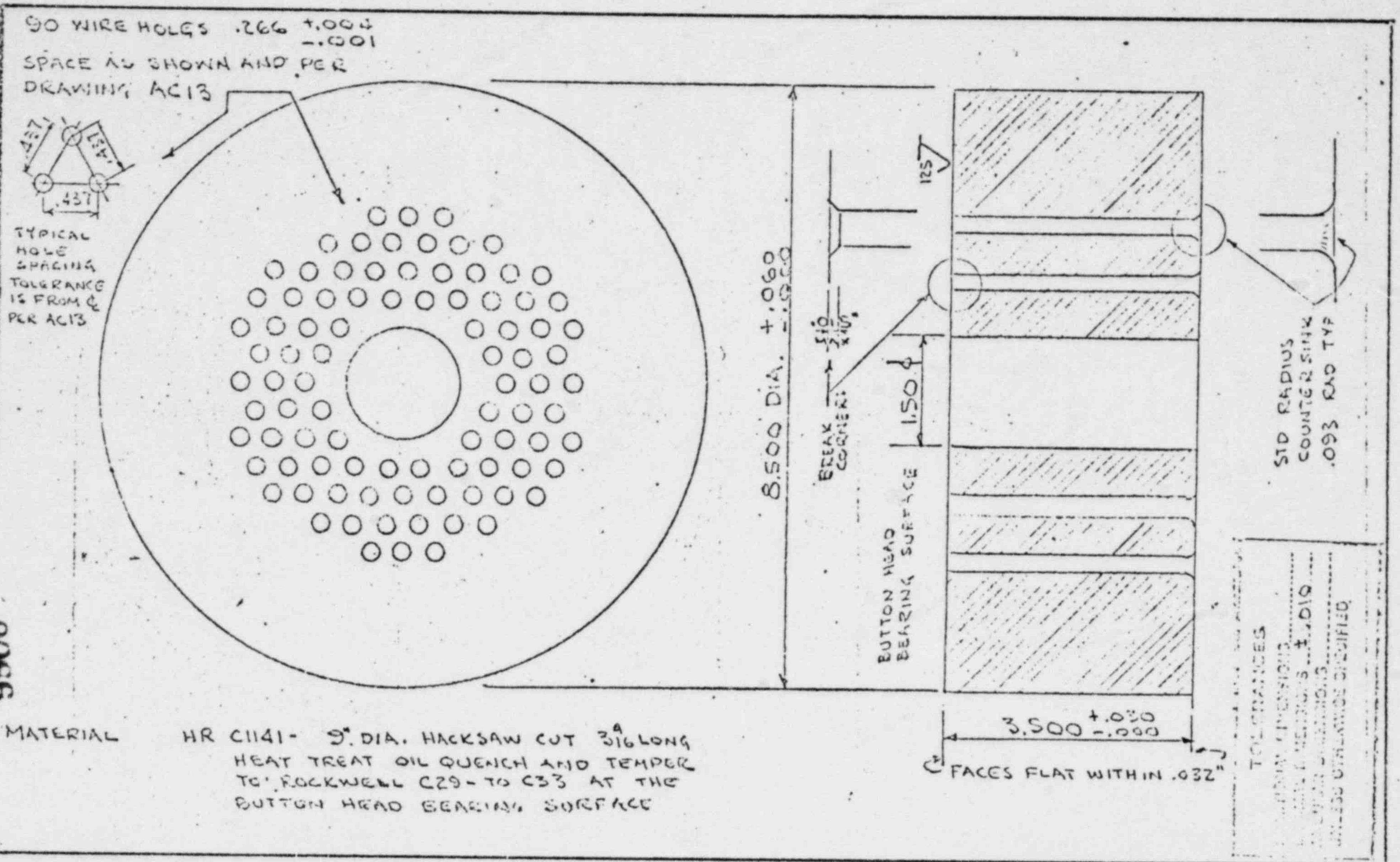
FOR INSPECTION & QUALITY CONTROL - TEST REPORTS (FOR NUCLEAR VESSEL WORK)



MATERIAL HR C1141 - 9" DIA. HACKSAW CUT $3\frac{9}{16}$ LONG
HEAT TREAT OIL QUENCH AND TEMPER
TO ROCKWELL C29 - TO C33 AT THE
BUTTON HEAD BEARING SURFACE

0066

90 WIRE ANCHOR HEAD (FIELD BUTTON HEADED END) NON STRESSING END	DRAWN BY AWS	DATE 3-20-67
	REVISED 3/27/67 SCL	
	APPROVED	
	DRAWING NO. SS VI 75	

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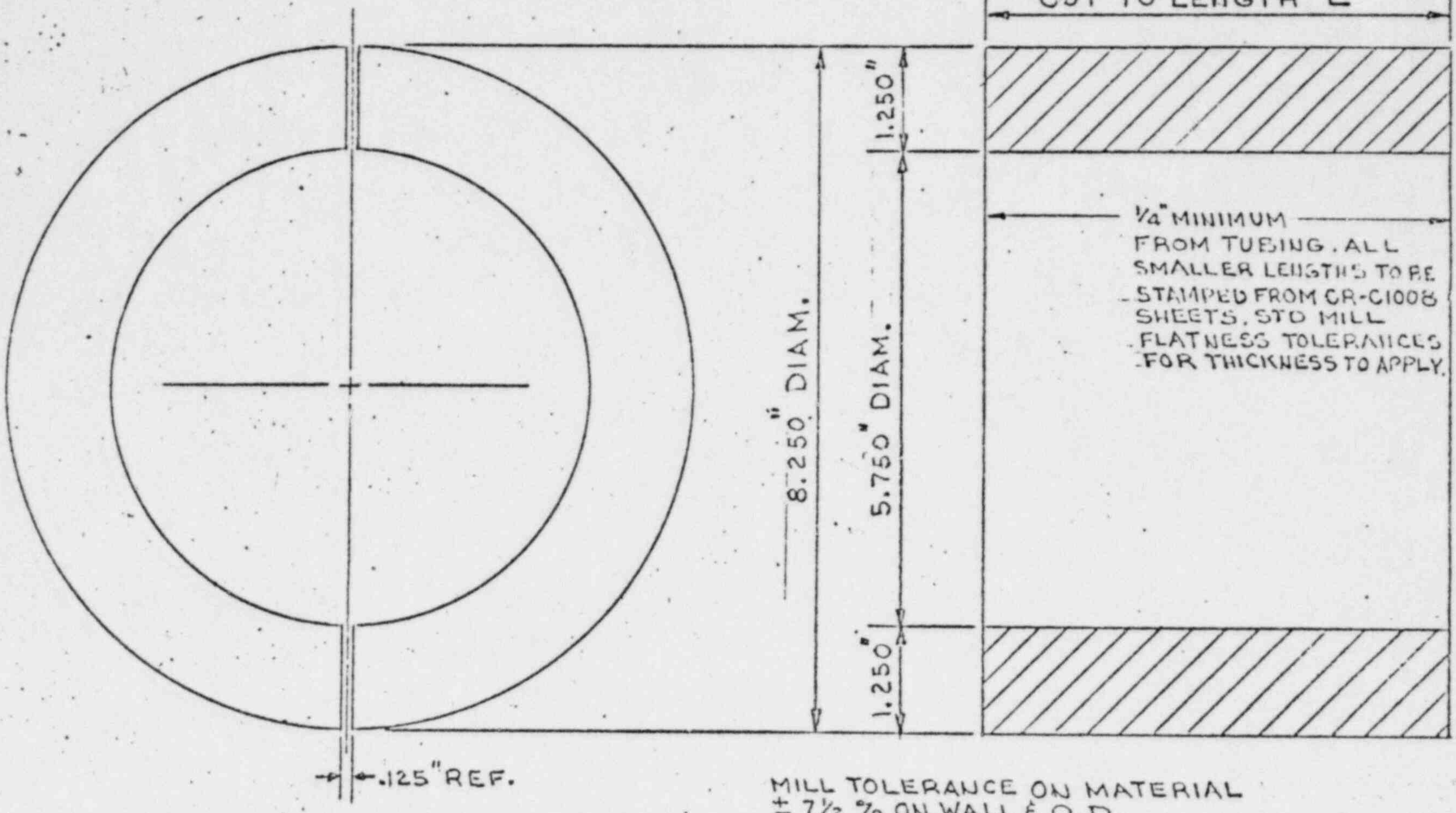

¼" MINIMUM FROM TUBING. ALL SMALLER LENGTHS TO BE STAMPED FROM CR-C1008 SHEETS. STD MILL FLATNESS TOLERANCES FOR THICKNESS TO APPLY.

MILL TOLERANCE ON MATERIAL
± 7½ % ON WALL & O.D.

CUT OUT OF SQUARE ± 1/16"
CUT LENGTH TOLERANCE ⅛" TOTAL

REMOVE BURRS FROM ALL EDGES & FACES.
PAIR HALVES TOGETHER FOR SHIPMENT

MATERIAL: HFSM TUBING C1026, 8¼" x 1¼" WALL, CUT TO LENGTH, SPLIT IN TWO	DRAWN BY ELS	DATE 1-17-68

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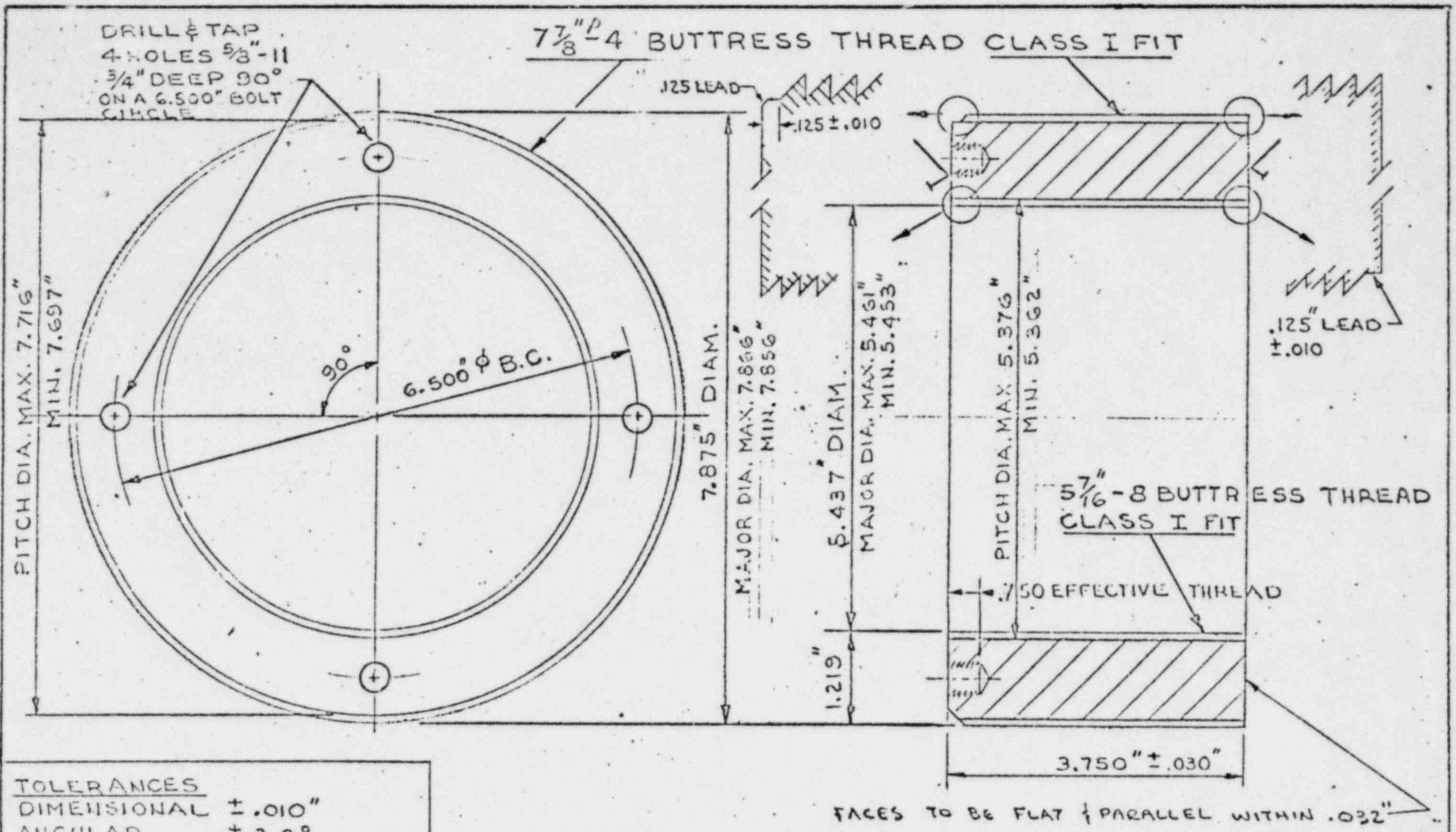
APPROVED BY

DRAWING NO.
90 W 5

FORM 734,136-1 NOV 67

FOR INSPECTION & QUALITY CONTROL TEST REPORTS (FOR NUCLEAR VESSEL WORK)



8900

TOLERANCES
DIMENSIONAL ± .010"
ANGULAR ± 2.0°
FINISH .125 WHERE NOTED ✓

MATERIAL: HFSM TUBING C1045, 8 1/8" O.D. x 1 1/2" WALL, HACKSAW CUT TO 3 7/8" $^{+1/16}_{-0}$" LENGTH

DRAWN BY ELS
DATE 1-13-68
REVISED 2/26/68
APPROVED BY
DRAWING NO. 90W15

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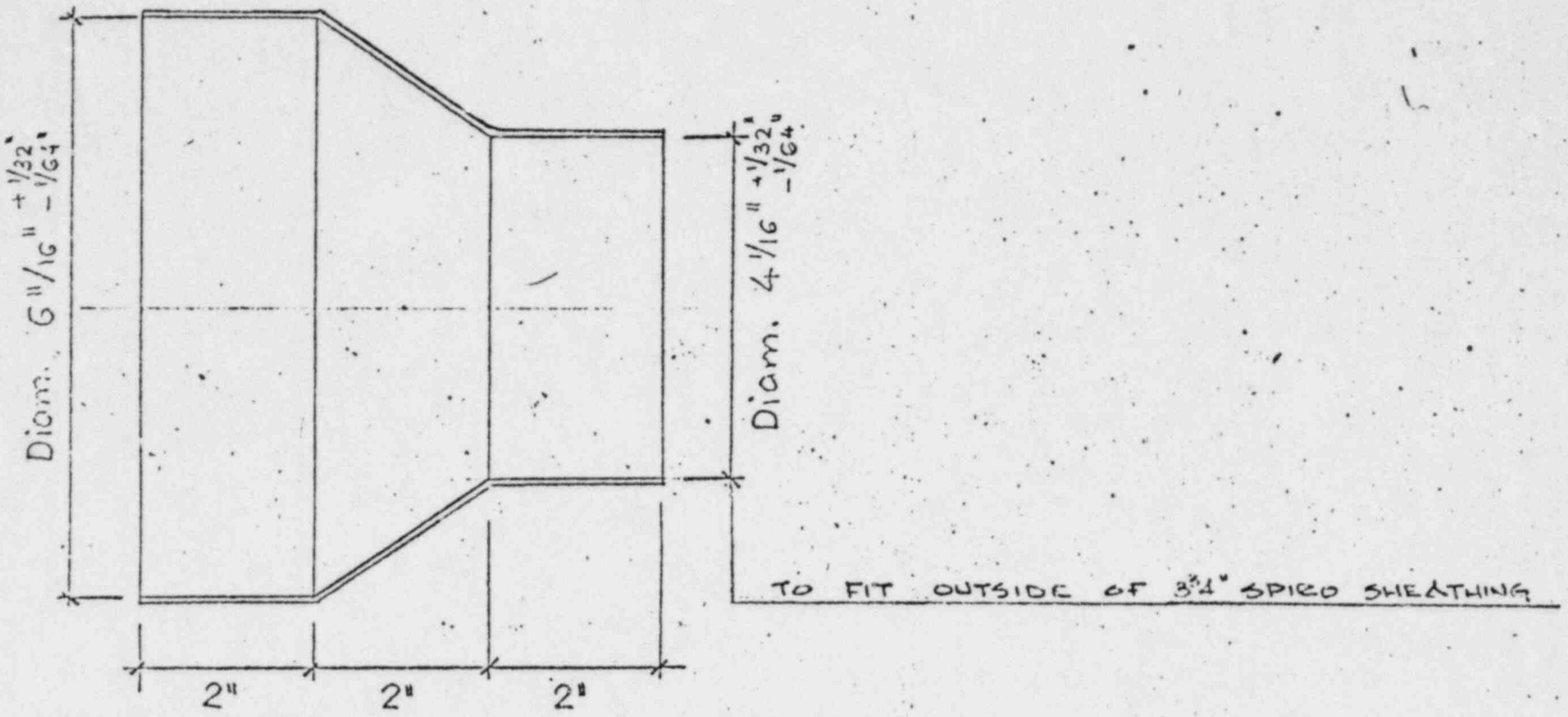
FORM 734.130-1 NOV 67

FOR INSPECTION & QUALITY CONTROL TEST REPORTS (FOR NUCLEAR VESSEL WORK)



Spin from:

Material: 18ga CR Steel Sheet

90 wire Funnel (for Shop Buttonheaded End)	DRAWN BY AWS / Ecc	DATE 2/6/68

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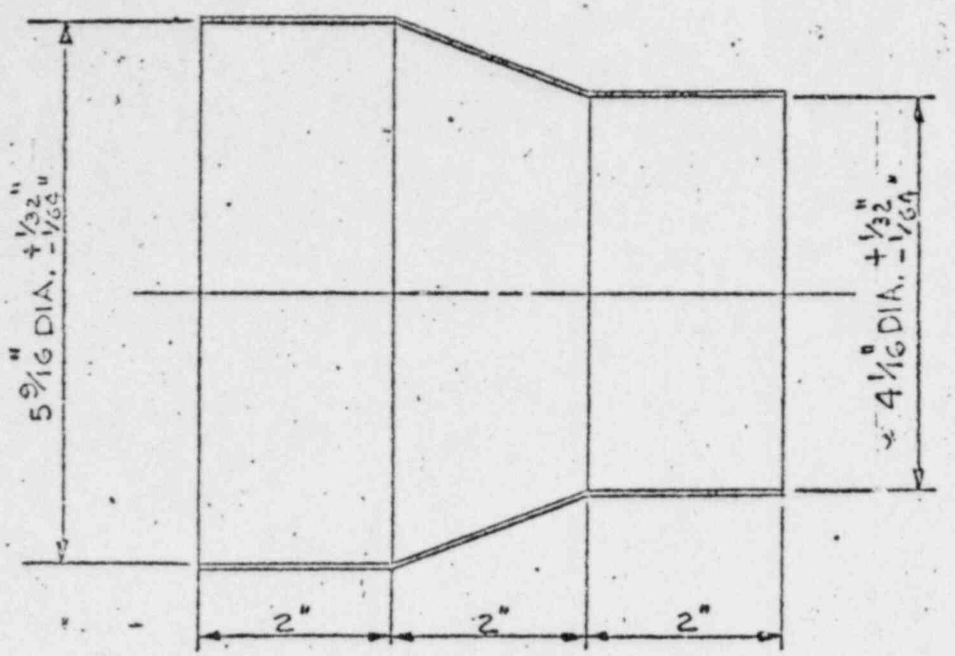
DRAWING NO. 90W-ACZ



MATERIAL: SPIN FROM 18 GA. CR STEEL SHEET

90 WIRE FUNNEL (FOR FIELD BUTTONHEADING END)

DRAWN BY AWS/ELS	DATE 2-6-68
APPROVED BY	
DRAWING NO. 90W-AC3	

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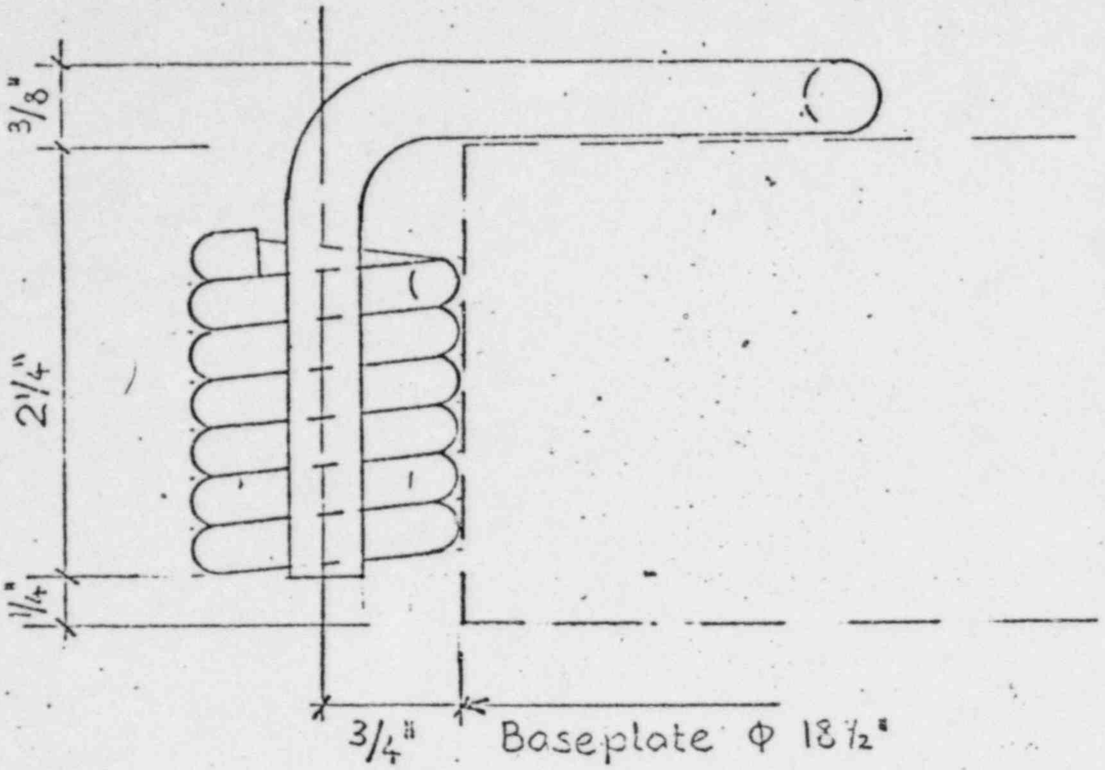

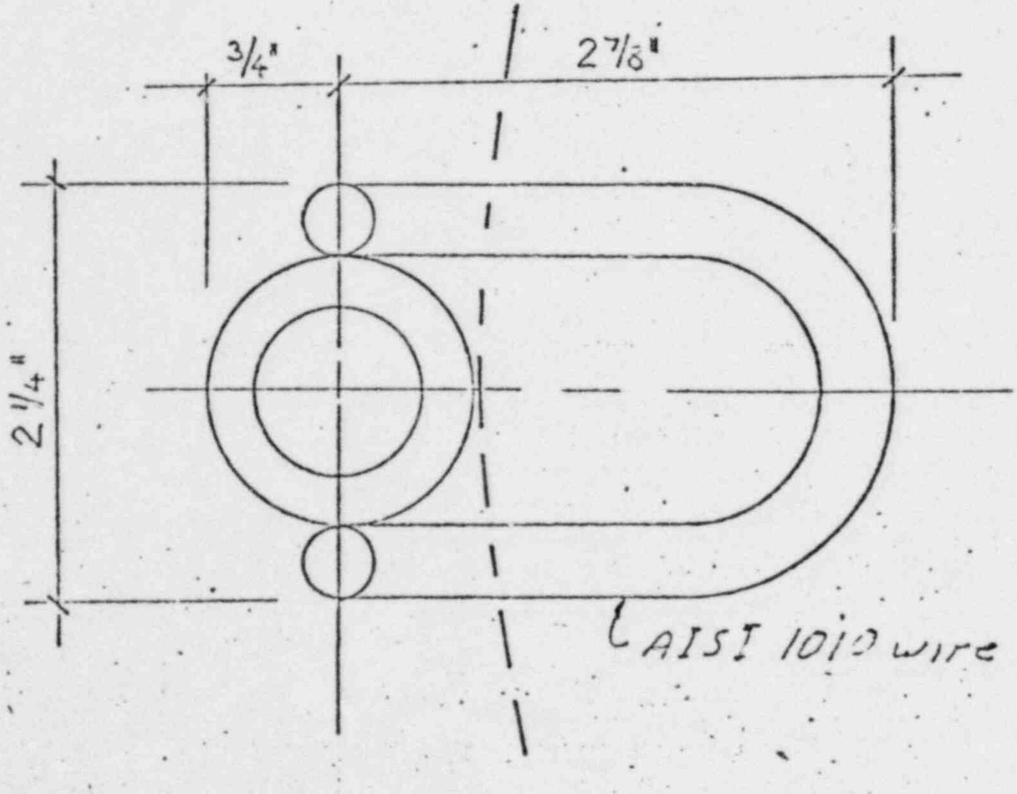

Coil Nuts Φ1", Special,
for Φ1" Coil Bolts

4 pieces to be welded to Baseplates as indicated.

DRAWN BY A.V.S./ac
DATE 2/6/...
APPROVED
DRAWING NO. 90 W - AC 7

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Coil Nuts Φ 1"

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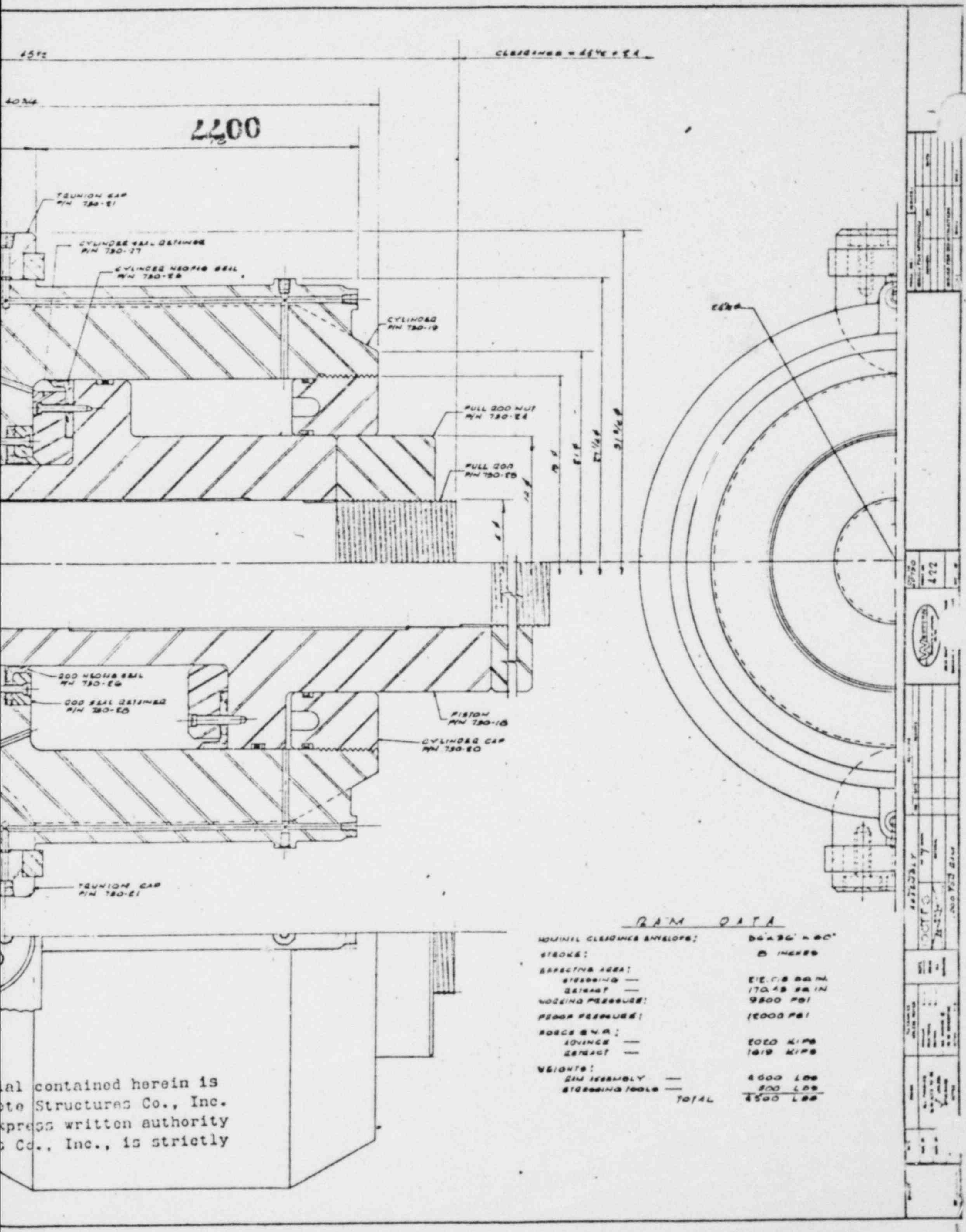
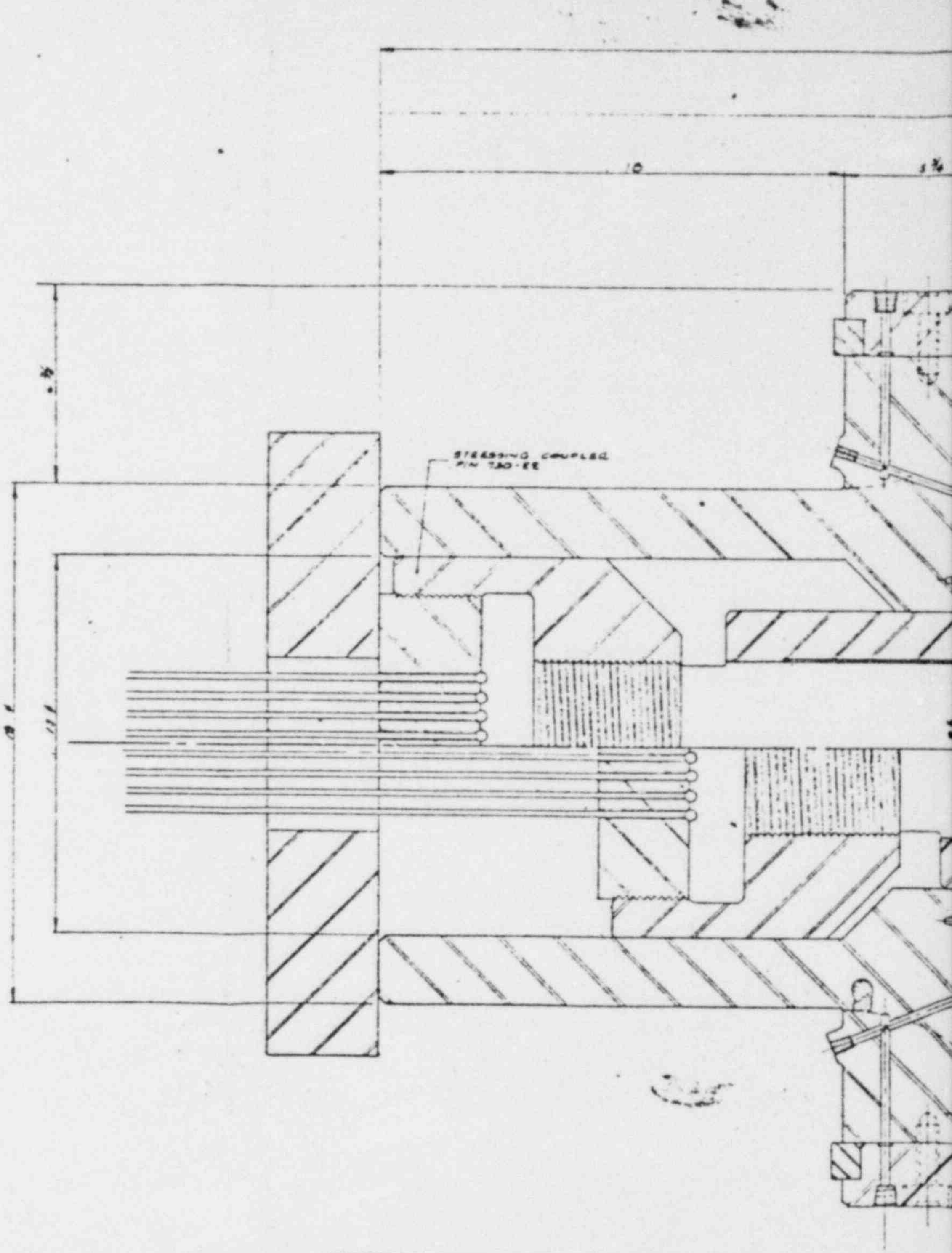


RAM DATA

NOMINAL CLEARANCE ENVELOPE:	36"x36" x 80"
STROKE:	8 INCHES
EFFECTIVE AREA:	
STRESSING —	212.18 SQ IN
RETRACT —	170.45 SQ IN
WORKING PRESSURE:	9500 PSI
PROOF PRESSURE:	12000 PSI
FORCE @ W.P.:	
ADVANCE —	2020 KIPS
RETRACT —	1619 KIPS
WEIGHTS:	
RAM ASSEMBLY —	4000 LBS
STRESSING TOOLS —	500 LBS
TOTAL	4500 LBS



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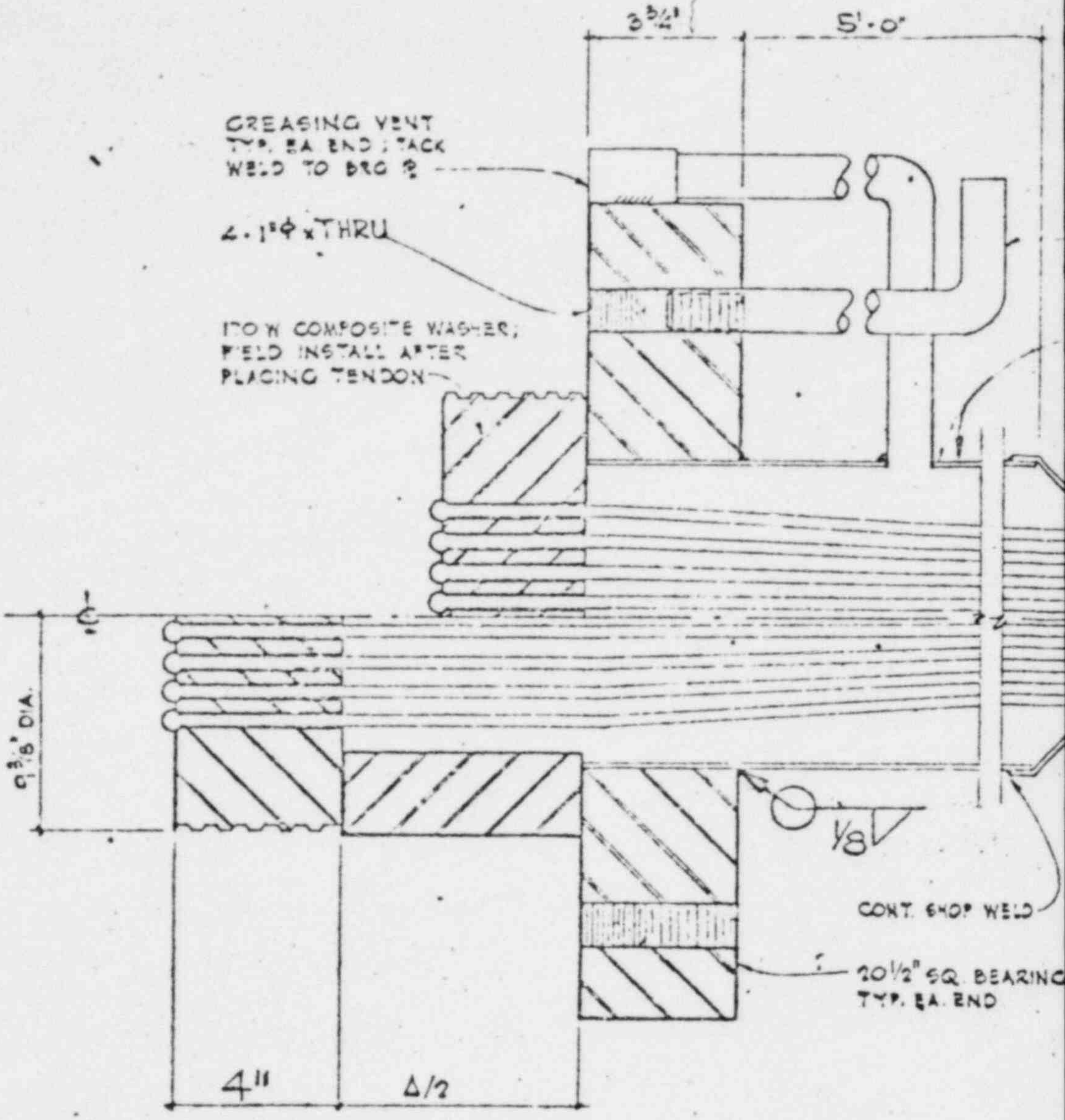
Any use thereof without the
of Western Concrete Structure
prohibited."



'B' END

TYPICAL

BEFORE STRESSIN

NOTE:

1. ALL DIMENSIONS NOMINAL

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Any use
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prohibit

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DATE 15 JULY 67
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DWN BY
CHKD BY

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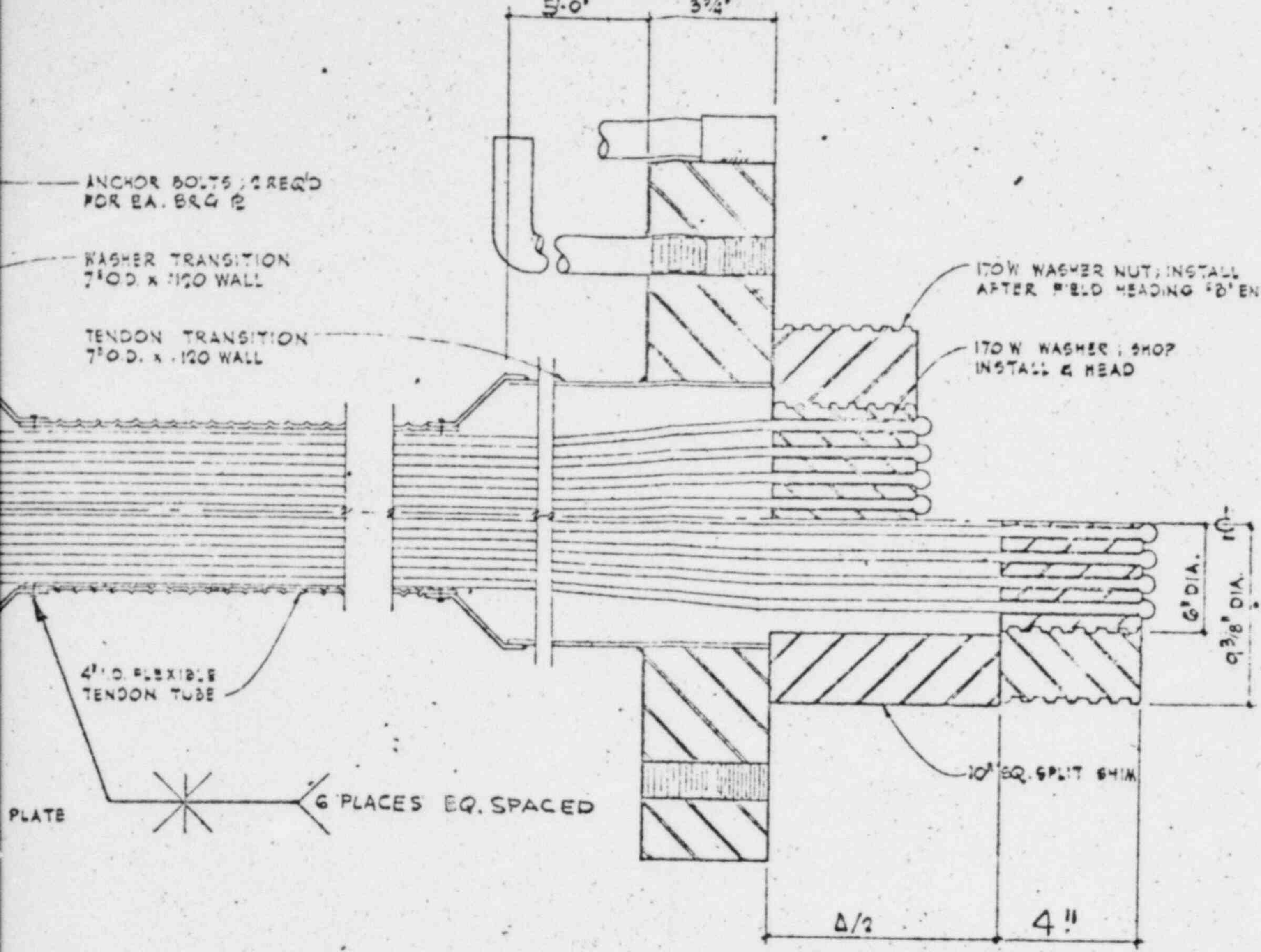

"A" END

TENDON ASSEMBLY

G ABOVE ℄ - AFTER STRESSING BELOW ℄

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thereof without the express written authority
rn Concrete Structures Co., Inc., is strictly
ed."

0080

TOLERANCES UNLESS NOTED
ANGULAR
FRACTIONAL
DECIMAL
DIA MARKED € TO BE CONCENTRIC WITHIN ___ T.I.R.

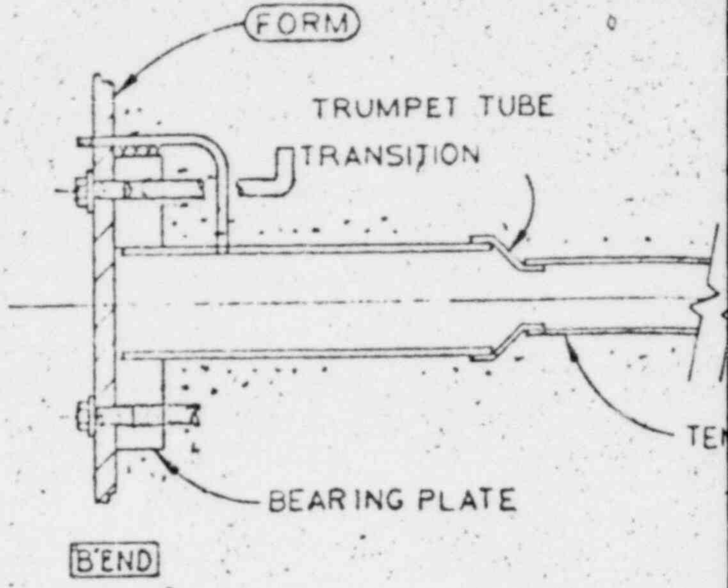
NOTE:
BREAK ALL CORNERS

PART NAME
PART NO 100117
NO PER MACH
SCALE
MATERIAL
MACHINE 20 MEP/170W

REVISIONS
NO. | DATE | REMARKS

WESTERN CONCRETE STRUCTURES CO. INC.
20113 SOUTH HAMILTON AVENUE
GARDENA • CALIFORNIA • 321-1571

PROJ. NO
PRINT NO
SHT ___ OF ___



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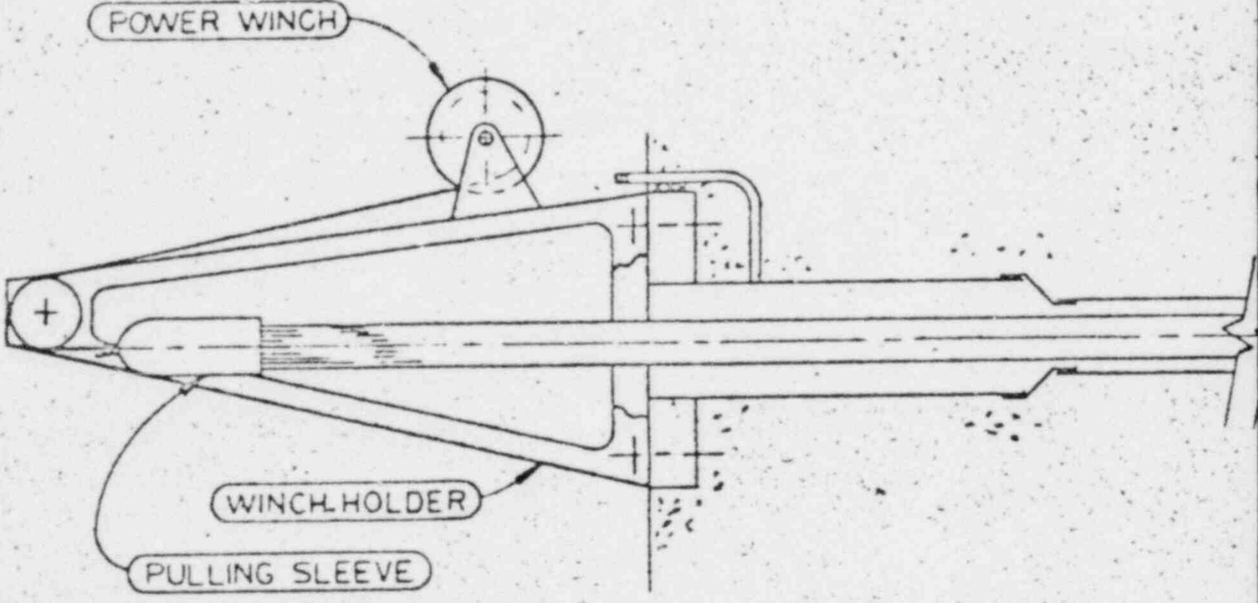


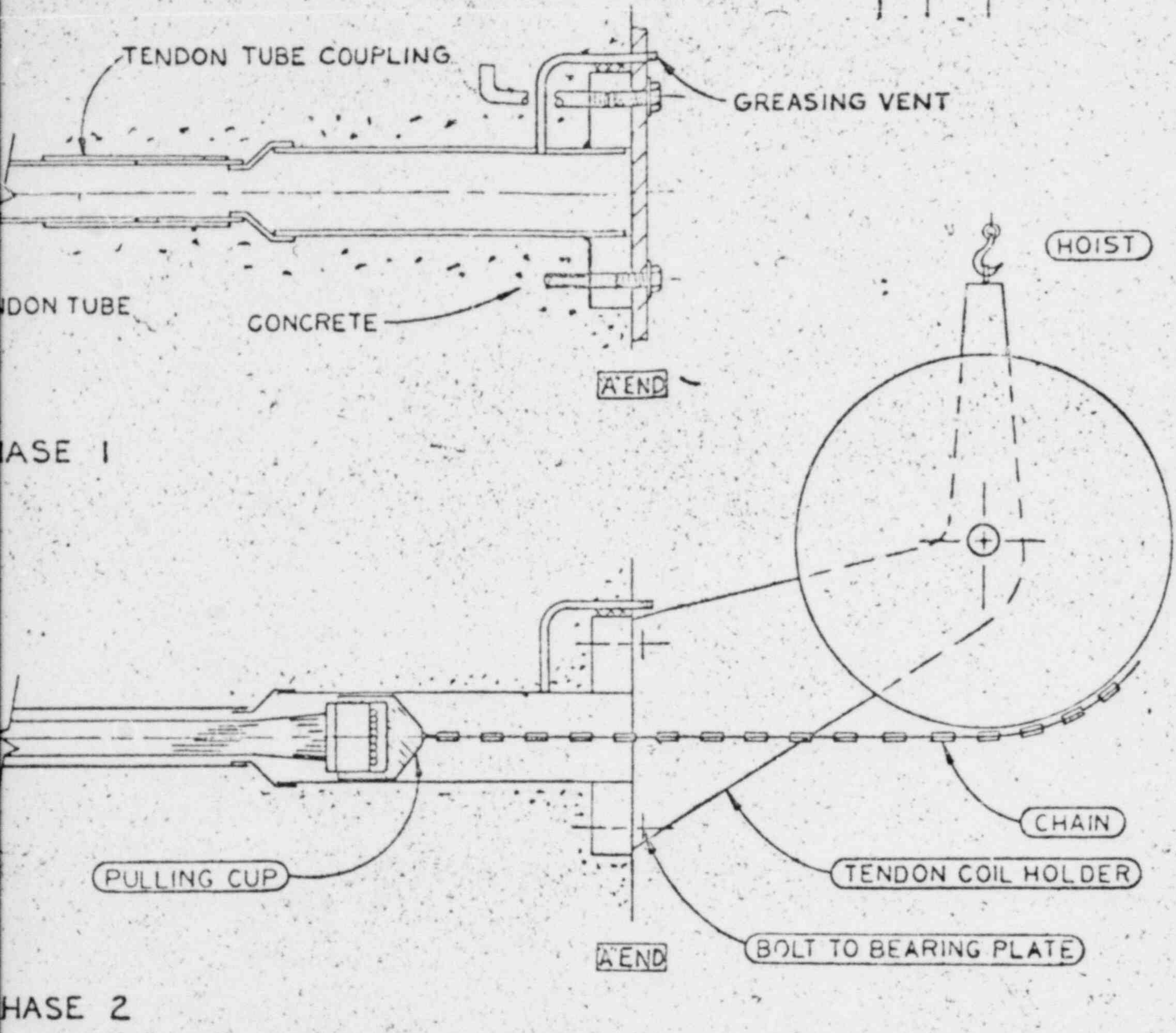
P

NOTE:

1. TEMPORARY EQUIPMENT INDICATED BY "( )"
2. 'B' END IS THE END OF THE TENDON AT WHICH ANCHORAGE HARDWARE AND HEADS ARE FIELD INSTALLED.

DATE
5/21/68
DES BY
DWN BY
CHKD BY

REVISIONS		
NO	DATE	REMARKS



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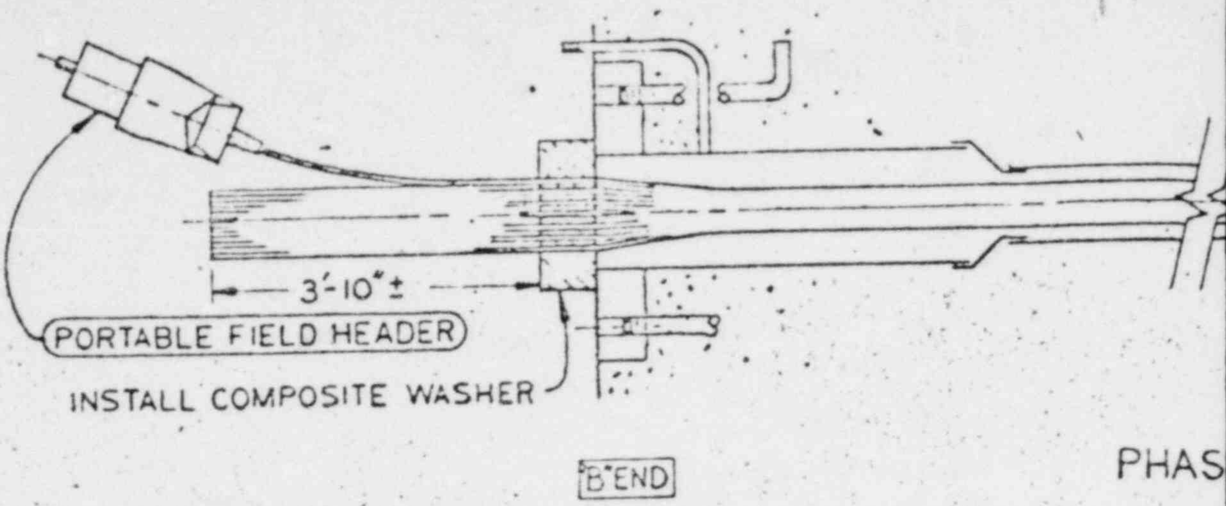
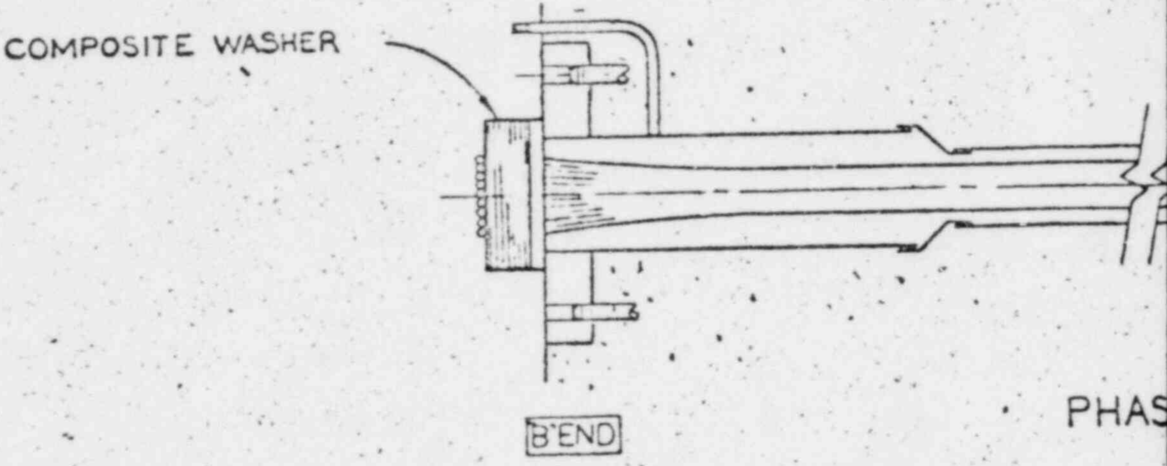
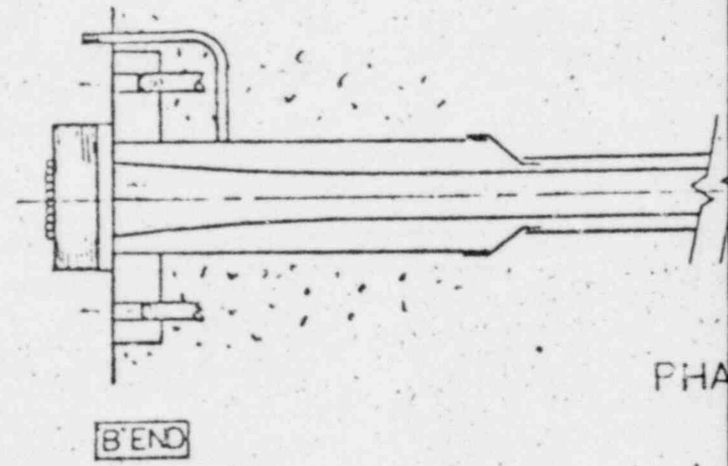
FINISH	TOLERANCES UNLESS NOTED	NOTE	PART NAME TENDON INSTL'N & STRESSING		WESTERN CONCRETE STRUCTURES CO. INC.	PROJ NO
ALL FINISHED SURFACES TO BE ✓ UNLESS OTHERWISE NOTED	ANGULAR ± FRACTIONAL ± DECIMAL ± DIA. MARKED ⊕ TO BE CONCENTRIC WITHIN ___ T.I.R.	BREAK ALL CORNERS	PART NO 100118	NO PER MACH.	19112 SOUTH HAMILTON AVENUE GARDENA • CALIFORNIA • 323-1171	PRINT NO 1
			SCALE NONE	MATERIAL		
			MACHINE 2.0 MEP			SHT 1 OF 3

9







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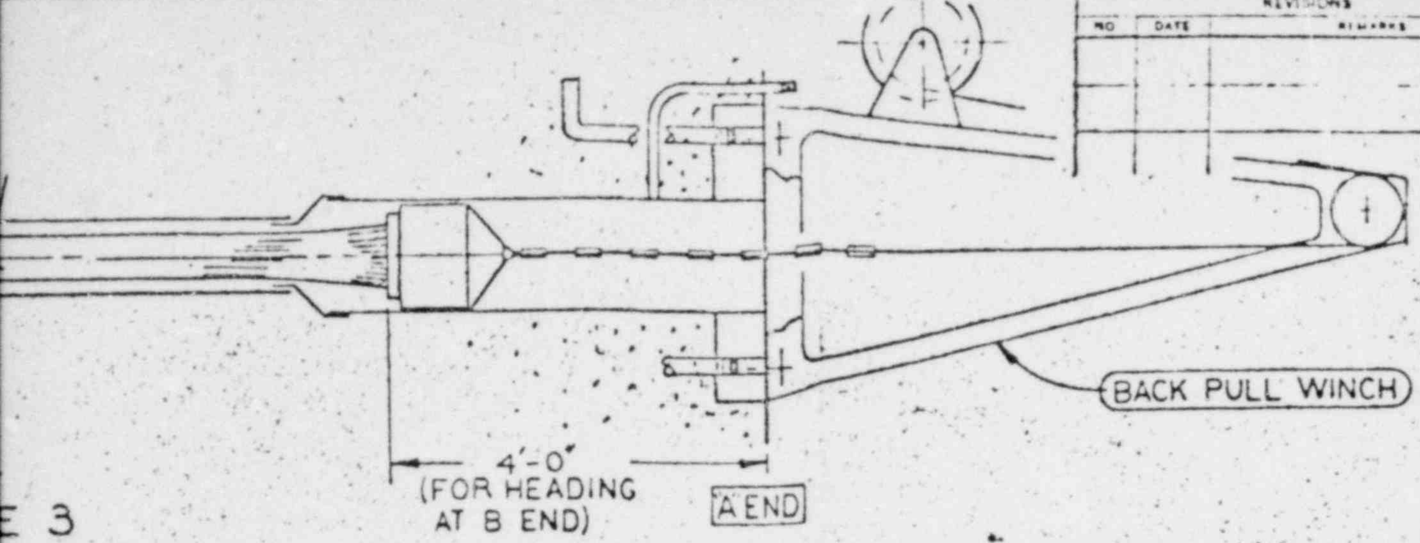
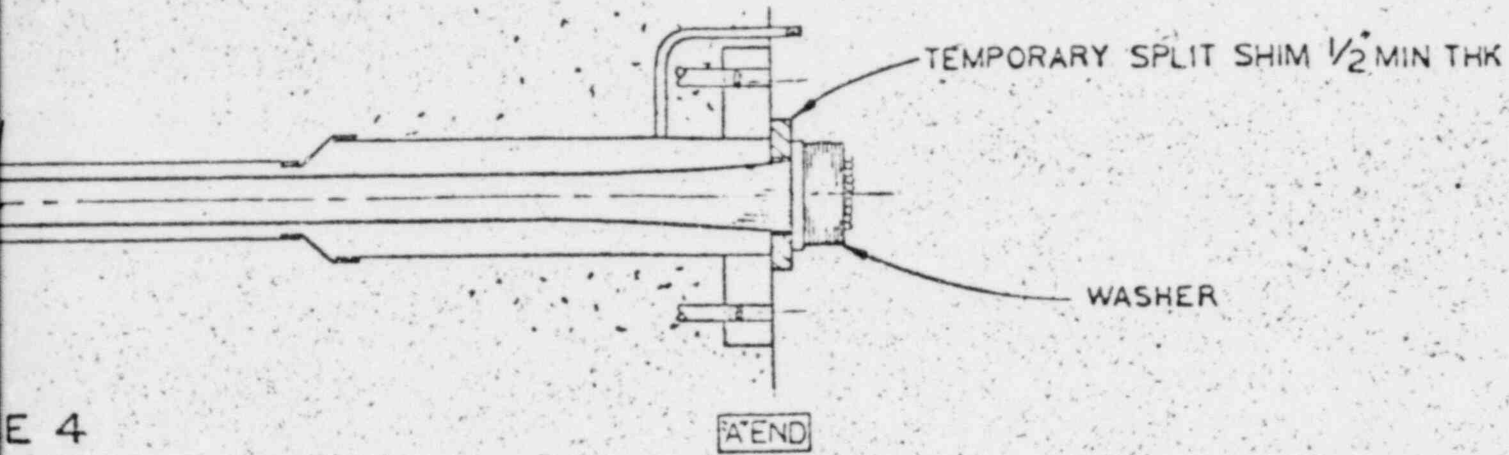
DATE 5/3/68
DES BY
DWN BY LIMMERMAN
CHKD BY

Sp#16

REVISIONS		
NO	DATE	REMARKS



E 3



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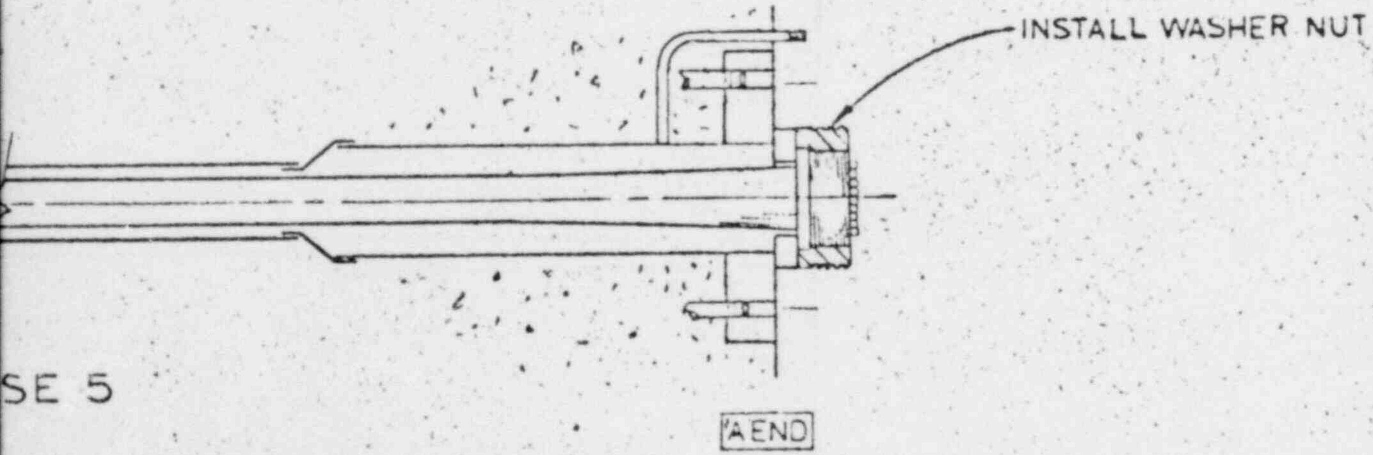
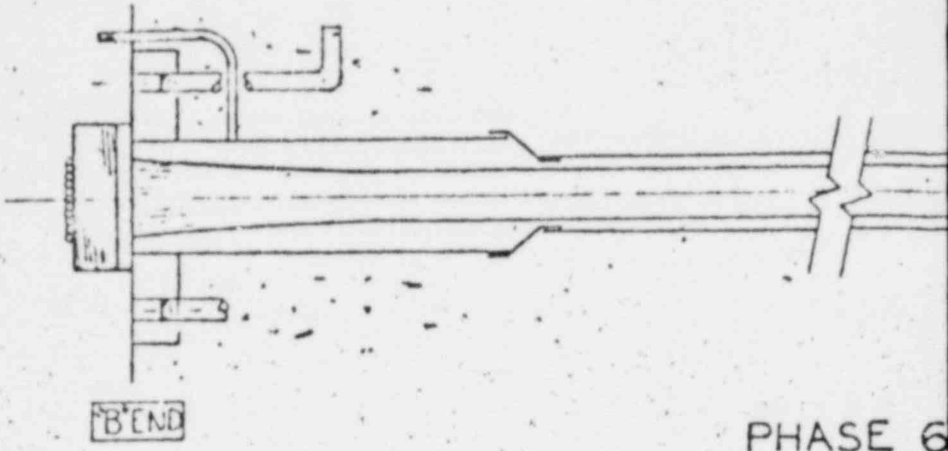


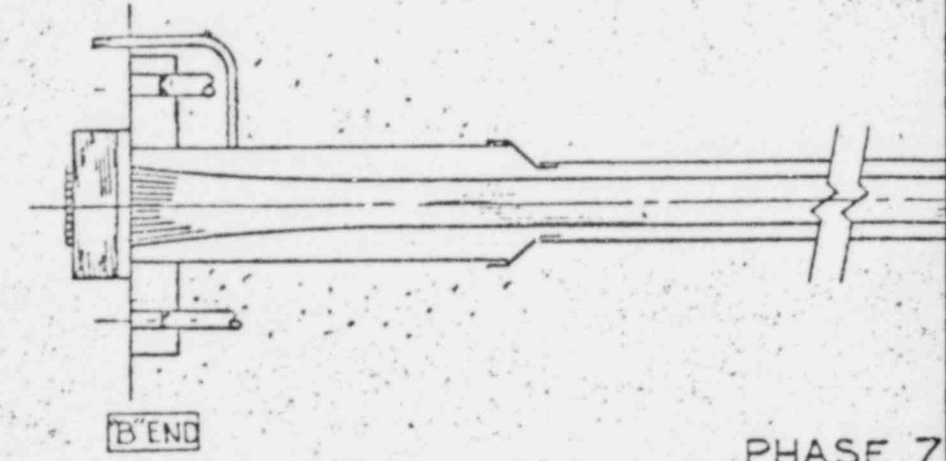
SE 5

FINISH	TOLERANCES UNLESS NOTED	NOTE	PART NAME			PROJ NO.
ALL FINISHED SURFACES TO BE ✓ UNLESS OTHERWISE NOTED	ANGULAR ± FRACTIONAL ± DECIMAL ± DIA. MARKED 6 TO BE CONCENTRIC WITHIN ____ T.I.R.	BREAK ALL CORNERS	TENDON INSTLN & STRESSING		WESTERN CONCRETE STRUCTURES CO INC. 19113 SOUTH HAMILTON AVENUE GARDENA • CALIFORNIA • 321-1871	PRINT NO 2
			PART NO 100118	NO PER MACH		
			SCALE	MATERIAL		
			MACHINE 2.0 MEP			SHT 2 OF 3

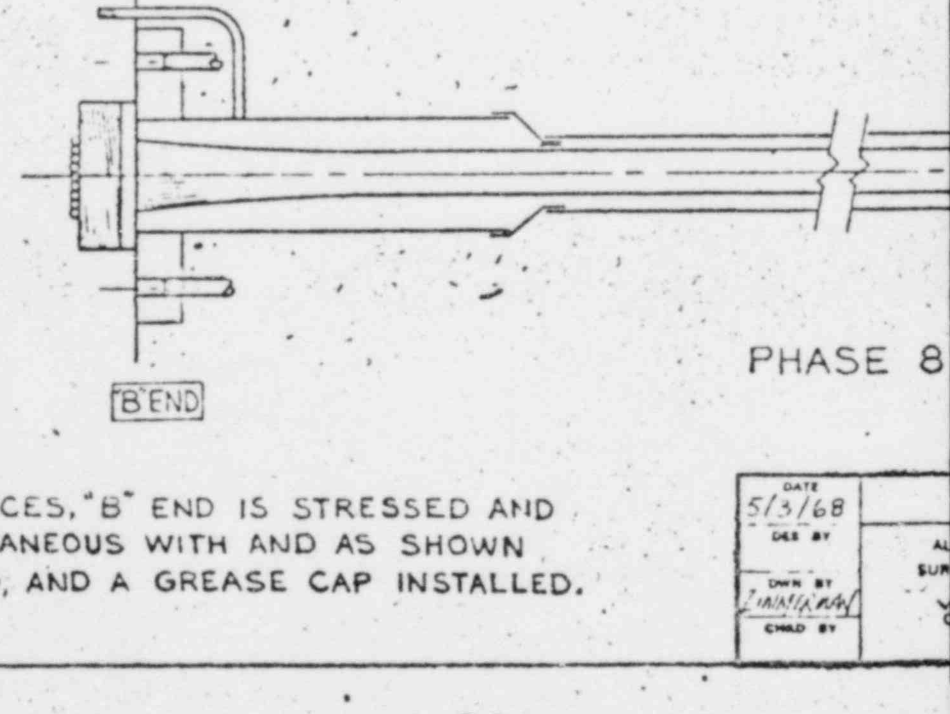
10



PHASE 6



PHASE 7



PHASE 8

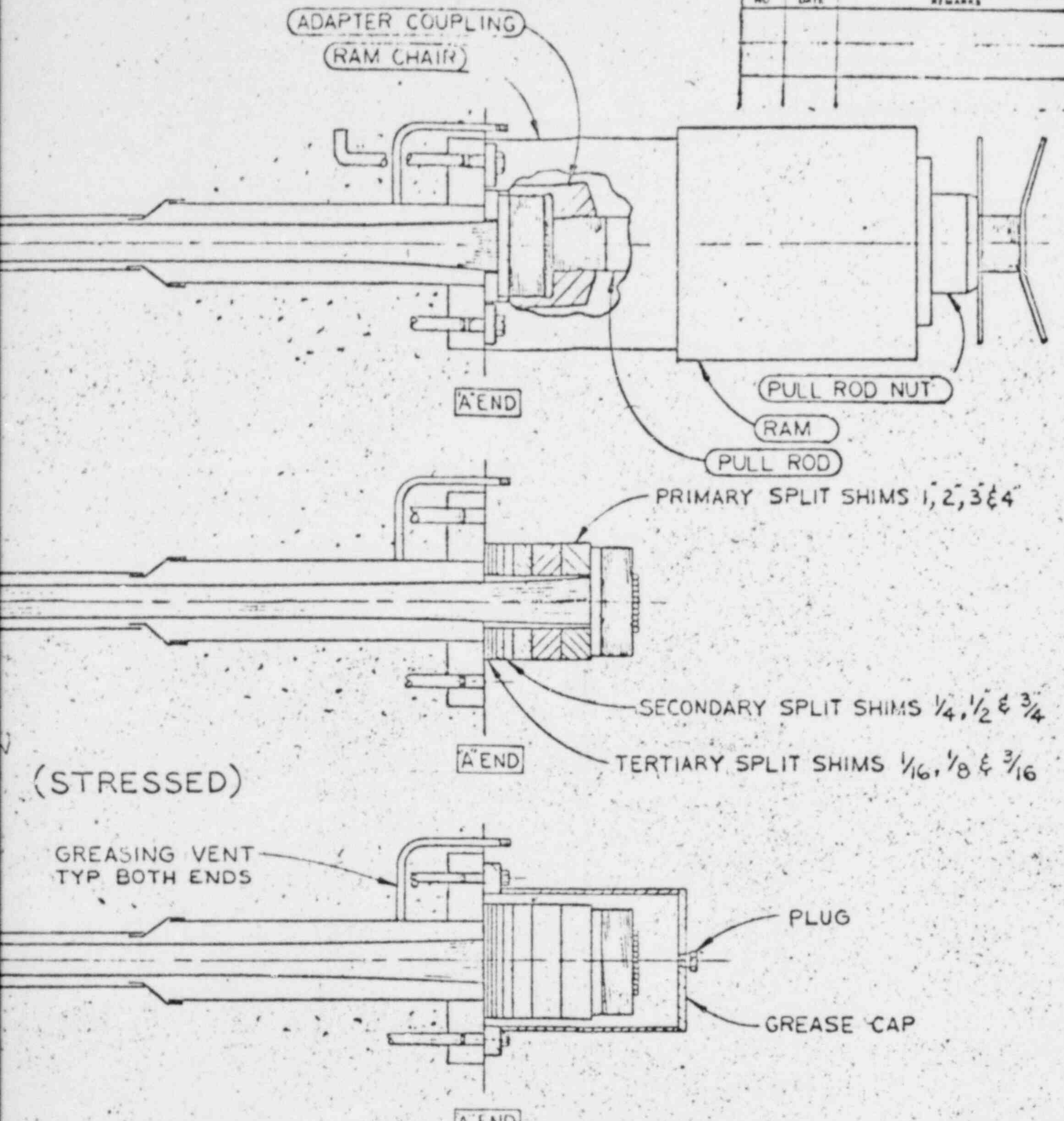
"This drawing and the material contained herein is the property of Western Concrete Structures Co., Inc. Any use thereof without the express written authority of Western Concrete Structures Co., Inc., is strictly prohibited."

NOTE:

1. IN SOME INSTANCES, "B" END IS STRESSED AND SHIMMED SIMULTANEOUS WITH AND AS SHOWN FOR THE "A" END, AND A GREASE CAP INSTALLED.

DATE 5/3/68	
DES BY	
DWN BY Linnikkan	
CHKD BY	

REVISIONS		
NO	DATE	REMARKS



FINISH
FINISHED
ACES TO BE
UNLESS
THERWISE
NOTED

TOLERANCES UNLESS NOTED
ANGULAR ±
FRACTIONAL ±
DECIMAL ±
DIA MARKED ⊖ TO BE CONCENTRIC WITHIN ____ T.I.R.

NOTE
BREAK ALL CORNERS

PART NAME: TENDON INSTALLATION & STRESSING
PART NO: 100118
NO PER MACH:
SCALE: NONE
MATERIAL:
MACHINE: MEP

WESTERN
CONCRETE STRUCTURES CO. INC.
19113 SOUTH HAMILTON AVENUE
GARDENA • CALIFORNIA • 321-1871

PROJ NO
PRINT NO: 3
SHT 3 OF 3

0086

3. "Certified test results of engineering data for tendon, including sectional area of wires (sq. in.), ultimate strength, yield strength, stress-strain curve and elongation at rupture."

The general properties of A-421 wire are shown in:

- ASTM Specification A-421
- Typical Stress-Strain Curve for A-421 Wire
- Stress-Strain Curve for Mill Heat #31636 (representative)

Tendon system tests for 90-wire tendons:

- Compression Test of 90-Wire Anchor Head Assembly
- Compressive Load Tests of 90-Wire Tendon Base Plate Test on Concrete Stand
- 90-Wire Tendon Test
- Friction Test on Large, Multiwire Post-Tensioning Tendons

Tendon system tests for the 170-wire system are reported in Chapter 3 of Technical Report Number 8.

Standard Specifications for

UNCOATED STRESS-RELIEVED WIRE FOR PRESTRESSED CONCRETE[1]

ASTM Designation: A 421 - 65

Adopted, 1964; Revised, 1965.[2]

This Standard of the American Society for Testing and Materials is issued under the fixed designation A 421; the final number indicates the year of original adoption as standard or, in the case of revision, the year of last revision.

Scope

1. These specifications cover two types of uncoated stress-relieved round high-carbon steel wire commonly used in prestressed linear concrete construction, as follows:

Type BA wire is used for applications in which cold-end deformation is used for anchoring purposes (Button Anchorage).

Type WA wire is used for applications in which the ends are anchored by wedges, and no cold-end deformation of the wire is involved (Wedge Anchorage).

Process

2. (*a*) The steel shall be made by the basic-oxygen, open-hearth, or electric-furnace process.

(*b*) The wire shall be cold drawn to size and suitably stress relieved after cold drawing by a continuous strand heat treatment to produce the prescribed mechanical properties.

(*c*) There shall be no welds or joints in the finished wire. Any welds or joints made during manufacture to promote continuity of operations shall be removed.

Discard

3. A sufficient discard shall be made from each ingot to ensure freedom from injurious piping and undue segregation.

Chemical Composition

4. (*a*) The ladle analysis of the steel shall conform to the following ranges:

Carbon, per cent..............	0.72 to 0.93
Manganese, per cent...........	0.40 to 1.10
Phosphorus, max, per cent.....	0.040
Sulfur, max, per cent.........	0.050
Silicon, per cent.............	0.10 to 0.35

(*b*) Variations in manufacturing processes and equipment among wire manufacturers necessitate the individual selection of an appropriate chemical composition, within the above ranges, at the discretion of the manufacturer.

(*c*) When requested, an analysis of each heat of steel showing the percentages of the elements specified in Para-

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[1] Under the standardization procedure of the Society, these specifications are under the jurisdiction of the ASTM Committee A-1 on Steel, and are the direct responsibility of Subcommittee V on Steel Reinforcement Bars.

[2] Latest revision accepted August 31, 1965, by action of the Society at the Annual Meeting and confirming letter ballot.

Prior to adoption as standard, this specification was published as tentative from 1958 to 1964, being revised in 1959.

graph (*a*) shall be furnished by the manufacturer.

Check Analysis Tolerances

5. An analysis may be made by the purchaser from finished wire representing each heat of steel. Samples for analysis shall be obtained by milling the wire in such a manner as to obtain a sample representative of the entire cross-section. Prior to milling, the surface shall be cleaned to remove all foreign matter. All such individual determinations shall not vary from the limits shown in Section 4(*a*) by more than the amounts prescribed in Table I.

TABLE I.—PERMISSIBLE VARIATIONS FOR CHECK ANALYSIS.

Element	Permissible Variation Over Maximum Limit or Under Minimum Limit, per cent
Carbon	0.04
Manganese	0.06
Phosphorus	0.008
Sulfur	0.008
Silicon	0.02

Tensile Strength

6. The tensile strength of type BA wire and type WA wire shall conform to the requirements prescribed in Table II.

TABLE II.—TENSILE STRENGTH REQUIREMENTS.

Nominal Diameter, in.	Tensile Strength, min, psi	
	Type BA	Type WA
0.192	[a]	250 000
0.196	240 000	250 000
0.250	240 000	240 000
0.276	[a]	235 000

[a] These sizes are not commonly furnished in type BA wire.

Yield Strength

7. (*a*) The minimum yield strength for all wire, measured by the 1.0 per cent extension under load method, shall not be less than 80 per cent of the specified minimum breaking strength.

(*b*) The extension under load shall be measured by an extensometer calibrated with the smallest division not larger than 0.0001 in. per in. of gage length.

(*c*) The initial load corresponding to the initial stress prescribed in Table III shall be applied to the specimen, at which time the extensometer is attached and adjusted to a reading of 0.001 in. per in. of gage length. The load shall then be increased until the extensometer indicates an extension of 1 per cent. The load for this extension shall be recorded. The stress corresponding to this load shall meet the requirements for stress at 1 per cent extension prescribed in Table III.

TABLE III.—YIELD STRENGTH REQUIREMENTS.

Nominal Diameter, in.	Initial Stress, psi	Minimum Stress at 1 per cent Extension, psi	
		Type BA	Type WA
0.192	29 000	[a]	200 000
0.196	29 000	192 000	200 000
0.250	29 000	192 000	192 000
0.276	29 000	[a]	188 000

[a] These sizes are not commonly furnished in type BA wire.

Elongation

8. The total elongation under load of all wire shall not be less than 4.0 per cent when measured in a gage length of 10 in. The elongation shall be determined by an extensometer which is placed on the test specimen after a load corresponding to the initial stress prescribed in Table III is applied. If the fracture takes place outside of the gage length, the elongation value obtained may not be representative of the material. If the elongation so measured meets the minimum requirements specified, no further testing is indicated; but if the elongation is less than the minimum requirements, the test shall be discarded and a retest made.

Permissible Variations in Dimensions

9. (*a*) The diameter of the wire shall not vary from the nominal diameter specified by more than ±0.002 in.

(*b*) The wire shall not be out-of-round by more than 0.002 in.

Cast

10. A wire sample of sufficient length, when laid free on a substantially flat surface, shall form an arc of a circle not less than 12 ft in diameter.

Button Anchorage

11. Type BA wire shall be of suitable quality to permit cold forming of buttons for anchorage. Splitting shall not be considered a cause for rejection if the button anchorage is capable of developing the full strength of the wire.

Number of Tests

12. Unless otherwise agreed upon between the manufacturer and the purchaser, one test specimen shall be taken from each 10 coils or less in a lot[3] and tested to determine compliance with Sections 6, 7, 8, 9, and 10.

Workmanship and Finish

13. (*a*) The wire shall be free from kinks.

(*b*) The wire shall be furnished in firmly tied coils, having a minimum inside diameter of 48 in. Each coil shall be of one continuous length.

(*c*) The wire shall not be oiled or greased. Slight rusting, provided it is not sufficient to cause pits visible to the naked eye, shall not be cause for rejection.

(*d*) Temper colors which may result from the stress-relieving operation are considered normal as regards the finished appearance of the wire.

Marking

14. The size of the wire, ASTM specification number, heat number, and name or mark of the manufacturer shall be marked on a tag securely attached to each bundle of wire.

Inspection

15. The purchaser shall state at the time of order whether outside inspection is required or waived. If outside inspection is required, the manufacturer shall afford the inspector representing the purchaser all reasonable facilities, without charge, to satisfy him that the material is being furnished in accordance with these specifications. All tests and inspections shall be made at the place of manufacture prior to shipment, unless otherwise agreed upon at the time of purchase, and shall be so conducted as not to interfere unnecessarily with the operation of the works. If outside inspection is waived, a manufacturer's certification that the material has been tested in accordance with and meets the requirements of these specifications shall be the basis of acceptance of the material.

Rejection

16. Unless otherwise specified, any rejection based on tests made in accordance with these specifications shall be reported to the manufacturer within a reasonable length of time.

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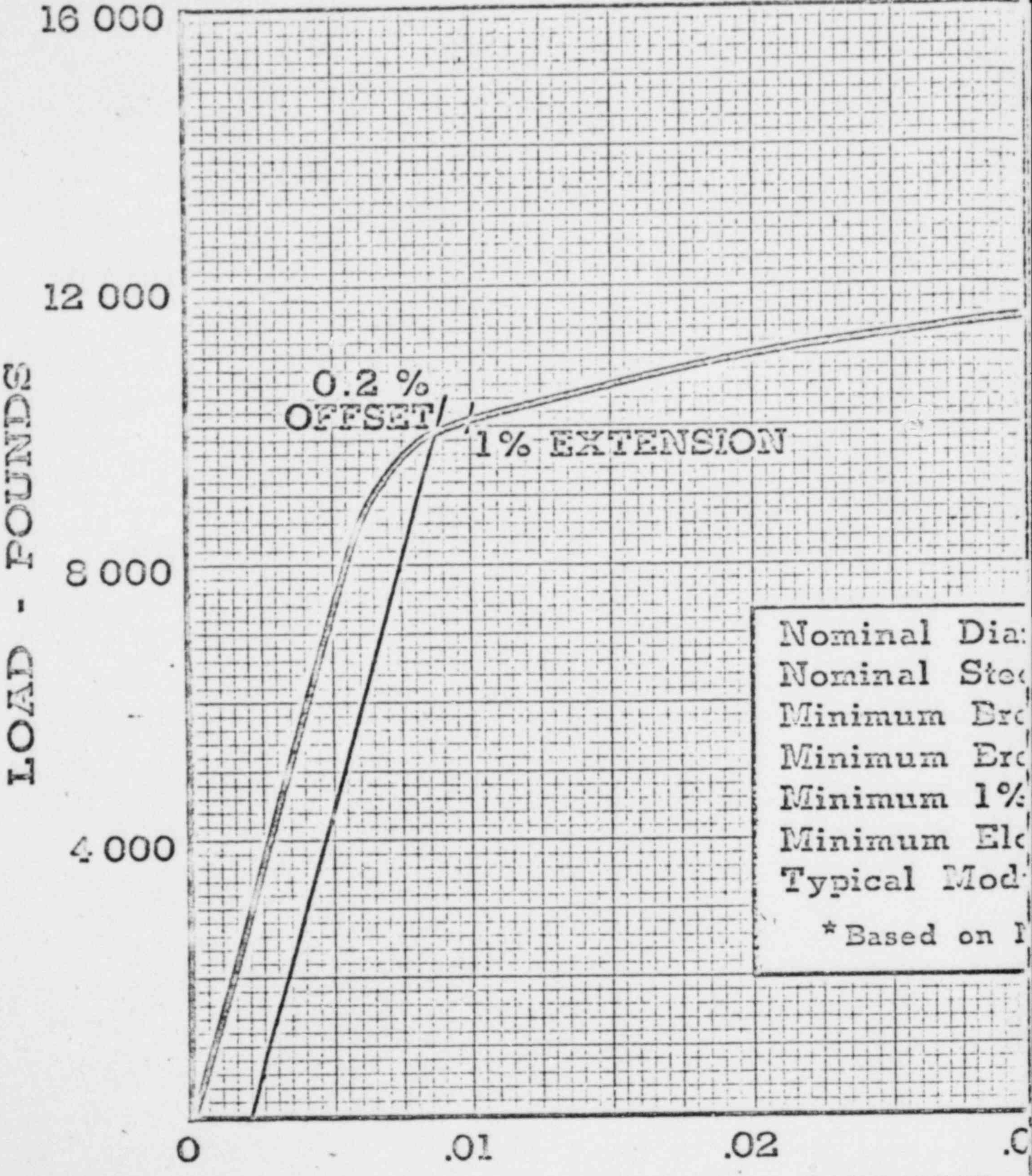
[3] The term "lot" means all the coils of wire of the same nominal wire size contained in an individual shipping release or shipping order.

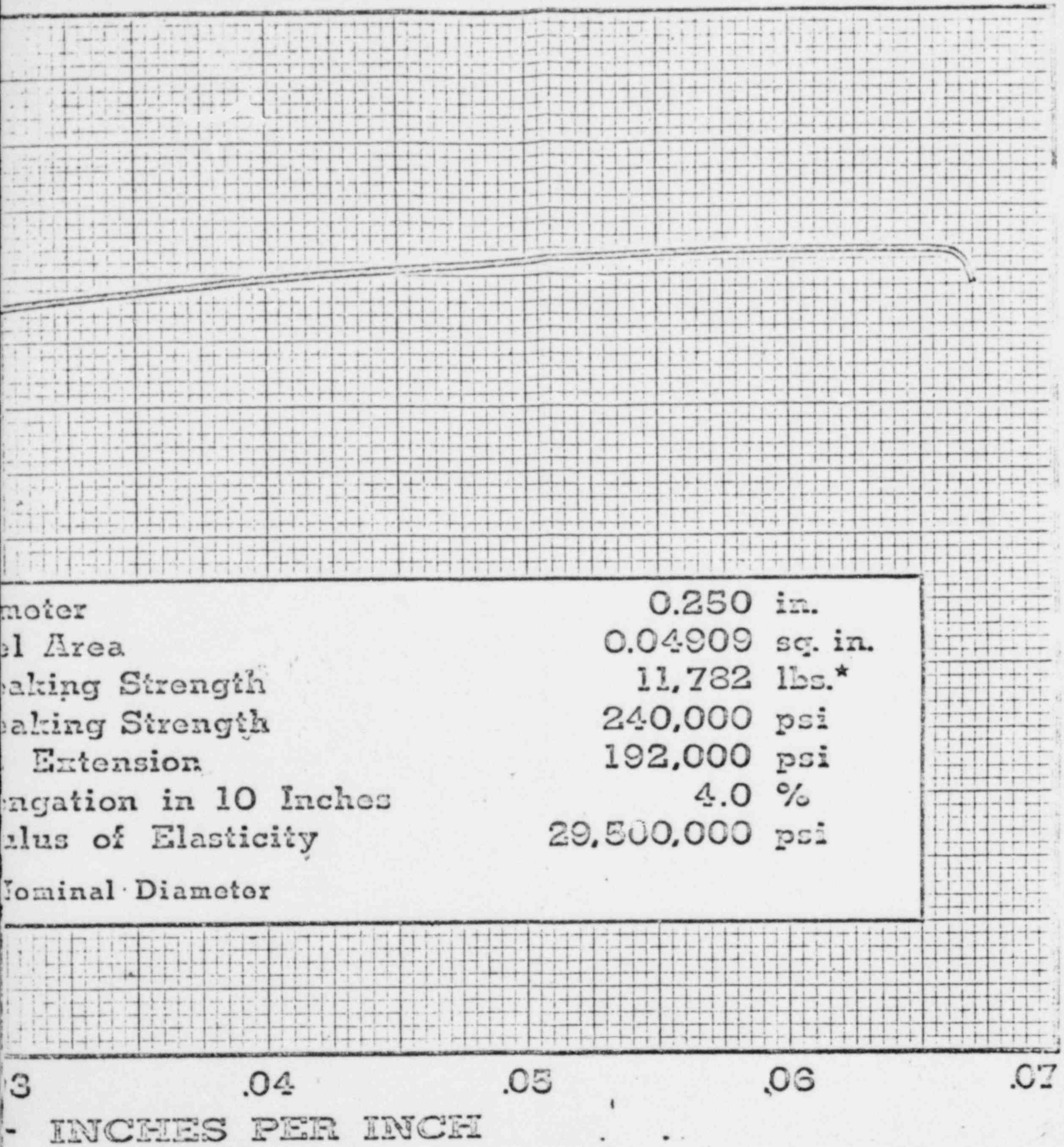
TYPICAL LOAD-STRAIN CURVE FOR



American Steel & W

Division

0.250" DIA SUPER-TENS STRESS-RELIEVED WIRE



moter	0.250	in.
el Area	0.04909	sq. in.
aking Strength	11,782	lbs.*
aking Strength	240,000	psi
Extension	192,000	psi
ngation in 10 Inches	4.0	%
lus of Elasticity	29,500,000	psi

ominal · Diameter

ire
of

United States Steel

0092

~~75~~

ARMCO
Sheffield Division
Union Wire Rope
Armco Steel Corporation
Kansas City 26, Missouri

CERTIFICATION OF TEST
TUFWIRE

DATE April 19, 1968

MINAL WIRE DIA. .250"

CUSTOMER Joseph T. Ryerson & Son Inc.
P. O. Box 8000-A
Chicago, Illinois

MIN. SPECIFICATIONS

REQ'D BREAKING STRENGTH 11,784 LBS. 240,000 P.S.I.

MINIMUM ELONGATION IN 10" 4.00 PERCENT

Customer Order No. OA 21161

SAMPLE NO.	ACTUAL DIAMETER	TENSILE STRENGTH LBS.	TENSILE STRENGTH P.S.I.	ELONGATION % IN 10"	SAMPLE NO.	ACTUAL DIAMETER	TENSILE STRENGTH LBS.	TENSILE STRENGTH P.S.I.	ELONGA % IN
1	.251	12,260	249,000.		31	.251	12,300	250,000	
2	.251	12,200	248,000		32	.251	12,300	250,000	
3	.251	12,080	246,000		33	.251	12,100	246,000	
4	.251	12,220	248,000	5.60%	34	.251	12,120	246,000	
6	.251	12,220	248,000		35	.251	12,040	245,000	
7	.251	12,240	249,000		36	.251	12,080	246,000	
	.251	12,340	251,000		37	.251	12,280	250,000	5.30
9	.250	12,280	250,000		38	.251	12,260	249,000	
10	.251	12,220	248,000		39	.251	12,220	248,000	
11	.251	12,080	246,000		40	.251	12,260	249,000	
12	.251	12,320	251,000		41	.251	12,340	251,000	
13	.251	12,400	252,000		42	.251	12,300	250,000	
14	.251	12,300	250,000		43	.250	12,220	248,000	
5	.251	12,000	244,000		44	.251	12,320	251,000	
16	.251	12,220	248,000		46	.251	12,260	249,000	
17	.251	12,180	248,000		48	.251	12,240	249,000	
18	.251	12,320	251,000	5.10%	49	.251	12,280	250,000	4.80
19	.251	12,380	252,000		50	.251	12,060	245,000	
20	.251	12,360	251,000		51	.250	12,220	248,000	
21	.251	12,200	248,000		52	.251	12,000	244,000	
25	.251	12,160	247,000		54	.251	12,240	249,000	
26	.251	12,320	251,000		55	.251	12,160	247,000	
27	.251	12,320	251,000		56	.251	12,120	246,000	
30	.251	12,480	254,000		57	.251	12,140	247,000	

48 Coils, 40,325 lbs

A S T M Specification A 421-65

HEAT NO: 30636

ANALYSIS: .81 C .85 MN .010 P .023 S .26 SI

WEIGHT OF ORDER

THE PHYSICAL OR MECHANICAL TESTS REPORTED ABOVE ARE CORRECT AS CONTAINED IN THE RECORDS OF THE COMPANY

Subscribed and sworn to before me a Notary Public,
in and for Jackson County, the State of Missouri,
This the [illegible] day of [illegible]...... 19[illegible]

My Commission Expires Apr. 5 1970

BY

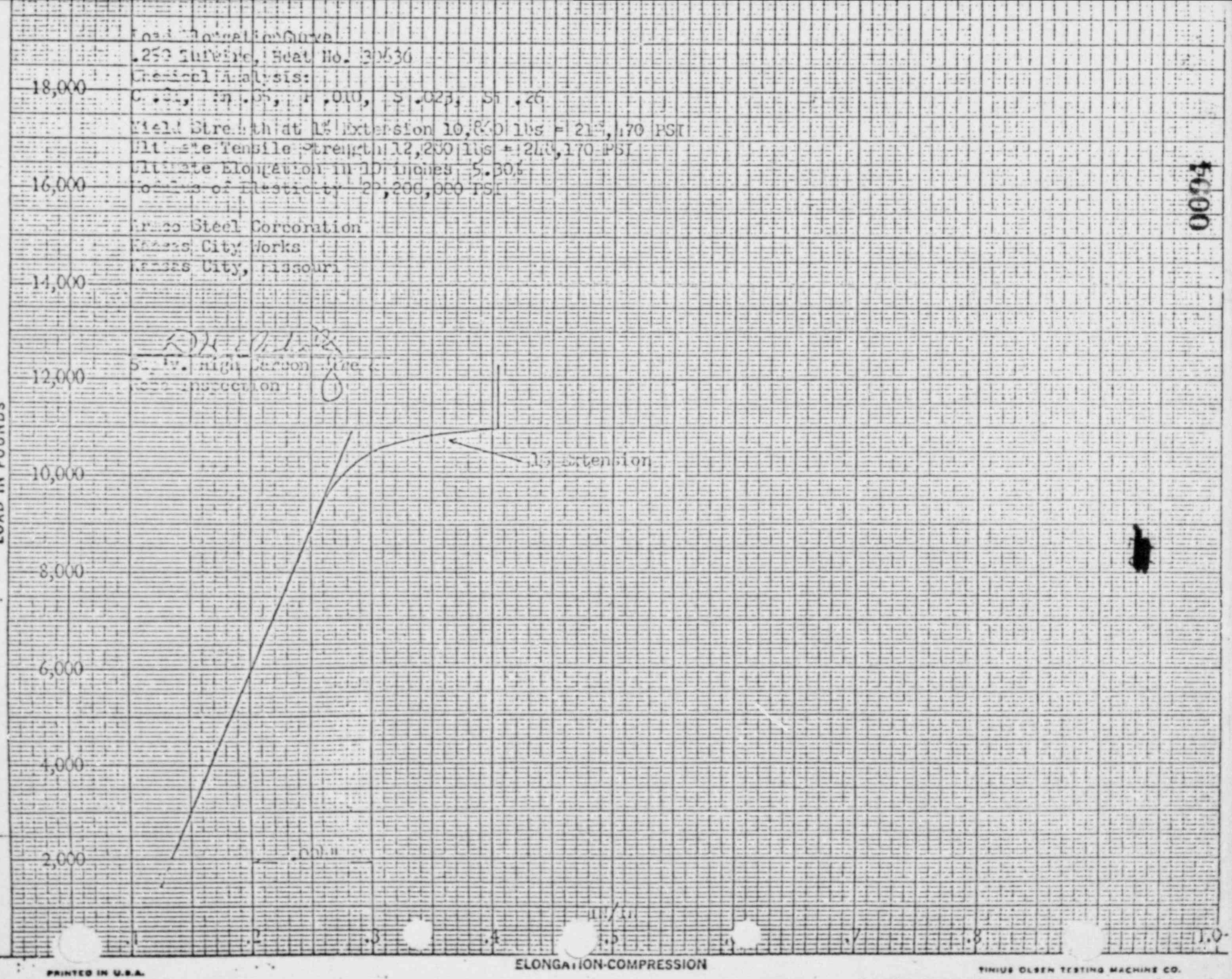
TITLE Sup'v. High Carbon Wire Rope Inspection

0093

MU-1966 REV. 8/62

Test No. Size. Area. Yield Point Lbs. Sq. In. Ultimate Str. Lbs. Sq. In.

Elongation / Compression } In. Inches. Per Cent. Elongation. Per Cent. Reduced Area. Date.



Load Elongation Curve
.250 Inwire, Heat No. 30636
Chemical Analysis:
C [illegible], Mn .65, P .010, S .023, Si .26

Yield Strength at 1% Extension 10,860 lbs = 215,170 PSI
Ultimate Tensile Strength 12,200 lbs = 248,170 PSI
Ultimate Elongation in 10 inches 5.30%
Modulus of Elasticity 29,200,000 PSI

Armco Steel Corporation
Kansas City Works
Kansas City, Missouri

Supv. High Carbon Wire
Rope Inspection

PRINTED IN U.S.A.

TINIUS OLSEN TESTING MACHINE CO.

3

FORM 407 REV.

PITTSBURGH TESTING LABORATORY

ESTABLISHED 1881

PITTSBURGH, PA.

LABORATORY No. 646099

October 24, 1966

ORDER No. CH-9583

CLIENT'S No. 21E341903-18

REPORT

Report of: Compression Tests of 90-Wire
Anchor Head Assembly

Report to: Joseph T. Ryerson & Son, Inc.
P. O. Box 8000-A
Chicago, Illinois 60680

We received two (2) 90-wire anchor head assemblies for compression tests in accordance with Drawing 90-PT-1A, 90-PT-2A and addendum dated 10/11/66.

The shims and anchor heads were assembled, loaded for two minutes and disassembled for examination in accordance with the drawings. The following observations were recorded.

ANCHOR HEAD ASSEMBLY 90-PT-1

Load	Remarks
742,000 lbs.	Button headed wires deformed anchor head. The 1/16" and 1/8" shims deformed slightly. Anchor head loosens by hand from adaptor lock nut.
848,000 lbs.	No apparent deformations except as noted above. Anchor head loosens by hand from adaptor lock nut.
954,000 lbs.	No apparent deformations except as noted above. Anchor head loosens by hand from adaptor lock nut.
1,007,000 lbs.	No apparent deformations except as noted above. Anchor head loosens by hand from adaptor lock nut.
1,060,000 lbs.	No apparent deformations except as noted above. Anchor head loosens by hand from adaptor lock nut.
1,200,000 lbs.	Deformations from the shim plates visible on adaptor. Anchor head no longer loosens by hand.

FORM 407 REV.

PITTSBURGH TESTING LABORATORY
ESTABLISHED 1881
PITTSBURGH, PA.

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LABORATORY No. 646099
ORDER No. CH-9583

CLIENT'S No. 21T341903-18

October 24, 1966

REPORT

ANCHOR HEAD ASSEMBLY S0-PT-2

Load	Remarks
742,000 lbs.	Button headed wires deformed anchor head. The 1/16" and 1/8" shims deformed slightly.
848,000 lbs.	No apparent deformations except as noted above.
954,000 lbs.	No apparent deformations except as noted above.
1,007,000 lbs.	No apparent deformations except as noted above.
1,060,000 lbs.	No apparent deformations except as noted above.
1,200,000 lbs.	No apparent deformations except as noted above.

PITTSBURGH TESTING LABORATORY

Earl Gallagher

Earl Gallagher, Manager
Physical Testing Department

cc: 3-Joseph T. Ryerson & Son, Inc.
Attn: Mr. Richard H. Tresselt
1-PTL Chicago

vs [redacted] Page 2 of 2

COMPRESSION TEST PROCEDURE

TEST OF 90 WIRE ANCHOR HEAD ASSEMBLY

SET UP TEST IN MACHINE PER DRAWING 90-PT-1A

APPLY COMPRESSION TO DESIGNATED LOAD (SEE TABLE BELOW)
(THIS IS A STATIC TEST, APPLY + RELEASE LOADS ACCORDINGLY)

HOLD EACH LOAD FOR A PERIOD OF TWO MINUTES

RELEASE LOAD AND DISASSEMBLE

CHECK AND REPORT ON ALL DEFORMATIONS, CRACKS, OR OTHER SIGNS OF FAILURE IN THE ANCHOR HEAD, ADAPTOR LOCK NUT, AND/OR TUBE SHIMS.

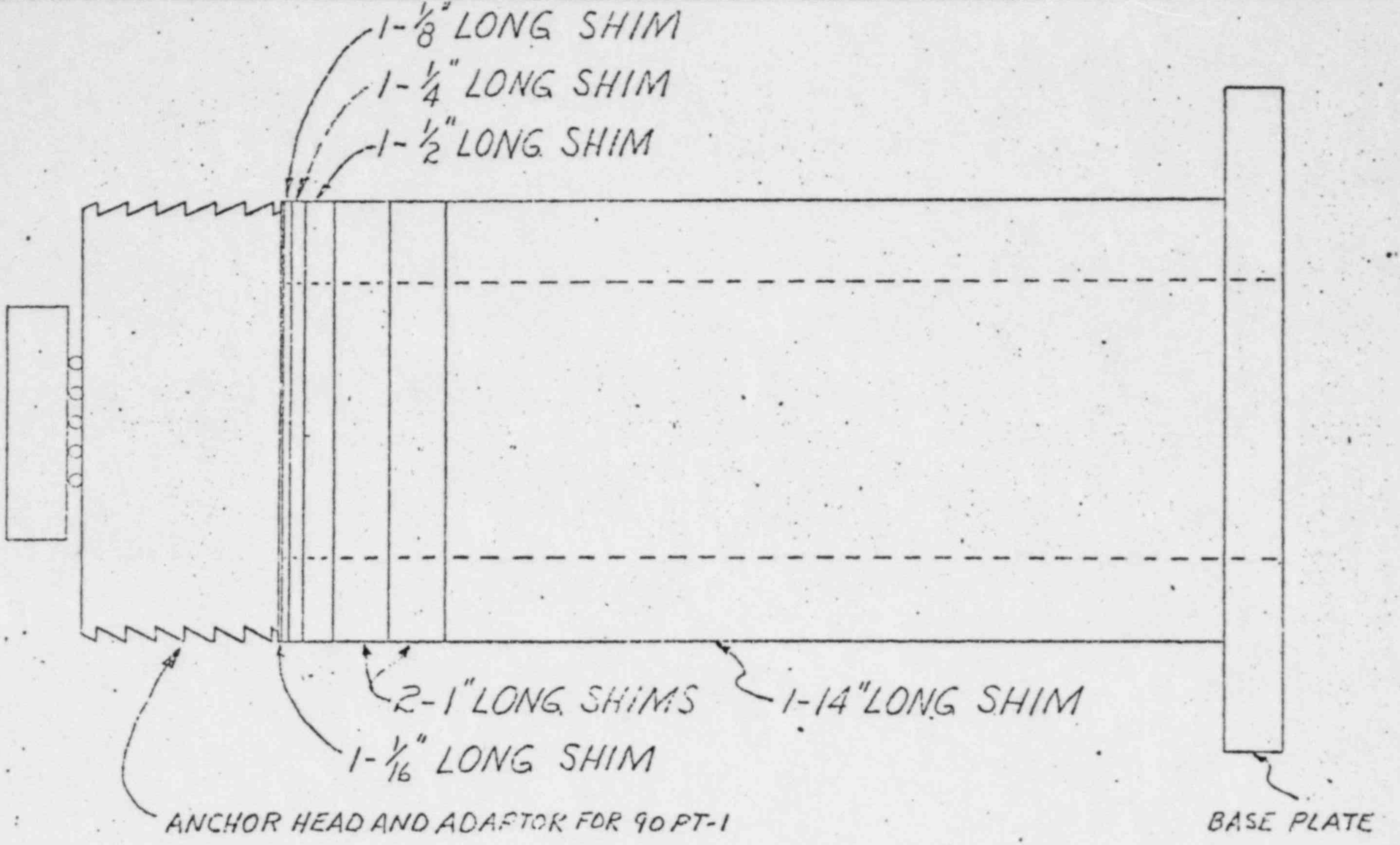
REASSEMBLE AND REPEAT AT NEXT HIGHER LOAD.

LOAD TABLE

742,000 LBS.	1,007,000 LBS.
848,000 "	1,060,000 "
954,000 "	MACHINE MAXIMUM

MADE BY	DATE		
RHT	7-25-66	RYERSON JOSEPH T. RYERSON & SON, INC. METALOGICS	CUSTOMER WIRE TEST
90-PT-1			ANCHOR HEAD

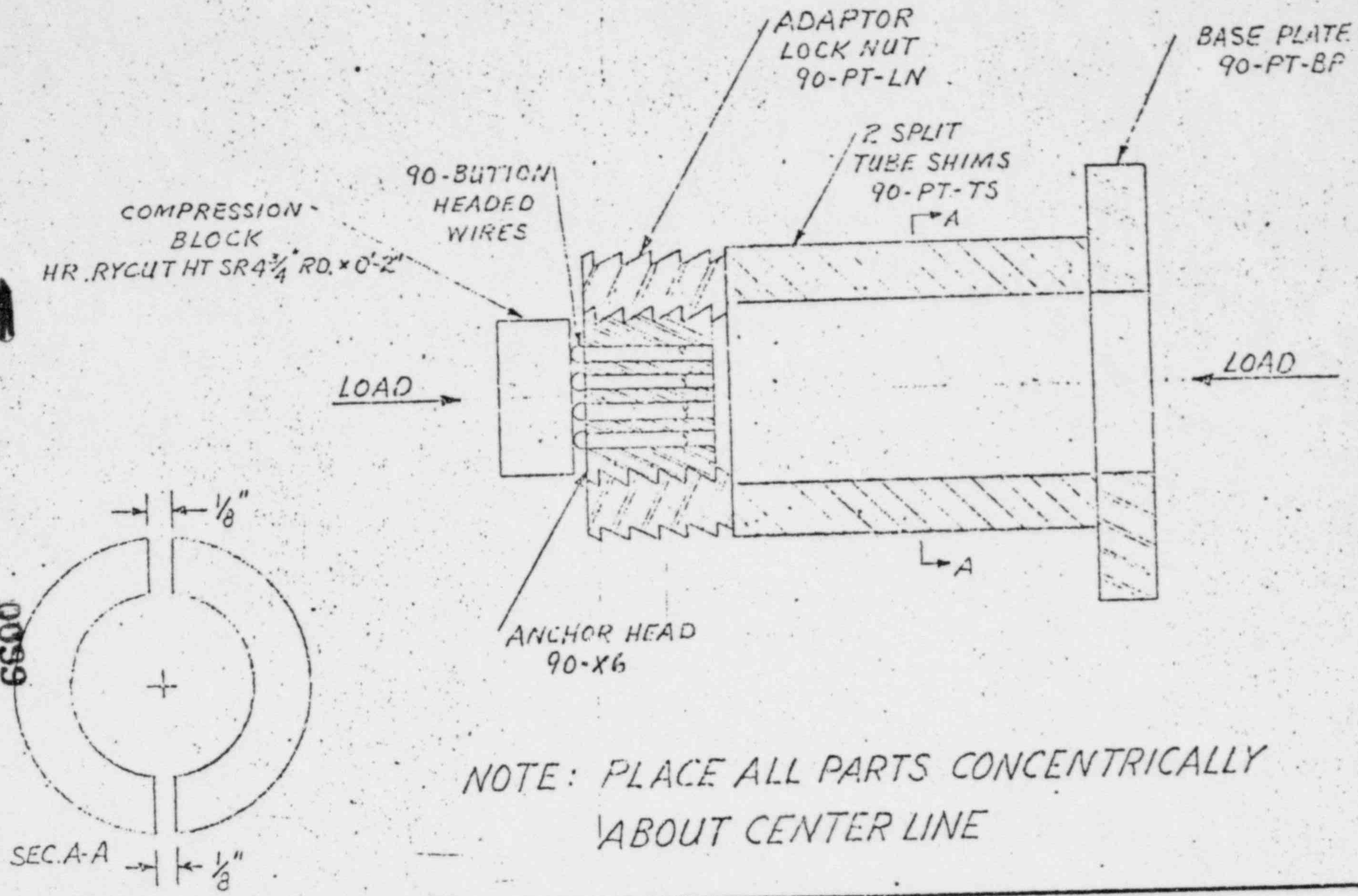
FORM 750.12-2 APR. 63



FOR TESTS 90-PT1 + 90-PT2 NOTE: CHANGE IN SHIMS TO BE APPLIED

MADE BY RHT	DATE 10-11-66	RYERSON JOSEPH T. RYERSON & SON, INC. METALOGICS
90-PT-1A+2A ADD		CUSTOMER SHIM REVISION

FORM 750.12-2 APR. 63

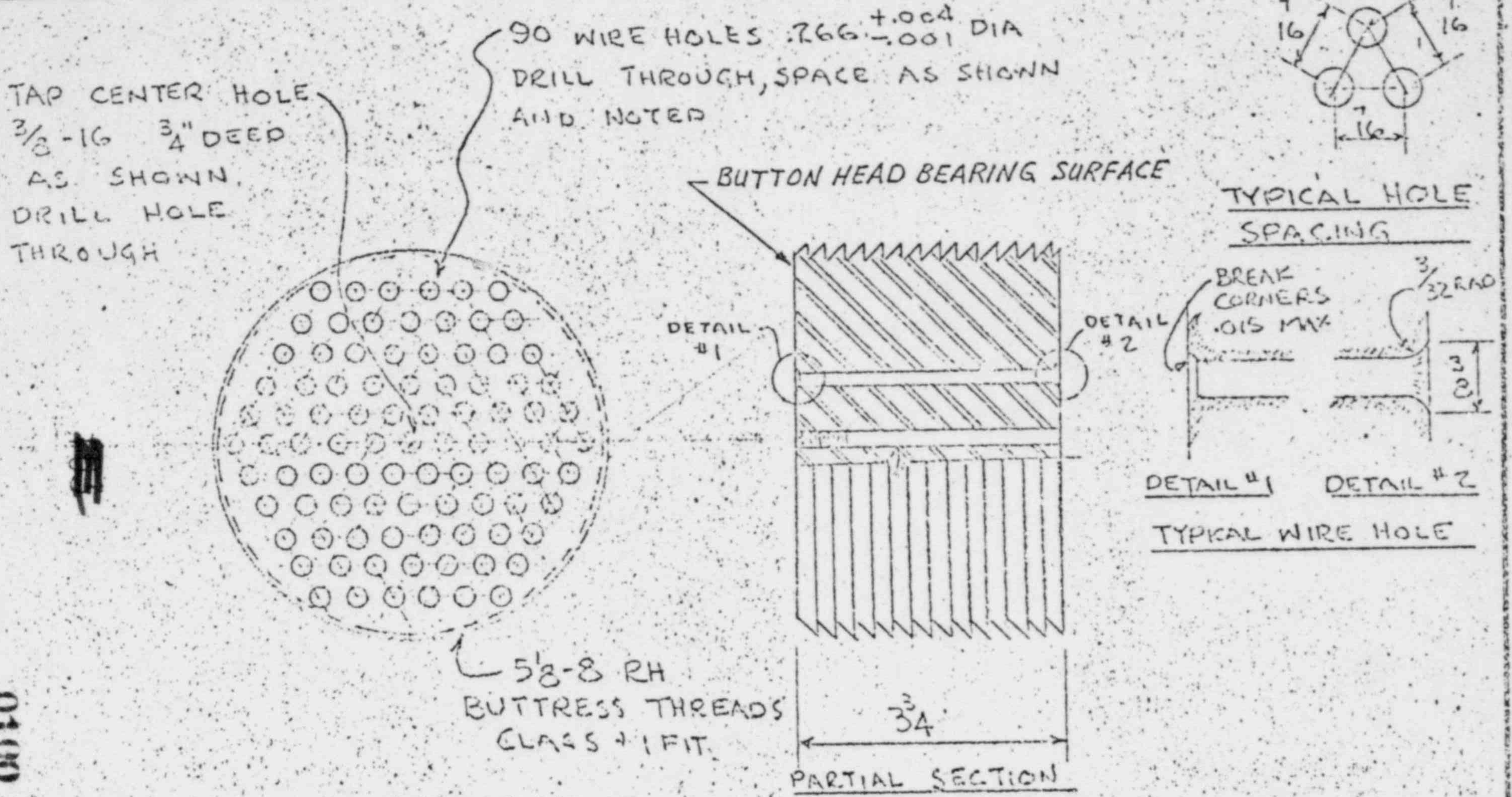


NOTE: PLACE ALL PARTS CONCENTRICALLY
ABOUT CENTER LINE

0099

MADE BY	DATE	RYERSON METALOGICS	CUSTOMER
RHT	10-8-66	JOSEPH T. RYERSON & SON, INC.	
90-PT-1A			

FORM 750.12-2 APR. 63



0100

90 WIRE ANCHOR HEAD

NOTICE

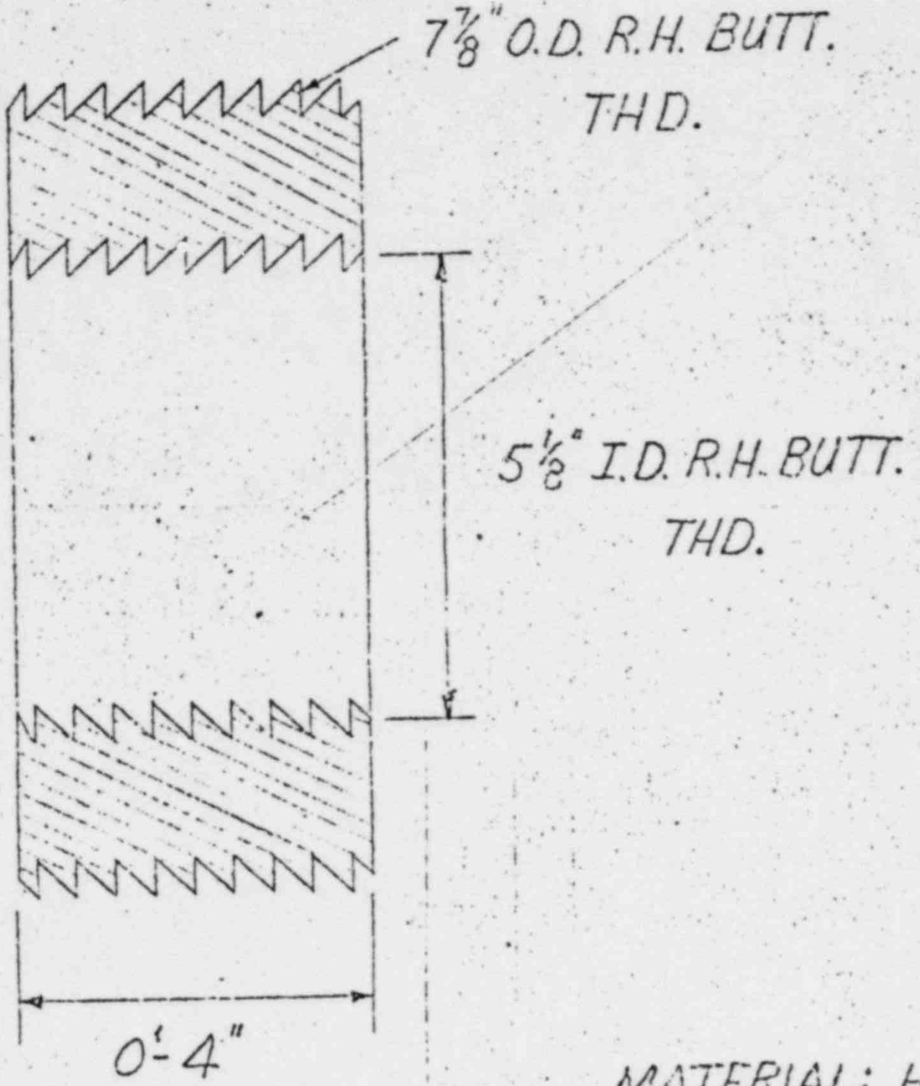
This drawing has not been published, it is the sole property of Joseph T. Ryerson & Son, Inc. It is lent to the recipient for his confidential use only, and upon the conditions and agreements following. In consideration of the loan of this drawing, the recipient promises and agrees to return it upon request, and that it shall not be reproduced, copied, lent or otherwise disposed of, directly or indirectly without Joseph T. Ryerson & Son, Inc. written consent, nor be used in any way detrimental to the interests of Joseph T. Ryerson & Son, Inc.

MATERIAL
C1141 5¼ DIA H.R. ROUND

HEAT TREAT

MADE BY	DATE	RYERSON JOSEPH T. RYERSON & SON, INC.	METALOGICS	CUSTOMER
CLYDE	6-1-66			
90-X6				

FORM 750.12-2 APR. 63



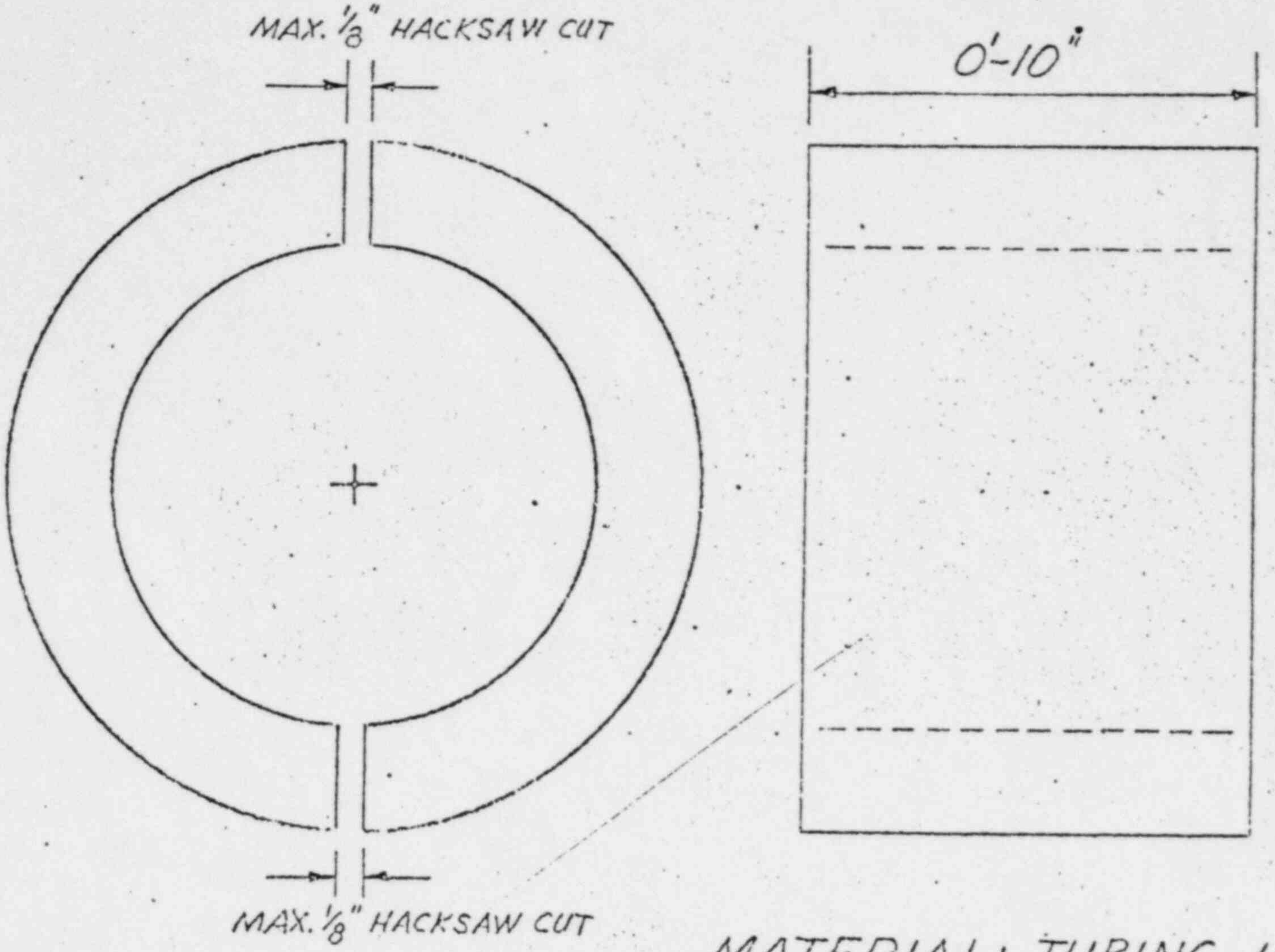
MATERIAL: HR1141 8"RD. × 0'-4"

MADE BY RHT
DATE 10-8-66
90-PT-LN

RYERSON
JOSEPH T. RYERSON & SON, INC.
METALOGICS

CUSTOMER
ADAPTOR LOCK NUT

0101



MATERIAL: TUBING HFSM
8" O.D. × 1 1/4" WALL × 0'-10"

MADE BY RHT	DATE 10-10-66
90-PT-TS	

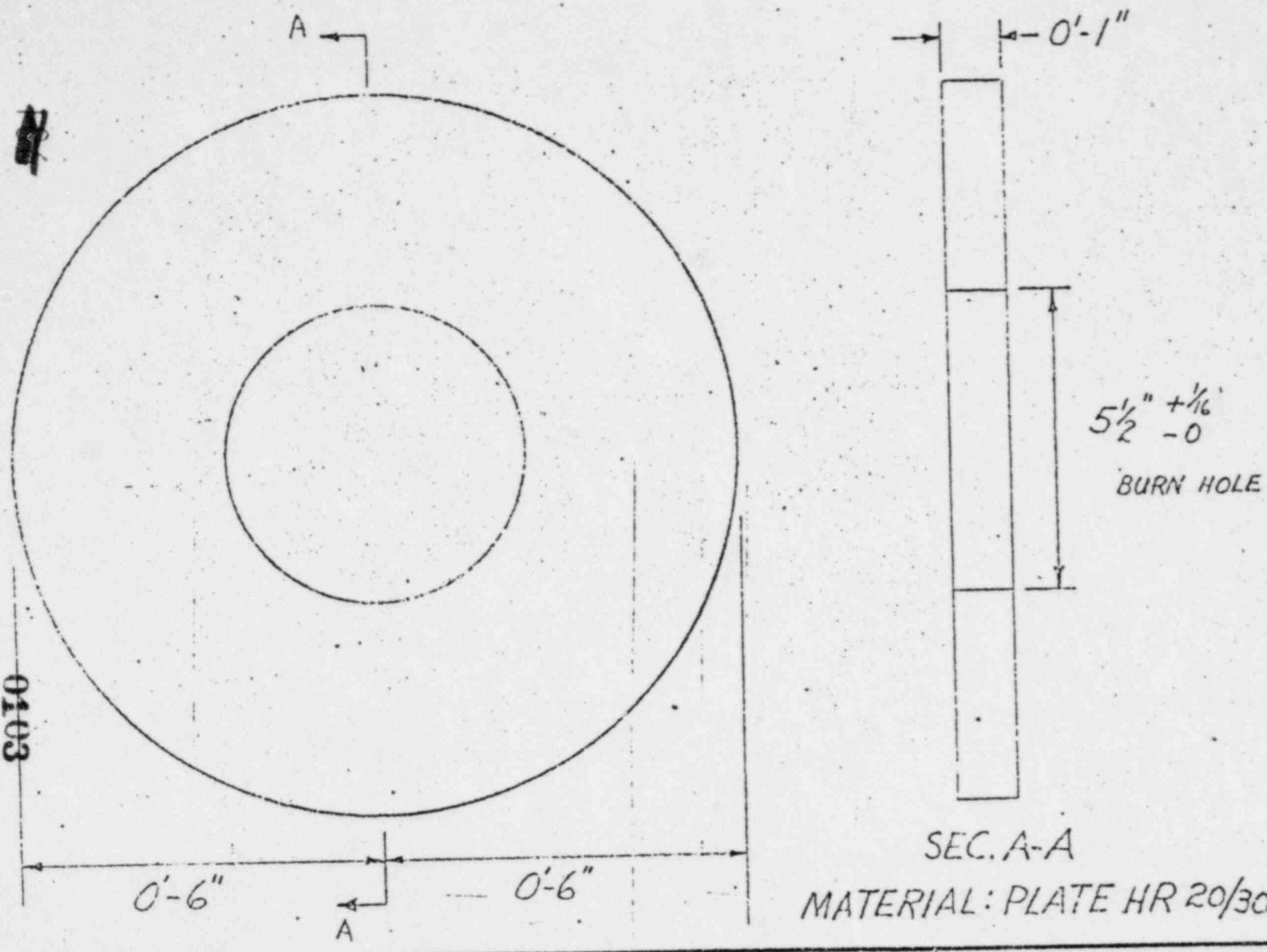
RYERSON
JOSEPH T. RYERSON & SON, INC.
METALOGICS

CUSTOMER TUBE SHIMS
FOR TEST ONLY

FORM 750.12-2 APR. 63

1

0103



SEC. A-A

MATERIAL: PLATE HR 20/30 C

MADE BY	DATE
RHT	10-6-66

90-PT-BP

RYERSON
JOSEPH T. RYERSON & SON, INC.
METALOGICS

CUSTOMER BASE PLATE

FOR TEST ONLY

780 12-2 APR 63

FORM 407 REV.

PITTSBURGH TESTING LABORATORY

ESTABLISHED 1881

PITTSBURGH, PA.

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LABORATORY No. 652603

March 29, 1967

ORDER No. PS-10519

CLIENT'S No. 2KT114-3

REPORT

Report of: Compressive Load Tests of
90 Wire Tendon Base Plate
Test on Concrete Stand

Report to: Joseph T. Ryerson & Son, Inc.
P. O. Box 8000A
Chicago, Illinois 60680

We were requested to fabricate a concrete base plate in accordance with Ryerson Drawing SPI-1 dated 1/20/67. A concrete mix design, reinforcing bars, base plate and trumpet were submitted for fabrication of the concrete base plate.

The following concrete properties were recorded.

CONCRETE MIX DESIGN PER CU. YD.

Type III Portland Cement	611 lbs.
Dravo Corp. Siliceous Sand ASTM C-33	1240 lbs. S.S.D.
Dravo Corp. Siliceous Gravel 1" Size	1850 lbs. S.S.D.
Water	300 lbs.
Slump	4 inches

COMPRESSIVE STRENGTHS

Date of Testing	Sectional Area Sq. In.	Crushing Load Lbs.	Crushing Strength PSI	Age Days
March 8, 1967	28.27	92,000	3250	2
March 8, 1967	28.27	81,000	2870	2
			3060 Average	
March 9, 1967	28.27	115,000	4070	3
March 9, 1967	28.27	120,000	4240	3
			4150 Average	
March 10, 1967	28.27	124,000	4390	4
March 10, 1967	28.27	121,000	4280	4
			4340 Average	

LABORATORY No. 652408

March 29, 1967

ORDER No. PG-18619

CLIENT'S No. 21T114-3

REPORT

When the concrete in the stand had reached the requested strength, the stand was tested by the following method.

A compressive load of 742,000 lbs. was applied in increments of 106,000 lbs., and then released in increments of 106,000 lbs. The gage readings tabulated below were obtained using a deflectometer designed as shown on Page 5 of Ryerson instructions dated 2/2/67.

Cycle One was repeated, recording the same gage readings.

On the third cycle, dial gage readings were recorded only up to 742,000 lbs. The loading continued in 106,000 lbs. increments to 1,200,000 lbs. At 954,000 lbs. hairline cracks appeared on the sides of the stand. There were no other apparent defects at 1,200,000 lbs.

The dial gage instrument was designed so that measurements, either compressive or expansive, were recorded at a specified distance from the center line of the concrete stand or metal base plate.

Gage No.	Location
1	On the concrete 3 inches from edge of base plate.
2	On the base plate 7-1/2 inches from center line of stand.
3	On the base plate 4-3/4 inches from center line of stand.
4	On the base plate 6 inches from center line of stand.
5	On the concrete 1 inch from edge of base plate.

LABORATORY No. 652408

March 29, 1967

ORDER No. PG-10619

CLIENT'S No. 21T116-3

REPORT

LOAD DEFORMATION MEASUREMENTS

1st Loading

Load Pounds	Gage				
	∅1	∅2	∅3	∅4	∅5
0	.000	.000	.000	.000	.000
106,000	-.001	.000	.002	.001	.000
212,000	-.002	.001	.006	.004	-.001
318,000	-.002	.002	.009	.005	-.004
424,000	-.003	.002	.011	.007	-.007
530,000	-.004	.003	.013	.009	-.009
636,000	-.005	.004	.016	.011	-.010
742,000	-.006	.004	.018	.013	-.012
636,000	-.006	.004	.017	.012	-.013
530,000	-.005	.004	.016	.012	-.013
424,000	-.005	.004	.015	.011	-.012
318,000	-.004	.003	.014	.010	-.012
212,000	-.004	.003	.012	.008	-.012
106,000	-.001	.002	.009	.006	-.012
0	.000	.000	.003	.002	-.002

2nd Loading

0	.000	.000	.000	.000	-.002
106,000	-.002	.001	.004	.003	-.007
212,000	-.003	.002	.004	.004	-.009
318,000	-.004	.003	.009	.006	-.011
424,000	-.005	.003	.010	.007	-.012
530,000	-.005	.003	.012	.008	-.013
636,000	-.006	.004	.013	.010	-.014
742,000	-.006	.004	.015	.011	-.015
636,000	-.006	.004	.014	.010	-.0145
530,000	-.006	.004	.013	.010	-.014
424,000	-.005	.0035	.012	.0085	-.013
318,000	-.005	.003	.011	.0075	-.0125
212,000	-.004	.003	.009	.006	-.0115
106,000	-.003	.002	.005	.004	-.010
0	.000	.000	.000	.000	-.002

FORM 407 REV.

PITTSBURGH TESTING LABORATORY

ESTABLISHED 1881

PITTSBURGH, PA.

LABORATORY No. 652403

March 29, 1967

ORDER No. FG-10619

CLIENT'S No. 21T114-3

REPORT

LOAD DEFORMATION MEASUREMENTS

3rd Loading

Load	Gage				
Pounds	01	02	03	04	05
0	.000	.000	.000	.000	-.002
106,000	-.003	.002	.004	.003	-.009
212,000	-.004	.002	.007	.0045	-.011
318,000	-.004	.003	.009	.006	-.012
424,000	-.005	.003	.011	.007	-.013
530,000	-.006	.0035	.012	.0085	-.014
636,000	-.006	.004	.0135	.010	-.015
742,000	-.007	.004	.015	.011	-.0155

954,000 Hair line cracks visible.

PITTSBURGH TESTING LABORATORY

Earl Gallagher

Earl Gallagher, Manager
Physical Testing Department

cc: 3-Ryerson Steel
1-PTL Chicago

BASEPLATE FOR 90-WIRE TENDON

A. LOADS

Loads developed by the 90-wire tendon:

Ultimate Strength: 1060^k

Overstressing Force: 848^k

Initial Force: 742^k*

Final Force: 636^k

*Design force for baseplate

B. SIZE

OD Diameter: 18-1/2" → 269 Sq. In.

ID Diameter: 6" → 29 Sq. In.

Net Bearing Area: 240 Sq. In.

Plate Thickness: 2-1/2"

C. BEARING STRESSES

1. Average Stress: 742,000/240 = 3909 psi
2. Minimum Spacing of Baseplates in 4000 Psi Concrete (Complying with ACI-318, Section 2605):

$f'_c = f'_{ci} = 4000$ psi

$f_{cp} = 0.6 \times 4000 \sqrt[3]{A'_b/269} = 3090$

$A_b = 573$ Sq. In.

Minimum Spacing = $\sqrt{573}$ = 2.4'
= 2'-4-1/2"

3. Check Baseplate in 5000 Psi Concrete:

$f'_c = f'_{ci} = 5000$

$.6 \times 5000 = 3000 \approx 3090$

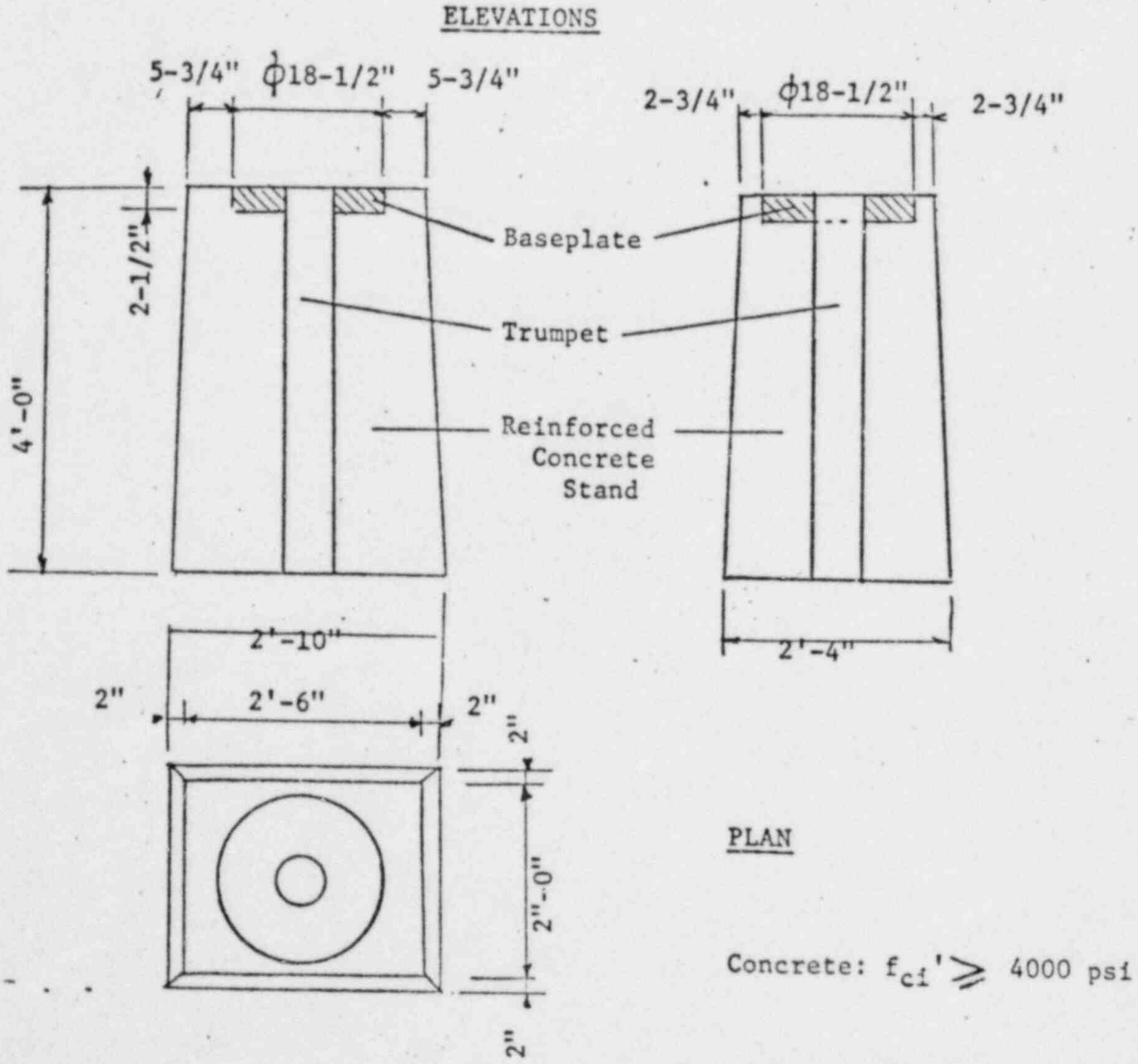
∴ Baseplate o.k. in 5000 psi concrete without separation.

D. BASEPLATE TEST

To verify the adequacy of plate thickness and plate material strength, the following test is proposed:

1. Test Setup

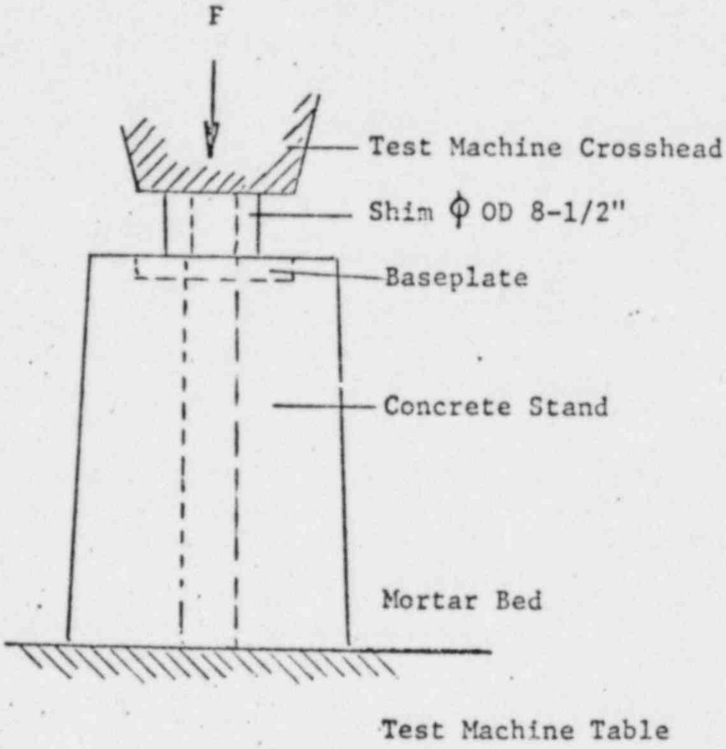
See Ryerson drawing SPT-1, dated 1-20-67.



Concrete: $f_{ci}' \geqslant$ 4000 psi

2. Application of Load

Concrete Strength
$f_{ci}' \geqslant 4000$ psi



a) Apply load in increments of 106^k to 742^k maximum.

b) Release load in increments of 106^k to zero.

c) Repeat a) and b).

d) Apply load in increments of 106^k to failure or test machine to capacity.

e) Measure deformations after each load increment of a), b), and c). (Setup see 3.)

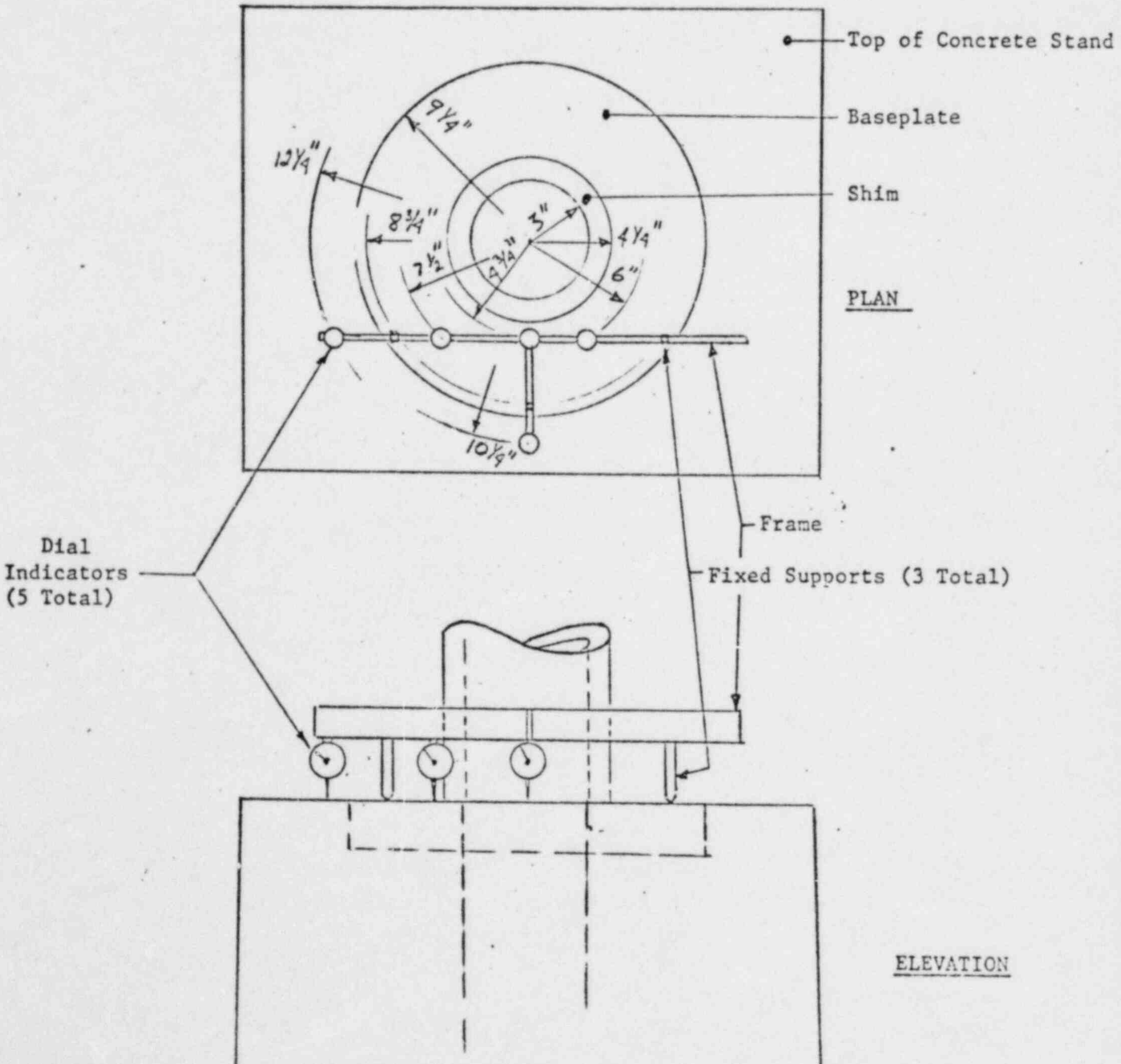
f) Observe concrete stand (for cracks).

3. Deformation Measurements

The instrumentation is shown only to illustrate the required readings. (See drawing next page).

[redacted]

DEFORMATION MEASUREMENTS



4. Anticipated Test Results

a) Observation of Concrete Stand

It is anticipated that the concrete stand does not crack (other than hairline cracks) up to the design load of 742^k. The hairline cracks to close after removing of the load. Spalling of the unreinforced (and nonstructural) concrete around the baseplate may occur and is insignificant.

b) Observation of the Baseplate

It is anticipated that the plate material is not subjected to stresses greater than the yield strength up to the design load of 742^k. The deformation measurements should therefore vary linear with the load and indicate complete (90%) recovery during unloading. The amount of deformation measurements to be determined later (maximum reading < 1/16").

The edge of the baseplate should stay flush with the edge of concrete. Slight seating in is permissible; "curling up" indicates undesirable uneven bearing stress distribution.

5. Concrete Mix

4000 psi concrete using a dolomitic limestone coarse aggregate with a 1" top size and a natural sand for fine aggregate, complying with ASTM C-33.

Perform the test if concrete test cylinders indicate a strength greater than 4000 psi. Test cylinders shall be broken on the same day as the bearing plate test is performed.

6. Baseplate Material

In compliance with ASTM A-36.

4

FORM 407 REV.

PITTSBURGH TESTING LABORATORY
ESTABLISHED 1881
PITTSBURGH, PA.

LABORATORY No. 655506

June 5, 1967

ORDER No. PG-18619

CLIENT'S No. Ltr. 3/13/67

REPORT

Report of: 90 Wire Tendon Test

Report to: Joseph T. Ryerson & Son, Inc.
P. O. Box 8000-A
Chicago, Illinois 60680

We received a sample which was identified to us as a 90 wire tendon. We were requested to test the sample in tension measuring elongation over a 120" gage length.

The sample consisted of 90 wires, 1/4" in diameter, with anchor heads on each end. The anchor heads were held on the wire by the wire button heads. The anchor head had external threads which threaded into a coupler. The coupler then threaded onto pull rods, 8" in diameter, which were installed in the upper and lower cross heads of our 1,200,000# testing machine.

An extensometer, modified to give a 120" gage length, was used to record sufficient data to plot the attached curve.

PITTSBURGH TESTING LABORATORY

Earl Gallagher

Earl Gallagher, Manager
Physical Testing Department

cc: 3-Client
1-PTL Chicago

VS

2-3-67

90-WIRE TENDON TEST

The purpose of this test is to verify that a tendon consisting of 90 wires, the wires being anchored at each end in anchorheads by means of buttonheads, is 90 times as strong as one wire. The test further allows the measuring of tendon elongation.

The complete end anchors have been previously tested beyond the ultimate strength of the tendon (see Ryerson 90-PT-1, dated 7-25-66 and 90-PT-2, dated 7-25-66 and the corresponding test report from PTL, dated 10-24-66).

A. LOAD

Minimum guaranteed ultimate strength of 1/4" diameter wire (see ASTM-421): 240,000 psi.

Minimum guaranteed ultimate strength of 90-wire tendon:
90 x 0.04909 x 240,000 = 1,060,000#.

Minimum yield strength of 90-wire tendon, measured under load at 1.0% extension: 80% x ultimate strength = 848,000#.

Anticipated test result: No wire break will occur before the load of 1060^k is reached.

B. ELONGATION

Minimum tendon elongation: 3%, measured under load in minimum gauge length of 10 ft. The elongation is to be measured as movement between the anchorheads.

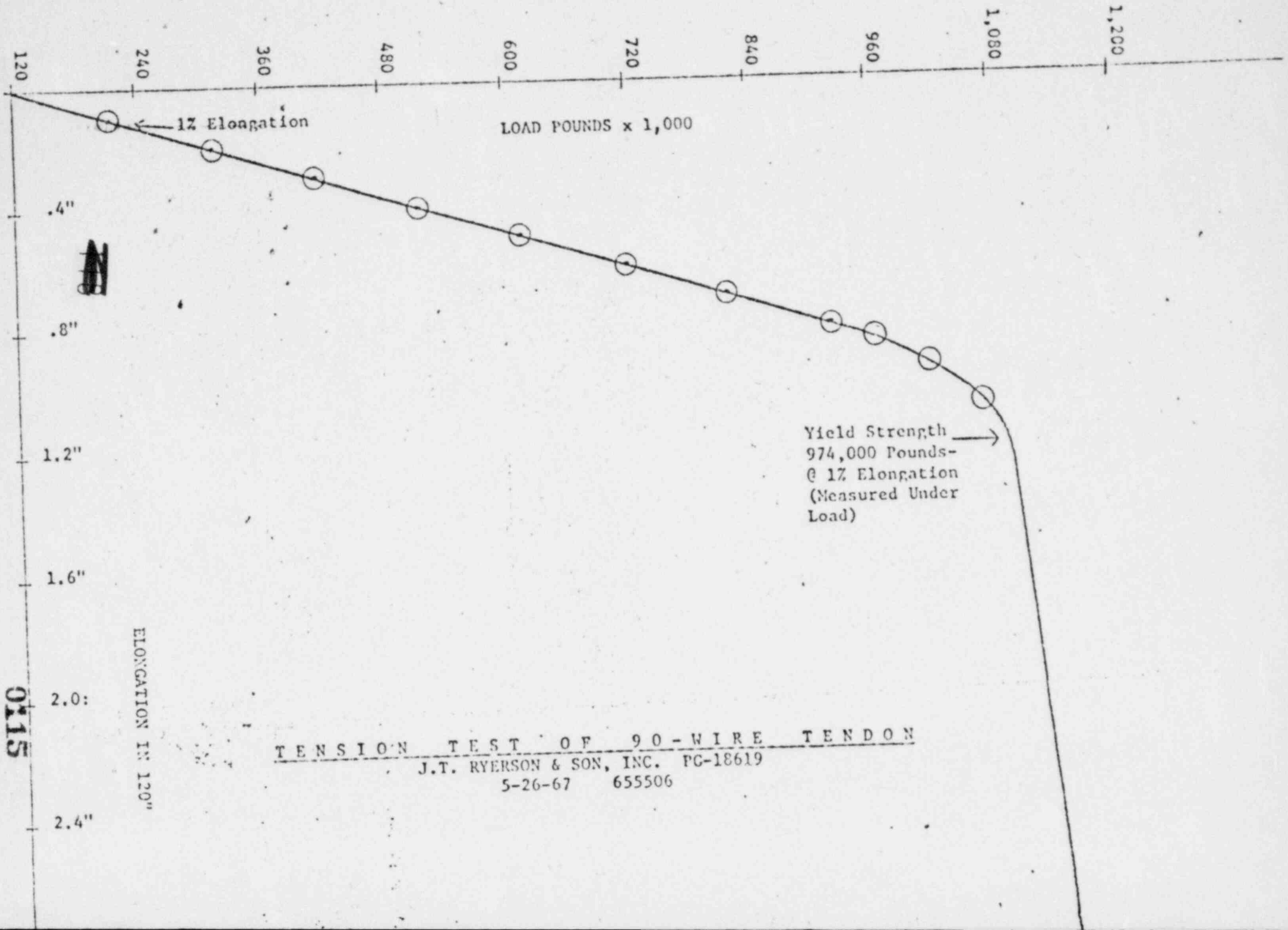
The wire length for the test tendon is 10'-0" → 120".

The method of measuring elongation shall be similar to the one specified in ASTM-421.

Initial elongation: 0.1% → 0.12" → 1/8"
Initial stress: 29,000 psi → 128^k

Yield at 1% extension: 1.20" → 1-3/16"
Minimum yield strength: 848^k

Minimum elongation: 3% → 3.60" → 3-5/8"
is to be reached before the first wire breaks



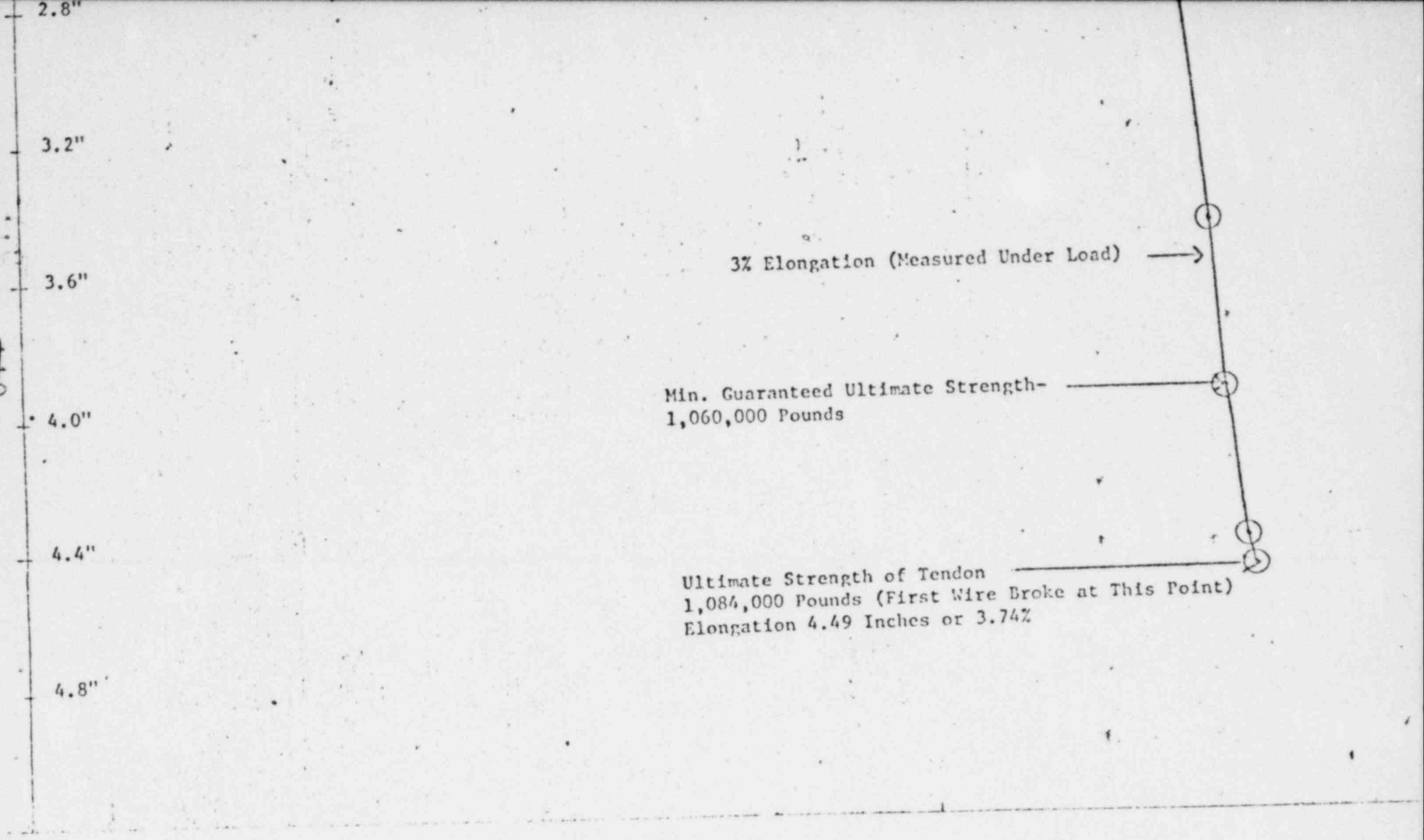
1% Elongation

Yield Strength
974,000 Pounds-
@ 1% Elongation
(Measured Under
Load)

TENSION TEST OF 90-WIRE TENDON

J.T. RYERSON & SON, INC. PC-18619

5-26-67 655506



3% Elongation (Measured Under Load)

Min. Guaranteed Ultimate Strength-
1,060,000 Pounds

Ultimate Strength of Tendon
1,084,000 Pounds (First Wire Broke at This Point)
Elongation 4.49 Inches or 3.74%

FRICTION TESTING ON LARGE, MULTIWIRE POST-TENSIONING TENDONS

by Howard Wahl and Ted Brown

With the advent of nuclear structures requiring large amounts of circumferential prestressing force, designers became concerned over the potential force loss due to friction. Attempting to apply the values suggested in ACI-318, Section 2607, appeared to be ultra-conservative for large parallel-wire tendons.

Other areas of little experience also concerned the designers and constructors of these structures -- such things as handling, installing, and stressing tendons of this size, the elastic and ultimate behavior of large tendons in a circular shape, and methods of corrosion protection, all of which required that a prototype tendon be installed in a test facility simulating the final structure. Such test facilities have been constructed in Frick, Switzerland, South Haven, Michigan, and Middletown, Pennsylvania, and the effects of friction studied at the time tendons were installed and stressed, hitting friction investigation.

FRICK FACILITY

BBR constructed a large, massive concrete test stand (refer to Appendix pages 1,2, & 3 for Drawing 4-108075 and Layout of Test Cable, Fig. 2 and Fig. 2B). The purpose of this structure was primarily to simulate problems that might be encountered in the Dungeness B Reactor Vessel now under construction in England. A variety of sheathing, both size and type, and tendon profiles have been cast into this facility; however, for the purpose of this paper, we will concern ourselves with only the two profiles shown on Drawing 4-108075. The sheating installed in these two tendon profiles was a corrugated, semirigid steel tube, formed from uncoated steel strip, spirally wound and closed with a Pittsburgh lock seam. The corrugations were turned in so that the prestressing steel was in contact with the rib forming the corrugation. Tendons consisting of 121 wires, each wire 7 mm in diameter, were cut to length, pulled into the test facility in such a fashion that each end of the tendon anchorage was visible during the stressing operation.

As the tendons were installed, a coating of Dronus B was sprayed on the tendon as a corrosion protection device. Wires used in fabricating the tendons were supplied by three different British wire manufacturers, each one supplying a material that would meet ASTM a-421 specifications.

Friction was measured for an included angle of 180° by applying a load at one end of the tendon and measuring the amount of force that is transmitted to the other end of the tendon. Each set of readings taken in this fashion results in a total friction factor for that load increment. Although readings were taken at load increments throughout the test, the table below gives only the average values obtained in the stressing range. Applying the formula $T_o = T_x e^{(\mu\alpha)}$ in which μ is the total angular deviation and assuming that the unintended angular deviation is .006 radians per meter, we have:

TEST NO.	39' RADIUS	20' RADIUS
1 & 4	.122	.116
2 & 5	.123	.122
3 & 6	.135	.141
AVERAGE	.128	.126

A detailed report on the above-mentioned tests is available on request to Joseph T. Ryerson & Son, Inc.

SOUTH HAVEN FACILITY

A 4'-high section, representing 1/3 of the containment structure, was constructed by Bechtel Corporation at the site of Consumers Power Palisades Plant near South Haven, Michigan. Refer to the photograph at the top of page 4 in the Appendix and Drawings SPT-2 and SPT-3, pages 5 and 6. This facility was built to gain general construction information on forming; placing reinforcing bars, sheathing, and concrete; installing and stressing tendons, along with investigating the general performance of curved tendons under 120° included angle.

The 90-wire tendons which were coated in Ryerson's shop with No-Oxid 490 for corrosion protection were pulled into 3/34" ID sheathing. The semirigid sheathing was plain steel, corrugated, with the corrugations turned out. In the friction test setup shown on Drawing SPT-6, as you will note, the buttonheads are exposed at the checking end as shown in the photograph at the bottom of page 4. This allowed observation of the buttonhead seating throughout the load increments of this test.

The results of each load increment for the bottom tendon are shown on page 8 in the Appendix and a load elongation of this tendon is shown on page 9. It is interesting to note that the load elongation curve pretty well defines a straight line, demonstrating that within the elastic range a curved tendon behaves in the same fashion as a straight tendon would and that there is no abrupt change in friction factors within this range. The same procedure was used on the upper tendon

This resulted in an overall friction factor of 1.28, as opposed to 1.36 for the lower tendon. We then applied the method of least squares, as defined in Experimental Statistics by M. G. Natrella, NBS Handbook 91, to both the Frick Tests and Palisades Test. This technique allows us to differentiate between k and μ and resulted in a μ factor of .124 and a k factor of .000313.

MIDDLETOWN, PENNSYLVANIA FACILITY

Two 5'-high sections were built by United Engineers and Constructors at the Metropolitan Edison Crawford Power Station site. These sections represented severely deflected tendons, similar to those which might be around a personnel lock or an equipment hatch, although much shorter in length. The photograph on the top of page 10 shows the general site and the two sections. The general dimensions of the section and the tendon profiles incorporated in them are shown on Drawing 154-1-C on page 11 of the Appendix.

Two types of sheathing were being considered by Gilbert Associates, Inc. These were a rigid steel pipe section, which had to be preformed, and the other was a semirigid corrugated sheath, similar to those used in the previous two test facilities. The test section on the west was constructed using 4" schedule 40 pipe and the test section the east contained a 24-gauge 3-3/4" ID, semirigid galvanized corrugated pipe with the corrugations turned outward. The 90-wire tendons were pulled into the structure, dry, and prepared for stressing as seen in the bottom of page 10 in the Appendix.

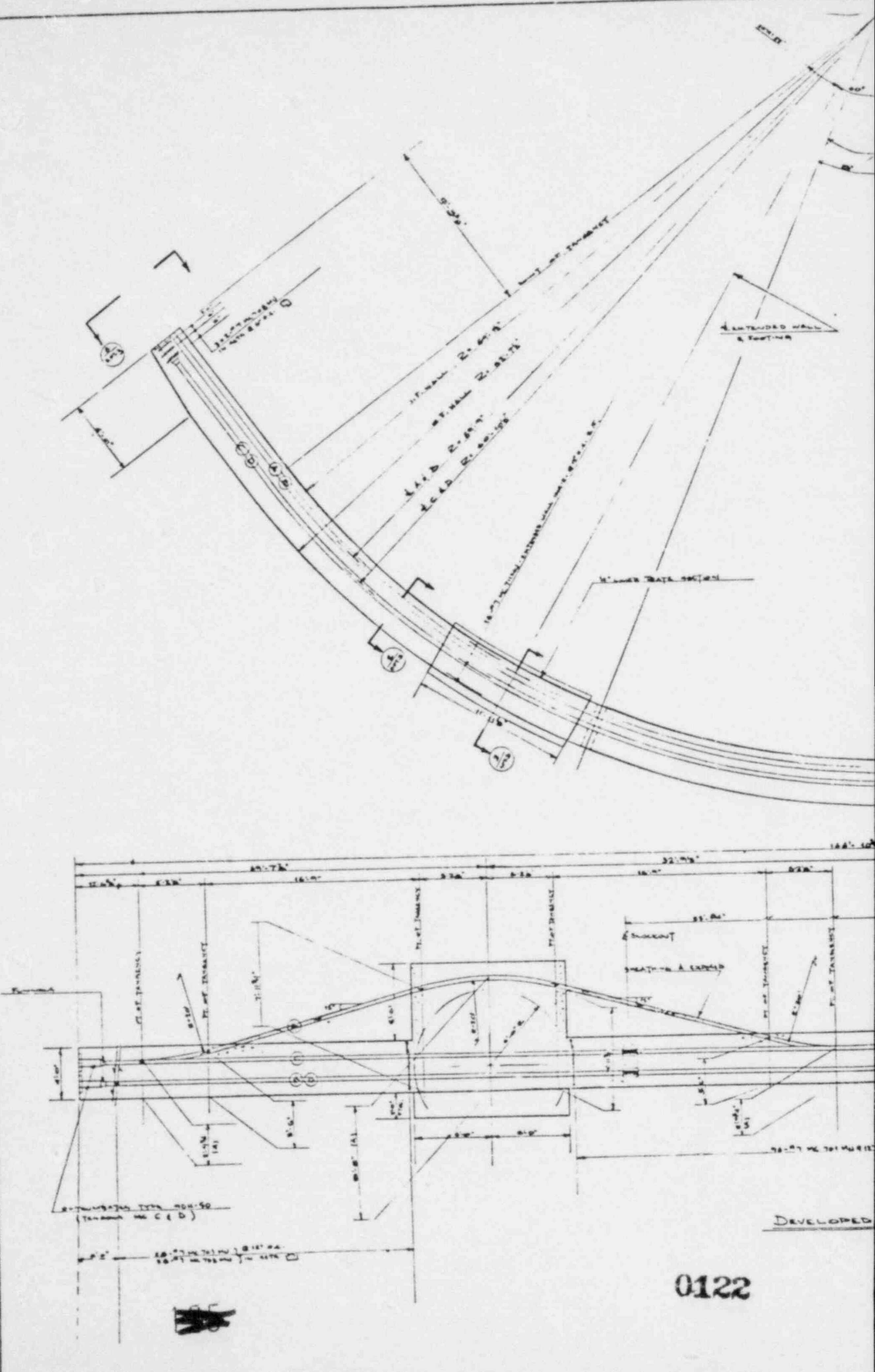
The loading procedure used here is essentially the same as the one used at the Palisades facility (see page 7 of the Appendix). The results of each load increment were reported in the same fashion and the load elongation plotted (see Appendix, pages 12 and 13). Again, these curves approach a straight line, although the load elongation curve for the west tendon shows some erratic behavior. This resulted from a poor connection between the funnel and the sheathing since the funnel, or transition piece, had to be altered in the field to fit the schedule 40 pipe.

Taking the friction factors resulting from an overstress of 80% of the u.t.s. of the tendon, which were 1.19 for the east tendon and 1.12 for the west tendon, including them with the results of the Frick Tests and applying the method of least squares, we arrived at an average μ of .123 and a k factor of .000316.

SUMMARY OF RESULTS

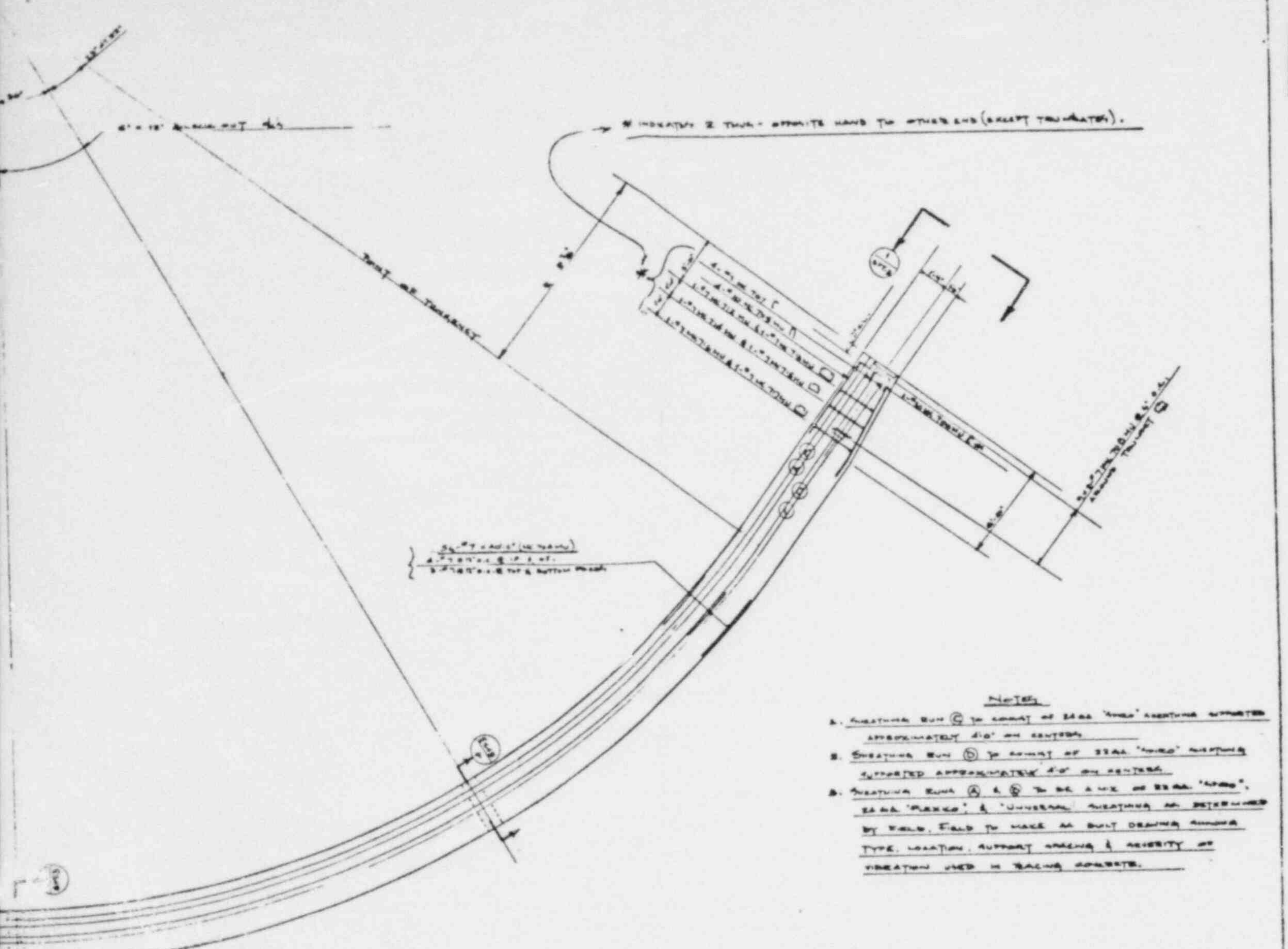
It is apparent that there is general agreement of test results from all three of these facilities.

When we consider that these results are obtained from tests utilizing four types of sheathing, although the sheathing is all of the same general category and that the coating materials varied from a water soluble oil to none at all, the high degree of repeated results would indicate that these friction factors are quite reliable and not sensitive to these variables.



POINT OF TANGENCY
Ⓒ Ⓓ
Ⓐ Ⓑ
EXTENDED WALL & FOOTING
PT. OF TANGENCY
SHEATHING & EXPAND
Ⓐ
Ⓒ
Ⓐ Ⓓ
DEVELOPED

0122

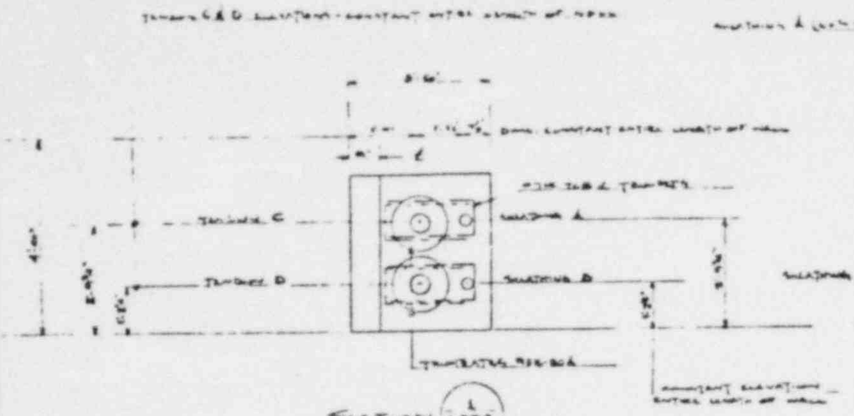


NOTES

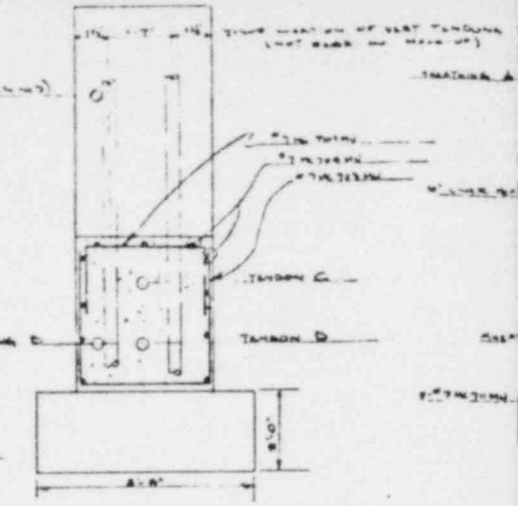
1. SHEATHING RUN Ⓒ TO CONSIST OF 22 GA. "AMEO" SHEATHING SUPPORTED APPROXIMATELY 4'-0" ON CENTERS.
2. SHEATHING RUN Ⓓ TO CONSIST OF 22 GA. "AMEO" SHEATHING SUPPORTED APPROXIMATELY 4'-0" ON CENTERS.
3. SHEATHING RUNS Ⓐ & Ⓑ TO BE A MIX OF 22 GA. "AMEO", 22 GA. "FLEXCO", & "UNIVERSAL" SHEATHING AS DETERMINED BY FIELD. FIELD TO MAKE AS BUILT DRAWING SHOWING TYPE, LOCATION, SUPPORT SPACING & SEVERITY OF VIBRATION USED IN PLACING CONCRETE.

0123

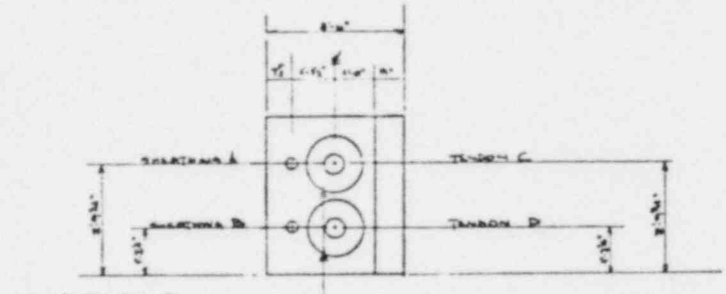
	WALL SECTION MOCK UP PLAN & DEVELOPED ELEVATION
3-7-67 3-7-'67	PALISADES PLANT CONSUMERS POWER COMPANY JOB NO. 5935-C-51
	ARCHITECT ENGINEER BECHTEL COMPANY CONTRACTOR
	RYERSON CENTRAL REINFORCING PRODUCTS
	DRAWN BY W.J.C. DATE 1-30-'67 CHECKED BY
	CONTRACT NO. 21T 11A · DRAWING NO. SPT-2



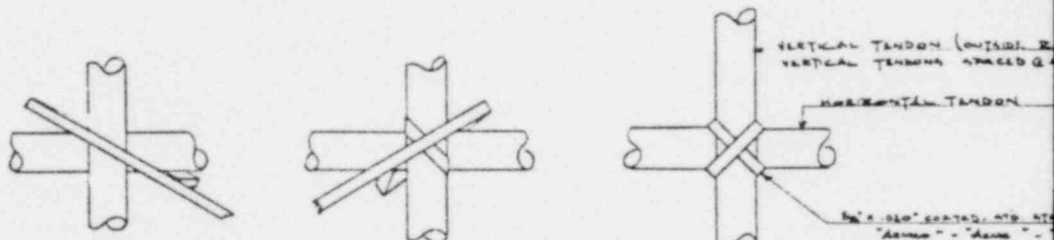
SECTION (1/SPT-3)



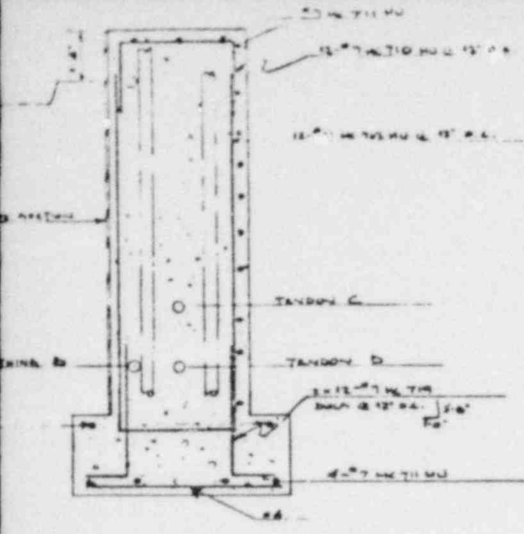
SECTION (2/SPT-3)



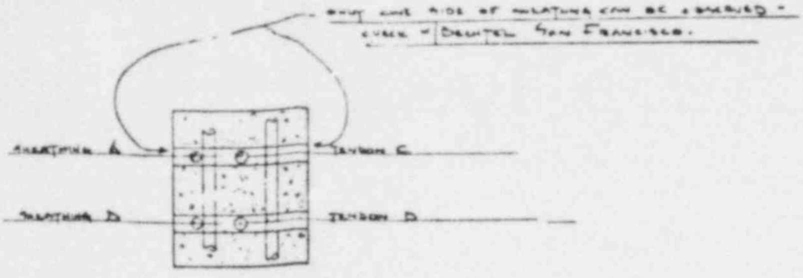
SECTION (5/SPT-3)



SUGGESTED HORIZONTAL TENDON SUPPORT METHOD



SECTION B/SPT-B



SECTION A/SPT-B

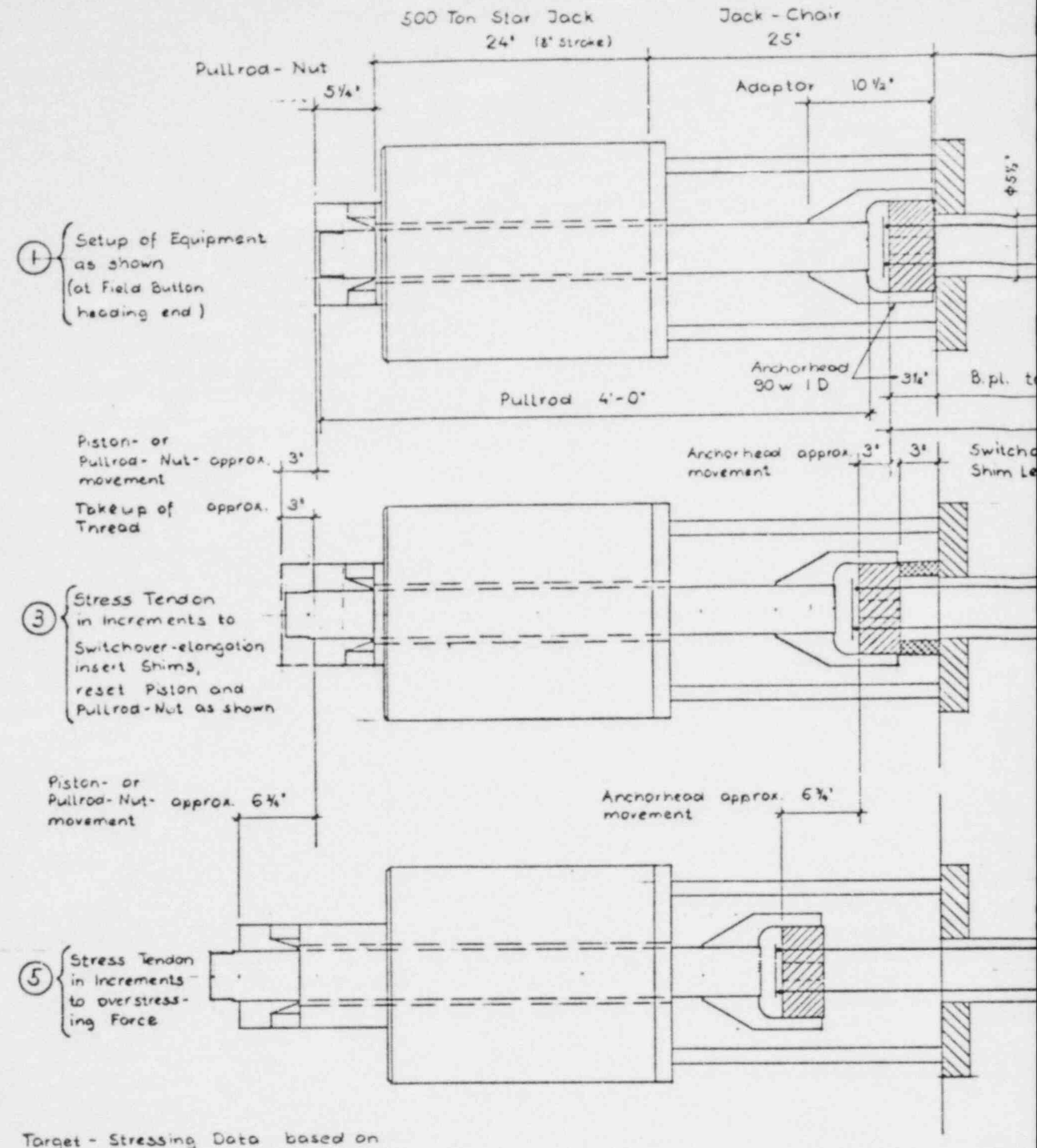
APPROX. 4'0" O.C.)

STRAPPING

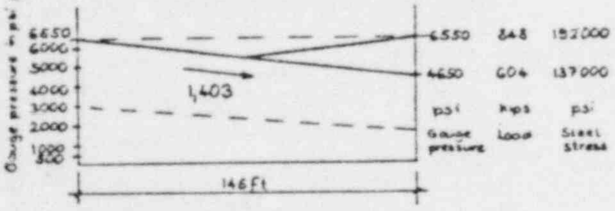
01

—	WALL MOCK UP SECTIONS & DETAILS
1-2-67 2-7-67	PALISADES PLANT CONSUMERS POWER COMPANY JOB No. 5935-C-51
	ARCHITECT: ENGINEER: BECHTEL COMPANY CONTRACTOR:
	RYERSON CENTRAL REINFORCING PRODUCTS
	DRAWN BY H.J.C. DATE 1-30-'67 CHECKED BY
	CONTRACT NO. 21T114 · DRAWING NO. BPT-3

10



Target - Stressing Data based on theoretical Values ; to be anticipated during Friction - Test



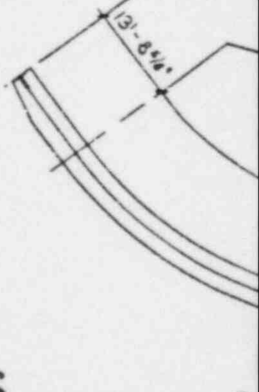
Elongation of Tendon while overstressing at ①

$e = \left[1/2 \left(192000 + 137000 \right) / 29\,500\,000 \right] \cdot 146 \cdot 12 = \underline{9\tfrac{3}{4}"}$

Approximate Elongation per 1000 psi $9.75 \frac{1000}{6550} = 1\tfrac{1}{2}"$

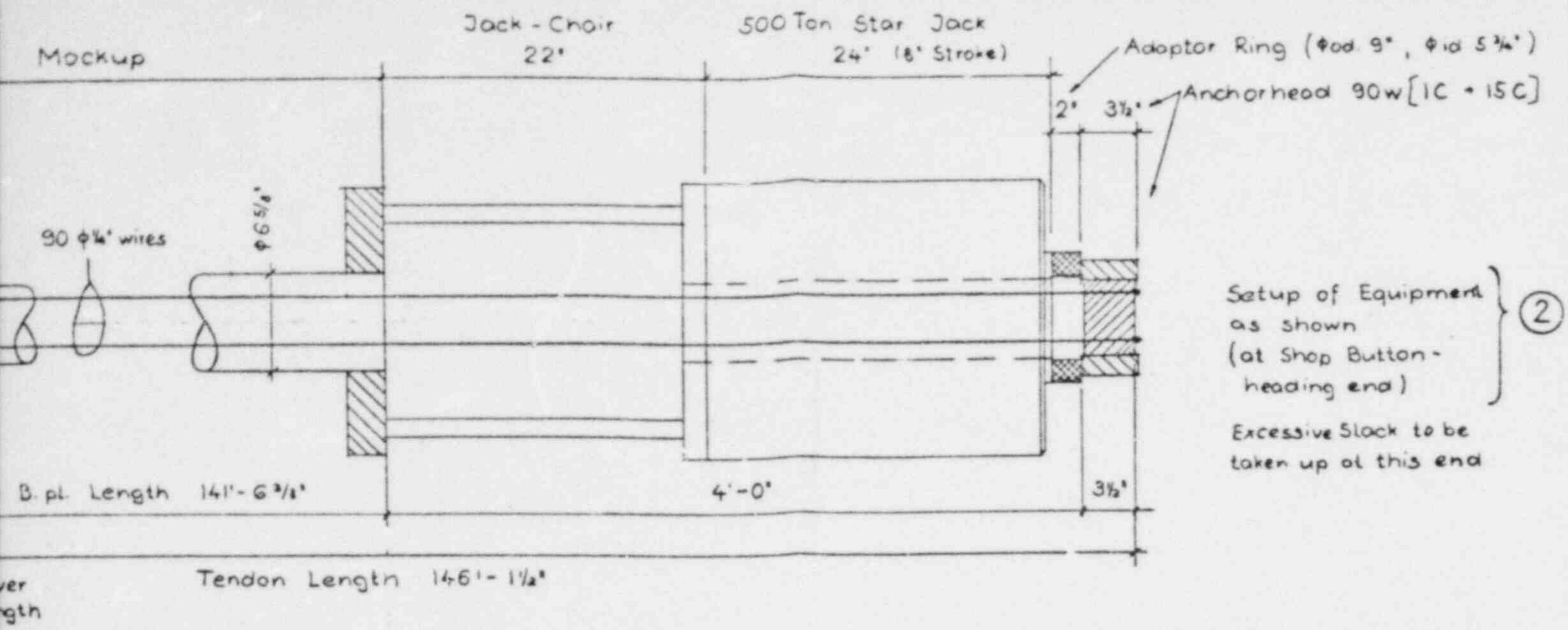
Additional Elongation while Overstressing at ②

$e = \left[1/2 \left(192000 - 137000 \right) / 29\,500\,000 \right] \cdot 1/2 \cdot 146 \cdot 12 = \underline{3/4" +}$



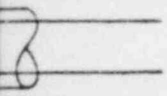
0126

P



Setup of Equipment as shown (at Shop Button-heading end) ②

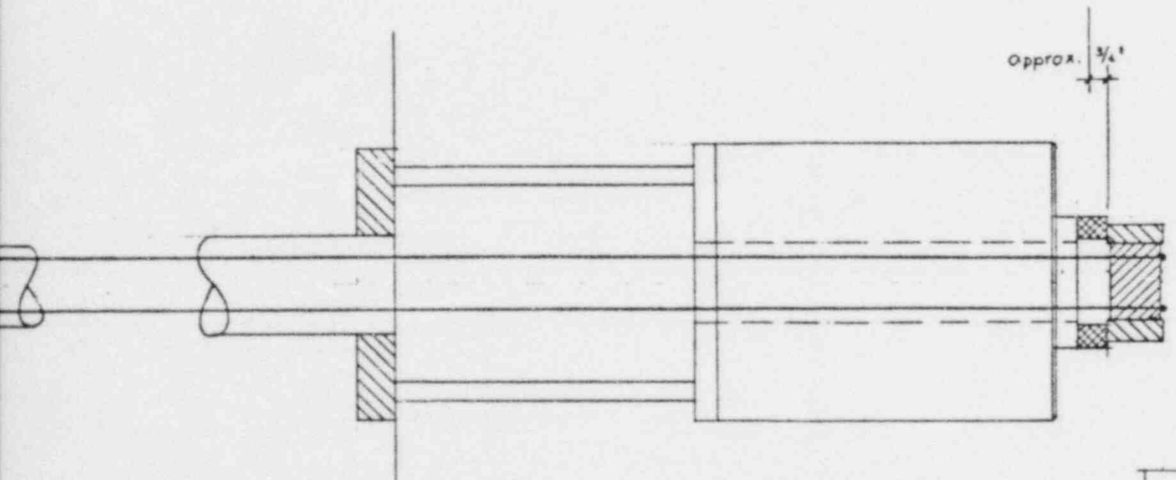
Excessive Slack to be taken up at this end



This Switchover-Step is required because the Stroke of the Jack of 8" is smalle than the Tendon elongation.

Check Prestressing Force in increments corresponding to ③ * after stressing Tendon, limited to a max. elongation of 1/32". ④

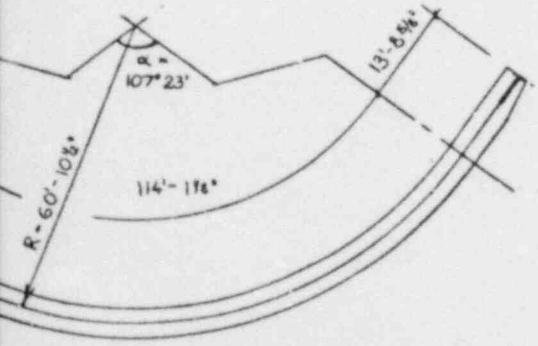
* This adjustment is necessary to compensate for internal Jack Friction.



Check Prestressing Force in increments corresponding to ⑤, * after stressing Tendon, which provides a max. elongation of 1/32". ⑥

Stress Tendon to overstressing Force ⑦

Always record Prestressing Force (Gauge pressure) and corresponding Elongation (Position of Piston vs. Housing)



an of Mockup

Theoretical Data

Wire : min. ult. strength 240'000 psi
max. overstr. stress 192'000
E = 29'500'000 psi

Tendon : 90 wires φ ¼"
$A_s = 90 \cdot 0.04909 = 4,418$ □"
max. overstr. Force = 848 ^K

Hydraulic Jack
Ram Area A = 129,35 □"
max. allowable Gauge Pressure at max over-stressing Force 6550 psi

[redacted]

Friction Factors k = 0,00030 (x = 141,5 ft)
μ = 0,158 (α = 1,8742)

$e^{(kx + \mu\alpha)} = e^{0.3388} = 1,403$

PALISADES PLANT #6935-C-81

MOCK UP FRICTION TEST

EQUIPMENT SET UP & PROCEDURE

ARCHITECT
ENGINEER BECHTEL CORP.
CONTRACTOR

RYERSON
CENTRAL REINFORCING PRODUCTS

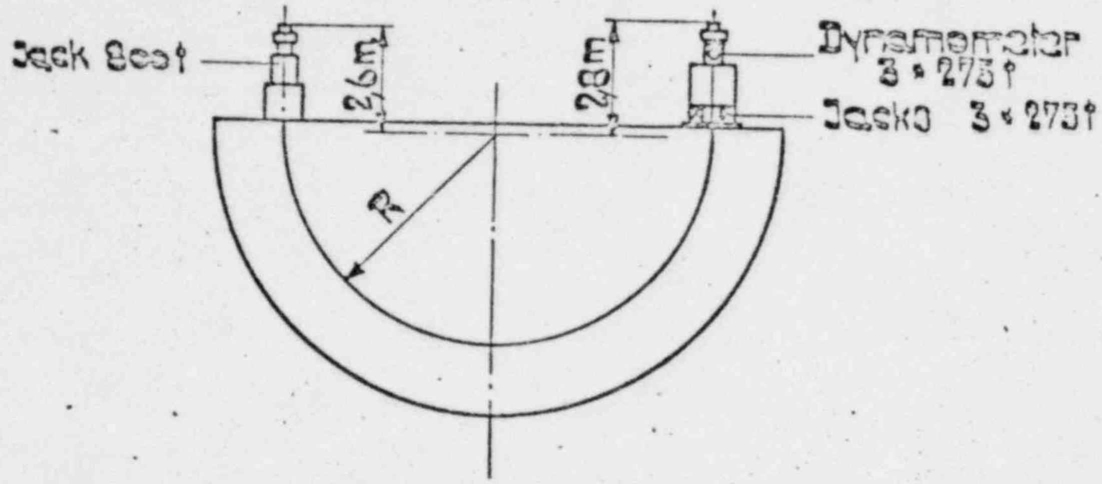
DRAWN BY A.W. DATE 4-11-67
CHECKED BY

CONTRACT NO. 21T114 DRAWING NO. SPT-6

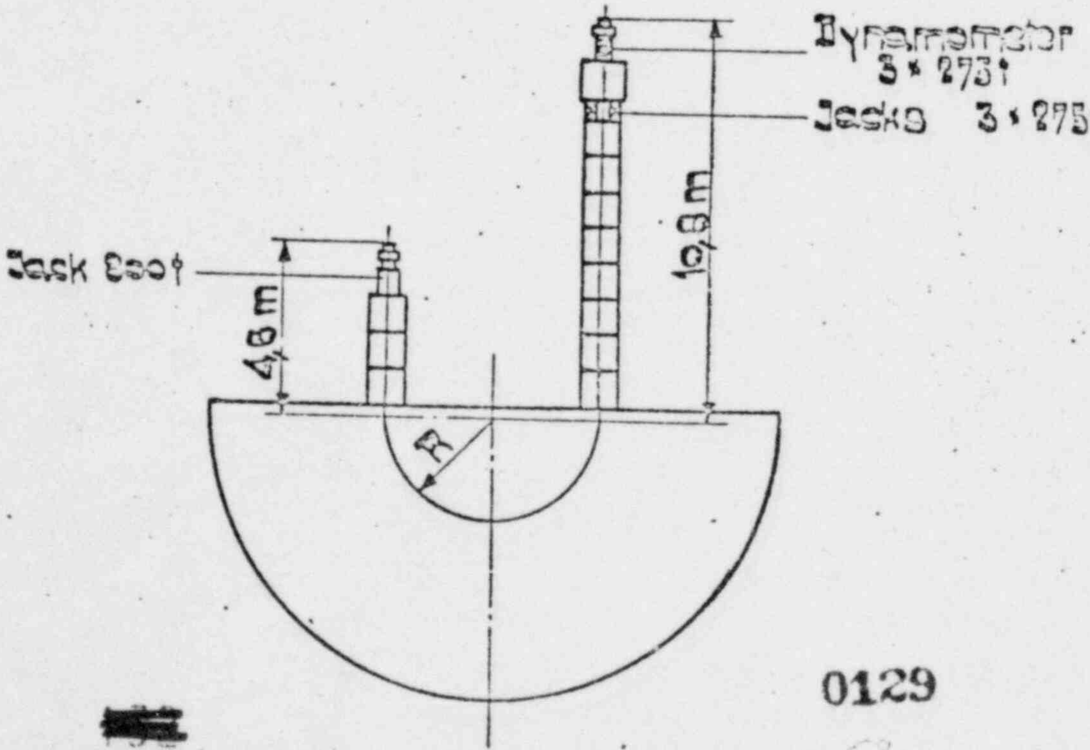
Compiling the results of all the above-mentioned tests and applying the method of least squares as shown on page 14 in the Appendix, we find a μ of .1217 and a k of 000343. Ryerson originally recommended the following friction factors: μ of .16 and k of .0003. it would seem prudent to continue to use these factors since there are certain construction variables that could cause an excessive amount of friction.

TESTING INSTALLATION BBRV FRICK

Cable with 12 m (39 feet) radius
Total Length 43,1 m (140 feet)



Cable with 6,2 m (20 feet) radius
Total Length 34,8 m (114 feet)



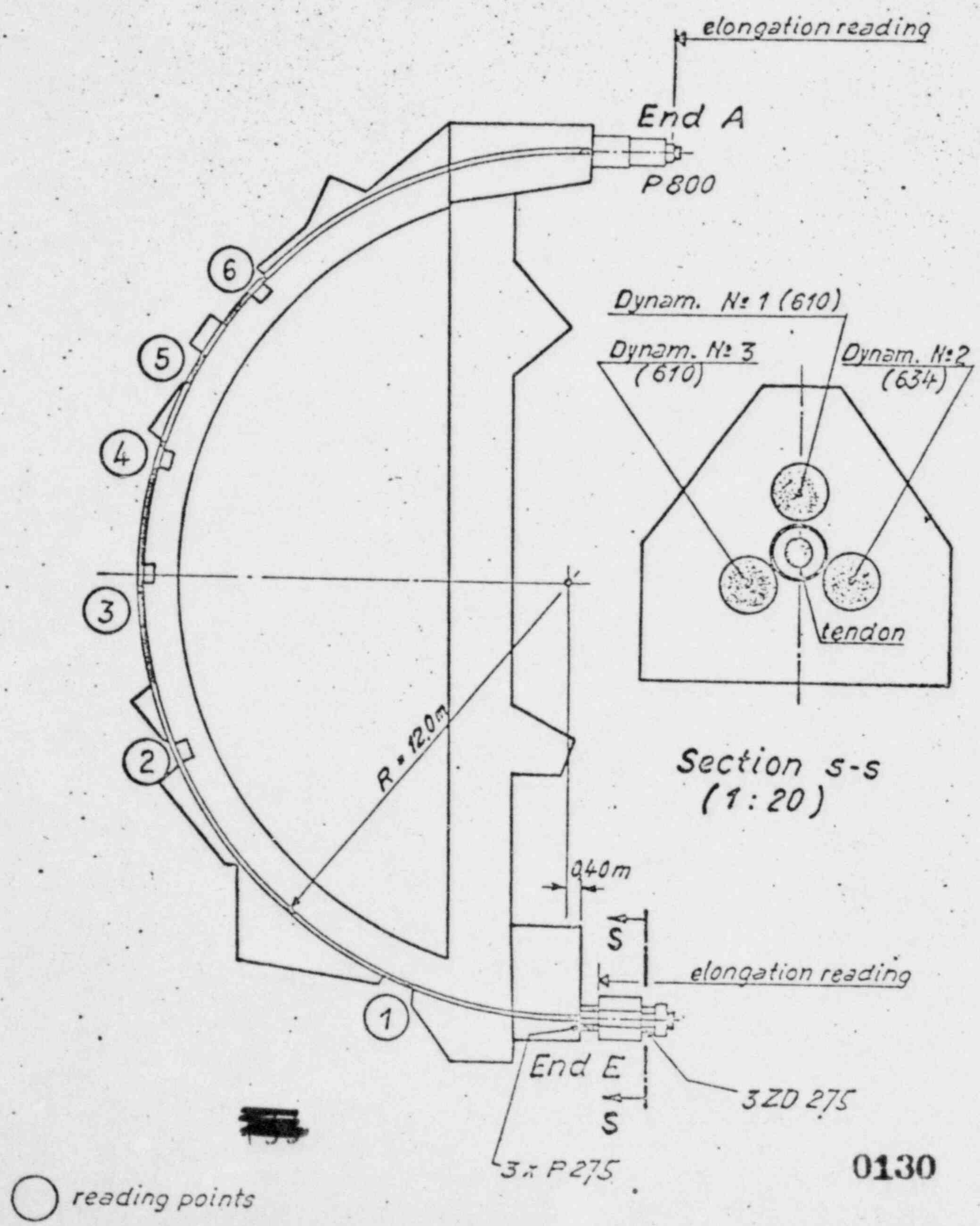
13.7.65

BUREAU BBR ZURICH

[illegible] 4·103073

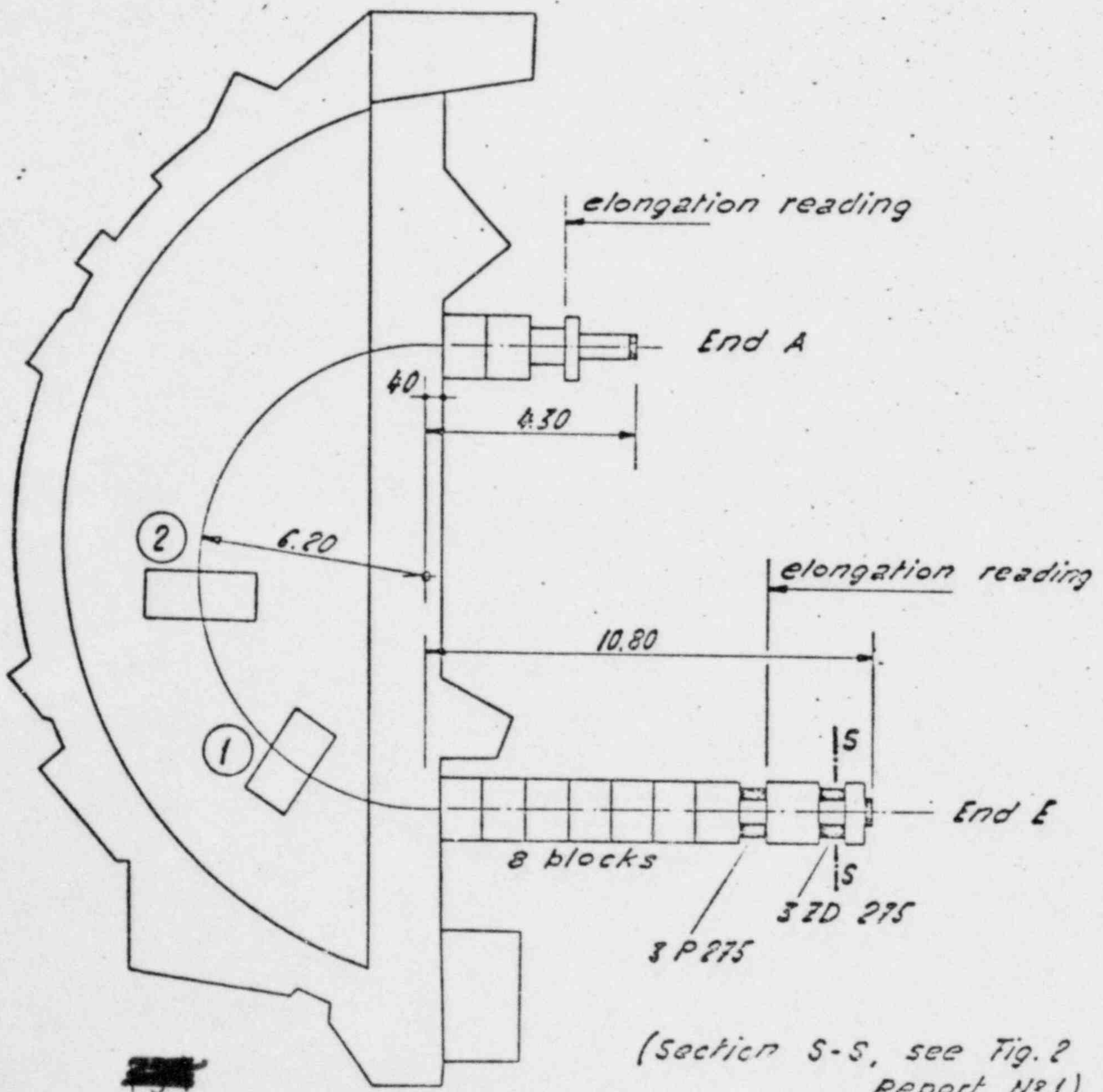
Layout of test cable (Fig. 2)

(Scale 1:150)



Layout of test tendon (Fig. 2b)

(Scale 1:150)



(Section S-S, see Fig. 2
Report No 1)

[redacted]

○ reading points

1. Mock-up structure comprising two full scale tendons. Structure represents 120° of arc of the full scale structure. Dimensions: 3 ft 6 ins. wide by 4 ft 10 ins. high by approximately 140 ft long.

2. 500 ton stressing unit.

chtel Corp. Palisades 5935-C-51

Mockup Friction Test 4/26/67.

Calculations to compare Force- and Elongation - Measurements for Top Tendon.

RYERSON
CENTRAL REINFORCING PRODUCTS
POST-TENSIONING SERVICE

A. Ws. 5 '67

SPT-9

Column → / Line ↓	A (m)	B A·(f1)	C A·(f2)	D	E (m)	F	G (m)	H G·(f1)	I G·(f2)	K	L (m)	M	N F+M	O N·(f3)	P (D+K)/2	Q P·(f4)	R A/G	S (m)	T S·(f5)	U H/T	V	W (D+V)/2	X W·(f4)
	Stressing End South						Checking End North																
	Gauge pressure psi	Force kips	Wire stress (based on 90 wires) ksi	Stress increment ksi	Pullrod position inch	Elongation increment inch	Gauge pressure psi	Force kips	Wire stress (based on 90 wires) ksi	Stress increment ksi	Ram position inch	Elongation increment inch	Total Elongation increment inch	Stress increment calculated ksi	Average Wire stress increment .. ksi	Elongation increment calculated inch	Friction Factor	Number of wires seated on N-End	Steel area of seated wires squ.in.	Wire stress ksi	Wire stress increment ksi	Average wire stress increment ksi	Elongation increment calculated inch
1.	0	0,0	0,0		5 13/16		0	0,0	0,0		6 1/2							20	0,982				
2	500	64,5	14,64	14,64	6 11/16	14/16	500	64,5	14,64	14,64	6 1/2		14/16	14,69	14,64	14/16	1,00				34,88	31,08	30/16+
3	1000	129,5	29,28	14,64	7 9/16	14/16	900	116,5	26,35	11,71	6 8/16		14/16	14,69	13,18	12/16+	1,11	68	3,338	34,88			
4	1500	194	43,92	14,64	8 3/8	13/16	1300	168	38,06	11,71	6 9/16		13/16	13,64	13,18	12/16+	1,16	76	3,731	45,07	10,19	12,42	12/16
5	2000	259	58,56	14,64	9 1/8	12/16	1600	207	46,84	8,78	6 9/16		12/16	12,59	11,71	11/16	1,25	78	3,829	54,05	8,98	11,81	11/16+
6	2500	323,5	73,19	14,63	10	14/16	2000	259	58,56	11,72	6 5/8		14/16	14,69	13,18	12/16+	1,25	79	3,878	66,71	12,66	13,65	13/16
7	3000	388,5	87,83	14,64	10 7/8	14/16	2500	323,5	73,19	14,63	6 5/8		14/16	14,69	14,64	14/16	1,20	82	4,025	80,34	13,63	14,14	13/16+
8	3500	453	102,47	14,64	11 5/8	12/16	2850	368,5	83,44	10,25	6 11/16		12/16	12,59	12,45	12/16	1,23	84	4,124	89,39	9,05	11,85	11/16+
9	4000	518	117,11	14,64	12 3/8	12/16	3200	414	93,69	10,25	6 11/16		12/16	12,59	12,45	12/16	1,25	85	4,173	99,19	9,80	12,22	11/16+
10	4500	582,5	131,75	14,64	13 1/16	11/16	3500	453	102,47	8,78	6 3/4		11/16	11,54	11,71	11/16	1,29	86	4,222	107,23	8,04	11,34	11/16
11	5000	647	146,39	14,64	13 15/16	14/16	3900	504,5	114,18	11,71	6 3/4		14/16	14,69	13,18	12/16+	1,28	89	4,369	115,46	8,23	11,44	11/16
12	5500	712	161,03	14,64	14 11/16	12/16	4300	556	125,90	11,72	6 3/4		12/16	12,59	13,18	12/16+	1,28	90	4,418	125,90	10,44	12,54	12/16
13	6000	766	175,67	14,64	15 1/2	13/16	4700	608	137,61	11,71	6 13/16		13/16	13,64	13,18	12/16+	1,28	↓	↓	see I	see K	see P	see Q
14	6580	848	192,65	16,98	16 7/16	15/16	5250	679	153,71	16,10	6 7/8		15/16	15,74	16,54	15/16+	1,26			↓	↓	↓	↓
15							6550	848	192,00	38,29	7 3/4	7/8	14/16										
16						10 5/8"									173,18	10 5/16"							

Factors (f1) = 0,12935
(f2) = 0,029278
(f3) = 1.04937 × 16
(f4) = 0,95294 / 16
(f5) = 0.04909

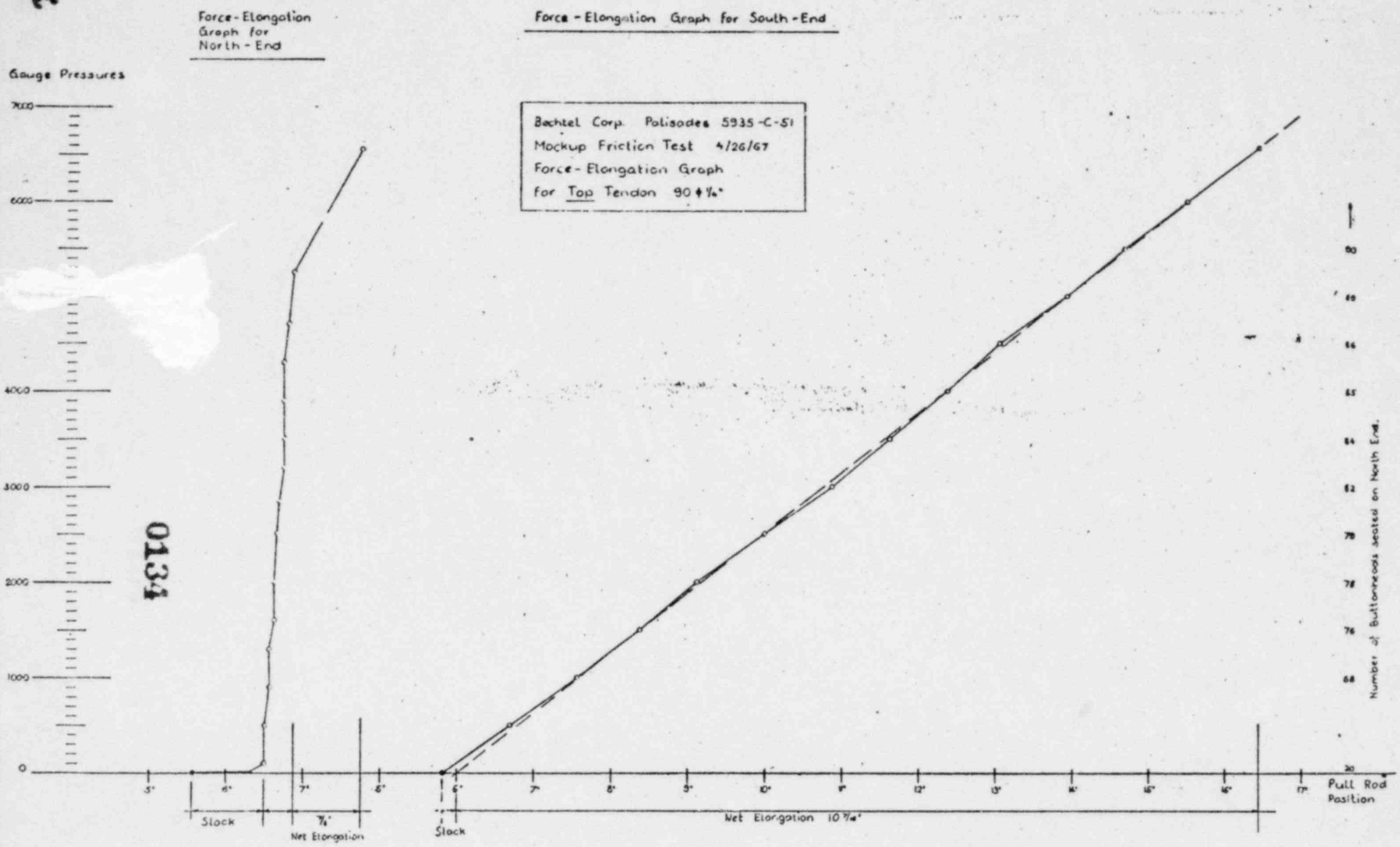
↑ Gross Elongation = Net Elongation + Slack

(m) → measured during Test

Compare Stress increments and Elongation increments.

⇧ Compare above Total calculated Elongation with Force-Elongation Graph (net Elongation 10 7/16")

[redacted]



Force-Elongation Graph for North-End

Force - Elongation Graph for South-End

Bechtel Corp. Palisades 5935-C-51
Mockup Friction Test 4/26/67
Force-Elongation Graph
for Top Tendon 90 φ 1/4"

0134

P-6118-C-6-19-1

Bechtel Corp. Palisades 5935-C-51

Mockup Friction Test 4/26/67.

Calculations to compare Force- and Elongation- Measurements for Bottom Tendon

RYERSON
CENTRAL REINFORCING PRODUCTS
POST-TENSIONING SERVICE
A.W. 5/1/67
SPT - 7

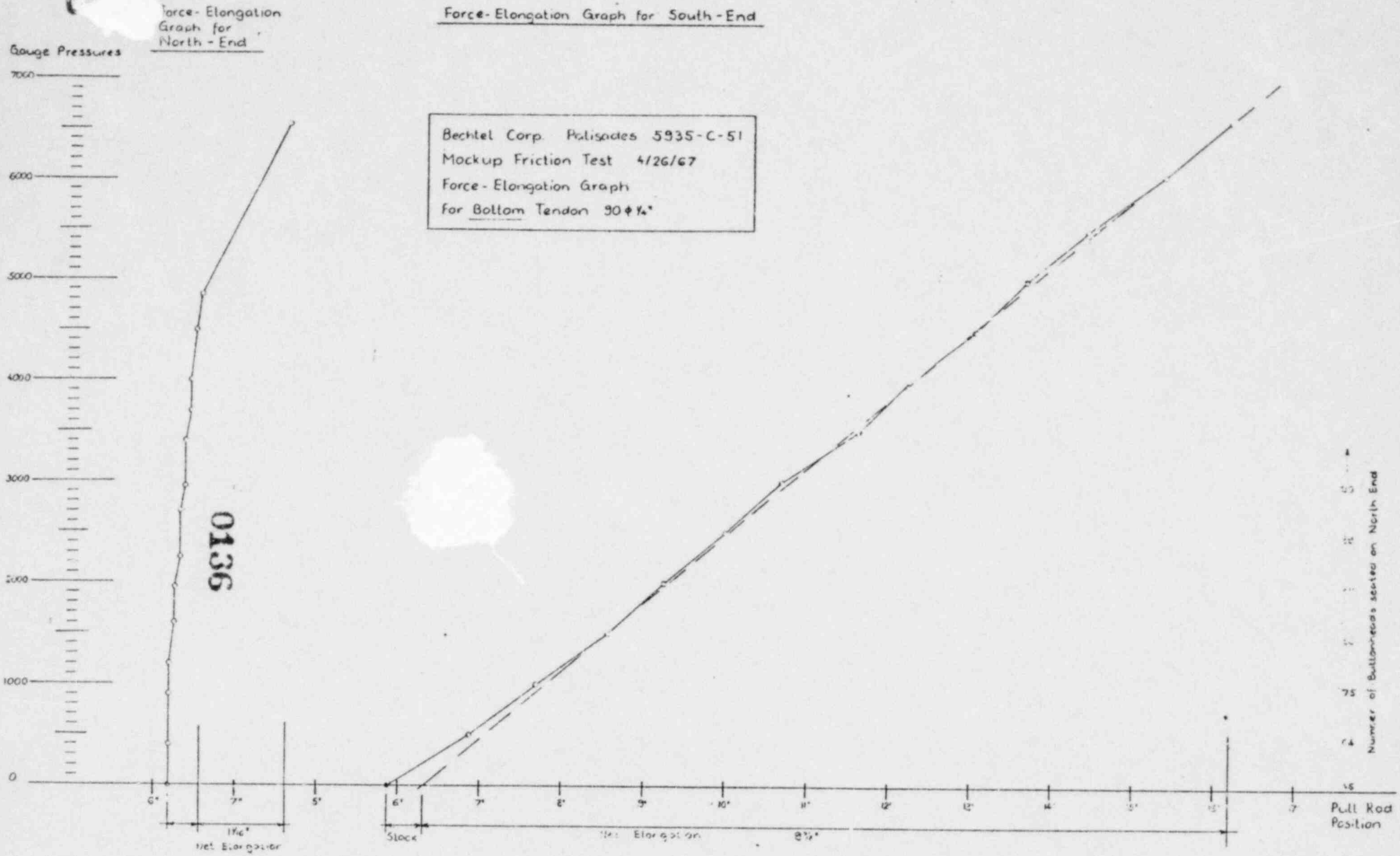
Column → / Line ↓	A	B	C	D	E	F	G	H	I	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
	(m)	A·(f1)	A·(f2)		(m)		(m)	G·(f1)	G·(f2)		(m)		F+M	N·(f3)	(D+K)/2	P·(f4)	A/G	(m)	S·(f5)	H/T		(D+V)/2	V·(f4)
	Stressing End South						Checking End North																
	Gauge pressure	Force	Wire stress (based on 90 wires)	Stress increment	Pull rod Position	Elongation increment	Gauge pressure	Force	Wire stress (based on 90 wires)	Stress	Ram position	Elongation increment	Total Elongation increment	Stress increment calculated	Average Wire stress increment	Elongation increment calculated	Friction Factor	Number of wires seated on N-End	Steel area of seated Wires	Wire stress	Wire stress increment	Average wire stress increment	Elongation increment calculated
	psi	kips	ksi	ksi	inch	inch	psi	kips	ksi	ksi	inch	inch	inch	ksi	ksi	inch			squ in	ksi	ksi	ksi	inch
1	0	0,0	0,0		5 7/8		0	0,0	0,0		6 3/16							46	2,258	0,0			
2	500	64,5	14,64	14,64	6 7/8	16/16	400	51,5	11,71	11,71	6 3/16		16/16	16,79	13,18	12/16 +	1,25	64	3,142	16,47	16,47	15,51	15/16
3	1000	129,5	29,28	14,64	7 11/16	13/16	900	116,5	26,35	14,64	6 3/16		13/16	13,64	14,64	14/16	1,11	75	3,682	31,62	15,15	14,90	14/16
4	1500	194	[illegible]	14,64	8 9/16	14/16	1200	155	35,13	8.78	6 3/16		14/16	14,69	11,71	11/16	1,25	85	4,173	37,17	5,55	10,10	9/16 +
5	2000	23		14,64	9 1/4	11/16	1600	207	46,84	11,71	6 1/4		11/16	11,54	13,18	12/16 +	1,25	89	4,369	47,37	10,20	12,42	12/16
6	2500	323,		[illegible]	10	12/16	1950	252	57,09	10,25	6 1/4		12/16	12,59	12,45	12/16	1,28	89	4,369	57,73	10,36	12,50	12/16
7	3000	388,5	87,83	[illegible]	10 9/16	11/16	2250	291	65,88	8,79	6 5/16		11/16	11,54	11,72	11/16	1,33	90	4,418	65,88	8,15	11,40	11/16
8	3500	453	102,47	14,64	11 5/8	15/16	2700	349	79,05	13,17	6 5/16		15/16	15,74	13,91	13/16	1,30	↓	↓	see I	see K	see P	see Q
9	4000	518	117,11	14,64	12 1/4	10/16	2950	381,5	86,37	7,32	6 3/8		10/16	10,49	10,98	10/16 +	1,36			↓	↓	↓	↓
10	4500	582,5	131,75	14,64	13 1/16	13/16	3400	440	99,55	13,18	6 3/8		13/16	13,64	13,91	13/16	1,32						
11	5000	647	146,39	14,64	13 11/16	10/16	3700	478,5	108,33	8,78	6 7/16		10/16	10,49	11,71	11/16	1,35						
12	5500	712	161,03	14,64	14 7/16	12/16	4000	517,5	117,11	8,78	6 7/16		12/16	12,59	11,71	11/16	1,38						
13	6050	783,5	177,13	16,10	15 3/8	15/16	4500	582	131,75	14,64	6 1/2		15/16	15,74	15,37	14/16 +	1,35						
14	6600	854,5	193,23	16,10	16 3/16	13/16	4850	627,5	142,00	10,25	6 9/16		13/16	13,64	13,18	12/16 +	1,36						
15							6550	848	192,00	50,00	7 5/8	1 1/16	17/16										
16						10 5/16"									167,62	9 7/8"							

Factors f(1) = 0,12935
f(2) = 0,029278
f(3) = 1.04937 × 16
f(4) = 0.95294 / 16

↑ Gross Elongation = Net Elongation + Slack

Compare Stress increments and Elongation increments

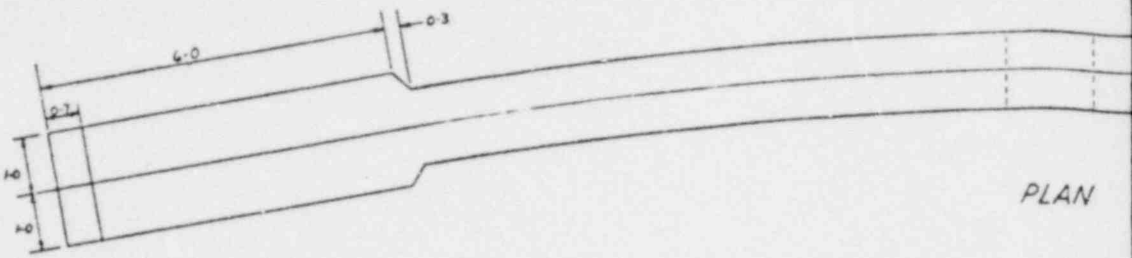
⇧ Compare above Total calculated Elongation with Force - Elongation



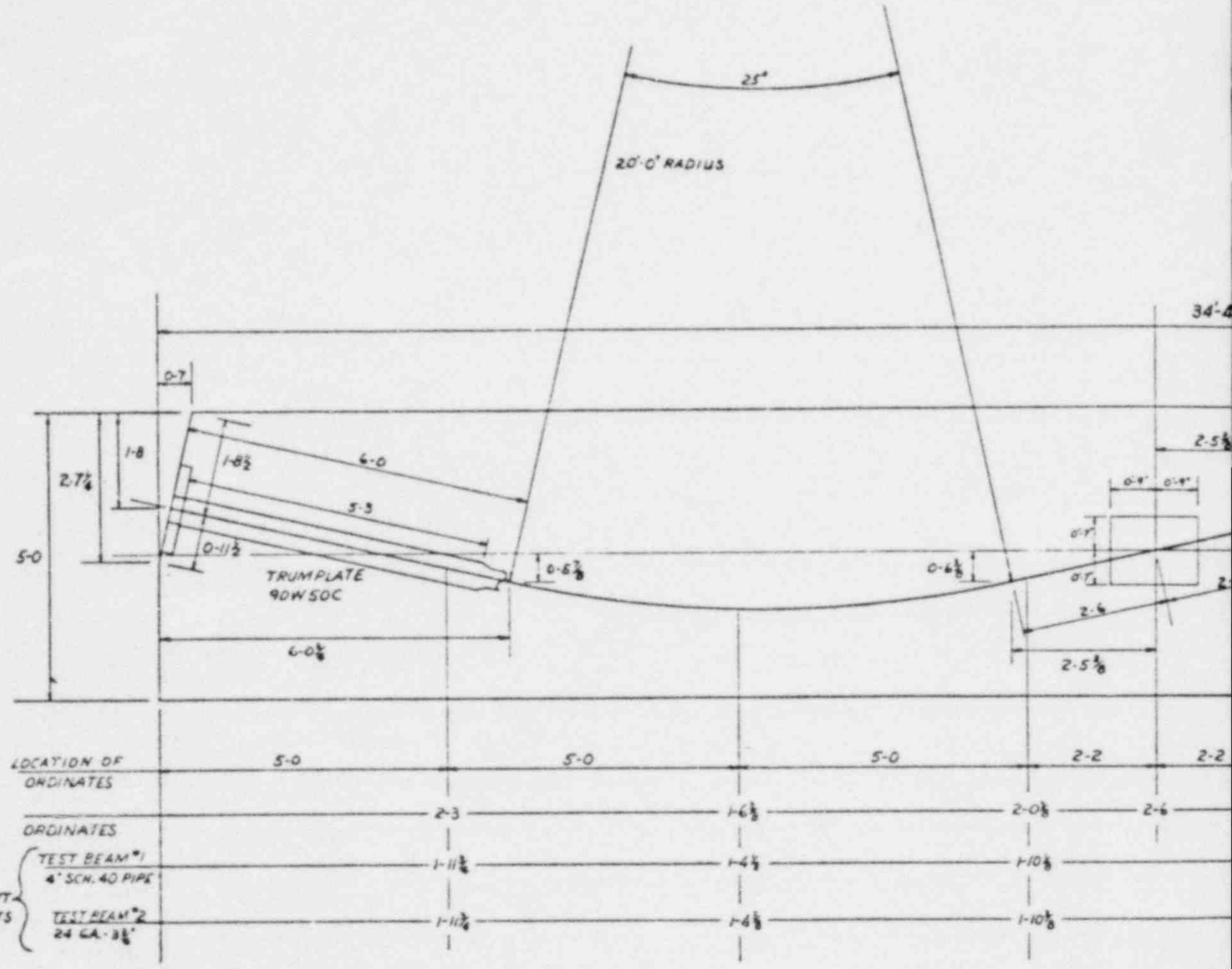
Bechtel Corp. Palisades 5935-C-51
Mockup Friction Test 4/26/67
Force- Elongation Graph
For Bottom Tendon 90 φ ¼"

0136

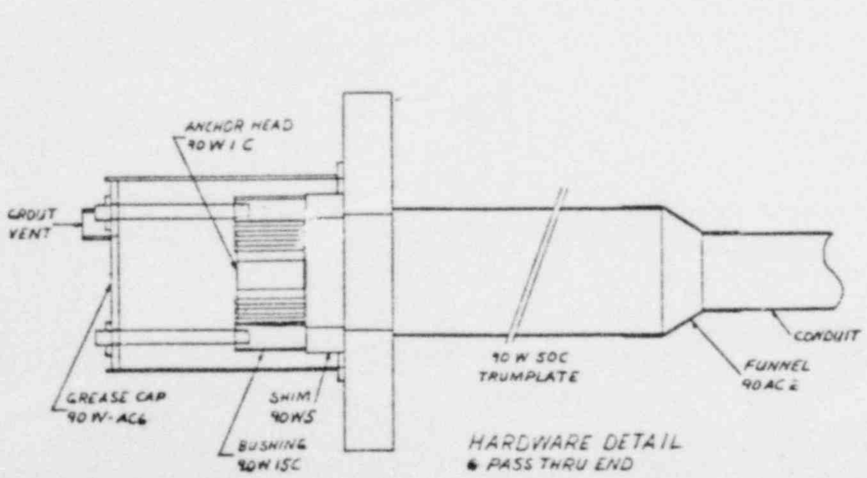
P-6118-C-6-18-1



PLAN

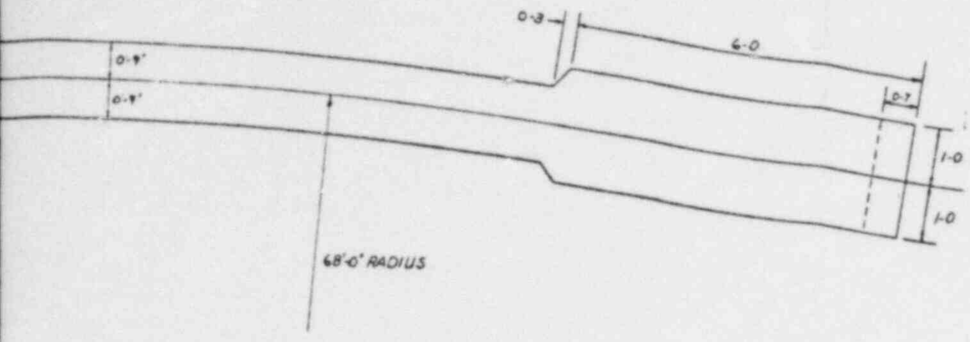


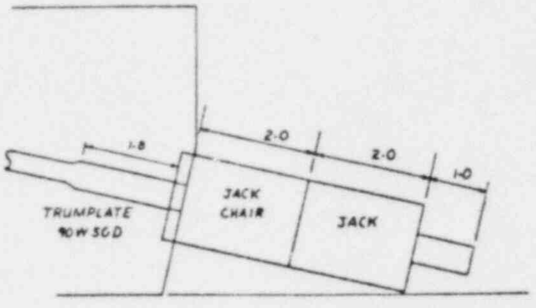
DEVELOPED WALL SECTION
@ 68 FOOT RADIUS



HARDWARE DETAIL
@ PASS THRU END

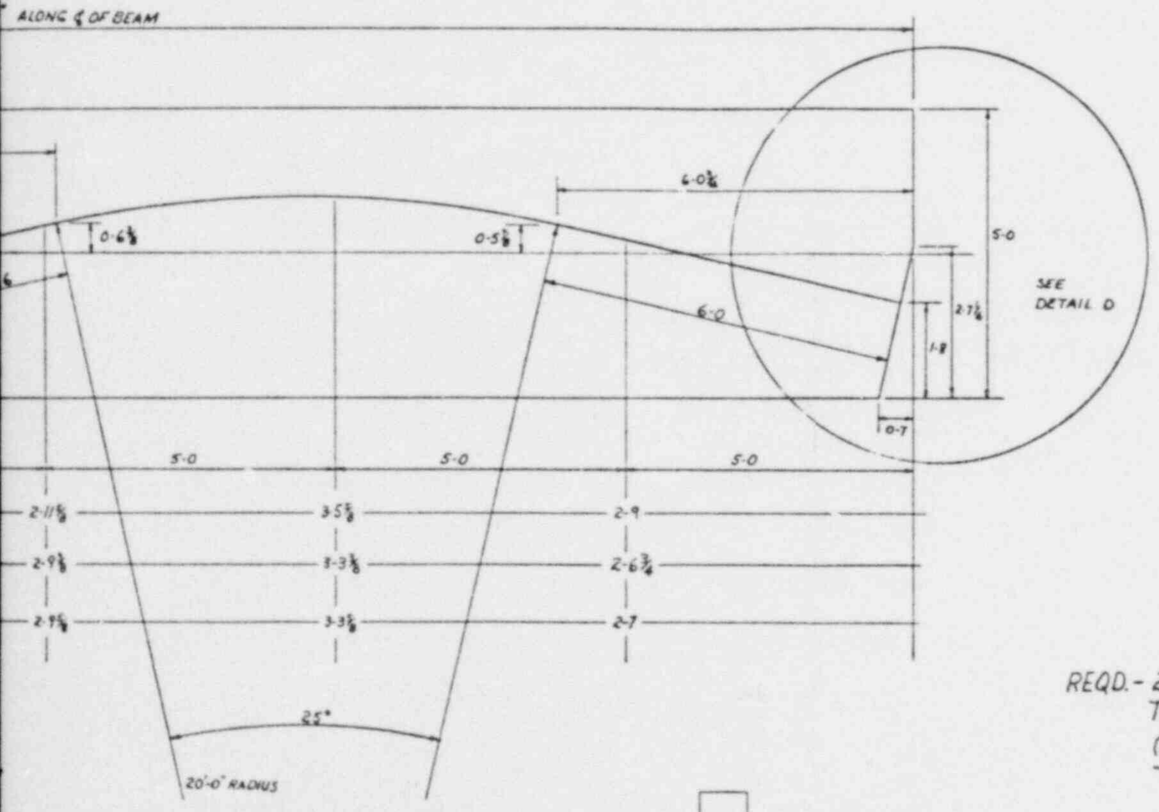
0137





DETAIL D

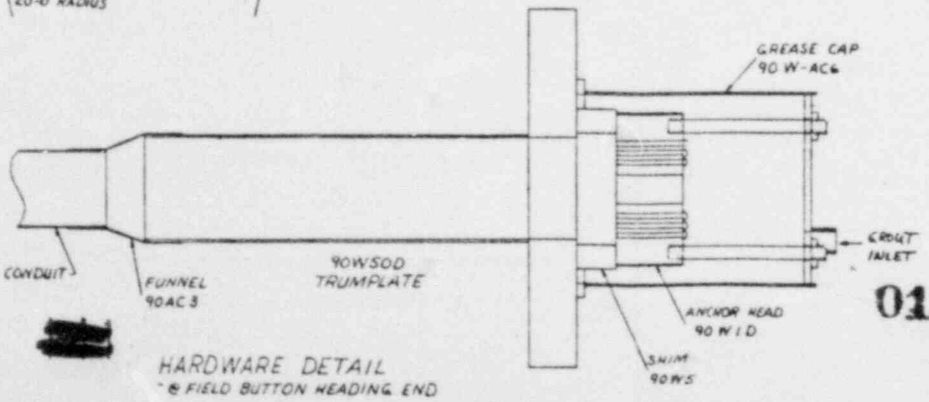
OPPOSITE END SIMILAR



REQD. - 2 TYP. 90 WIRE TENDONS × 34'-5½"

(WIRE CUTTING LENGTH - 35'-1½")

-CONDUIT BY OTHERS-



HARDWARE DETAIL

@ FIELD BUTTON HEADING END

0138

TEST BEAMS

9-15 METROPOLITAN EDISON

9-19. THREE MILE ISLAND

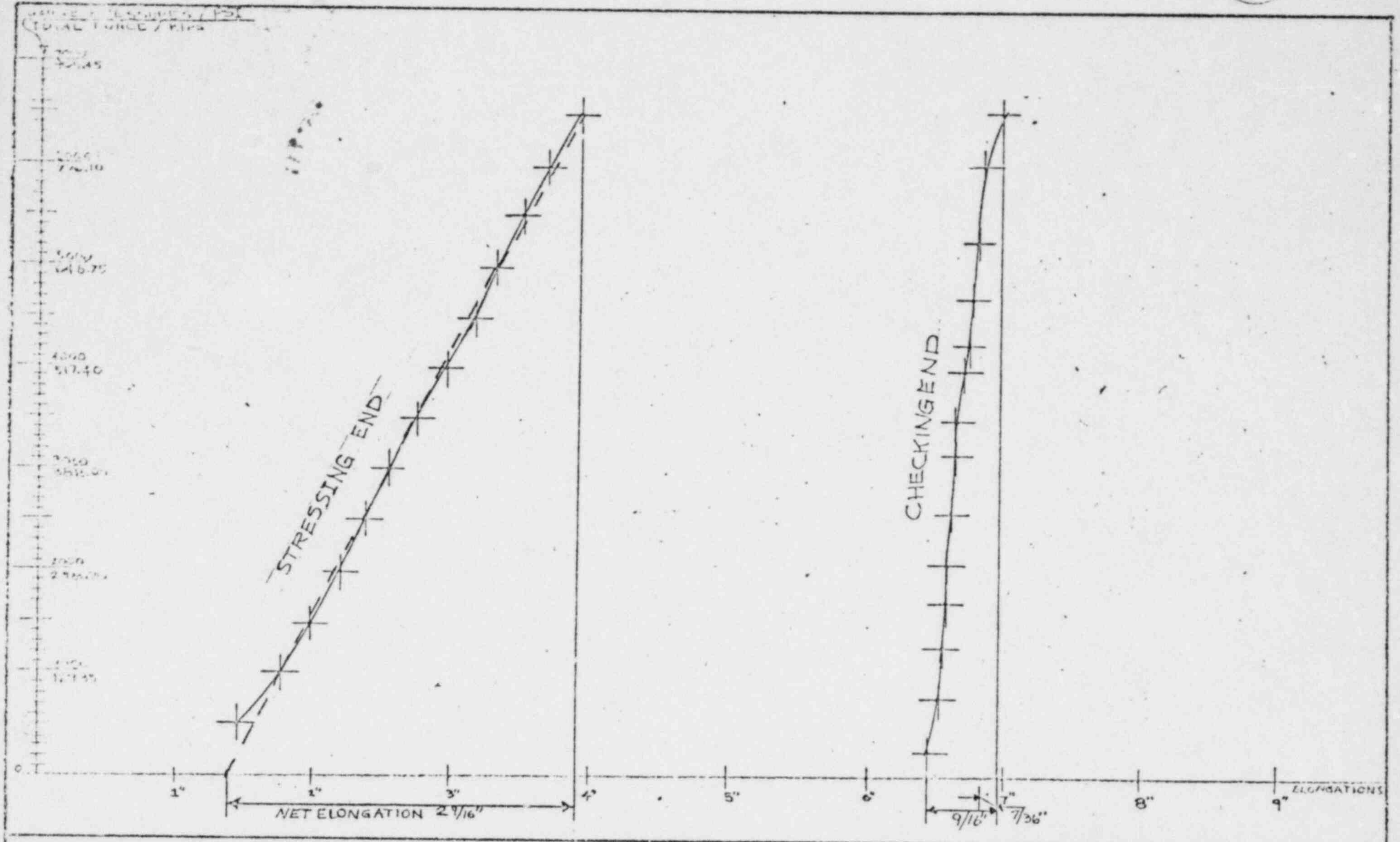
ARCHITECT
ENGINEER GILBERT ASSOC., INC.
CONTRACTOR

RYERSON

CENTRAL REINFORCING PRODUCTS

DRAWN BY RHT
DATE
CHECKED BY

CONTRACT NO. 02T154
DRAWING NO. 154-1-C



FORCE ELONGATION GRAPH FOR EAST TENDON — 3 MILE ISLAND

DRAWN BY ETR

DATE 11-14-67

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RYERSON

JOSEPH T. RYERSON & SON, INC

METALOGICS

CENTRAL REINFORCING PRODUCTS

POST-TENSIONING SERVICE

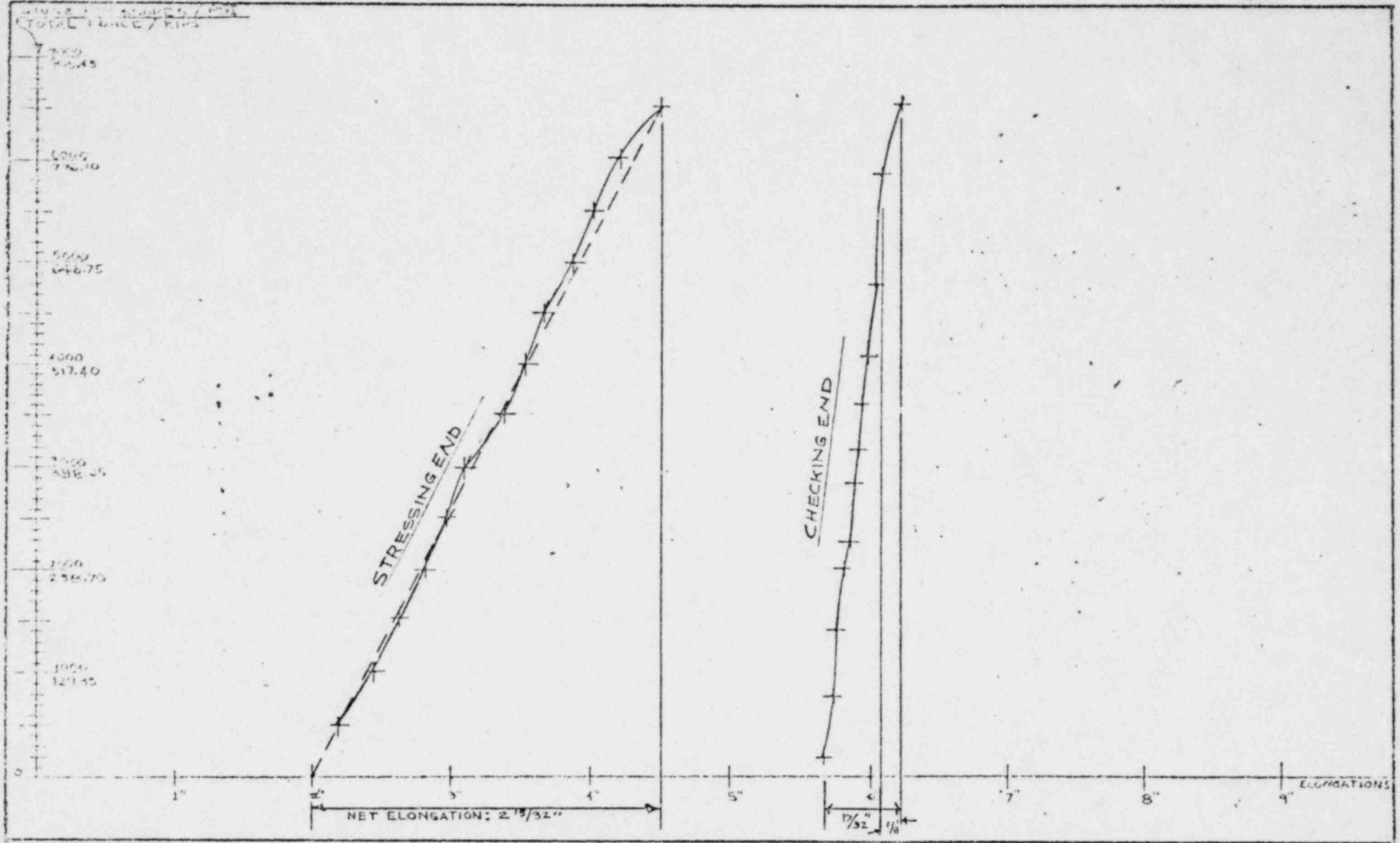
02T154

METRO.-ED. TEST

GILBERT ASSOC.

DRAWING NO SKETCH — 1

0139



FORCE ELONGATION GRAPH FOR WEST TENDON ~ THREE MILE ISLAND

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DATE 11-14-67

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RYERSON
JOSEPH T. RYERSON & SON, INC.
METALOGICS

CENTRAL REINFORCING PRODUCTS

POST-TENSIONING SERVICE 02T154

METRO. ED. TEST

GILBERT ASSOC.

DRAWING NO. SKETCH-2

0140

	T_o/T_x	C	α	L	α^2	$\alpha \cdot L$	$\alpha \cdot C$	L^2	$L \cdot C$
AVER. I, II, + III	1.536	0.429	3.142	123.0	9.872	386.47	1.348	15129	52.790
AVER. IV, V, + VI	1.507	0.410	3.142	63.0	9.872	197.95	1.288	3969	25.830
EAST TENDON	1.12	0.1133	1.194	35.208	1.425	42.038	0.1353	1239.6	3.989
WEST TENDON	1.19	0.1740	1.194	35.208	1.425	42.038	0.2078	1239.6	6.126
VII	1.28	0.246	1.874	141.0	3.512	264.23	0.461	19881	34.686
VIII	1.36	0.307	1.874	141.0	3.512	264.23	0.575	19881	43.287
					29.618	1196.96	4.015	61339	166.71

$$\mu = \frac{4.015-[(166.71)(1196.96)/61339]}{29.618-[(1196.96)^2/61339]} = 0.1217$$

$$K = \frac{4.015-[(29.618)(166.71)/1196.96]}{1196.96-[(61339)(29.618)/1196.96]} = .000343$$

MADE BY	DATE
RHT	11-15-67

PAGE 14

RYERSON METALOGICS

JOSEPH T. RYERSON & SON, INC.

CUSTOMER COMPOSITE

FRICTION FACTORS

FORM 780.12-2 APR. 63

TECHNICAL REPORT NUMBER 8

THE WCS 2.0 Mep/170 W
POST-TENSIONING SYSTEM

INTERIM REPORT:

CHAPTER 3 - END ANCHORAGE, JANUARY, 1968

[redacted]

WESTERN CONCRETE STRUCTURES, INC.
19113 SOUTH HAMILTON AVENUE · GARDENA · CALIFORNIA · 90247 · TELEPHONE 213/321-1571

25 March 1968

Subject: Tests Conducted on the WCS 2.0 Mep/170W Post-Tensioning System

The WCS 2.0 Mep/170W Post-Tensioning System was developed specifically to post-tension the PCRV's of HTGR's (in particular for the Fort St. Vrain Nuclear Generating Station) and secondary containments where total required force and/or spacing of tendons makes the use of large capacity tendons advantageous. In general, the system utilizes button-headed wires of 0.250-inch diameter anchored by heat treated alloy steel end fittings. It is the most extensively tested system in the world at the present time. A brief description of the tests conducted to date, their purpose, and results, follows:

1.0 HEAD – WIRE – SEAT SYSTEM TESTS

1.1 Static Tests - Stress-Relieved Wire

300 specimens 15" long, having variable dimensions, to determine parameters controlling performance of headed wires in general and the WCS 1.5 FS Head-Seat System in particular.

Tolerances to provide 100% efficiency were established as reported in WCS TR-6.

1.2 Fatigue Tests – Stress-Relieved Wire with WCS 1.5 FS Head

35 specimens were tested at $0.6 f_s''$ ± 15,000 psi at 6 - 8,000 cycles per minute to establish fatigue life and effect of fatigue loading on static properties.

Fatigue life of 10×10^6 cycles. No reduction of static properties. Results not yet published.

1.0 HEAD – WIRE – SEAT SYSTEM TESTS (continued)

1.3 Static Tests – "Stabilized" Wire

25 specimens 15" long, having controlled dimensions, to determine validity of tolerances established for heads on stress-relieved wires per 1.1 above.

100% head-seat system efficiency was obtained within limits of tolerances established for stress-relieved wire as reported in WCS TR-6.

1.4 Fatigue Tests – Stabilized Wire

49 specimens were tested at $0.6 f_s''$ ± 16,000 psi at 8,000 cycles per minute to determine fatigue life and effect of fatigue loading on static properties.

Tests still in process. Preliminary results indicate 10×10^6 cycles with no reduction in static properties.

1.5 Evaluation of Flaws in Heads

1,400 specimens 15" long, from various coils of wire selected to produce cracked heads are being tested to determine the effect of flaws (both slip type cracks, longitudinal cracks, or a combination of both) on static and fatigue properties of the head - wire - seat system.

Tests still in process. Preliminary results indicate that in approximately 0.1% frequency, flaws in both wire and heads combine to cause a reduction in strength of the system.

1.6 Production Tests

6,000 wires (12,000 heads) fabricated during production into specimens 15" to 30' in length were tested to ultimate to verify tolerances of the WCS 1.5 Head - Seat System, evaluate production variables and evaluate performance of WCS heading equipment.

No head failures, all heads 100% efficient.

2.0 TESTS ON 2.0 MEP/170W STRAIGHT TENDONS

2.1 Ultimate Load Tests on Short Tendons

7 - 170-wire tendons 4' - 0" long were tested to ultimate using production stressing equipment in order to determine ultimate load of 4' - 0" tendons, performance of end anchorage hardware at tendon ultimate, and performance of production stressing equipment at tendon ultimate.

All tendons failed at loads greater than minimum guaranteed tendon ultimate (2,002.8 kips) with no permanent deformation of end anchorage hardware and no damage to stressing equipment, all as reported in WCS TR-8.

2.2 Ultimate Load Tests on Long Tendons

2 - 170-wire tendons 30' - 0" long were tested to ultimate in order to determine load-elongation characteristics.

Load-elongation curve plotted to tendon ultimate followed that determined for short (10" gauge length) wires; tendon ultimate load and elongations were both above minimum guaranteed values (2,002.8 kips and 4% elongation); no permanent deformation in end anchorage hardware or damage to production stressing equipment, all as reported in WCS TR-8.

2.3 Cyclic Tests on a Long Tendon

1 - 168-wire tendon x 100' long was tensioned from 5 - 1,128 kips (approximately 0 - 0.7 f'_s) for 150 cycles of 7-3/4" stroke at a rate of 3.5 minutes per cycle in order to determine performance of production stressing equipment for the maximum number of cycles per set of equipment for a specific contract. Performance of the end anchorage hardware, wire, and button heads for relatively few cycles at a relatively large stress variation was considered a secondary purpose.

Stressing equipment performed with no problems, no leakage, and no damage. No wires or heads failed and there was no damage to end anchorage hardware.

3.0 ULTIMATE LOAD FOR CRITICAL FAILURE MODES OF 2.0 MEP/170W END ANCHORAGE HARDWARE

3.1 Threads

5 sets of end anchorage hardware were tested to ultimate of the thread shear failure mode.

Mean failure value was 2,866 kips, within 1.5% of predicted load, with consistent results showing a coefficient of variation of 3%. Safety factors were higher than those established by design criteria.

3.2 Web Shear

5 sets of end anchorage hardware were tested to ultimate of the web shear failure mode.

Mean failure was at an equivalent tendon force of 2,862 kips, within 4% of predicted load, with consistent results showing a coefficient of variation of 1%. Safety factors were higher than those established by design criteria, all as reported in WCS TR-8.

4.0 CURVED TENDON FRICTION, ULTIMATE STATIC AND CYCLIC LOAD TESTS

4.1 25 - 168-wire tendons from 50' to 100' in length were fabricated, greased and coiled by WCS and installed by GGA using WCS equipment and methods. Tendons curved through 180° on 10' to 16' radii of curvature were tested for stressing friction and ultimate by GGA.

4.2 1 - 168-wire tendon was loaded for 1,000 cycles from $0.7 f'_s \pm$ 15 ksi using WCS designed and built production stressing equipment.

4.3 4 - 25-wire tendons and surrounding concrete were tested for long term losses at elevated temperatures.

The 4.0 tests were conducted by GGA with satisfactory but as yet unpublished results. The program established as a secondary objective the validity of WCS designed fabrication, greasing, handling, installation, field heading and stressing methods and equipment.

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CHAPTER 3.0 END ANCHORAGE

3.1 GENERAL

3.1.1 COMPONENTS

The end anchorage hardware of the WCS 2.0 Mep/170 W Post-Tensioning System is made up of the components listed in Table 3.1-1. The terminology "A end" is used to designate the end of the tendon which has the Washer installed and wires shop headed during tendon fabrication. The tendon tube at the A end has an enlarged section of sufficient diameter and length to allow the Washer to be recessed approximately 6 feet inside the face of the Bearing Plate, so that the unheaded wires can project approximately 6 feet beyond the Bearing Plate at the opposite end (B end) of the tendon. The "B end" is the end of the tendon (opposite the A end) which allows a Composite Washer (or optionally a Washer and Washer Nut) to be installed on the projecting wires, which are then field headed.

NAME	PART & DRAWING NO.	MATERIAL	REQUIRED FOR	
			TYPICAL A END	TYPICAL B END
Washer	100103	4140 Heat Treated	Yes	No*
Washer Nut	100104	4140 Heat Treated	Yes	No*
Composite Washer	100105	4140 Heat Treated	No	Yes*
Split Shims	100106	ASTM A7 or A36	Yes	Yes
Bearing Plate	100107	ASTM A7 or A36	Yes	Yes

* An assembly consisting of a Washer and Washer Nut can be substituted for the Composite Washer on the B End.

TABLE 3.1-1: Tendon end anchorage components of the WCS 2.0 Mep/170 Post-Tensioning System.

3.1.2 PERFORMANCE CRITERIA

The basic criteria for performance of the end anchorage of an unbonded tendon system for a prestressed concrete reactor vessel (PCRV) or other nuclear containment is that it must reliably: 1) sustain the permanent long term load on the tendon for the life of the structure, 2) sustain any variations in tendon load for the life of the structure, and 3) have sufficient overload capacity to allow the full actual ultimate strength and ultimate elongation of the tendon wires to be developed. Expressed more simply, the end anchorage must be stronger than the tendon which it anchors, for all types of loading condition.

The actual physical and mechanical properties of the tendon wire can be determined by statistical analysis of test data. As discussed in Section 3.3.4, a long ($\geqslant$ 30 feet) tendon composed of 170 individual ASTM A421 wires of 0.250 inch diameter can be expected to produce an ultimate load $\geqslant$ 2002.8 kips, and an ultimate elongation $\geqslant$ 3.5%. Due to the mode of failure of a multiple wire tendon, resulting from variation of the individual wires, the average or the maximum values of either ultimate load or ultimate elongation will not greatly exceed the minimums. The ultimate load capacity of the end anchorage components can be determined by ultimate load tests conducted on prototype components so as to test all critical failure modes. It can be assumed that the ultimate load capacity of production anchorage components will fall within a range of the mean ultimate load capacity of the most critical failure mode ($\overline{X}$) plus or minus three standard deviations (σ) of test results. Many specifications require that end anchorage components may not yield at the minimum guaranteed tendon strength. Therefore the basic performance criteria for the end anchorage of the 2.0 Mep/170 W System can be established as: $P = (\overline{X} - 3\sigma) \times (F_y \div F_u) \geqslant 2002.8$ kips.

Since neither the mean ultimate load capacity ($\overline{X}$) nor the standard deviation (σ) are known until after prototype tests are completed, it is necessary to establish a preliminary criteria for design purposes. Previous experience indicates that designing for a Safety Factor of 1.5 will produce test results meeting the basic criteria. This gives: Component Design Ultimate Strength (P') $\approx 1.5 \times 2002.8 \approx 3004.2$ kips.

Another independent consideration influences the design ultimate capacity of the end anchorage components. Due to the critical structural application, a proof load test of all critical components to minimum tendon ultimate (2002.8 kips) has been established as an essential part of quality assurance procedures. It follows that all components must be below their yield point at the proof test load in order that the proof test be a non-destructive procedure. For 4140 steel heat treated to R_C 40-44, the tensile yield point is approximately 90% of the tensile ultimate; and as a practical consideration, to reduce rejections from the proof load testing, the proof test load should not exceed 90% of the minimum yield point at R_C 40. It therefore follows that the design ultimate strength (P') of the weakest failure mode for each component should be:

$$P' \geqslant \frac{P170}{0.90 \times 0.90} \geqslant \frac{2002.8}{0.81} \geqslant 2472.6 \text{ kips}$$

Taking all of the above into account, the preliminary criteria for prototype end anchorage component design ultimate strength is 3004.2 kips for the most critical failure mode with the final criteria for performance being:

$$(\overline{X} - 3\sigma) \times (F_y \div F_u) \geqslant 2002.8 \text{ kips}$$

3.2 PROTOTYPE DESIGN

3.2.1 GENERAL

Fabrication drawings for prototype end anchorage components are shown in Fig's. 3.2-1 thru 3.2-5 as follows:

COMPONENT NAME	FIGURE
Washer	3.2-1
Washer Nut	3.2-2
Composite Washer	3.2-3
Split Shims	3.2-4
Bearing Plate	3.2-5

The load on the tendon at all major loading conditions is presented in Table 3.2-1 as a function of the guaranteed minimum tendon strength (P'170) which is 2002.8 kips.

CONDITION	AUTHORITY	FACTOR × P'_{170}	LOAD (kips)
Prototype Anchorage Design Ultimate	Section 3.1.2	1.5	3004.2
Minimum Guaranteed Strength	Section 3.2.1	1.0	2002.8
Approximate Tendon Yield Strength	Analysis of Wire	0.9	1802.5
Maximum Jacking Force (temporary)	ACI 318	0.8	1602.2
Maximum Anchoring Force (short term)	ACI 318	0.7	1402.0
Maximum Final Force (permanent)	ACI 318	0.6	1201.7

TABLE 3.2-1: Tendon load at various conditions presented as a function of guaranteed minimum tendon strength (P'_{170}).

Several factors may cause the calculated ultimate load based on alytical calculations to differ from the actual ultimate load. Among these are: a) stress concentrations due to notches and/or geometry, b) variation in material strength, and c) variation in the area of material resisting applied loads. The net effect of all these factors can be reduced to a simple ratio concept called the rupture factor (k_r) which is the ratio of the failure load as determined by calculation ($F_u \times A'_s$) to the actual failure load as determined by ultimate load test of the component (P''). Therefore $k_r = (F_u \times A'_s) \div P''$, where A'_s is nominal area of steel. k_r is normally greater than 1.0. The value of k_r is determined from previous testing of similar mechanism designed in accordance with the same type of calculation. Each series of tests allows determination of revised rupture factors, so that calculated failure loads become more accurate as more testing experience is gained. The rupture factors initially used herein are taken from WCS Technical Report Number 7, "Behavior of the WCS 520 [illegible]/44 Post-Tensioning System Under Static Loads".

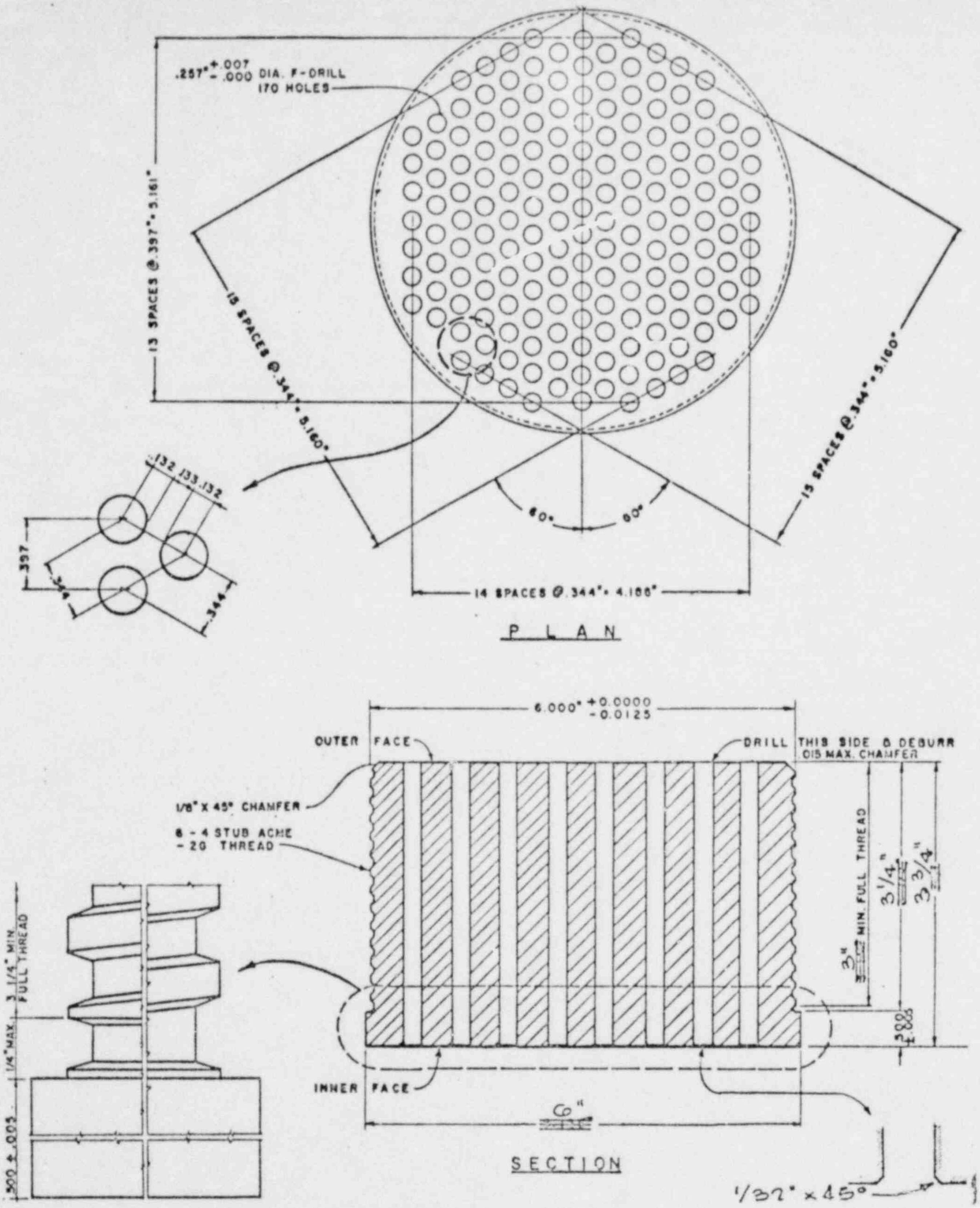
Mechanical properties for the various steels used in the prototype end anchorage components are shown in Table 3.2-2 for various strength levels. Strength levels are listed by equivalent hardness on the Rockwell B or C scales (R_B or R_C) since quality assurance is based upon determination and control of hardness. Values for mechanical properties shown in Table 3.2-2 are derived from curves contained in Fig. 3.2-6 in which: 1) the curve for ultimate tensile strength (F_{tu}) vs hardness (R_C or R_B) is constructed from information contained in the 1965 SAE Handbook, and 2) curves for other mechanical properties are plotted as they relate to F_{tu} based on information contained in MIL-HDBK-5 "Metallic Materials and Elements for Flight Vehicle Structures", and from appropriate ASTM specifications.

MECHANICAL PROPERTIES	SYMBOL (ksi)	ASTM		AISI	AISI or SAE 4140 at R_C				
		A7	A36	1025	40	41	42	43	44
Ultimate Tensile Strength	F_{tu}	60 - 75	58 - 80	55	180	187	193	200	207
Tensile Yield Strength	F_{ty}	33	36	36	163	168	173	176	183
Compressive Yield Strength	F_{cy}	33 ②	36 ②	36	179	186	192	198	205
Ultimate Shear Strength	F_{su}	38 ②	37 ②	35	109	113	115	119	121
Shear Yield Strength	F_{sy}								
Ultimate Bearing Strength ①	F_{bru}	98 ②	95 ②	90	326	335	344	355	364
Bearing Yield Strength ①	F_{bry}				256	265	272	280	289

Notes: ① For e/D = 2.0

② Derived using ratio ($F_{bru} \div F_{tu}$) as indicated for AISI 1025 times F_{tu} for A7 or A36

TABLE 3.2-2: Mechanical properties of various steels used in end anchorage components. Refer to Fig. 3.2-6 for derivative curves.

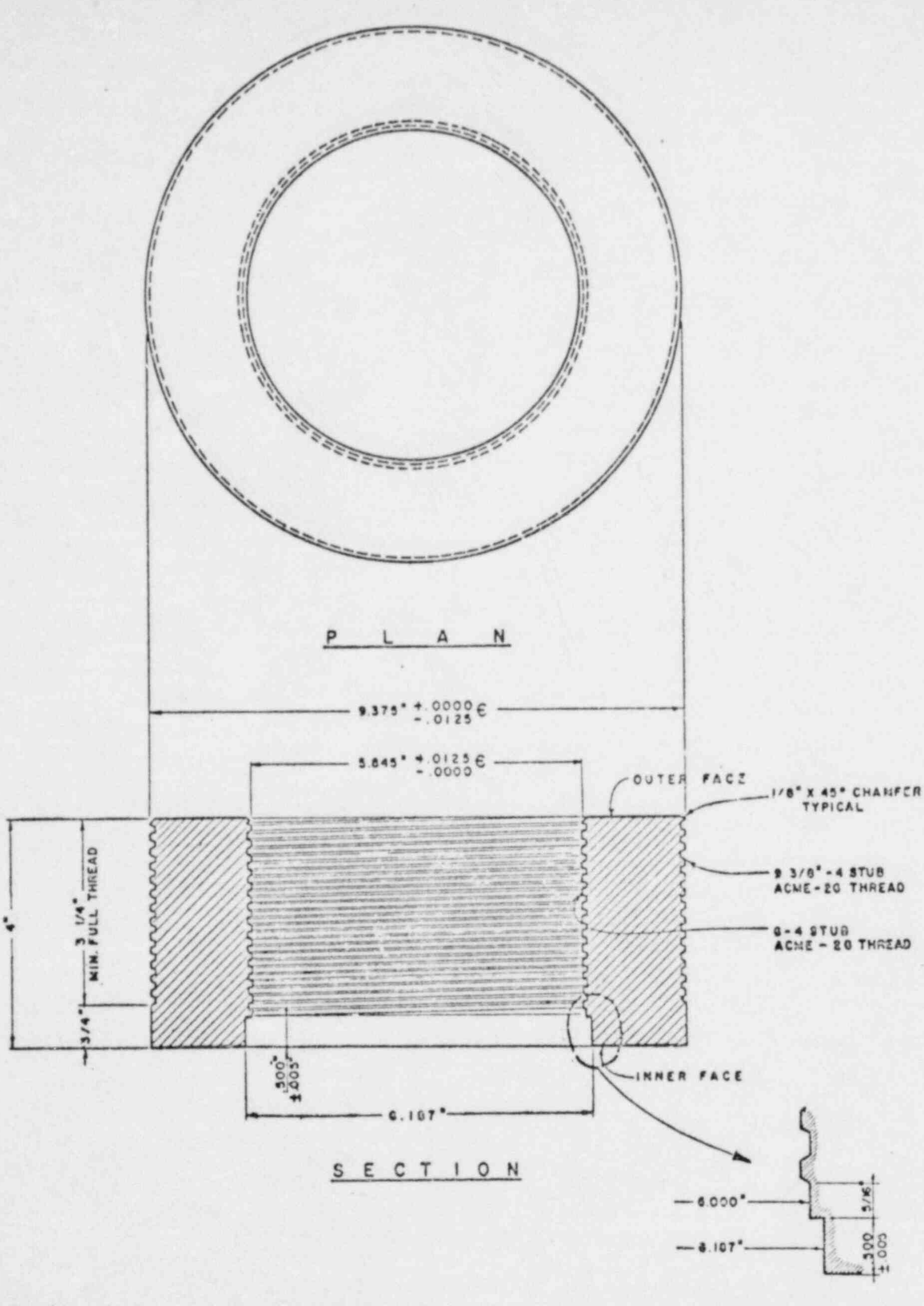


170 wire Washer; R & D Part No. 730-02; R & D Drawing No. 346

Material: 4140 commercial grade, hot finished, leaded, annealed, 6-1/2" diameter bar.

Heat Treat after all machining to R_c 40-44

FIG. 3.2-1: Prototype Washer Drawing

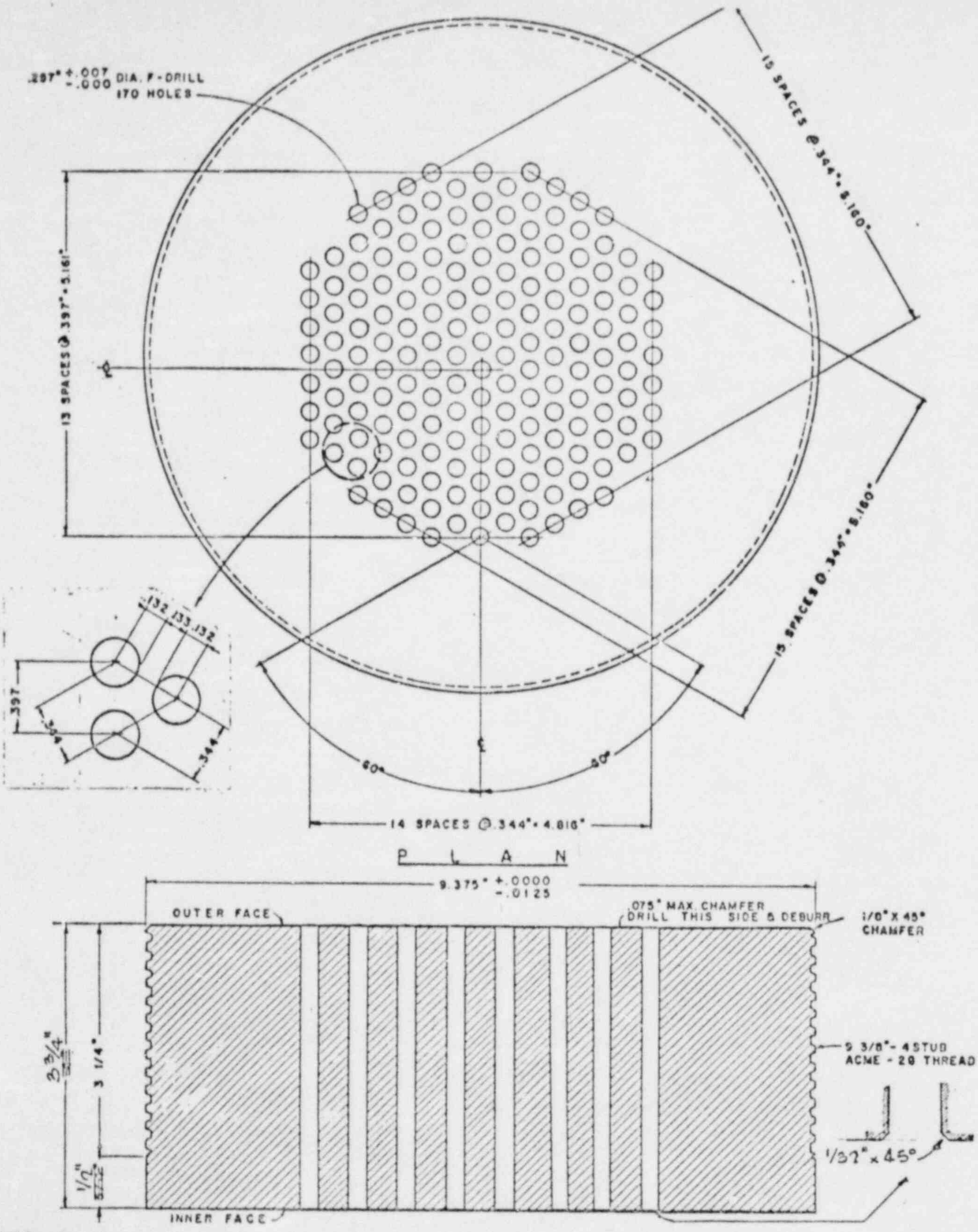


170 wire Washer Nut; R & D Part No. 730-04; R & D Drawing No. 348

Material: 4140 commercial grade, hot finished, 4-inch plate, flame cut 9-3/4 inch O.D., 5-1/2-inch I.D. and normalize.

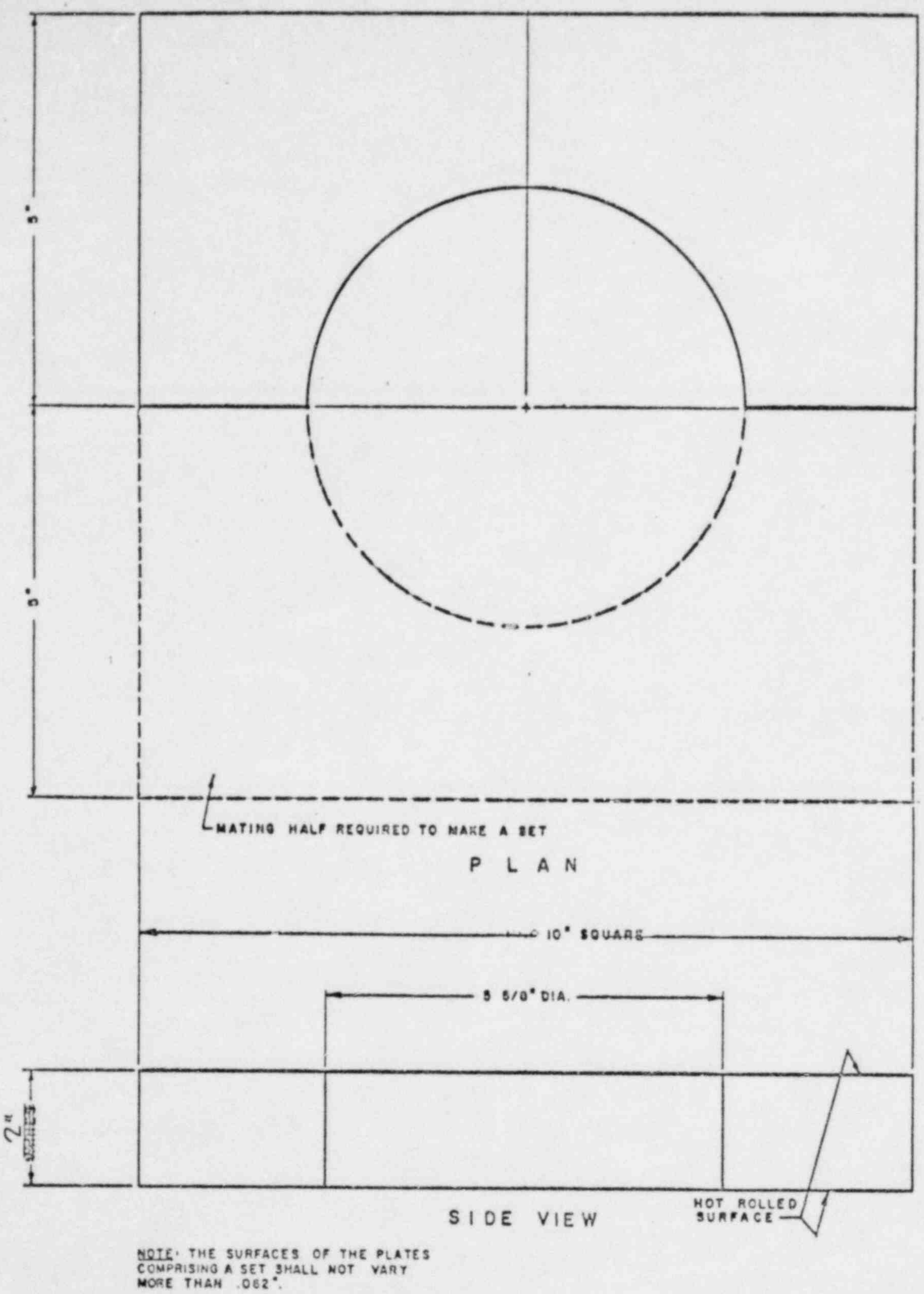
Heat Treat after machining to R_c 40-44

FIG. 3.2-2: Prototype Washer Nut Drawing



170 wire Composite Washer; R & D Part No. 730-05; R & D Drawing No. 349
Material: 4140 commercial grade, hot finished, 9-3/4 inch diameter bar
Heat Treat after machining to R_c 40-44

FIG. 3.2-3: Prototype Composite Washer Drawing

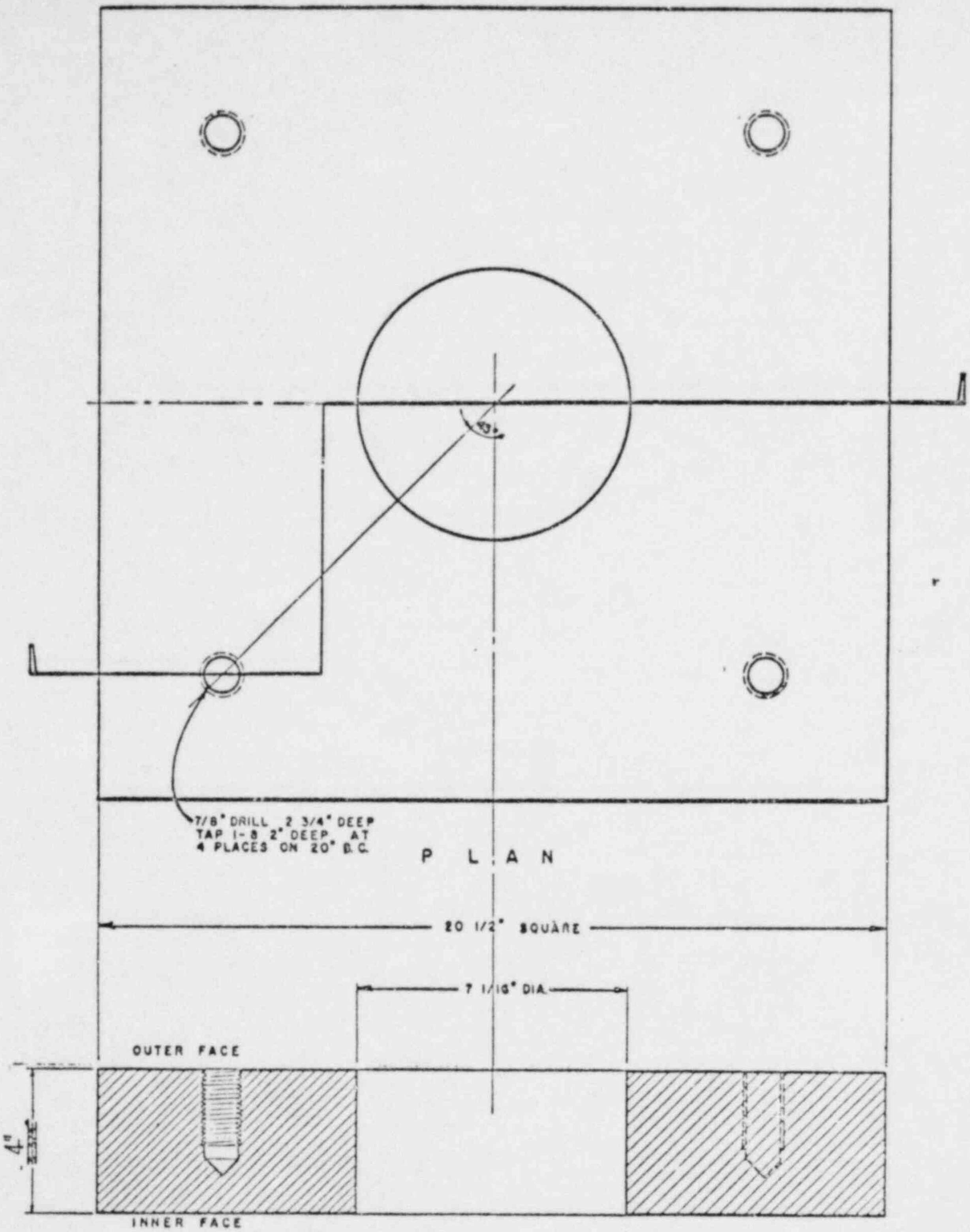


170 wire Split Shims; R & D Part No. 730-06; R & D Drawing No. 350

Material: A7, hot finished, 2 inch plate. Flame cut 5 inches x 10 inches with 5-5/8 inch diameter hole. 2 pieces per set.

Heat Treat: None

FIG. 3.2-4: Prototype Shim Drawing



170 wire Bearing Plate; R & D Part No. 730-09; R & D Drawing No. 357

Material: A7, hot finished, 4-inch plate, flame cut 20-1/2 inches × 20-1/2 inches with 7-1/16 diameter center hole.
Drill and tap four holes for 1 inch diameter × 8 t.p.i. bolt on a 20 inch bolt circle.

Heat Treat: None

FIG. 3.2-5: . Prototype Bearing Plate Drawing

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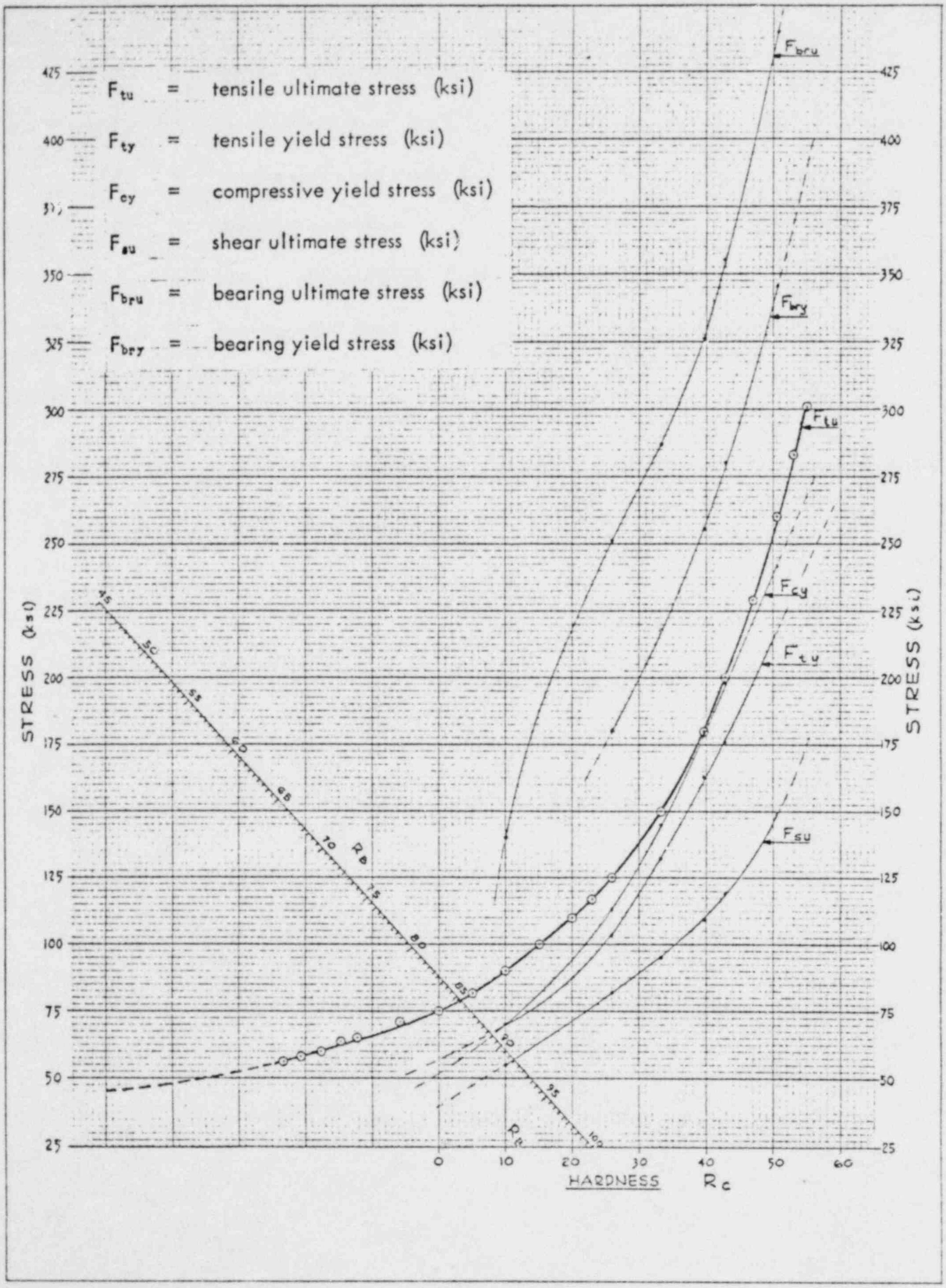

FIG. 3.2-6: Mechanical properties vs. hardness. The curve for tensile ultimate (F_{tu}), showing UTS plotted against Rockwell Hardness (R_B or R_C) is derived from information contained in the 1965 SEA Handbook, pages 107 and 109. Curves designated F_{bru}, F_{bry}, F_{cy}, F_{ty} and F_{su} show other mechanical properties relative to F_{tu} and are derived from Tables 2.2.1.1 and 2.3.1.1 (a) of MIL-HDBK-5.

All possible failure modes are listed by components in Table 3.2-3, which also shows for each failure mode the type of stress, calculated ultimate load, maximum applied temporary load, and maximum applied long term loads. Safety factors are shown for each applied load and calculated as the ratio of the calculated ultimate load to the applied load. For each component, the critical failure mode is that having the lowest safety factor. Validity of calculated ultimate loads and resulting safety factors and criticality of failure modes must be established as a result of prototype tests reported in Section 3.3.

Stresses, strains, and ultimate load capacity of components influenced by the supporting concrete are dependent upon the strength, elastic modulus, creep characteristics and reinforcement in the anchorage zone concrete and are not within the scope of this section.

Component	Failure Mode	Type of Stress	Predicted UTS (kips)	Max. Load (Temp. Overload)		Max. Permanent Load		Failure Mode Critical
				(kips)	S.F.	(kips)	S.F.	
Supporting Concrete	Anchorage Zone Bearing ℄ Interface	Principal Tension Compression	Failure is dependent on mechanical and physical properties of the supporting concrete and is not considered in this section.					
Tendon Tubing	Anchorage Zone Anchorage Zone	Axial Compression Radial Compression						
Bearing Plate	Concrete Interface Internal	Compression Flexural						
	Shim Interface	Bearing	3527.9	2002.8	1.76	1201.7	2.94	
Split Shims	Bearing ℄ Interface *	Bearing	3527.9	2002.8	1.76	1201.7	2.94	No *
	Washer Interface *	Bearing	3357.7	2002.8	1.68	1201.7	2.79	Yes *
Composite Washer	Shim Interface *	Bearing	7908.2	2002.8	3.95	1201.7	6.58	No *
	Web *	Shear and Flexure	2864.4	2002.8	1.43	1201.7	2.38	Yes *
	9-3/8" Threads	Shear	4342.7	1602.2	2.71	None	∞	No
Washer Nut	Shim Interface *	Bearing	7908.2	2002.8	3.95	1201.7	6.58	No *
	9-3/8" Threads	Shear	4342.7	1602.2	2.71	None	∞	No
	6" Threads with Shims*	Shear	3276.5	2002.8	1.64	1201.7	2.73	Yes *
Washer	Web	Shear and Flexure	2864.4	2002.8	1.43	1201.7	2.38	Yes
	6" Threads with Shims*	Shear	3276.5	2002.8	1.64	1201.7	2.73	No *

TABLE 3.2-3: Possible Failure Modes of 2.0 Mep/170 W System End Anchorage Components. Safety Factor (S.F.) is the predicted ultimate load divided by the applied load. * Indicates failure modes to be tested.

3.2.2 SPLIT SHIM - BEARING PLATE INTERFACE (Ref. Fig. 3.2-7)

Nominal Area: $A_s' = 10.0 - \frac{\pi \times 7.0625^2}{4} = 60.83$ sq. in.

Rupture Factor: $k_r = 1.0$

$F_{cy} = 36$ ksi for A36 per Table 3.2-2. $\therefore .9\ F_{cy} = 32.4$ ksi

LOADING CONDITION	FORMULATE FOR P or f	LOAD (kips)	STRESS (ksi)	REMARKS
Calculated UTS	$P = F \times A_s'$	3527.9	58	> 3004.2
Predicted UTS	$P = F \times A_s' \times 1/k_r$	3527.9	58	> 3004.2
Proof Test Load	$f = P \div A_s'$	2002.8	32.93	< 33
Jacking	↓	⊖	⊖	Unloaded till trans.
Anchoring		1402.0	23.05	< 32.4 = .9 F_{cy}
Max. Final		1201.7	19.76	↓

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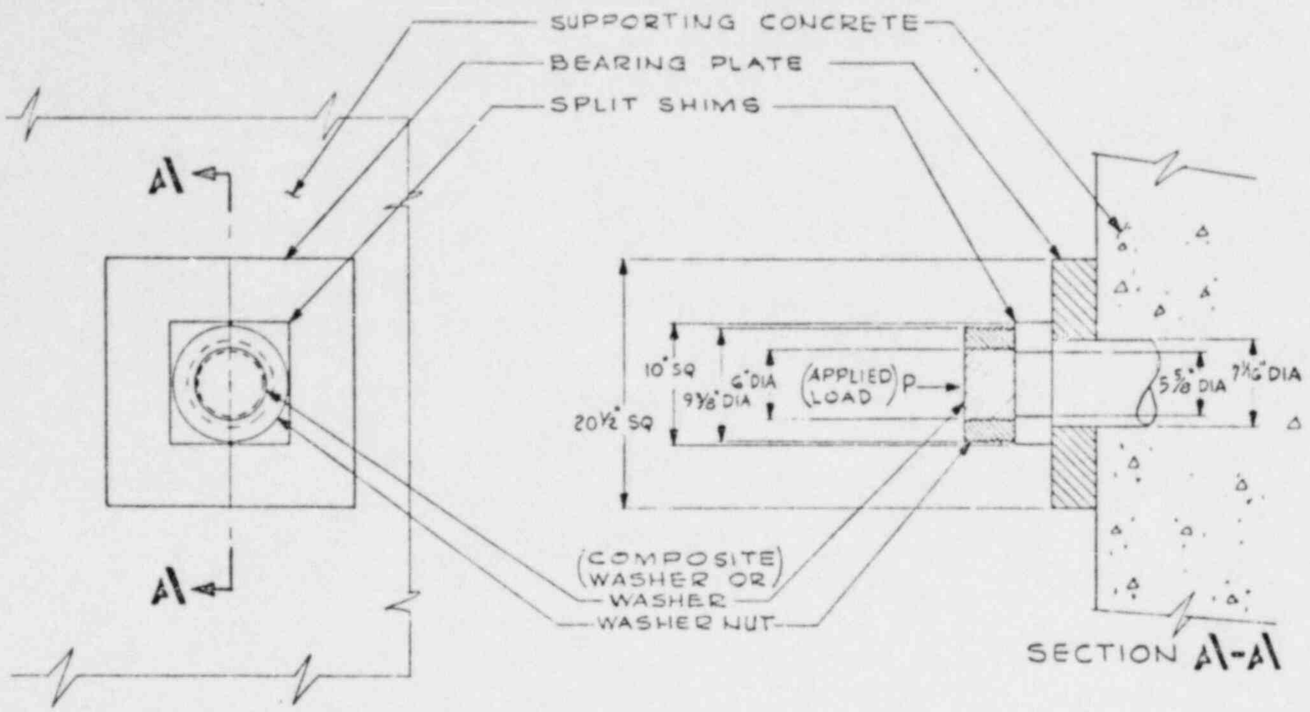


FIG. 3.2-7: Arrangement of Anchorage Components

3.2.3 COMPOSITE WASHER - SPLIT SHIM INTERFACE (REF. FIG. 3.2-7)

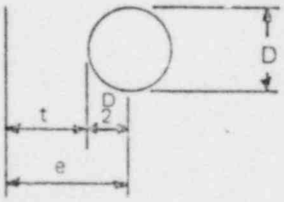
Nominal Area: $A'_s = \pi \frac{(9.375^2 - 5.625^2)}{4} = 44.18$ sq. in.

Rupture Factor: $k_r = 1.0$

F_{cy} = 36 ksi for split shim

LOADING CONDITION	FORMULATE FOR P or f	LOAD (kips)	STRESS (ksi)	REMARKS
Calculated UTS	$P = F \times A'_s$	3357.7	76 ①	> 3004.2
Predicted UTS	$P = F \times A'_s \times 1/k_r$	3357.7	76 ①	> 3004.2
Proof Test Load	$f = P \div A'_s$	2002.8	45.33 ②	$< F_{cy} = 179$ for R_C^{40}
Jacking	↓	—	—	No load till trans.
Anchoring		1402.0	31.73	$< 32.4 = .9\ F_{cy}$
Max. Final		1201.7	27.20	↓

Note:



① equivalent $D = \frac{9.375 - 5.625}{2} = 1.875$

equivalent $e = t + \frac{D}{2} = 2 + \frac{1.875}{2} = 2.94$ for t = 2.0 min.

$\therefore\ e/D = \frac{2.94}{1.875} = 1.57 > 1.5$

F_{bru} (for e/D = 1.5) ≈ .8 F_{bru} (for e/D = 2.0)

$\therefore\ F_{bru}$ (for e/D = 1.5) = .8 × 95 = 76 ksi

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② The bearing stress of 45.33 at Proof Test Load exceeds $F_{cy} \approx 36$ ksi for the A7 or A36 split shims which would therefore be expected to show permanent deformations. The split shims do not require a proof load test and the bearing stress is well below F_{cy} of 4140 steel at R_C 40.

③ For the composite washer side of the interface F_{bru} = 326 ksi and F_{cy} = 179 ksi.

3.2.4 9-3/8 O.D. THREAD

$$A_s' = \frac{(L_e - p) \times \pi \times E}{2} \quad ; \text{where:}$$

A_s' = nominal shear area

L_e = length of thread engagement = 3.250 inches

n = number of threads per inch = 4

p = pitch = 1 ÷ n = 0.250 inches

D = nominal diameter = 9-3/8 = 9.375 inches

E = nominal pitch diameter

= D - 0.3 p = 9.375 - (0.3 x 0.250) = 9.300 inches

$$A_s' = \frac{(3.25 - 0.25) \times 3.1416 \times 9.30}{2} = 43.83 \text{ sq. in.}$$

$$P' = \frac{F_{su} \times A_s'}{k_r} \quad \text{and } f_s = \frac{P \times k_r}{A_s'}$$

P' = Predicted ultimate load

F_{su} = Ultimate shear strength (See Table 3.2-2)

k_r = Rupture factor = 1.1 (Ref.: WCS Technical Report No. 7)

f_s = Calculated shear stress

LOADING CONDITION	HARD. R_C	LOAD (kips)	STRESS (ksi)	REMARKS
Calculated UTS ①	40	4777.0	109	> 3002.4
Predicted UTS	40	4342.7	109	↓
	41	4502.1	113	↓
	42	4581.7	115	↓
	43	4741.1	119	↓
	44	4820.8	121	↓
Proof Test Load	40	2002.8	50.27	< (.9 F_{sy} = .9 x .9 x F_{su} = 88.3)
Jacking ②	40	1602.2	40.21	< 0.4 F_{su}

Notes:

① Calculated UTS does not make use of k_r, $\therefore P_c = F_{su} \times A_s'$

② The 9-3/8 thread is unloaded after transfer

[redacted]

3.2.5 6 INCH O.D. THREAD - VITHOUT SHIMS (REF. FIG. 3.2-7)

$A'_s = \frac{(L_e - p) \times \pi \times E}{2}$; where:

A'_s = nominal shear area

L_e = length of thread engagement = 3.250 inches

n = number of threads per inch = 4

p = pitch = 1 ÷ n = 0.250 inches

D = nominal diameter = 6.000 inches

E = nominal pitch diameter

= D - 0.3 p = 6.0 - (0.3 x 0.250) = 5.925 inches

$A'_s = \frac{(3.25 - 0.25) \times 3.1416 \times 5.925}{2} = 27.92$ sq. in.

Calculated Ultimate Load:

$P_c = P_s = F_{su} \times A'_s$

Predicted Ultimate Loads and Stresses:

$P' = P'_s = \frac{F_{su} \times A'_s}{k_r}$; and $f_s = \frac{P \times k_r}{A'_s}$; where

F_{su} = Ultimate shear strength (See Table 3.2-2)

k_r = Rupture factor = 1.1 (Ref. WCS Technical Reoprt No. 7)

f_s = Calculated shear stress

LOADING CONDITION	HARD. R_C	LOAD (kips)	STRESS (ksi)	REMARKS
Calculated UTS	40	3043.4	109	> 3004.2
Predicted UTS	40	2766.7	109	
	41	2868.2	113	
	42	2919.0	115	
	43	3020.5	119	
	44	3071.3	121	
Proof Test Load	---	2002.8	78.9	< .9 F_{sy} (.9 x .9 x 109 = 88.3)
Jacking	—	1602.2	63.1	= 58 x F_{su} (min.)
Anchoring	—	1402.0	55.2	= 51 x
Max. Final	—	1201.7	47.3	= .43 x

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3.2.6 6 INCH O.D. THREADS - WITH SHIMS (Ref. Fig. 3.2-7)

The 6" washer bears on the split shims over an area A_{br} and thus results in a force, $P_{br} = f_{br} \times A_{br}$. This bearing force ($P_{br}$) plus the shear force ($P_s$) as derived in Section 3.2.5 reacts against any applied load (P), so that: $P = P_s + P_{br}$. At ultimate load levels, all component materials are stressed within the plastic range, and we can expect f_{br} to be equal to F_{bru} which is quite high in terms of F_{tu}, but is rather indeterminate. MIL-HDBK-5 gives data for F_{bru} of AISI 1025 steel for e/D = 2.0, but this in the average stress at ultimate rather than the peak stress since it is based on a round pin of diameter D in a slightly oversized hole. If we assume a sinusoidal stress distribution F_{bru} (average) = 0.636 F_{bru} (peak), or F_{bru} (peak) = 1.57 F_{bru} (average) Data for AISI 1025 steel indicates that $F_{bru} = (90 \div 55)\ F_{tu} = 1.64\ F_{tu}$. The washer-split shim interface is a plane surface where it can be assumed that average and peak bearing stresses are the same. F_{tu} for either A7 or A36 steel can be determined approximately from the R_B hardness. Therefore, we can derive an approximate expression for P_{br} as follows:

$$P_{br} \approx F_{bru} \times A_{br} \approx 8.79\ F_{tu}\text{; where:}$$

$$A_{br} = \frac{\pi}{4}(6.00^2 - 5.625^2) = 3.42 \text{ sq. in.}$$

$$F_{bru} \approx 1.64\ F_{tu} \times 1.57 \approx 2.57\ F_{tu}$$

F_{tu} is determined by hardness test from Fig. 3.2-6.

$$\text{Therefore } P' = P'_s + P_{br} \approx P'_s + 8.79\ F_{tu}$$

Shear stresses in the threads resulting from an applied load can be determined in much the same manner except that for loads substaintially below ultimate, we must assume a relatively uniform stress over the entire bearing surface as follows:

$$P = f_{br} \times A_{br}\ (\text{total}) = 44.18\ f_{br}\text{; or } f_{br} = \frac{P}{44.18}\text{; where:}$$

$$A_{br}\ (\text{total}) = \frac{\pi}{4}(9.375^2 - 5.625^2) = 44.18 \text{ sq. in.}$$

$$\text{Therefore: } P_{br} = f_{br} \times A_{br} = \frac{P}{44.18} \times 3.42 = 0.077\ P$$

$$\text{Since: } P = P_s + P_{br} = P_s + .077\ P$$

$$P_s = 0.923\ P = f_s \times A_s = f_s \times 27.92 \text{ (Section 3.2.5)}$$

$$f_s = \frac{0.923\ P}{27.92} = 0.033\ P$$

3.2.7 WIRE HOLE WEB SHEAR

As shown in Fig. 3.2-8, shear failure of the web between the wire holes can occur along either of two critical paths. The load applied by the wire heads to the portion of the washer inside the shear plane (P_s) is less than the total applied load (P) since part of the load applied by the wires on the shear path is applied to the portion of the washer outside the shear plane. This ratio of load distribution and the number of webs on the shear plane can be determined by inspection of Fig. 3.2-8, which gives the following results:

SHEAR PATH	WIRES RELATIVE TO SHEAR PLANE		TOTAL WIRES	LOAD RATIO $R_p = P_s/P$	NUMBER OF WEBS (N)	STRESS RATIO $R_s = R_p/N$
	INSIDE	OUTSIDE				
Shear Path 1	141	29	170	0.829	44	0.0189
Shear Path 2	133	37	170	0.782	40	0.0196

For any given condition, the web width (w), the washer thickness (t) and the applied load (P) are constants, so that the computed shear stress (f_s) varies directly with the stress ratio ($R_s = R_p/N$) as follows:

[redacted]

$$f_s = \frac{P_s}{A_s} = \frac{R_p \times P}{N \times w \times t} = \frac{R_p}{N} \times \frac{P}{w \times t} = R_S \times C$$

It can thus be seen that the shear stress along shear path 1 will be slightly lower than that along shear path 2, which will be used in following calculations, however, the difference is small and, due to manufacturing variables, web shear failure can be expected to occur along either shear path.

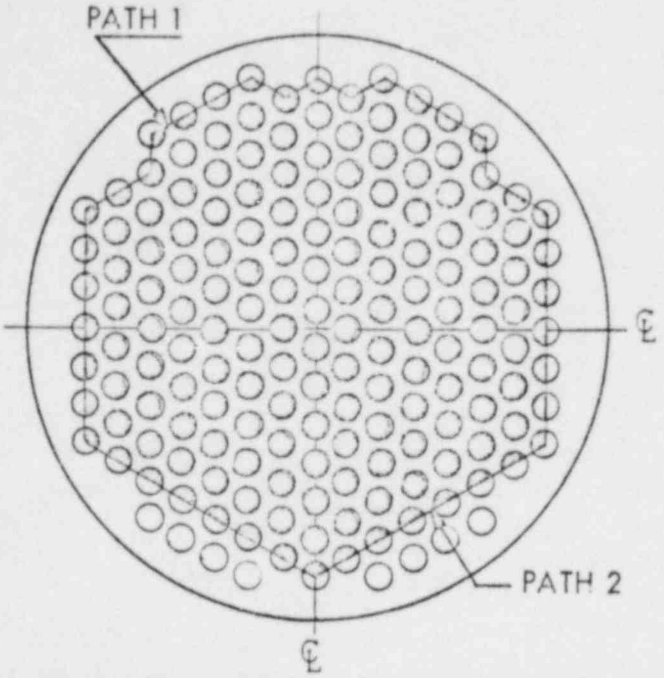

FIG. 3.2-8: Alternate shear paths for wire hole web shear failure with Path 1 shown above horizontal ℄ and Path 2 below. Path 2 is slightly more critical than Path 1.

While the center to center spacing between adjacent wire holes can vary ± 0.010, or 7.5% of the nominal web width ($w = 0.133$), the total spacing along any line of holes has the same tolerance of ± 0.010, which is only 0.2%. Therefore the average web is the nominal center to center hole spacing (0.397) minus the hole diameter (0.260 nominal or 0.264 maximum). The area of steel resisting web shear (A_s) along the critical Path 2 is therefore:

$$A_s' = N \times w' \times t = 40 \times 0.137 \times 3.750 = 20.55 \text{ sq. in.}$$

$$A_{s\text{-min.}} = N \times w_{\text{min.}} \times t = 40 \times 0.133 \times 3.750 = 19.95 \text{ sq. in.}$$

N = number of webs along Path 2 = 40

w' = nominal web width = 0.397 - 0.260 = 0.137 in.

$w_{\text{min.}}$ = minimum web width = 0.397 - 0.264 = 0.133 in.

t = washer thickness = 3-3/4 = 3.750 in.

Calculated ultimate load (P_c') and predicted ultimate load (P') are the same since the rupture factor (k_r) is taken as 1.0. Loads and stresses are given by:

$$P_s' = \frac{F_{su} \times A_s'}{k_r} = \frac{109 \times 20.55}{1.0} = 2240 \text{ kips}$$

$$P' = \frac{P'_s}{R_p} = \frac{P_s'}{0.782} = \frac{2240}{0.782} = 2864.4 \text{ kips}$$

$$f_s = \frac{R_p \times P}{A_s'} = \frac{0.782 \times P}{20.55} = 0.0381 \text{ P ksi}$$

where: P = any applied tendon load

P' = tendon ultimate tensile strength

P_s' = predicted ultimate shear (test) load

R_p = load ratio = 0.782 from chart above

k_r = rupture factor = 1.0 (Ref. WCS Technical Report No. 7)

A_s = nominal shear area for Path 2 = 20.55 sq. in.

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LOADING CONDITION	HARD. R_C	LOAD (kips)	STRESS (ksi)	REMARKS
Predicted UTS	40	2864.4	109	
↓	41	2969.5	113	
	42	3022.1	115	> 3004.2
	43	3127.2	119	↓
	44	3179.7	121	
Proof Test Load		2002.8	76.2	$< .9\ F_{sy}$ (.9 x .9 x 109 = 88.3)
Jacking		1602.2	61.0	$= .56\ F_{su}$
Anchoring		1402.0	53.4	$= .49\ F_{su}$
Max. Final		1201.7	45.7	$= .42\ F_{su}$

For shear failure along Path 1:

$$A_s' = N \times w' \times t = 44 \times 0.137 \times 3.750 = 22.61 \text{ sq. in.}$$

$$A_s \text{ min.} = N \times w_{min.} \times t = 44 \times 0.133 \times 3.750 = 21.94 \text{ sq. in.}$$

$$P_s' = \frac{F_{su} \times A_s'}{k_r} = \frac{109 \times 22.61}{1.0} = 2464.5 \text{ kips}$$

P' = equivalent tendon ultimate strength

$$= \frac{P_s}{R_p} = \frac{P_s}{0.829} = \frac{2464.5}{0.829} = 2972.8 \text{ k}$$

$$f_s = \frac{R_p \times P}{A_s'} = \frac{0.829 \times P}{22.61} = .0366 \text{ P ksi}$$

3.2.8 FAILURE MODE ANALYSIS

ACI 318-63 limits the concrete compressive stress on the bearing area supporting a tendon bearing plate to:

$$f_{cp} = 0.6\ f_{ci}' \quad \sqrt[3]{A_b'/A_b};\ \text{but} < f_{ci}'$$

In customary practice, f_{cp} is considered to be a uniform stress and the bearing plate thickness is then set to limit flexural stress in the bearing plate to F_{ty} at minimum guaranteed tendon ultimate. Although this procedure results in satisfactory performance, it does not represent the actual conditions which exist and has no significance in analizing the mode of failure. While $f_{cp} = P/A_b$ gives the average stress on the bearing area, the distribution is not uniform in any case, and is dependent upon the modulus of elasticity, poissons ratio, and creep properties of both the plate and the supporting concrete. The maximum concrete stress is a function of bearing plate deflection. Since the bearing plate flexural stress could not possibly exceed F_{ty} without causing concrete failure, the bearing plate can not fail. The failure mode is thus determined by the supporting concrete, not the plate, and will not be considered in this Section. This subject is covered in WCS Technical Report No. 2.

Table 3.2-3 lists all failure modes for each component. For each component, the critical failure mode is that having the lowest Safety Factor (S.F.). The purpose of the prototype testing reported in Section 3.3 is to determine actual ultimate load for all critical failure modes.

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3.3 PROTOTYPE TEST

3.3.1 DESCRIPTION OF TEST PROGRAM

The test program was designed to test the ultimate load, ultimate elongation, and failure mode of 170 wire tendons of lengths up to 30'; and to determine the ultimate capacity of the individual anchorage hardware components when loaded in such a manner as to test the critical failure mode of each component.

Testing was divided into four categories, Series PL - ultimate load tests of 170 wire tendons and anchorages 4' long; Series A - ultimate load and elongation tests of 170 wire tendons and anchorages 30' l(; Series B - ultimate shear load of web (honeycomb); and Series C - ultimate shear load of 6 inch diameter thread.

3.3.2 PROTOTYPE ANCHORAGE HARDWARE

Prototype hardware was fabricated in accordance with drawings per Figs. 3.2-1 thru 3.2-5. Prior to testing, components were designated by R and D drawing and part numbers. After tests had validated design, final drawing and part numbers were assigned. These are listed in Table 3.3-1 for reference.

Part Name	R & D Identification			Final
	Part No.	Drawing No.	Revision Date	Part and Drawing No.
Washer	730-02	346	10-21-66	100103 - 00
Washer Nut	730-04	348	10-21-66	100104 - 00
Composite Washer	730-05	349	10-21-66	100105 - 00
Shims	730-06	350	10-21-66	100106 - 00
Bearing Plate	730-09	357	10-10-66	100107 - 00

TABLE 3.3-1: Prototype Anchorage Hardware Designation

Each prototype washer, washer nut and composite washer was assigned a serial number for identification and record. Tables 3.3-2 thru 3.3-4 show the material, material supplier, chemical analysis, machining practice, heat-treatment, and hole diameter and spacing tolerances for the washer, washer nut and composite washers respectively. Also listed in the same tables are the measured dimensions and loading history for each serial numbered part.

It should be noted that prototype anchorage hardware dimensions and material do not agree exactly with drawings and manufacturing standards shown in Section 3.4. Even though tests on the prototype hardware were entirely satisfactory and and conform to design criteria, some dimensions were changed in the interest of standardization. In particular, the thickness of the washer and composite washers were increased from 3-3/4 inches to 4 inches in order to conform with the washer nut; and alloy tubing for the washer nut and alloy bar (pressed round) materials are shown as preferred over flame cut plate used for prototype hardware. Since these changes are all on the conservative side and increase the strength of the respective part, the prototype tests are applicable. Predicted failure loads for the production parts have been established by linear increase of prototype test results to account for the increased strength due to these changes. All such changes are clearly noted in the analysis of each series of tests.

3.3.3 TEST SERIES PL

The objective of Series PL tests was to provide preliminary results by loading prototype anchorage hardware to the tendon ultimate in such a way as to limit the release of energy in the event of failure of an anchorage hardware component. All anchorage hardware components used for: 1) Series A tests (170 wire x 30 foot long tendon ultimate tests), 2) 170 wire structural tendons in the 4.0 Mep test bed, and 3) General Atomic ultimate tests of both straight and curved tendons up to 100' long were tested in this series. A secondary objective was to provide additional statistical data in support of the design criteria that the anchorage hardware must be stronger than the minimum guaranteed tendon strength (2002.8 kips). A third objective was to repeatedly test the stressing equipment at a load equal to tendon design ultimate.

The test set-up is shown in Fig. 3.3-1. End anchorage hardware consisting of a washer and washer nut (typical A-end) on the right and either a composite washer (typical B-end) or a

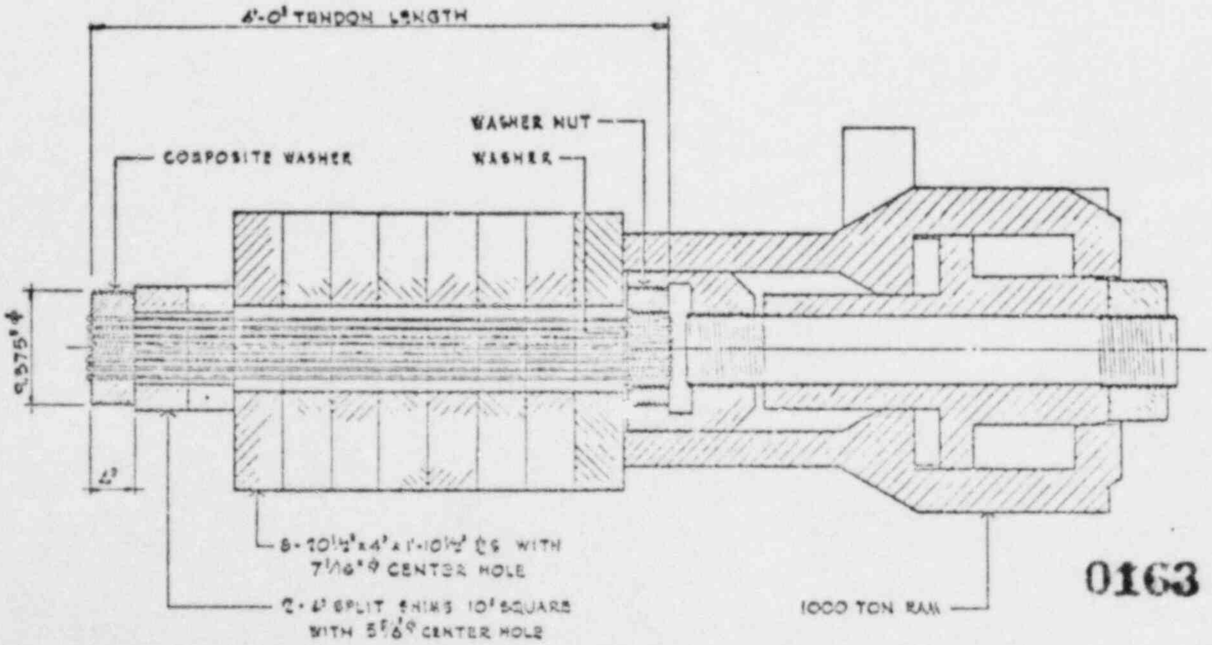

FIG. 3.3-1: Setup for Series PL tests.

PART NAME : WASHER
PART NUMBER : RD 730-02; Print: RD 730-346; Final Part and Drawing No.: 100103
MATERIAL : 6-1/2 inch diameter, hot finished, bar stock, leaded and annealed per AISI 4142 Commercial Grade
MATERIAL SUPPLIER : United States Steel Corporation
CHEMICAL ANALYSIS :

C	Mn	P	S	Si	Cr	Mo	Pb
.47	.83	.008	.020	.27	.92	.18	.15/.35

MACHINING : Rough machine and thread on a conventional engine lathe. Hole drill on an automatic drill press using conventional feeds and speeds and a "Burghmaster" floating index table.
HEAT TREAT : Per MIL-H-6875B; protective atmosphere furnace for hardening and tempering; circulating oil for quenching. Quench flat in a single layer to facilitate web quench. Hardness as quenched R_c 54/55.
HOLE DIAMETER : Holes checked with hole micrometers and "Go-No Go" gauges ran to maximum metal side of tolerance.
HOLE CENTER SPACING : Within ± .010 on outer (drill in) face
Within ± .030 on inner (drill out) face
THICKNESS : 3-3/4 inches overall; 3-1/4 inch thread length

Serial Number	Measured Dimensions							Load History					
	Major Diameter	Thread Depth	Clearance		Hardness			Series PL	Series A		Test Bed	Series B & C	General Atomic Tests
			Pitch Dia.	Axial	R_c	≈ B	Lab.						
001	5.998	.075	.015	.020	41.5	390	-	PL-4					5a, 6d
002	5.992	.076	.017	.025	41.5	390	-	PL-3	A-1	A-2			5c, 8a
003	5.996	.075	.015	.020	41.5	390	-	PL-7					6a, 8b
004	5.996	.076	.014	.015	42.0	401	-	PL-5					6b, 9a
005	5.991	.080	.028	.018	41.0	388	-	PL-1			Bed		
006	5.995	.072	.014	.017	41.5	390	-	PL-5					6c, 9b
007	5.995	.074	.015	.012	41.0	388	-	PL-6					#10
008	5.996	.080	.015	.011	42.0	401	-	PL-6					5b
009	5.992	.073	.013	.014	41.5	390	-	PL-2			Bed		
010	5.980		.015	.014	42.0	401	375					C2-7	
011	5.993		.018	.015	41.0	388	363					C1-10	
012	5.995		.020	.018	40.5	385	375					C2-8	
013	5.995		.015	.012	39.0	370	363					C2-9	
014	5.986		.014	.020	41.0	388	352					C1-4	
015	5.987		.023	.018	41.5	390	-						
n	15	9	15	15	15	15	5						
$\bar{X}$	5.992	.076	.0167	.0166	41.23	390	365.6						
σ	0.00465	.00262	.00394	.00368	0.727	53.5	8.66						
v	.077%	3.4%	23.6	22.2	1.76	13.7	2.4						

TABLE 3.3-2: WASHER - dimensions and load history.

PART NAME : WASHER NUT
PART NUMBER : RD 730-04; Print: RD 730-348; Final Part and Drawing No.: 100104
MATERIAL : AISI 4142, annealed, 4 inch hot rolled plate, commercial grade. Flame cut 9-3/4 inches outside diameter with a 5-1/2 inch center hole and annealed.
MATERIAL SUPPLIER : Lukins Steel Company
CHEMICAL ANALYSIS :

C	Mn	P	S	Si	Cr	Mo	Pb
.38	.76	.008	.025	.240	.90	.15	-

MACHINING : Rough machine and thread on a conventional engine lathe.
HEAT TREAT : Per MIL-H-6875B, protective atmosphere furnace for hardening and tempering; circulating oil for quenching; Hardness as quenched R_c 54/55.
THICKNESS : 4 inch overall, 3-1/2" length internal threads, 3-1/4" length external threads.

Serial Number	Measured Dimensions										Load History						
	External Thread				Internal Thread												
	Major Diameter	Thread Depth	Clearance		Minor Diameter	Clearance		R_c	≈ BHN	Lab	Series PL		Series A		Test Bed	Series B & L	General Atomic Tests
			Pitch Dia	Axial		Pitch Dia	Axial										
001	9.364	.065	.028	.029	5.860	.021	.010	40.5	385	388	PL-4					C2-9	
002	9.372	.068	.022	.020	5.855	.019	.014	41.0	388	363	PL-7					C2-10	
003	9.365	.089	.031	.020	5.852	.020	.015	41.5	390	363	PL-3		A-1	A-2			
004	9.364	.086	.026	.014	5.860	.015	.007	40.0	375	-	PL-5						5a, 5c, 6b, 6d, 8b, 9b
005	9.368	.089	.028	.021	5.870	.030	.018	41.7	400	352	PL-6					C2-7	
006	9.362	.089	.028	.023	5.863	.023	.012	40.5	385	-	PL-5						5b, 6a, 6c, 8a, 9a
007	9.368	.089	.025	.019	5.892	.032	.010	40.0	375	-	PL-1	PL-2			Bed		Pull Rod Test
008	9.370	.087	.031	.019	5.866	.025	.008	42.0	401	363	PL-6					C1-4	
n	8	8	8	8	8	8	8	8	8	5							
$\bar{X}$	9.367	.0876	.0274	.0206	5.8648	.0231	.0118	40.90	387.4	365.8							
σ	.00320	.00148	.00282	.00397	.0116	.00532	.00349	.721	9.15	11.9							
v	.03	1.7	10.3	19.3	.20	23.0	29.6	1.76	2.36	3.25							

TABLE 3.3-3: WASHER NUT - dimensions and load history.

PART NAME		COMPOSITE WASHER
PART NUMBER	:	RD 730-05, Print: RD 730-349, Final Part and Drawing No.: 100105
MATERIAL	:	AISI 4142 Commercial Grade, 9-1/2 inch diameter pressed round, annealed
MATERIAL SUPPLIER	:	Bethlehem Steel Corporation
CHEMICAL ANALYSIS	:	C .43 Mn .93 P .008 S .024 Si .20 Cr .97 Mo .19 Pb —
MACHINING	:	Rough machine and thread on a conventional engine lathe. Hole drill on an automatic drill press using conventional feeds and speeds and a "Burghmaster" floating index table.
HEAT TREAT	:	Per MIL-H-6875B; protective atmosphere furnace for hardening and tempering; circulating oil for quenching. Quench flat in a single layer to facilitate web quench. Hardness as quenched R_c 54/55.
HOLE DIAMETER	:	Hole checked with hole micrometers and "Go-No Go" gauges ran to maximum metal side of tolerance
HOLE CENTER SPACING	:	Within ± .010 on outer (drill in) face Within ± .030 on inner (drill out) face
THICKNESS	:	3-3/4 inches overall; 3-1/4 inch thread length

	Measured Dimensions							Load History					
Serial Number	Major Diameter	Thread Depth	Clearance		Hardness			Series PL	Series A		Test Bed	Series B & C	General Atomic Tests
			Pitch Dia.	Axial	R_c	≈ BHN	Lab						
001	9.361	.070	.030	.021	41.5	390	341					B1-2	
002	9.372	.078	.030	.015	40.5	385	341					B1-1	
003	9.364	.075	.030	.017	42.0	401	-	PL-1			Bed		
004	9.365	.074	.028	.017	41.2	388	341					B1-3	
005	9.364	.072	.029	.014	42.0	401	352					B2-6	
006	9.362	.072	.031	.017	40.0	375	-	PL-2			Bed		
007	9.369	.075	.028	.016	40.0	375	-	PL-4 PL-7					5a, 5b, 5c, 6a, 6c, 8a, 9a
008	9.365	.071	.030	.017	40.0	375	-	PL-3	A-1	A-2			*10, 6b, 6d, 8b, 9b
009	9.369	.075	.032	.018	42.6	408	375					B2-5	
010	9.368	.082	.029	.019	40.0	375	-						
011	9.364	.073	.030	.025	42.0	401	-						
012	9.360	.069	.032	.018	41.0	388	-						
013	9.362	.070	.025	.018	40.5	385	-						
014	9.362	.073	.027	.017	41.0	388	-						
015	9.358	.070	.029	.020	40.0	375	-						
					1								
n	15	15	15	15	15	15	5						
$\bar{X}$	9.364	.0733	.0293	.0179	40.95	387.3	350						
σ	.00368	.00334	.00178	.00254	.869	10.85	13.21						
v	.039	4.55	6.06	14.2	2.12	2.80	3.77						

TABLE 3.3-4: COMPOSITE WASHER - dimensions and load history.

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washer and washer nut on the left were connected by 170 0.250 inch diameter wires 4 feet long with button-heads. The washer on the right hand side of the 4 foot tendon was inserted thru a block consisting of eight bearing plates (R&D Part No. 730-09 per Fig. 3.2-5). After installation of the washer nut, shims (R&D Part No. 730-06 per Fig. 3.2-4) were installed on the left hand side as spacers and the 1000 ton stressing jack was connected to the washer nut on the right. In the initial tests of this series, the jacking load was increased until failure of two or three wires occurred. In later tests the load was stopped at 2100 k. All anchorage hardware tested in Series PL was subsequently reused in other tests. Elongations at failure were not recorded. Series PL test results are summarized in Table 3.3-5.

Test Series PL - Test Results								
Test Number	Test Date	Max. Load (kips)	Part Serial Numbers					Remarks
			Left			Right		
			Washer	Nut	Compo	Washer	Nut	
PL-1	1-28-67	1988	-	-	003	005	007	
PL-2	1-30-67	2090	-	-	006	009	007	
PL-3	1-30-67	2150	-	-	008	002	003	
PL-4	4-7-67	2100	-	-	007	001	001	
PL-5	4-7-67	2100	004	004	-	006	006	
PL-6	4-7-67	2100	007	008	-	008	005	
PL-7	4-7-67	2100	-	-	007	003	002	

TABLE 3.3-5: Summary of Series PL Test Results.

3.3.4 TEST SERIES A

Series A tests were conducted on 30 foot nominal length straight tendons made up of 170 wires of 0.250 inch diameter anchored by means of button-heads to prototype anchorage hardware.

The objectives of Series A tests were to determine: 1) the load-elongation characteristics up to tendon ultimate, and 2) the mode of failure. The maximum force which a multi-wire tendon can resist, tendon ultimate, is that force at which 2-3% of the wires fail (3 to 6 wire failures for a 170 wire tendon), even though the remaining wires will continue to elongate at a reduced force. The number of wires which fail at each increased elongation increment can be expected to follow a normal distribution curve, imposing increasing shock loads and higher energy release. Since this would risk injury to test personnel and visitors, and damage the testing equipment, all without contributing any additional significant information, Series A tests were terminated at the total elongation which produced four wire failures.

Tests were conducted using the 4.0 million pound capacity test bed and the 1000 ton capacity stressing equipment. The test set-up is shown schematically in Fig. 3.3-2 and by photographs which are typical of both A-1 and A-2 tests (Fig. 3.3-3 thru 3.3-7). An assembled and banded 170 wire tendon having a prototype composite washer on the east end and a prototype washer on the west end was installed in the test bed from east to west. A prototype washer nut was installed on the west end and the tendon centered ready for test. Two 4" thick bearing plates are used under the anchorage hardware at both ends in

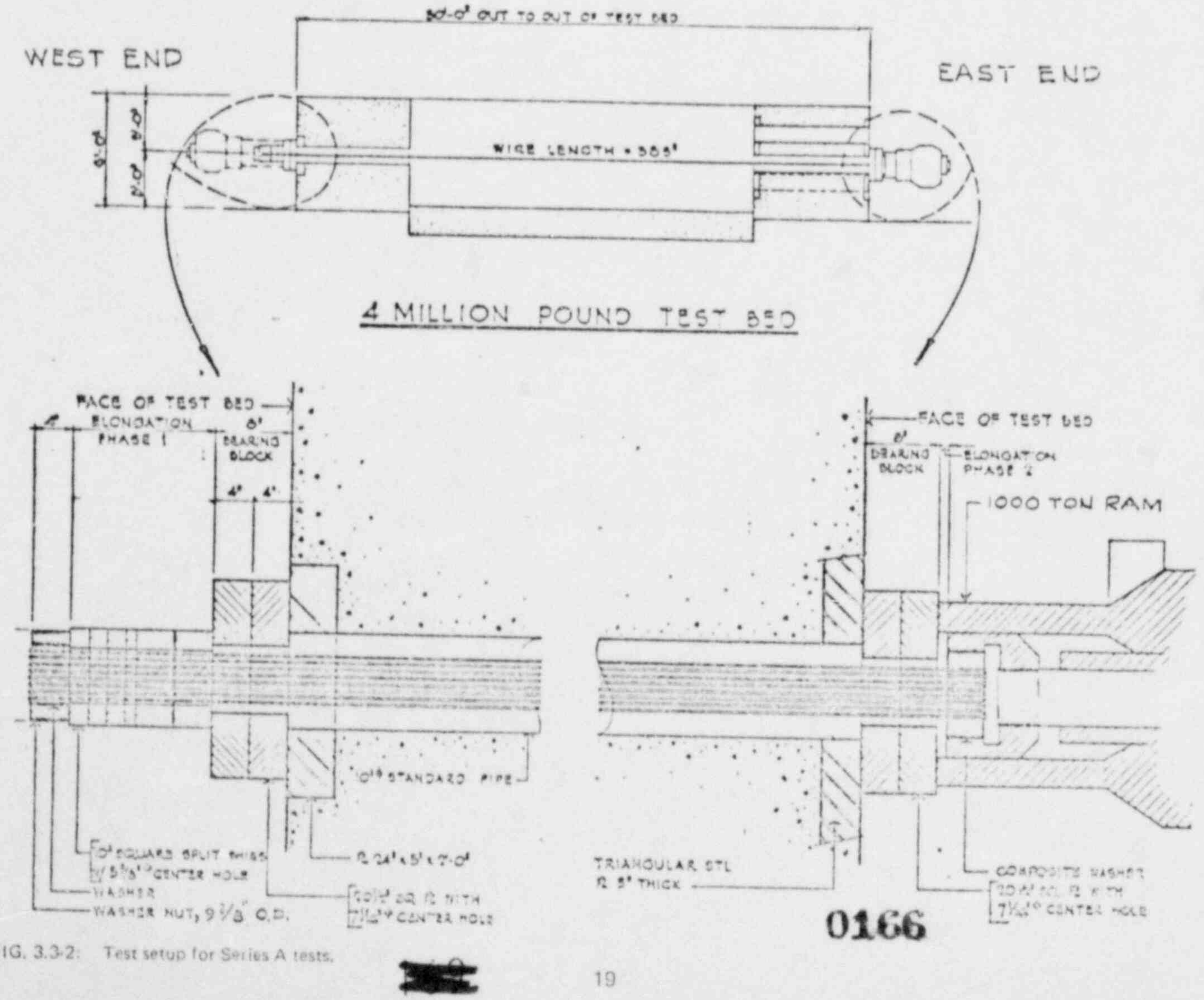

FIG. 3.3-2: Test setup for Series A tests.

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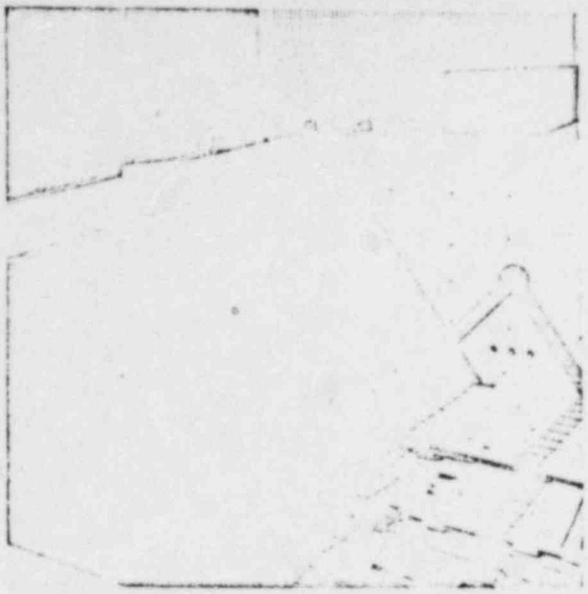


FIG. 3.3-3: Series A. 170 wire banded tendon installed through center hole of 4.0 Mep test bed.

FIG. 3.3-4 Series A. Stressing jack attached to tendon at west end for Phase I elongation.

FIG. 3.3-5: Series A. West end after Phase I elongation, showing 14" to 16" shims is place retaining elongation of prototype washer - washer nut anchorage hardware.

FIG. 3.3-6: Series A. Prototype composite washer at east end at the same test stage as that shown in Fig. 3.3-5. The wire deflector plate, shown in place, is removed prior to installation of 1,000-ton Stressing Ram for Phase II elongation.

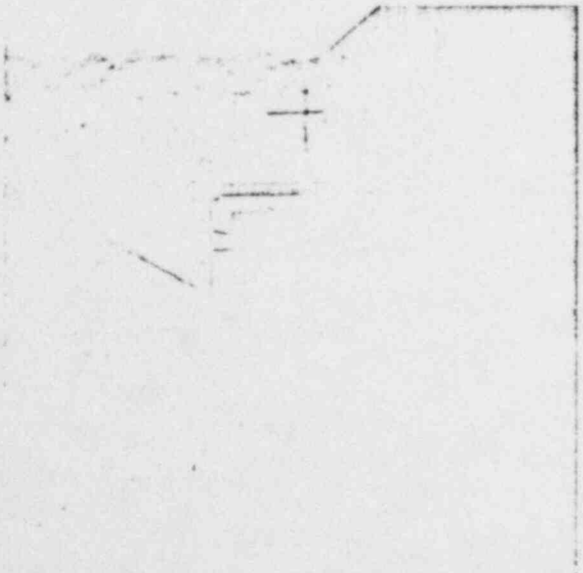


FIG. 3.3-7: Series A. West end during test A-2. Two wires have failed at a force of 2,054k at an elongation of 17.0 inches and can be seen against the deflector plates. At this stage of the test, Phase II elongation is being applied at the opposite (east) end of the tendon.

order to transfer shear forces around the oversize (10") hole in the test bed. These bearing plates are not considered to be a part of the assembly being tested.

A 1000 ton Stressing Ram having an 8 inch stroke was attached to the west end for Phase I elongation. (Fig. 3.3-4). At approximately full 8 inch ram stroke, shims were stacked under the anchorage hardware to maintain elongation. The jack was retracted, blocked by means of a chair extension load, re-applied, and more shims stacked. This cycle was continued to completion of Phase I elongation, shown in Fig. 3.3-5 just after removal of the Stressing Ram. Tendon elongation during Phase I was designed to be safely below tendon ultimate, but sufficiently great that tendon ultimate force could be obtained within a single 8 inch stroke of the Stressing Ram attached to the east end for Phase II elongation. This was for the safety of personnel and protection of the test equipment.

The wire used for Series A tests was tested to determine mean values of actual ultimate strength, yield strength, and elongation as shown in Tables 3.3-6 and 3.3-7 for tests A-1 and A-2 respectively.

Applied load was recorded at intermediate values of applied elongation. Elongation was measured by means of a steel tape, accurate to 0.01 inches, which measured Stressing Ram piston travel. Loads were measured by both a calibrated hydraulic gauge and by a calibrated hydraulic pressure transducer having a digital read-out. Calibrations were performed with a setup similar to that shown in Fig. 3.3-1 except that a 1000 kip capacity load cell, accurate to 1% full scale traceable to the National Bureau of Standards, was added between the washer and the split shims at the left end. Although capacity of the load cell was only one-half that of the applied loads, load cell vs either transducer or hydraulic gauge readings showed a linear relationship to 1000 kips and can be extrapolated linearly with sufficient accuracy. Test data for Series A, test A-1 and A-2 are shown in Tables 3.3-8 and 3.3-9 respectively.

WIRE FOR TEST A-1

Source: United States Steel Corporation
Heat Number 87 B756
Coil Number 56

E_s : 29.3×10^6

① Determined by .2% off-set
② Determined by total strain under load (elastic + plastic)
③ Determined by plastic strain remaining after rupture.

Sample No.	Lab.	Position of Sample in Coil	F_{su} (kips)	F_{sy} ① (kips)	% Elongation ②	% Elongation ③
1	Western	Front (1st wire)	11.82	-		5.40
2			11.99	-		5.77
3			11.85	-	6.8	5.06
4			11.94	-	7.2	5.72
5		Back -	11.90	-	7.2	5.30
6		-	11.77	-	7.1	5.25
7		-	11.92	-	6.9	5.65
8		Middle (170th wire)	12.20	-	-	5.20
9			12.32	-	-	5.12
10			12.20	-	-	5.28
11			12.26	-	-	5.57
12	Durkee		12.00	10.90	7.0	6.0
13			12.02	10.90	6.1	5.7
14			12.00	10.90	-	5.8
15			12.05	10.85	-	6.0
16	U.S.S.	Front (1st wire)	12.00	-	-	-
17	U.S.S.	Back	12.00	-	-	-
n	(units)		17	4	7	15
$\overline{X}$	(kips)		12.014	10.89	6.900	5.520
σ	(kips)		.1490	.0217	.3546	.3022
v	(%)		1.24	.199	5.14	5.47

TABLE 3.3-6: Test results and mean values of mechanical properties for wire used for Series A, test A-1.

WIRE FOR TEST A-2

Source: United States Steel Corporation
Heat Number 87 B756
Coil Number 63

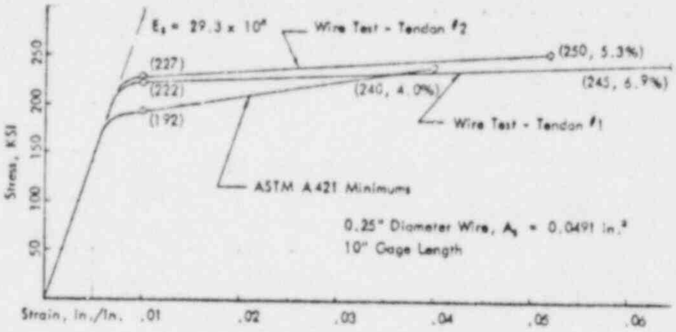
E_s : 29.3×10^6

① Determined by .2% off-set
② Determined by total strain under load (elastic + plastic)

Sample No.	Lab.	Position of Sample in Coil	F_{su} (kips)	F_{sy} ① (kips)	% Elongation ②	
1	Durkee	Front	12.35	11.25	5.4	
2			12.20	11.25	4.8	
3			12.30	11.25	5.5	
4		Back	12.20	11.00	5.2	
5			12.20	11.00	5.5	
6	U.S.S.	Front	12.20	-	-	
7	U.S.S.	Back	12.30	-	-	
n	(units)		7	5	5	
$\overline{X}$	(kips)		12.250	11.150	5.280	
σ	(kips)		.0598	.1225	.2638	
v	(%)		.488	1.098	5.00	

TABLE 3.3-7: Test results and mean values of mechanical properties for wire used in Series A, test A-2.

The relationship of the actual properties of wire used for Series A, tests A-1 and A-2 as compared to the minimum properties required by ASTM: A 421 can be seen on Fig. 3.3-8. The stress-strain curve shown has the same shape as a load-elongation curve and is based on the 10 inch gauge length specified in ASTM: A 421. It can be seen that the wire used has an average yield point 16.9% greater, an average ultimate 3.1% greater, and an average elongation 52.5% greater than corresponding minimums specified by ASTM: A 421.



INDIVIDUAL WIRE PROPERTIES

FIG. 3.3-8: Stress-Strain curve showing mechanical properties for wire used in Series A, tests A-1 and A-2, shown superimposed on the theoretical curve for a wire having properties per ASTM: A421 specified minimums.

TEST A-1 DATA

Gauge Length : 385 inches
Stressing Ram Effective Area : 212.65 sq. in.
Transducer : ADX-38 Serial No. 208; GP46F Serial No. 3929
Test Date : 7 February 1967
Personnel : H.R. Reuter, R.E. Hunter, A.H. Stubbs

Load			Elong.	
ADX (kips)	Hydraulic Gauge (psi)	Hydraulic Gauge (kips)	(inches)	Remarks
96	440	94	0.00	Approximately 1.5 inches of slack. Stressing Jack installed on left.
200	940	200	0.2	
300	1410	300	0.35	
401	1860	396	0.50	
515	2400	510	0.75	
605	2760	587	0.90	
698	3240	689	1.05	
794	3700	787	1.20	
892	4160	885	1.40	
992	4640	987	1.60	
1091	5110	1087	1.75	
1191	5580	1187	1.90	
1295	6050	1287	2.10	
1400	6570	1397	2.30	
1502	7040	1497	2.50	
1600	7500	1595	2.70	
1700	7990	1699	2.95	
1792	8440	1795	3.40	
1810	8510	1810	4.00	
1840	8720	1854	4.50	
1865	8700	1850	5.00	Installed 6" shims.
0	0	0	4.65	Transferred load to shims and reset jack.
1865	8710	1852	5.30	
1895	8910	1895	6.00	
1902	9140	1944	7.00	
1958	-	-	7.41	Installed 2-1/2" shims - 8-1/2" total.
0	0	0	7.15	Transferred load to shims and reset jack.
1940	9100	1935	8.00	
1970	9200	1956	9.00	
1978	9360	1990	10.00	
2019	9460	2012	11.00	
2020	9500	2020	12.00	
-	9580	2037	13.00	ADX indicator off scale.
-	9630	2048	14.00	
-	9660	2054	14.50	Installed 15-1/4" total shims.
-	0	0	14.10	Transferred load to shims. Removed jack and installed on right. Two hour delay.
1795	8450	1797	14.40	
1896	8900	1893	14.60	
2003	9400	1999	14.90	
-	9800	2084	16.00	ADX indicator off scale.
-	9800	$\boxed{2084}$	16.20	2 wires failed at heads.
-	9750	2073	$\boxed{16.63}$	2 wires failed at heads.

TABLE 3.3-8: Test data for Series A, test A-1.

TEST A-2 DATA

Gauge Length : 384 inches
Stressing Ram Effective Area : 212.65 sq. in.
Transducer : ADX-38 Serial No. 208; GP46F Serial No. 3929
Test Date : 17 February 1967
Personnel : H.R. Reuter, R.E. Hunter, A.H. Stubbs

Load			Elong.	
ADX	Hydraulic Gauge			
(kips)	(psi)	(kips)	(inches)	Remarks
298	-	-	0.50	Jack on west end.
504	-	-	0.65	
600	-	-	0.80	Reset elongation scale at 1.00 inches.
702	3660	778	1.15	
804	3620	770	1.35	
904	4080	868	1.50	
1003	4540	965	1.67	
1104	4990	1061	1.85	
1201	5430	1155	2.00	
1301	5890	1253	2.20	
1402	6360	1352	2.37	
1503	6820	1450	2.55	
1602	7260	1544	2.75	
1700	7720	1642	2.97	
1796	8190	1742	3.27	
1848	-	-	3.75	
1894	-	-	4.10	
0	0	0	3.75	Set load off on 4" shims.
1882	8820	1876	5.10	
1900	8860	1884	6.00	
1924	9030	1920	7.00	
1950	9120	1939	8.00	
			7.85	Set load off on 8" shims. Added 8" chair piece. Down 10 minutes.
514			8.00	
1947	9130	1941	8.75	
1938	9130	1941	9.00	
1980	9130	1941	10.00	
2002	9390	1997	10.90	1 wire failed (in wire)
1996	9410	2005	12.00	
2010	9470	2014	13.00	
1980	9510	2022	13.80	
2006	9530	2026	14.00	
off scale	9500	2020	14.25	
	-	-	13.85	Set load off on 14" shims.
	9570	2035	15.00	
	9610	2043	16.00	
	9610	2043	16.25	
	0	0	15.80	Set load off on 16" shims. Moved ram to East end.
	9610	2043	16.60	
	9660	2054	17.00	Second wire failed (in wire)
	9710	$\boxed{2065}$	$\boxed{17.50}$	Third and fourth wires failed (in wire). Test terminated.

TABLE 3.3-9: Test data for Series A, test A-2.

The load-elongation data for Series A, tests A-1 and A-2 is plotted in Fig. 3.3-9. For clarity, only the resulting curve is shown without intermediate points. A theoretical curve for a tendon having mechanical properties per ASTM A 421 minimums is superimposed.

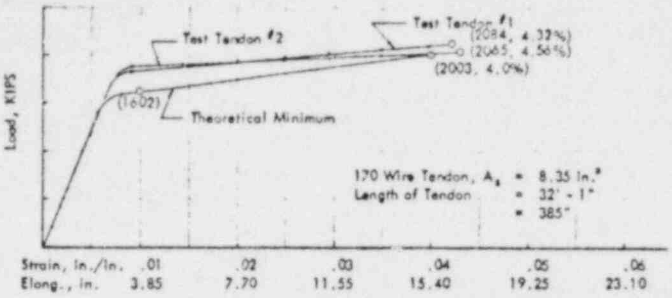


FIG. 3.3-9: Load-Elongation curve of Series A, test A-1 and A-2 results, shown superimposed on the theorectical curve for a tendon having properties per ASTM: A421 specified minimums.

The summary and analysis of Series A test results are tabulated in Table 3.3-10. Following procedures established in prior WCS Technical Reports, performance is rated by: 1) nominal efficiency - that is, performance of the tendon relative to the minimum guaranteed wire properties, and 2) actual efficiency - that is, performance of the tendon relative to actual wire mechanical properties. Both nominal and actual efficiencies are shown for both ultimate load capacity and ultimate elongation, using notations defined in Table 3.3-10. These efficiencies are theoretical, for comparison purposes, and cannot be considered an exact measure of performance of a multi-wire tendon for several valid reasons.

First, the mechanical properties of sample wires are determined by tests on a 10 inch gauge length per requirements of ASTM: A 421. There is no valid correlation of performance based on a 10 inch gauge length to performance based on much longer gauge lengths - 385 inches in Series A.

Second, a multi-wire tendon cannot be assumed to perform as the sum of the individual wire performances due to individual differences in the wires. since it is obviously impossible for a multi-wire tendon to be any stronger than the sum of the individual wires, it follows that it must be weaker, since to be of equal strength would be a coincidence. Therefore, it is theoretcaily impossible to have actual efficiency ratios (tR_p and tR_E) greater than 1.0. It further follows that nominal efficiency

Test No.	Test Date	Part Serial Number			Test Results		Gauge Length (inches)	Elong (%)	Analysis of Ultimate Force Results				Analysis of Ultimate Elongation Results			
		East	West		Load (P_i'') (kips)	Elong (E_i'') (inches)			P'_{im} ⑤ (kips)	P''_{im} ⑥ (kips)	nR_p ⑦	tR_p ⑧	E_i' ⑨ (inches)	E_i'' ⑩ (inches)	nR_E ⑪	tR_E ⑫
		Compo.	Washer	Nut												
A-1	2-7-67	008	002	003	① 2084	① 16.65	385 ①	4.325	2002.8	2042.4	1.041	1.020	15.40	26.57	1.081	0.627
A-2	2-17-67	008	002	003	② 2065	② 17.50	384 ②	4.557	2002.8	2082.5	1.031	0.992	15.36	20.28	1.139	0.863
n (units)					2	2		2			2	2			2	2
$\bar{X}$ (kips)					2074.5	17.075		4.441			1.036	1.006			1.110	0.745
σ (kips)					9.500	.425		.116			0.005	0.014			0.029	0.118
v (%)					.458	2.489		2.612			.483	1.392			2.613	15.839
$\bar{X}$ + 3σ (kips)					2103.0	18.350		4.789			1.051	1.048			1.197	1.099
$\bar{X}$ - 3σ (kips)					2046.0	15.800		4.093			1.021	[illegible]			1.023	0.391

Notes:
① Refer to TABLE 3.3-8
② Refer to TABLE 3.3-9
③ Refer to TABLE 3.3-6
④ Refer to TABLE 3.3-7
⑤ P'_{im} = 170 × P'_u = 170 × 11.781 = 2002.8 kips
⑥ P''_{im} = 170 × P''_u = 170 × 12.041 = 2042.4 kips for test A-1 ③
170 × 12.250 = 2082.5 kips for test A-2 ④
⑦ nR_p = P_i'' / P'_{im}
⑧ tR_p = P_i'' / P''_{im}
⑨ E_i' = nominal elongation of tendon = nominal elongation of wire (E_u') × gauge length. E_u' = 4.0%
⑩ E_i'' = theoretical actual elongation of tendon = actual elongation of wire (E_u'') × gauge length
For A-1, E_u'' = $\bar{X}$ (elongation) = 6.9% ③. Therefore E_i'' = 0.069 × 385 = 26.57 inches
For A-2, E_u'' = $\bar{X}$ (elongation) = 5.28% ④. Therefore E_i'' = 0.0528 × 384 = 20.28 inches
⑪ nR_E = E_i'' / E_i'
⑫ tR_E = E_i'' / E_i''

TABLE 3.3-10: Summary and Analysis of Series A Test Results.

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ratios (nR_p and nR_E) can only be greater than 1.0 if the wire is actually better than specified minimums. As it relates to ultimate tendon elongation, General Atomic has taken this into account by requiring an ultimate elongation of 3.5% for a 30 foot gauge length, thus requiring that $nR_E \geqslant 0.875$.

If the mechanical properties are determined for each coil of wire in any given lot of material prior to selection (such as a mill heat), the quantitative values of any property for all coils will follow a normal distribution curve similar to that shown in Fig. 3.3-10 for ultimate tensile strength. ASTM: A 421 requires a minimum ultimate tensile strength of 240 ksi (or 11.78 k) for 0.250 inch diameter. Theoretically, all wire shipped could have this minimum tensile strength and no more. In actual practice however, this is impossible. In order to limit rejects, the steel mills must aim to produce a product higher than the minimums, as shown by the horizontal position of the vertical line representing mean tensile value ($\bar{X}$). Approximately all coils (99.7%) will have a tensile strength within the range of the mean tensile value plus or minus three standard deviations ($\bar{X} \pm 3\sigma$), and therefore the variance of the product, as measured by σ, determines how much higher the aimed for value ($\bar{X}$) must be over the specified minimum in order to limit rejects. To aim for a $\bar{X}$ which is too high is to risk rejects for other specified properties, e.g. coils having the highest tensile strength may be rejected due to low elongations.

As can be seen by reference to Tables 3.3-6 and 7, the variance, as measured by the coefficient of variation (ν), is quite small for tensile strength, but is four to ten times greater for elongation.

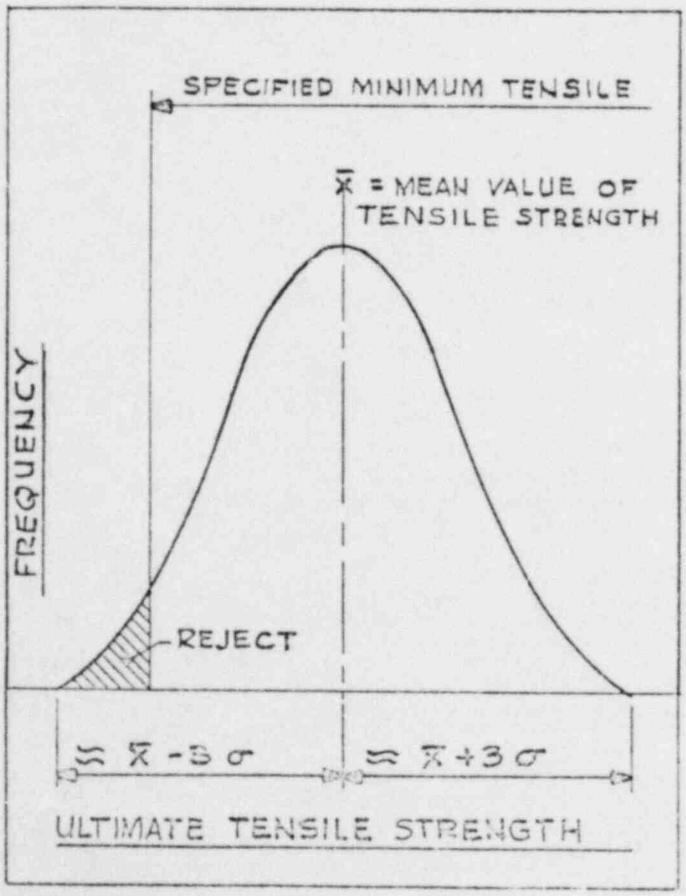

FIG. 3.3-10: Frequency distribution of ultimate tensile strength for all coils of a mill heat of 0.250 inch diameter ASTM: A421 wire.

There is insufficient experimental data available to draw any valid conclusions as to the theoretical true efficiency of the tendon, that is the relationship of the tendon actual failure load (or elongation) and the sum of the actual wire properties. Series A would indicate: 1) a relatively high true efficiency for tensile ultimate (tR_p = 0.992 to 1.020) with a small variance, and 2) a somewhat lower true efficiency for ultimate elongation (tR_E = 0.627 to 0.863) with a large variance. Should this hold true in all cases, then it could be expected that a 30 foot long test tendon fabricated from 170 wires having exactly minimum properties (that is, 11.78 k UST and 4% elongation) could fail at 1986.7 k and 2.5% elongation, but the confidence in the accuracy of this expectation would be quite low.

From the above discussion, it is reasonable to conclude 30 foot long test tendons should exhibit efficiency ratios of $nR_p \geqslant 1.0$ for tensile and $nR_E \geqslant 0.875$ for elongation. It must be expected however that test tendons fabricated from wire having minimum properties would fall below these efficiency ratios. This should be of no concern as the actual strength of all tendons, both test tendons and those used in the structure, will exhibit the same frequency distribution as the wire itself.

Series A tests show that the two tendons tested exceed specification requirements for both ultimate load and elongation. They also contribute significant information on the behavior of long multi-wire tendons loaded to ultimate, from which more exact criteria and code requirements can eventually be derived.

3.3.5 TEST SERIES B AND C - GENERAL

In general, Series B tests were conducted to determine web (honeycomb) shear ultimate both with split shims (Series B1) and without split shims (Series B2); and Series C tests were conducted to determine shear ultimate load for the 6 inch diameter thread, which couples the Washer to the Washer Nut, both with split shims (Series C1) and without split shims (Series C2). Specific details which apply to each of the four series (B1, B2, C1 and C2), including discussion, objective, test procedure, test results and analysis, are presented separately for each series in succeeding sections.

In relation to the anchorage hardware components or assemblies, the term "outer face" is used to describe the surface on which the wire heads bear, that is, the face on which the load is applied; and the term "inner face" is used to describe the opposite surface, that is, the face which has a reactive force in the opposite direction to the applied load.

The interior well of the 4 million pound capacity test bed was used to apply the test load as shown schematically in Fig. 3.3-11 and by photos in Fig. 3.3-12 a) thru c). Three - 1000 ton stressing rams were attached to the inside east end of the test bed and were hydraulically interconnected to a stressing power unit located on top of the bed. Ram force was transmitted thru a movable load block to the component being tested. Load reaction was provided by a fixed spacer block reacting against the inside west end of the bed.

Redundant determination of the applied test load is provided by means of: 1) a Martin-Decker, 12" dial, 0-10,000 psig hydraulic gauge measuring to 20 psig subdivisions the oil pressure being applied equally (in parallel) to three identical rams and 2) by a Transducers Inc. Model GP-46F-10,000-7103 hydraulic transducer attached to one ram and reading to 50 pound subdivisions on a Transducers Inc. Model ADX-38 Automatic Digital Indicator. Both the gauge and ADX-38 were mounted on the hydraulic control-power unit installed on top of the test bed. Both the hydraulic gauge and the transducer-indicator were calibrated to the capacity of a 1000 ton load cell.

Applied test load as measured by the gauge is determined by multiplying the gauge reading (corrected to the calibration curve) by the total effective area of the three rams (A_R = 3 x 212.65 = 637.95 sq. in.). Applied test load as measured by the transducer-indicator is determined by multiplying the indicator reading (corrected to the calibration curve) by three. Calibration by means of an eight million pound capacity load cell installed in lieu of the test assembly would be more accurate but no load cell even close to this capacity was available. However, failure load as determined by the mean of gauge determined load and transducer-indicator determined load is considered to be accurate to at least 1.0 k ± since: a) all rams are identical, b) all rams are connected in parallel by equal length lines to the hydraulic pump, c) calibrations showed a linear relationship, and d) there is close correlation between gauge and transducer-indicator calibrations.

In order to determine the degree of uniformity throughout the section of the heat-treated components, Composite Washer-Serial No. 002 was sectioned after being tested to web shear failure (Series B1, Test 1) and Rockwell C scale hardness was measured at approximately 100 points across one face. The center section of a Composite Washer was chosen as being the most critical for uniform heat treat results due to this compo-

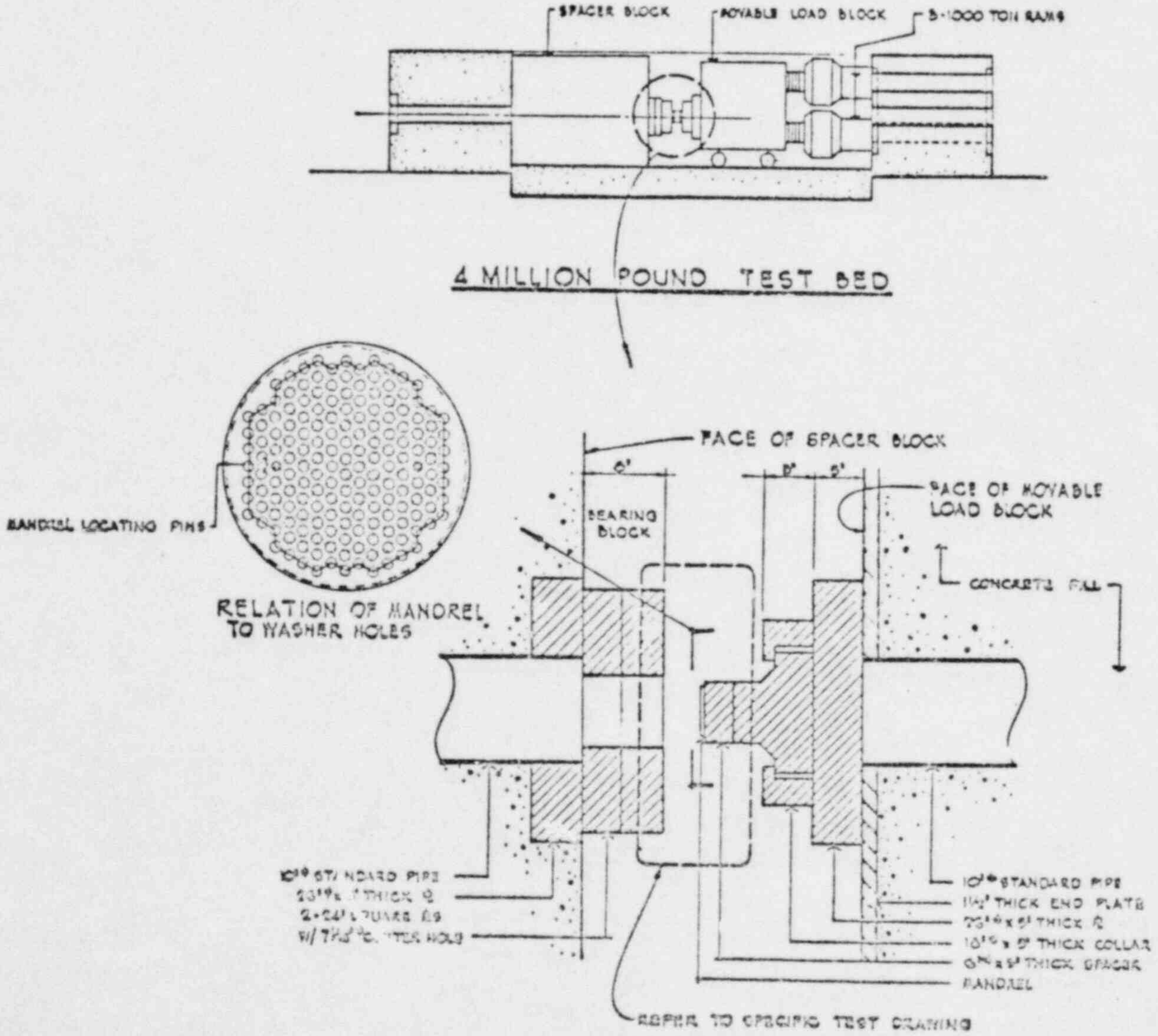

FIG. 3.3-11: Schematic drawing of Test Bed setup for Series B and C tests, showing general arrangement and general detail of test fixture. Actual detail of test fixture varies for each series and is shown separately for each specific series.

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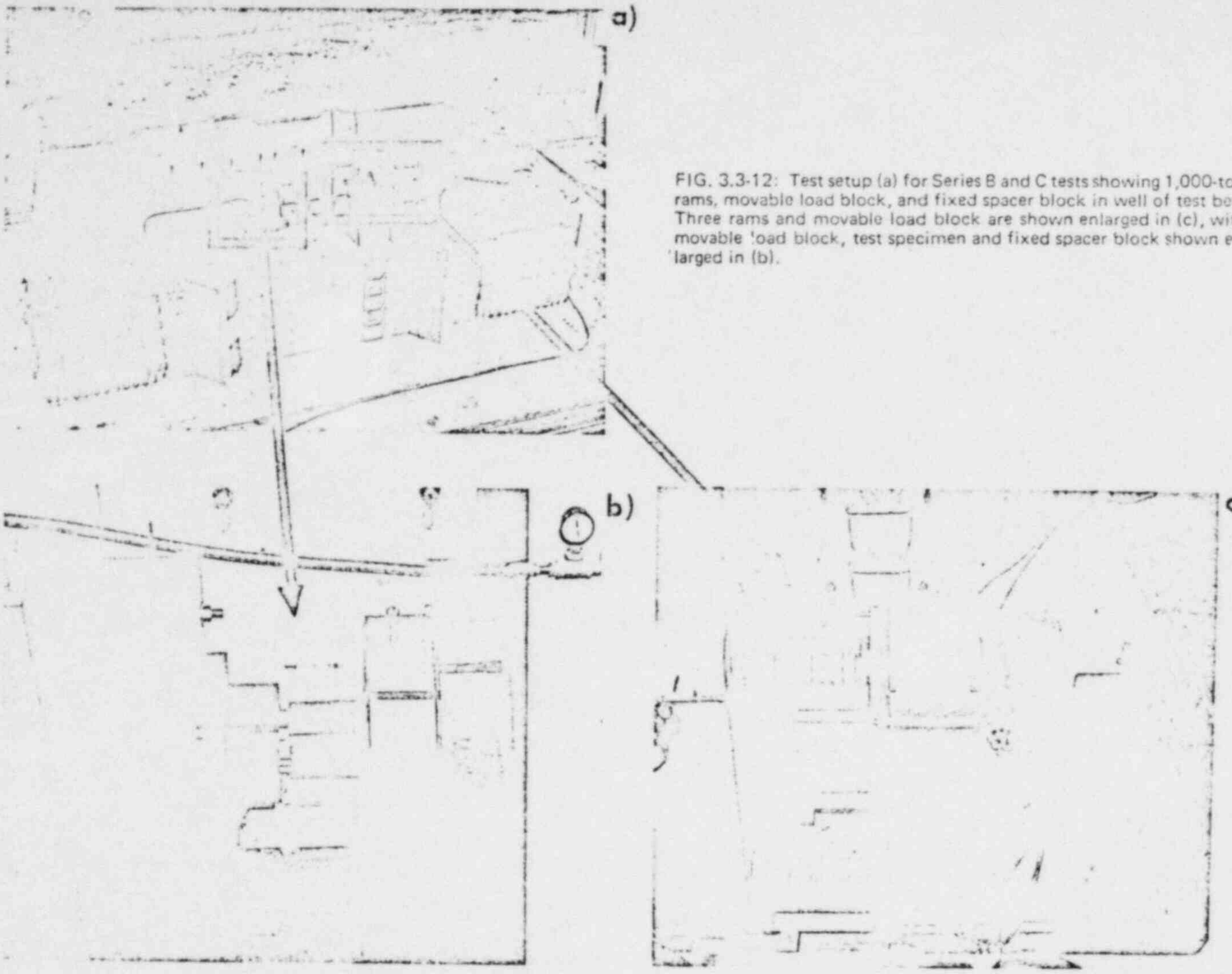


FIG. 3.3-12: Test setup (a) for Series B and C tests showing 1,000-ton rams, movable load block, and fixed spacer block in well of test bed. Three rams and movable load block are shown enlarged in (c), with movable load block, test specimen and fixed spacer block shown enlarged in (b).

nent having the greatest dimensions and mass. The location of the section tested and iso-hardness lines are shown in Fig. 3.3-13. Hardness distribution was approximately as expected. The lowest hardness of R_C 30 occurs in the center of mass of the annulus outside the critical shear path at a location where stresses are low and ductility is of more importance than strength. Hardness along the shear path shows a mean value of R_C 38.2 for the same component where predicted ultimate was based on a value of R_C 40.5 as measured on the outer face. It is interesting to note that the ratio of average measured hardness along the shear path to measured hardness on the outer face (38.2 ÷ 40.5 = 0.943) is quite close to the ratio of predicted ultimate to actual ultimate (2509.7 ÷ 2613 = 0.9605), indicating that variation in F_{su}, as measured by hardness, accounts for most of the small (3.9%) error in predicted ultimate. This is an example of the type of variable which is conveniently handled by use of a repture factor (k_r).

A summary of data and results for all Series B and C tests is shown in Table 3.3-11. It can be seen that actual failure loads average 0.4% higher than those predicted by calculation in Section 3.2. This extremely small error gives considerable confidence in the design and in the assumptions on which it was based. It can also be seen that the safety factor of 1.5 x min. guaranteed tendon strength which was established as a preliminary criteria for component design, is met for all tests except Series C2. This is of no concern since the condition tested by Series C2 does not exist in the structure contemplated and, in any event, the reduction in preliminary S.F. is small.

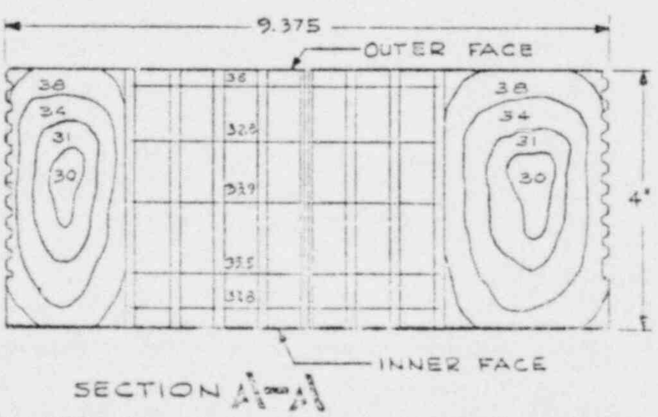


FIG. 3.3-13: Schematic drawing of section cut from Composite Washer Serial No. 002 after having been loaded to web failure in test B1-1. R_c hardness values were measured for approximately 100 points. Distribution of material hardness throughout the cross section is as shown by the schematic iso-hardness lines.

Test Designation		Description	Test Date	Components (with Serial No.)				Failure Load		Error (Note 1) ± (%)	Equiv. Tendon UTS (Note 2)	Safety Factor (Note 3)	Remarks
Series	No.			Washer	Washer Nut	Compo. Washer	Split Shims	Predicted (kips)	Actual (kips)				
B1-1	1	Web Shear - With Shims	5-1-67	—	—	002	Yes	2509.7	2613	- 4.0	3152	1.574	
B1-2	2		5-1-67	—	—	001	Yes	2577.5	2682	- 3.9	3236	1.616	
B1-3	3		5-1-67	—	—	004	Yes	2564.0	2586	- 0.9	3120	1.558	
B2-1	5	Web Shear - Without Shims	5-1-67	—	—	009	No	2654.4	2541	+ 4.5	3065	1.530	
B2-2	6		5-1-67	—	—	005	No	2600.2	2518	+ 3.3	3038	1.517	
C1-1	4	6" Thread Shear - With Shims	5-1-67	014	008	-	Yes	3430.5	3378	+ 1.6	3378	1.687	
C1-2	10		5-3-67	011	002	-	Yes	3483.2	3561	- 2.2	3561	1.778	
C2-1	7	6" Thread Shear - Without Shims	5-2-67	010	005	-	No	2903.5	2922	- 0.6	2922	1.459	
C2-2	8		5-2-67	012	003	-	No	2817.2	2930	- 3.8	2930	1.463	
C2-3	9		5-2-67	013	001	-	No	2741.0	2745	- 0.1	2745	1.371	

Notes:
1. Error = (Predicted Load - Actual Load) ÷ Actual Load; Therefore, minus error means component is actually stronger than predicted.
2. Equivalent Tendon Ultimate Load = Actual Test Load at failure ÷ R_e; (R_e = 0.829 for Series B)
3. Safety Factor = Equiv. Tendon Ult. ÷ Minimum guaranteed tendon ultimate. S.F. = Equivalent Tendon Ultimate ÷ 2002.8.

TABLE 3.3-11: Series B1, B2, C1 and C2 - Summary of Data and Results.

3.3.6 TEST SERIES B1 - WEB SHEAR WITH SHIMS

Web shear is a critical failure mode for both the Composite Washer and the comparable assembly of Washer-Washer Nut. In addition to shear along the critical shear path, low order flexural stresses exist due to bending, resulting in combined shear and flexural tension on the inner face of the washer. The effect of flexural tension will be less for the assembly of Washer-Washer Nut as tension cannot be transmitted in the radial direction through the 6" thread connecting the components, resulting in a shorter lever arm as compared to the single piece Composite Washer. Therefore the Composite Washer was selected for testing as representing the most critical condition.

From the calculations (Section 3.2.7) and analysis, there is no reason to assume any difference in ultimate strength of the web shear failure mode for assemblies either with or without split shims. The principal reasons for testing three assemblies with split shims in Series B1 were to: 1) verify the above assumption by comparison with results of tests conducted without split shims (Series B2), 2) establish a minimum ultimate strength for the bearing failure mode at the Split Shim - Composite Washer interface as analized in Section 3.2.3, and 3) assist in analysis of the effect of bearing on the ultimate strength of the 6" thread tested with split shims (Series C1).

The test fixture for Series B1 tests is shown schematically in Fig. 3.3-14. The double bearing plates are used to transfer shear around the oversize (10 inch diameter) hole in the spacer block and are not considered as part of the components being tested except for the Bearing Plate - Split Shim Interface (ref. Section 3.2.2), which is an accurate duplication of actual conditions. After application of an approximate 400 kip preload to seat all parts of the loading train, the load is reduced to 1.0 kips and any gap existing between the mandrel and Washer is measured and recorded as an indication of degree of eccentricity of applied load application.

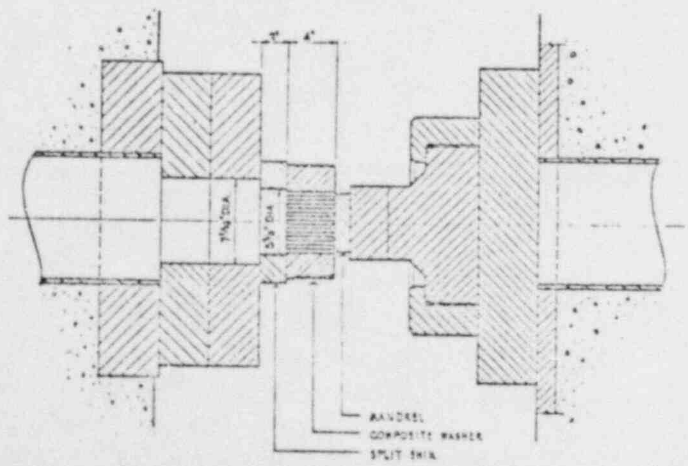


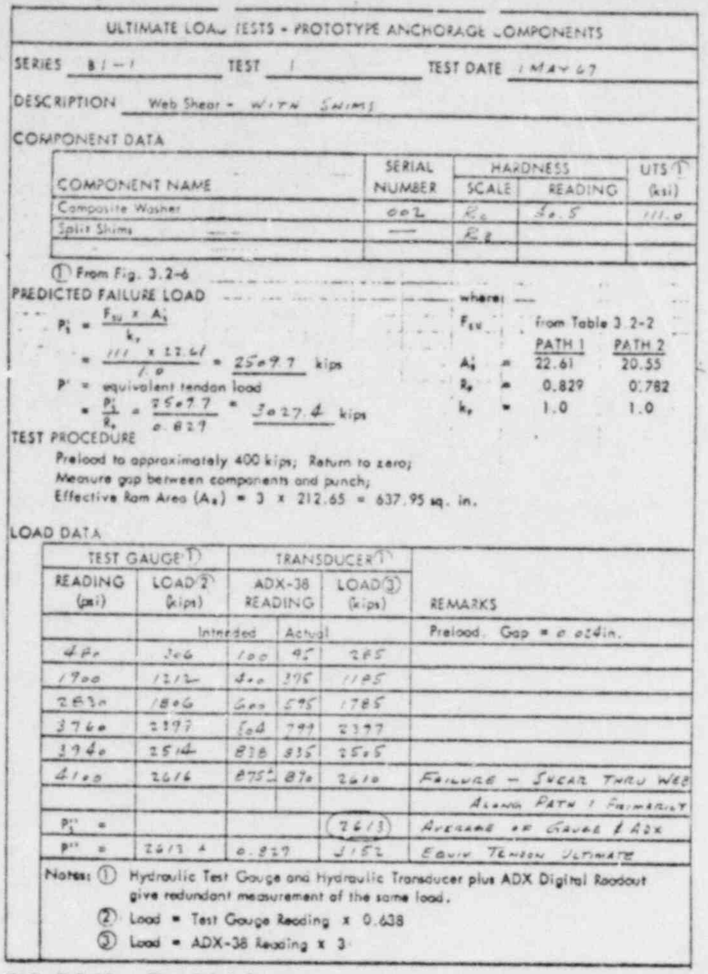
FIG. 3.3-14: Fixture for Series B1 tests. Components being tested are shown shaded. Mandrel conforms to shape illustrated in Fig. 3.3-11 for Path 1 shear failure mode.

Test results for the three tests of Series B1 are shown in Figs. 3.3-15 thru 17, and are summarized and analyzed in Table 3.3-12 which shows the method of calculating values indicated. The low coefficient of variation (ν) for actual test results (P'') indicated consistency in both components and test procedures. The small error, -2.93% average, indicates that predicted loads (P_s'') are quite accurate but conservative since actual test loads (P'') are higher in all cases. This is probably due to the fact that predicted loads are based on nominal steel shear area (A_s' = 22.61 sq. in.) while the actual area (A_s'') may be slightly higher. This is probably why the Rupture Factor (average k_r = 0.971) is less than 1.0. Such a small variance between predicted and actual values does not indicate any change in k_r = 1.0 for use in identical calculations of similar mechanisms designed in the future.

Test Desig.	Calculated UTS (P_c') ① (kips)	Predicted UTS (P_s') ② (kips)	Actual UTS (P'') (kips)	Error Note ③ (%)	Revised k_r Note ④	Min. Equiv. Tendon UTS ⑤ (kips)	Safety Factor Note ⑥
B1-1	2509.7	2509.7	2613	- 4.0	0.960	3095.2	1.55
B1-2	2577.5	2577.5	2682	- 3.9	0.961	3093.3	1.54
B1-3	2564.0	2564.0	2586	- 0.9	0.991	2998.4	1.50
n	3	3	3	3	3	3	3
$\bar{x}$	2550.4	2550.4	2627	- 2.93	0.971	3062.3	1.53
σ	29.30	29.30	40.42	1.44	.014	45.19	.022
ν	1.15	1.15	1.54	49.0	1.48	1.48	1.41
$\bar{x} + 3\sigma$	2638.3	2638.3	2748.3	+ 1.39	1.014	3177.9	1.59
$\bar{x} - 3\sigma$	2462.5	2462.5	2505.7	- 7.25	0.928	2926.7	1.47

Notes:
1. Calculated UTS (P_c') = F_{su} × A_s' without use of Rupture Factor (k_r)
2. Predicted UTS (P_s') = P_c'/k_r; $P_s' = (F_{su} \times A_s')/k_r$; k_r = 1.0
3. Error = (P_s' - P'') × 100 ÷ P'' percent.
4. Revised Rupture Factor: $k_r = P_c'/P''$
5. Minimum Equivalent Tendon UTS: P'' corrected to minimum F_{su}
   P_s' (min.) = (P''/R_e) × (Min. F_{su} @ R_c 40/F_{su} of Specimen)
   For failure along shear Path 1, R_e = 0.829
   For the specified minimum R_c = 40, F_{su} = 107 ksi
6. Safety Factor: SF = P_s' (min.)/P_{sm}' = P_s' (min.)/2002.8

TABLE 3.3-12: Summary Analysis of Series B1 Test Results



ULTIMATE LOAD TESTS - PROTOTYPE ANCHORAGE COMPONENTS

SERIES B1-1 TEST 1 TEST DATE 1 MAY 67

DESCRIPTION Web Shear - WITH SHIMS

COMPONENT DATA

COMPONENT NAME	SERIAL NUMBER	HARDNESS SCALE	HARDNESS READING	UTS ① (ksi)
Composite Washer	002	R_c	40.5	111.0
Split Shims	—	R_B		

① From Fig. 3.2-6

PREDICTED FAILURE LOAD

$P_i' = \frac{F_{su} \times A_i'}{k_r}$

$= \frac{111 \times 22.61}{1.0} = 2509.7$ kips

P' = equivalent tendon load

$= \frac{P_i'}{R_e} = \frac{2509.7}{0.829} = 3027.4$ kips

where:

F_{su} from Table 3.2-2

		PATH 1	PATH 2
A_i'	=	22.61	20.55
R_e	=	0.829	0.782
k_r	=	1.0	1.0

TEST PROCEDURE

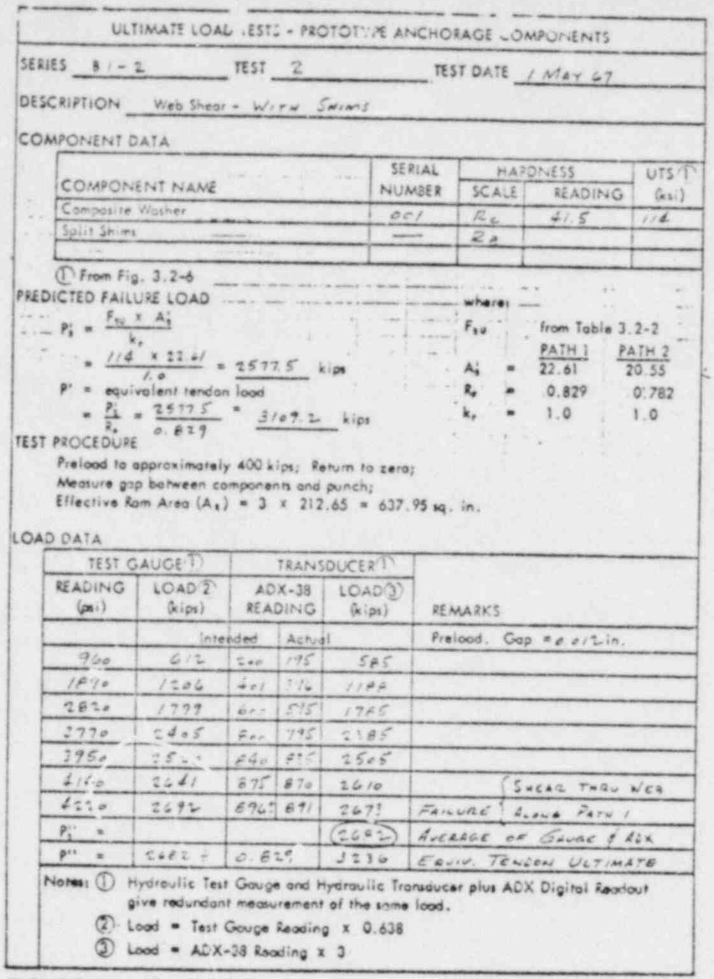
Preload to approximately 400 kips; Return to zero;
Measure gap between components and punch;
Effective Ram Area (A_R) = 3 x 212.65 = 637.95 sq. in.

LOAD DATA

TEST GAUGE ① READING (psi)	TEST GAUGE ① LOAD ② (kips)	TRANSDUCER ① ADX-38 READING Intended	TRANSDUCER ① ADX-38 READING Actual	TRANSDUCER ① LOAD ③ (kips)	REMARKS
					Preload. Gap = 0.024in.
480	306	100	95	285	
1900	1212	400	395	1185	
2830	1806	600	595	1785	
3760	2399	800	799	2397	
3940	2514	838	835	2505	
4100	2616	875±	870	2610	FAILURE — SHEAR THRU WEB
					ALONG PATH 1 PRIMARILY
P_i'' =				⃝2613	AVERAGE OF GAUGE & ADX
P'' =	2613 ÷	0.829		3152	EQUIV TENDON ULTIMATE

Notes: ① Hydraulic Test Gauge and Hydraulic Transducer plus ADX Digital Readout give redundant measurement of the same load.
② Load = Test Gauge Reading x 0.638
③ Load = ADX-38 Reading x 3

FIG. 3.3-15: Test B1-1 Data



ULTIMATE LOAD TESTS - PROTOTYPE ANCHORAGE COMPONENTS

SERIES B1-2 TEST 2 TEST DATE 1 MAY 67

DESCRIPTION Web Shear - WITH SHIMS

COMPONENT DATA

COMPONENT NAME	SERIAL NUMBER	HARDNESS SCALE	HARDNESS READING	UTS ① (ksi)
Composite Washer	001	R_c	41.5	114
Split Shims	—	R_B		

① From Fig. 3.2-6

PREDICTED FAILURE LOAD

$P_i' = \frac{F_{su} \times A_i'}{k_r}$

$= \frac{114 \times 22.61}{1.0} = 2577.5$ kips

P' = equivalent tendon load

$= \frac{P_i'}{R_e} = \frac{2577.5}{0.829} = 3109.2$ kips

where:

F_{su} from Table 3.2-2

		PATH 1	PATH 2
A_i'	=	22.61	20.55
R_e	=	0.829	0.782
k_r	=	1.0	1.0

TEST PROCEDURE

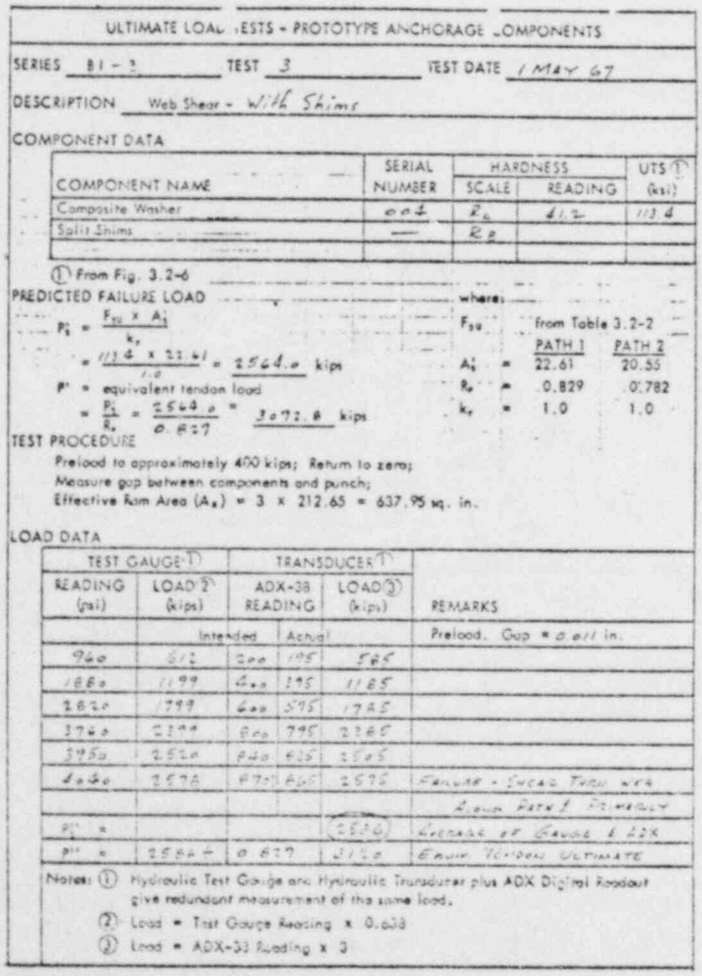
Preload to approximately 400 kips; Return to zero;
Measure gap between components and punch;
Effective Ram Area (A_R) = 3 x 212.65 = 637.95 sq. in.

LOAD DATA

TEST GAUGE ① READING (psi)	TEST GAUGE ① LOAD ② (kips)	TRANSDUCER ① ADX-38 READING Intended	TRANSDUCER ① ADX-38 READING Actual	TRANSDUCER ① LOAD ③ (kips)	REMARKS
					Preload. Gap = 0.012in.
960	612	200	195	585	
1890	1206	401	396	1188	
2820	1799	600	595	1785	
3770	2405	800	795	2385	
3950	2520	840	835	2505	
4140	2641	875	870	2610	{ SHEAR THRU WEB
4220	2692	896±	891	2673	FAILURE { ALONG PATH 1
P_i'' =				⃝2682	AVERAGE OF GAUGE & ADX
P'' =	2682 ÷	0.829		3236	EQUIV. TENDON ULTIMATE

Notes: ① Hydraulic Test Gauge and Hydraulic Transducer plus ADX Digital Readout give redundant measurement of the same load.
② Load = Test Gauge Reading x 0.638
③ Load = ADX-38 Reading x 3

FIG. 3.3-16: Test B1-2 Data



ULTIMATE LOAD TESTS - PROTOTYPE ANCHORAGE COMPONENTS

SERIES B1-3 TEST 3 TEST DATE 1 MAY 67

DESCRIPTION Web Shear - With Shims

COMPONENT DATA

COMPONENT NAME	SERIAL NUMBER	HARDNESS SCALE	HARDNESS READING	UTS ① (ksi)
Composite Washer	004	R_c	41.2	113.4
Split Shims	—	R_B		

① From Fig. 3.2-6

PREDICTED FAILURE LOAD

$P_i' = \frac{F_{su} \times A_i'}{k_r}$

$= \frac{113.4 \times 22.61}{1.0} = 2564.0$ kips

P' = equivalent tendon load

$= \frac{P_i'}{R_e} = \frac{2564.0}{0.829} = 3072.8$ kips

where:

F_{su} from Table 3.2-2

		PATH 1	PATH 2
A_i'	=	22.61	20.55
R_e	=	0.829	0.782
k_r	=	1.0	1.0

TEST PROCEDURE

Preload to approximately 400 kips; Return to zero;
Measure gap between components and punch;
Effective Ram Area (A_R) = 3 x 212.65 = 637.95 sq. in.

LOAD DATA

TEST GAUGE ① READING (psi)	TEST GAUGE ① LOAD ② (kips)	TRANSDUCER ① ADX-38 READING Intended	TRANSDUCER ① ADX-38 READING Actual	TRANSDUCER ① LOAD ③ (kips)	REMARKS
					Preload. Gap = 0.011 in.
960	612	200	195	585	
1880	1199	400	395	1185	
2820	1799	600	595	1785	
3760	2399	800	795	2385	
3950	2520	840	835	2505	
4040	2578	875±	865	2595	FAILURE - SHEAR THRU WEB
					ALONG PATH 1 PRIMARILY
P_i'' =				⃝2586	AVERAGE OF GAUGE & ADX
P'' =	2586 ÷	0.829		3120	EQUIV TENDON ULTIMATE

Notes: ① Hydraulic Test Gauge and Hydraulic Transducer plus ADX Digital Readout give redundant measurement of the same load.
② Load = Test Gauge Reading x 0.638
③ Load = ADX-38 Reading x 3

FIG. 3.3-17: Test B1-3 Data

[redacted]

The test results do not prove that Shear Path 1 is more critical than Shear Path 2, in contradiction to predictions based on analysis, since the mandrel used applied load to Shear Path 1 and therefore forced failure along this path. In fact, examination of the Composite Washers after failure indicates that shear failure was trying to occur along Shear Path 2 in spite of the fact that the mandrel applied the test load to Shear Path 1. In several instances failure started along Shear Path 1 at the outer face of the Composite Washer (directly under the mandrel), but ended along Shear Path 2 at the inner face of the washer. Reference to Section 3.2.7 shows that minimum equivalent tendon UTS for failure along Shear Path 2 should be 0.964 times that along Shear Path 1. Since the analysis of Section 3.2.7 and the examination of components after failure both indicate that Shear Path 2 is critical, the average minimum equivalent tendon UTS of 3062.3 kips should be reduced to:

$$\text{Revised } P'_T \text{ (min.)} = 0.964 \times 3062.3 = 2950.6$$

Since the value of standard deviation is not effected by this correction, it follows that the lowest equivalent tendon ultimate would be Revised P'_T (min.) - 3 σ = 2950.6 -3 x 45.19 = 2815.0 kips, thus giving a revised S.F. = 1.41. This correction is on the conservative side since the actual failure mode is probably along a composite of both shear paths.

The final acceptance criteria established in Section 3.1.2 says that the proof test load equal to minimum guaranteed tendon UTS must be 90% of the yield point of the weakest failure mode predicted from statistical analysis of test results. There is no well defined shear yield point and, in fact, shear yield and shear ultimate probably conicide, so we may conservatively assume $F_{sy} = .9 F_{su}$. Therefore, final acceptance criteria may be expressed as:

$$0.9 (\overline{X} - 3\sigma) \times \frac{F_{sy}}{F_{su}} \geqslant P_{PT} = P'_{170} = 2002.8 \text{ kips}$$

$$\overline{X} - 3\sigma \geqslant \frac{2002.8}{0.90 \times 0.90} \geqslant 2472.6 \text{ kips}$$

The revised P'_T (min.) of 2815.0 is 1.14 times greater than the 2472.6 kips required for acceptance of test results, indicating that the web shear failure with split shims exceeds requirements. This series also shows that the bearing at the Split Shim - Bearing Plate Interface and at the Split Shim-Composite Washer Interface are not critical failure modes as both sustained loads as high as 2682 kips without failure.

Figs. 3.3-18 and 19 are photos of the outer and inner faces respectively of both Composite Washer and Split Shims after being loaded to failure in test B1-3. They are typical for all tests of Series B1.

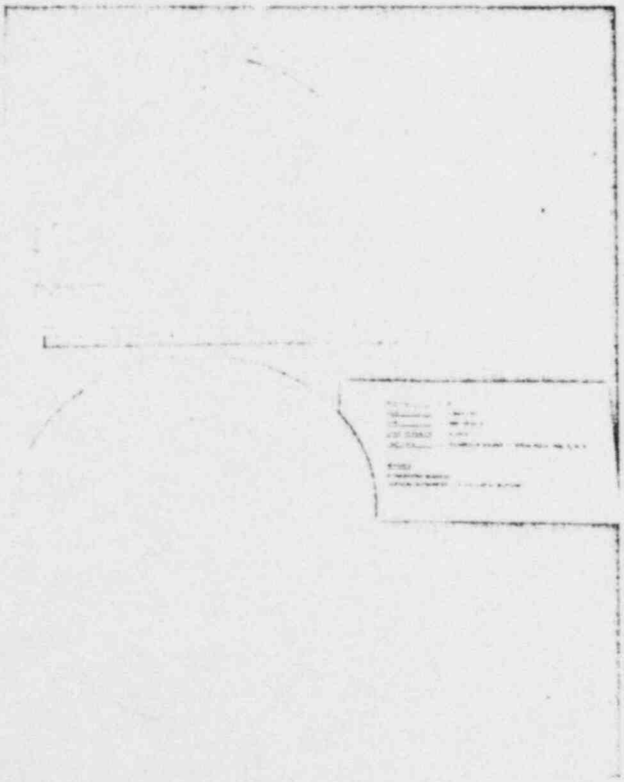


FIG. 3.3-18: Outer face of Composite Washer and Split Shims of test B1-3 after being loaded to ultimate. Note that shear failure is along Path 1 only. Photos here and in Fig. 3.3-19 are typical for all tests in Series B1.

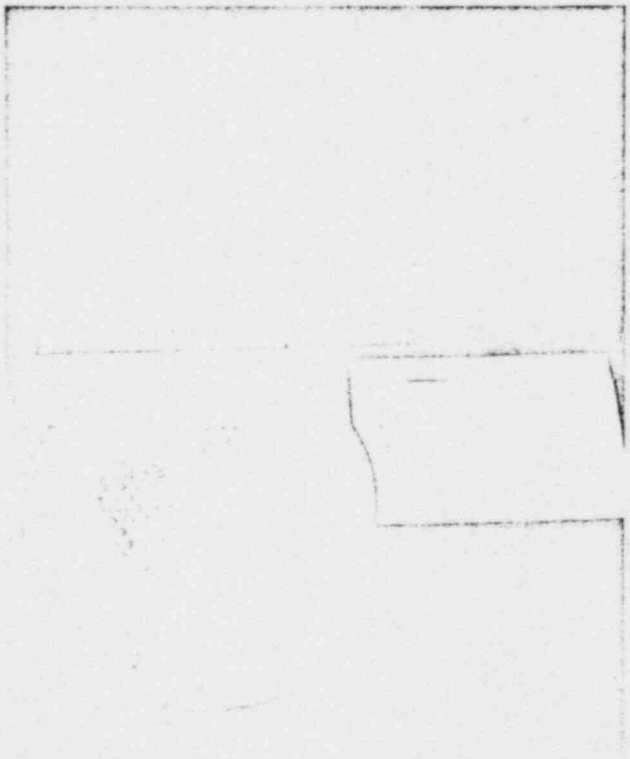


FIG. 3.3-19: Inner face of Composite Washer and Split Shims of test B1-2 after being loaded to ultimate. Note that shear failure is along both Paths 1 and 2.

3.3.7 TEST SERIES B2 - WEB SHEAR WITHOUT SHIMS

The Composite Washer without split shims could only be used on a "fixed end", that is a non-stressed end of a tendon. However, even for a tendon which will only be stressed from one end, there are advantages to using split shims at both ends. The split shims distribute the force from the washer over a greater area of the bearing plate, thus reducing the flexural moment arm and stiffen the bearing plate, both of which permit use of a thinner bearing plate than would be allowable without split shims. Using split shims at both ends of a tendon stressed from only one end allows both bearing plates to be of the same thickness and further provides a convenient method of taking up slack in the tendon prior to stressing.

The purpose of the two tests in Series B2 was primarily to provide additional test data on web shear strength and secondarily to determine if the presence of split shims has a significant effect on web shear failure.

The test setup is shown schematically in Fig. 3.3-20. Test procedures were comparable to those used in Series B1. Data for each test is shown in Figs. 3.3-21 and 22 and is summarized and analized in Table 3.3-13.

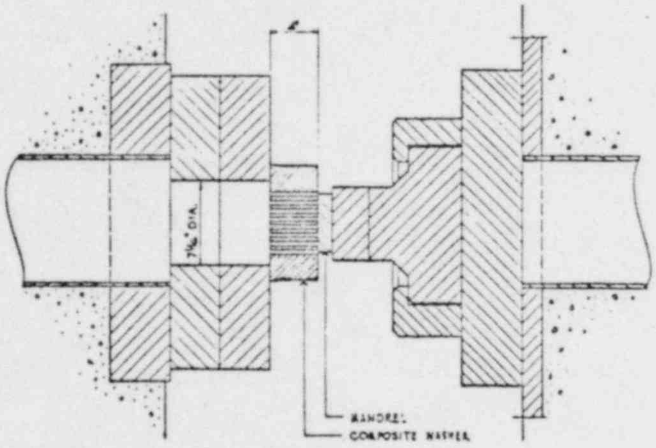


FIG. 3.3-20: Test setup for the two tests in Series B2.

Test Desig.	Calculated UTS (P_t') ① (kips)	Predicted UTS (P_i') ② (kips)	Actual UTS (P'') (kips)	Error Note ③ (%)	Revised k_r Note ④	Min. Equiv. Tendon UTS ⑤ (kips)	Safety Factor Note ⑥
B2-1	2654.4	2654.4	2541	+ 4.5	1.045	2845.8	1.42
B2-2	2600.2	2600.2	2518	+ 3.3	1.033	2878.9	1.44
n	2	2	2	2	2	2	2
$\bar{X}$	2627.3	2627.3	2529.5	+ 3.9	1.039	2862.4	1.43
σ	27.10	27.10	11.5	0.60	0.006	16.55	0.01
v	1.03	1.03	0.45	15.38	0.58	0.58	0.70
$\bar{X}$ + 3σ	2708.6	2708.6	2564.0	5.70	1.057	2912.0	1.46
$\bar{X}$ - 3σ	2546.0	2546.0	2495.0	2.10	1.021	2812.7	1.40

Notes:

1. Calculated UTS (P_t') = F_{su} × A_i' without use of Rupture Factor (k_r)
2. Predicted UTS (P_i') = P_t'/k_r; P_i' = $(F_{su} \times A_i')/k_r$; k_r = 1.0
3. Error = (P_i' - P'') × 100 ÷ P'' (percent)
4. Revised Rupture Factor: k_r = P_t'/P''
5. Minimum Equivalent Tendon UTS: P'' corrected to minimum F_{su}

   P_i' (min.) = (P''/R_e) × (min. F_{su} @ R_c 40/F_{su} of Specimen)

   For failure along shear Path 1, R_e = 0.829

   For the specified minimum R_c = 40, F_{su} = 109 ksi
6. Safety Factor: SF = P_i' (min.)/P_{1w} = P_i' (min.)/2002.8

TABLE 3.3-13: Summary Analysis of Series B2 Test Results.

ULTIMATE LOAD TESTS - PROTOTYPE ANCHORAGE COMPONENTS

SERIES B2-1 TEST 5 TEST DATE 1 MAY 67

DESCRIPTION Web Shear - WITHOUT SHIMS

COMPONENT DATA

COMPONENT NAME	SERIAL NUMBER	HARDNESS SCALE	HARDNESS READING	UTS ① (ksi)
Composite Washer	009	R_c	42.6	117.4
~~Split Shims~~				

① From Fig. 3.2-6

PREDICTED FAILURE LOAD

$P_i' = \frac{F_{su} \times A_i'}{k_r}$

$= \frac{117.4 \times 22.61}{} = 2654.4$ kips

P' = equivalent tendon load

$= \frac{P_i'}{R_e} = \frac{2654.4}{0.829} = 3201.9$ kips

where:

F_{su} from Table 3.2-2

		PATH 1	PATH 2
A_i'	=	22.61	20.55
R_e	=	0.829	0.782
k_r	=	1.0	1.0

TEST PROCEDURE

Preload to approximately 400 kips; Return to zero;
Measure gap between components and punch;
Effective Ram Area (A_e) = 3 × 212.65 = 637.95 sq. in.

LOAD DATA

TEST GAUGE ① READING (psi)	TEST GAUGE ① LOAD ② (kips)	TRANSDUCER ① ADX-38 READING		TRANSDUCER ① LOAD ③ (kips)	REMARKS
		Intended	Actual		Preload. Gap = 0.016 in.
940	600	200	195	585	
1860	1187	400	395	1185	
2800	1786	600	595	1785	
3730	2380	800	795	2385	
—	—	852	847	2541	FAILURE - NO GAUGE READING
					TAKEN. SHEAR THRU WEB
					ALONG PATH 1
P_i'' =				2541	
P'' =	2541 ÷	0.829		3065	EQUIV. TENDON ULTIMATE

Notes: ① Hydraulic Test Gauge and Hydraulic Transducer plus ADX Digital Readout give redundant measurement of the same load.
② Load = Test Gauge Reading × 0.638
③ Load = ADX-38 Reading × 3

FIG. 3.3-21: Test B2-1 Data

ULTIMATE LOAD TESTS - PROTOTYPE ANCHORAGE COMPONENTS

SERIES B2-2 TEST 6 TEST DATE 1 MAY 67

DESCRIPTION Web Shear - WITHOUT SHIMS

COMPONENT DATA

COMPONENT NAME	SERIAL NUMBER	HARDNESS SCALE	HARDNESS READING	UTS ① (ksi)
Composite Washer	005	R_c	42.0	115.0
~~Split Shims~~				

① From Fig. 3.2-6

PREDICTED FAILURE LOAD

$P_i' = \frac{F_{su} \times A_i'}{k_r}$

$= \frac{115 \times 22.61}{} = 2600.2$ kips

P' = equivalent tendon load

$= \frac{P_i'}{R_e} = \frac{2600.2}{0.829} = 3136.5$ kips

where:

F_{su} from Table 3.2-2

		PATH 1	PATH 2
A_i'	=	22.61	20.55
R_e	=	0.829	0.782
k_r	=	1.0	1.0

TEST PROCEDURE

Preload to approximately 400 kips; Return to zero;
Measure gap between components and punch;
Effective Ram Area (A_e) = 3 × 212.65 = 637.95 sq. in.

LOAD DATA

TEST GAUGE ① READING (psi)	TEST GAUGE ① LOAD ② (kips)	TRANSDUCER ① ADX-38 READING		TRANSDUCER ① LOAD ③ (kips)	REMARKS
		Intended	Actual		Preload. Gap = 0.017 in.
930	593	200	195	585	
1860	1187	400	395	1185	
2800	1786	600	595	1785	
3740	2386	800	795	2385	
3960	2526	842	839	2518	FAILURE - SHEAR THRU WEB
					ALONG PATH 1 PRIMARILY
P_i'' =				2518	
P'' =	2518 ÷	0.829		3039	EQUIV. TENDON ULTIMATE

Notes: ① Hydraulic Test Gauge and Hydraulic Transducer plus ADX Digital Readout give redundant measurement of the same load.
② Load = Test Gauge Reading × 0.638
③ Load = ADX-38 Reading × 3

0176

FIG. 3.3-22: Test B2-2 Data

As shown in Table 3.3-13, the minimum equivalent tendon ultimate which would be expected from the statistical analysis of test results would be 2812.7. For reasons set forth in Section 3.3.6, this value should be reduced to give: P'_T (min.) = 0.964 x 2812.7 = 2711.4 kips. This is 1.10 times greater than the minimum strength of 2472.6 required by the basic acceptance criteria.

By comparing the values of $\overline{X}$ for P'_T (min.) as given for Series B1 and B2, we can see that the use of split shims gives a 7% increase in equivalent ultimate strength, contrary to pre-test expectations. Comparision of Fig. 3.3-20 to 3.3-14 shows that, without shims, the moment arm is greater resulting in higher flexural stress which would reduce the ultimate load of the washer without shims due to the effect of combined shear and tension stresses. The components after being tested to ultimate were the same as shown in Fig. 3.3-18 and 19.

3.3.8 TEST SERIES C2 - 6 INCH THREAD WITHOUT SHIMS

Series C2 is reported out of sequence, that is before Series C1, in order that C2 results and analysis may be used in analizing Series C1. For the same reasons discussed in Section 3.3.7, the assembly of a Washer and Washer Nut would normally be used in conjunction with split shims.

The primary objective of Series C2 tests is to determine the ultimate shear capacity of the 6" O.D. threads (P'_s) isolated from the effect of additional load capacity resulting from bearing on the split shims (P'_{br}). The secondary objective is to provide relevant data for condition where it might be advantageous to use a Washer-Washer Nut assembly without split shims on the fixed (non-stressing) end of a tendon.

The test setup is shown schematically in Fig. 3.3-23, and test procedures were similar to those described for Series B1.

Test data for each of the three Series C2 tests are shown separately in Figs. 3.3-24 through 26. Summary and analysis of test results is contained in Table 3.3-14 which also shows the method used to calculate tabulated values.

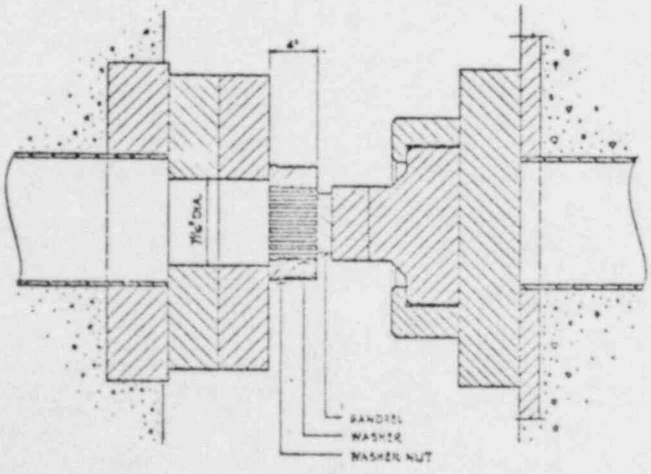
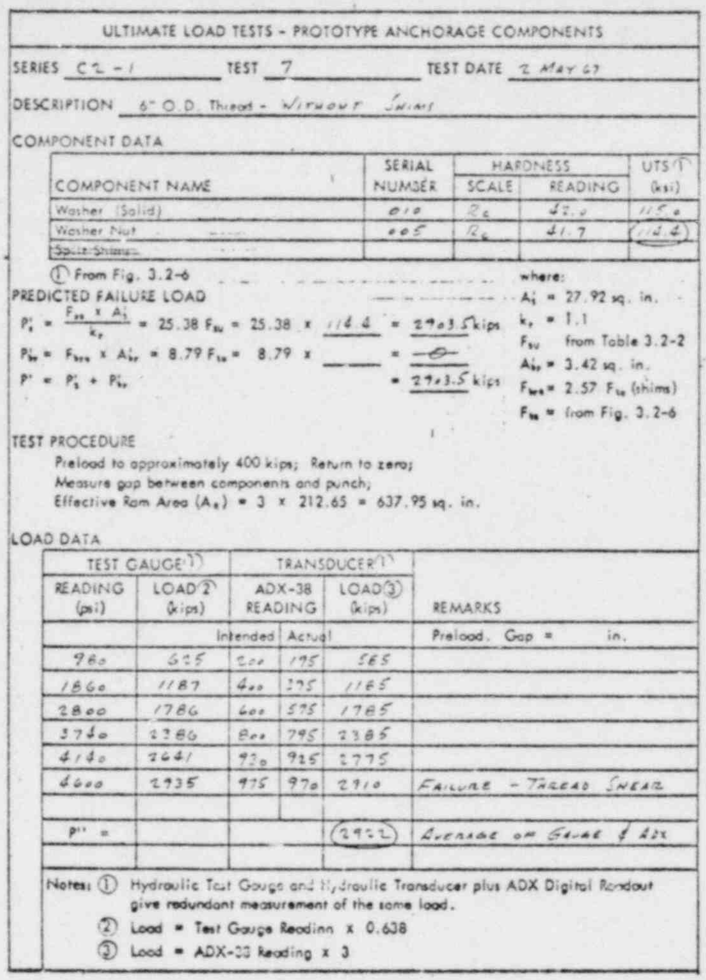


FIG. 3.3-23: Test setup for the three tests in Series C2.



ULTIMATE LOAD TESTS - PROTOTYPE ANCHORAGE COMPONENTS

SERIES C2 - 1 TEST 7 TEST DATE 2 MAY 67

DESCRIPTION 6" O.D. Thread - WITHOUT SHIMS

COMPONENT DATA

COMPONENT NAME	SERIAL NUMBER	HARDNESS		UTS ① (ksi)
		SCALE	READING	
Washer (Solid)	010	Rc	42.0	115.0
Washer Nut	005	Rc	41.7	114.4
~~Split Shims~~				

① From Fig. 3.2-6

PREDICTED FAILURE LOAD

$P'_s = \frac{F_{su} \times A'_t}{k_r} = 25.38 F_{su} = 25.38 \times$ 114.4 = 2903.5 kips

$P'_{br} = F_{brs} \times A'_{br} = 8.79 F_{su} = 8.79 \times$ ____ = -0-

$P' = P'_s + P'_{br}$ = 2903.5 kips

where:
A'_t = 27.92 sq. in.
k_r = 1.1
F_{su} from Table 3.2-2
A'_{br} = 3.42 sq. in.
F_{brs} = 2.57 F_{su} (shims)
F_{su} = from Fig. 3.2-6

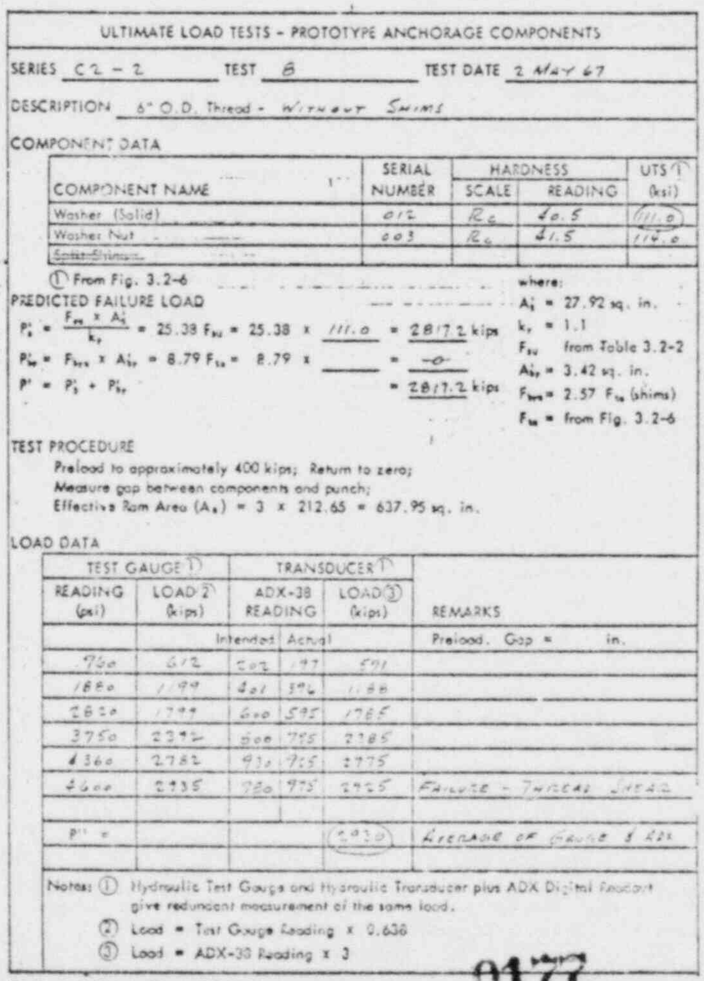
TEST PROCEDURE
Preload to approximately 400 kips; Return to zero;
Measure gap between components and punch;
Effective Ram Area (A_R) = 3 x 212.65 = 637.95 sq. in.

LOAD DATA

TEST GAUGE ①		TRANSDUCER ①			REMARKS
READING (psi)	LOAD ② (kips)	ADX-38 READING		LOAD ③ (kips)	
		Intended	Actual		Preload. Gap = in.
960	625	200	195	585	
1860	1187	400	395	1185	
2800	1786	600	595	1785	
3740	2386	800	795	2385	
4140	2641	920	925	2775	
4600	2935	975	970	2910	FAILURE - THREAD SHEAR
P'' =				2922	AVERAGE OF GAUGE & ADX

Notes: ① Hydraulic Test Gauge and Hydraulic Transducer plus ADX Digital Readout give redundant measurement of the same load.
② Load = Test Gauge Readinn x 0.638
③ Load = ADX-38 Reading x 3

FIG. 3.3-24: Test C2-1 Data



ULTIMATE LOAD TESTS - PROTOTYPE ANCHORAGE COMPONENTS

SERIES C2 - 2 TEST 8 TEST DATE 2 MAY 67

DESCRIPTION 6" O.D. Thread - WITHOUT SHIMS

COMPONENT DATA

COMPONENT NAME	SERIAL NUMBER	HARDNESS		UTS ① (ksi)
		SCALE	READING	
Washer (Solid)	012	Rc	40.5	111.0
Washer Nut	003	Rc	41.5	114.0
~~Split Shims~~				

① From Fig. 3.2-6

PREDICTED FAILURE LOAD

$P'_s = \frac{F_{su} \times A'_t}{k_r} = 25.38 F_{su} = 25.38 \times$ 111.0 = 2817.2 kips

$P'_{br} = F_{brs} \times A'_{br} = 8.79 F_{su} = 8.79 \times$ ____ = -0-

$P' = P'_s + P'_{br}$ = 2817.2 kips

where:
A'_t = 27.92 sq. in.
k_r = 1.1
F_{su} from Table 3.2-2
A'_{br} = 3.42 sq. in.
F_{brs} = 2.57 F_{su} (shims)
F_{su} = from Fig. 3.2-6

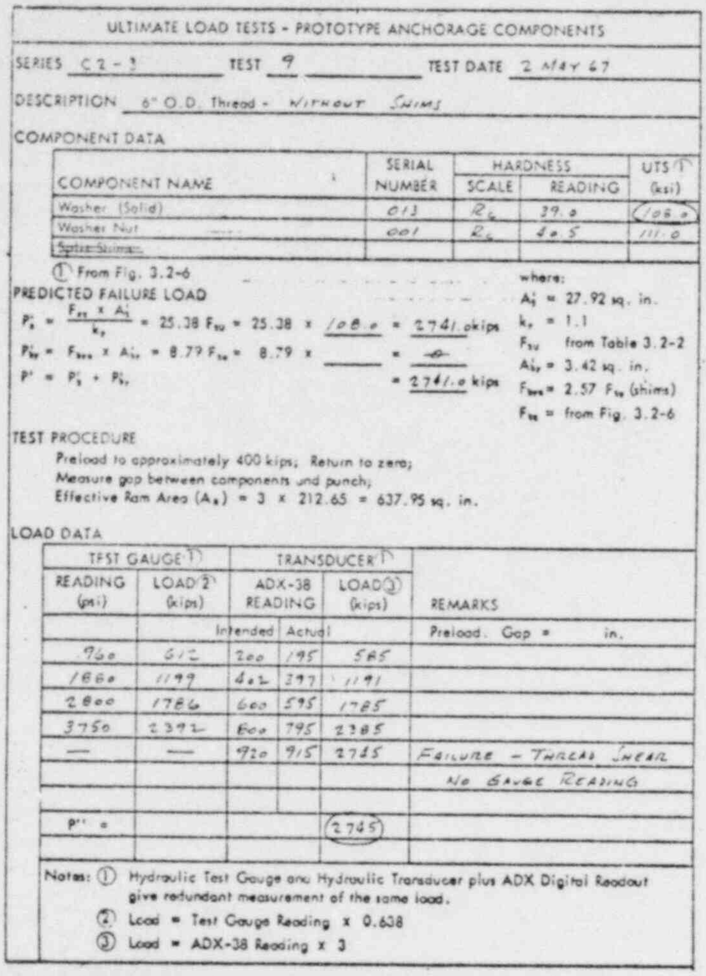
TEST PROCEDURE
Preload to approximately 400 kips; Return to zero;
Measure gap between components and punch;
Effective Ram Area (A_R) = 3 x 212.65 = 637.95 sq. in.

LOAD DATA

TEST GAUGE ①		TRANSDUCER ①			REMARKS
READING (psi)	LOAD ② (kips)	ADX-38 READING		LOAD ③ (kips)	
		Intended	Actual		Preload. Gap = in.
960	612	202	197	591	
1880	1199	401	396	1188	
2820	1799	600	595	1785	
3750	2392	800	795	2385	
4360	2782	930	925	2775	
4600	2935	980	975	2925	FAILURE - THREAD SHEAR
P'' =				2930	AVERAGE OF GAUGE & ADX

Notes: ① Hydraulic Test Gauge and Hydraulic Transducer plus ADX Digital Readout give redundant measurement of the same load.
② Load = Test Gauge Reading x 0.638
③ Load = ADX-38 Reading x 3

FIG. 3.3-25: Test C2-2 Data



ULTIMATE LOAD TESTS - PROTOTYPE ANCHORAGE COMPONENTS

SERIES C2-3 TEST 9 TEST DATE 2 MAY 67

DESCRIPTION 6" O.D. Thread - WITHOUT SHIMS

COMPONENT DATA

COMPONENT NAME	SERIAL NUMBER	HARDNESS		UTS ① (ksi)
		SCALE	READING	
Washer (Solid)	013	R_c	39.0	108.0
Washer Nut	001	R_c	40.5	111.0
~~Split Shims~~				

① From Fig. 3.2-6

PREDICTED FAILURE LOAD

$P'_s = \frac{F_{su} \times A'_s}{k_r} = 25.38 F_{su} = 25.38 \times$ 108.0 = 2741.0 kips

$P'_{br} = F_{brs} \times A'_{br} = 8.79 F_{su} = 8.79 \times$ ____ = -0-

$P' = P'_s + P'_{br}$ = 2741.0 kips

where:

$A'_s = 27.92$ sq. in.

$k_r = 1.1$

F_{su} from Table 3.2-2

$A'_{br} = 3.42$ sq. in.

$F_{brs} = 2.57 F_{su}$ (shims)

F_{su} = from Fig. 3.2-6

TEST PROCEDURE

Preload to approximately 400 kips; Return to zero;
Measure gap between components und punch;
Effective Ram Area (A_R) = 3 × 212.65 = 637.95 sq. in.

LOAD DATA

TEST GAUGE ①		TRANSDUCER ①			REMARKS
READING (psi)	LOAD ② (kips)	ADX-38 READING		LOAD ③ (kips)	
		Intended	Actual		Preload. Gap = in.
960	612	200	195	585	
1860	1199	402	397	1191	
2800	1786	600	595	1785	
3750	2392	800	795	2385	
—	—	920	915	2745	FAILURE - THREAD SHEAR
					NO GAUGE READING
P'' =				2745	

Notes: ① Hydraulic Test Gauge and Hydraulic Transducer plus ADX Digital Readout give redundant measurement of the same load.
② Load = Test Gauge Reading × 0.638
③ Load = ADX-38 Reading × 3

FIG. 3.3-26: Test C2-3 Data

Test Desig.	Calculated UTS (P'_{s-c}) ① (kips)	Predicted UTS (P'_s) ② (kips)	Actual UTS (P'') (kips)	Error Note ③ (%)	Revised k_r Note ④	Min. Equiv. UTS (P'_T min) ⑤ (kips)	Safety Factor Note ⑥
C2-1	3193.8	2903.5	2922	- 0.6	1.09	2784.1	1.39
C2-2	3098.9	2817.2	2930	- 3.8	1.06	2877.2	1.44
C2-3	3015.1	2741.0	2745	- 0.1	1.10	2770.4	1.38
n	3	3	3	3	3	3	3
$\bar{x}$	3102.6	2820.6	2865.7	- 1.5	1.08	2810.6	1.40
σ	73.00	66.38	85.39	1.64	.017	47.45	.026
v	2.35	2.35	2.98	109.3	1.57	1.69	1.87
$\bar{x} + 3\sigma$	3321.6	3019.7	3121.8	- 6.42	1.13	2952.9	1.48
$\bar{x} - 3\sigma$	2883.6	2621.4	2609.5	+ 3.42	1.03	2668.2	1.32

Notes:

1. Calculated Shear UTS (P'_{s-c}) = F_{su} (actual) × A'_s without use of Shear Rupture Factor (k_{r-s}). F_{su} (actual) is the ultimate shear strength based on actual value of R_c. A'_s = nominal shear area = 27.92 sq. in.
2. Predicted Shear UTS (P'_s) = F_{su} (actual) × A'_s/k_{r-s}. k_{r-s} = 1.1 from past testing of similar mechanisms.
3. Error = (P'_s - P'')/P''. Negative error indicates component is stronger than predicted.
4. Revised Shear Rupture Factor (k_{r-s}) = P'_{s-c}/P''.
5. Minimum Equivalent UTS (P'_T min.) is P'' revised to F_{su} min. P'_T (min.) = P'' × F_{su} (min) / F_{su} (actual) = P'' × 109/F_{su} (actual).
6. Safety Factor (S.F.) = P'_T (min.)/min. guaranteed tendon UTS. S.F. = P'_T (min.)/ 2002.3

TABLE 3.3-14: Summary Analysis of Series C2 Test Results.

As discussed in the analysis of Series B1 and B2, the $\bar{x} - 3\sigma$ value for minimum equivalent UTS (P'_T min.) represents the minimum strength expected in a population of Washer-Washer Nut assemblies as derived from a statistical analysis of test results, is based on nominal shear area and is corrected to the shear strength corresponding to the lowest value of R_C allowed by the quality assurance provisions established for the 2.0 Mep/170 W Post-Tensioning System. The value of $\bar{x} - 3\sigma$ for P'_T (min.) is shown to be 2668.2 kips which is 1.08 times the 2472.6 kips established as the minimum by the basic criteria for acceptance. The mean value of 1.08 for the revised Shear Rupture Factor (k_{r-s}) is quite close to k_r = 1.1 used in predicting UTS. Photos of components after being tested in failure are shown in Fig's. 3.3-27 and 28.

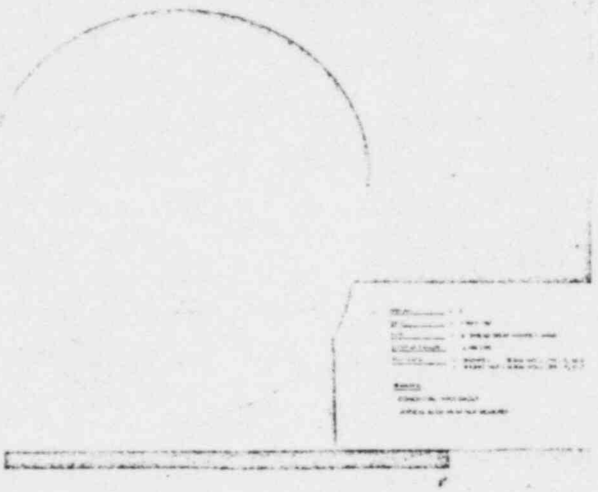


FIG. 3.3-27: Outer face of Washer Serial No. 010 and Washer Nut Serial No. 005 after being loaded to ultimate in Test C2-1.

FIG. 3.3-28: Inner face of components shown in Fig. 3.3-27. Both photos are typical for Series C2 components after failure.

3.3.9 TEST SERIES C1 - 6 INCH THREAD WITH SHIMS

The test setup for Series C1 is shown in Fig. 3.3-29. Test procedures were similar to those previously described. Data for the two tests of Series C1 is contained in Fig's. 3.3-30 and 31; and a summary analysis of the data is contained in Table 3.3-15.

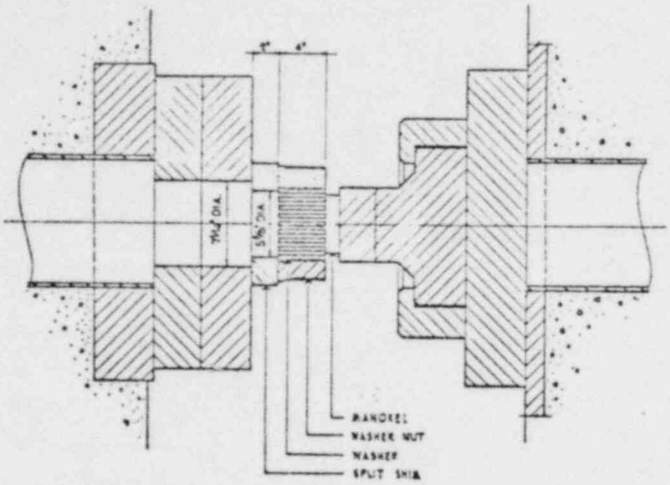


FIG. 3.3-29: Test setup for the two tests of Series C1.

Test Desig.	Predicted UTS (kips) Shear (P_s') Note ①	 Bearing (P_{br}') Note ②	 Total (P') Note ③	Actual UTS (P'') (kips)	Error Note ④ (%)	Revised C_{br} Note ⑤	Min. Equiv. UTS (P_s' min.) ⑥ (kips)	Safety Factor Note ⑦
C1-1	2913.7	562.6	3476.3	3378	+ 2.91	2.12	3231.1	1.61
C1-2	2913.7	615.3	3529.0	3561	- 0.90	2.70	3346.2	1.67
n	2	2	2	2	2	2	2	2
$\bar{x}$	2913.7	589.0	3502.6	3469.5	1.01	2.41	3288.6	1.64
σ	0	26.35	26.35	91.5	1.905	0.29	57.55	0.030
v	0	4.47	0.75	2.64	95.01	12.03	1.75	1.83
$\bar{x}+3\sigma$	2913.7	668.0	3581.7	3744.0	6.72	3.28	3461.3	1.73
$\bar{x}-3\sigma$	2913.7	509.9	3423.6	3195.0	- 4.71	1.54	3116.0	1.55

Notes:

1. Predicted Shear UTS (P_s') is based on experience gained from Series C2. Therefore, $P_s' = \bar{x}$ for P_s' (min.) from Table 3.3-14 × the ratio of F_{su} (actual) to F_{su} (min.) where F_{su} (min.) = 109 ksi, $P_s' = 2810.6 \times F_{su}$ (actual)/109
2. Predicted Bearing UTS (P_{br}') = $F_{brs} \times A_{br}' = C_{br} \times F_{tu}$ (for shims) $\times A_{br}'$. In predicting P_{br}', C_{br} was set at 2.57, therefore $P_{br}' = C_{br} \times F_{tu}$ (for shims) $\times A_{br}' = 2.57\ F_{tu} \times 3.42$
3. $P' = P_s' + P_{br}'$
4. Error = $(P' - P'')/P''$
5. Revised UBS constant (C_{br}) = $(P'' - P_s')/3.42 \times F_{tu}$ (for shims) where $A_{br}' = 3.42$ sq. in.
6. See discussion in text.
7. Safety Factor (S.F.) = P_s' (min.)/2002.8

TABLE 3.3-15: Summary Analysis of Series C1 Test Results.

ULTIMATE LOAD TESTS - PROTOTYPE ANCHORAGE COMPONENTS

SERIES C1 - 1 TEST 4 TEST DATE 1 MAY 67

DESCRIPTION 6" O.D. Thread - WITH SHIMS

COMPONENT DATA

COMPONENT NAME	SERIAL NUMBER	HARDNESS SCALE	 READING	UTS ① (ksi)
Washer (Solid)	014	R_c	41.0	113.0
Washer Nut	008	R_c	42.0	115.0
Split Shims	—	R_B	77	64.0

① From Fig. 3.2-6

PREDICTED FAILURE LOAD

$P_s' = \frac{F_{su} \times A_s'}{k_r} = 25.38\ F_{su} = 25.38 \times \underline{113.0} = \underline{2867.9}$ kips

$P_{br}' = F_{brs} \times A_{br}' = 8.79\ F_{tu} = 8.79 \times \underline{64.0} = \underline{562.6}$

$P' = P_s' + P_{br}' \qquad = \underline{3430.5}$ kips

where:
$A_s' = 27.92$ sq. in.
$k_r = 1.1$
F_{su} from Table 3.2-2
$A_{br}' = 3.42$ sq. in.
$F_{brs} = 2.57\ F_{tu}$ (shims)
F_{tu} = from Fig. 3.2-6

TEST PROCEDURE

Preload to approximately 400 kips; Return to zero;
Measure gap between components and punch;
Effective Ram Area (A_R) = 3 × 212.65 = 637.95 sq. in.

LOAD DATA

TEST GAUGE ① READING (psi)	 LOAD ② (kips)	TRANSDUCER ① ADX-38 READING Intended	 Actual	 LOAD ③ (kips)	REMARKS
					Preload. Gap = in.
940	600	200	195	585	
1870	1193	400	395	1185	
2810	1793	600	595	1785	
3740	2386	800	795	2385	
4360	2782	930	925	2775	
4700	2999	1000	995	2985	
4900	3126	1050	1045	3135	
5300	3381	1130	1125	3375	FAILURE - THREAD SHEAR
P'' =				3378	AVERAGE OF GAUGE & ADX

Notes: ① Hydraulic Test Gauge and Hydraulic Transducer plus ADX Digital Readout give redundant measurement of the same load.
② Load = Test Gauge Reading x 0.638
③ Load = ADX-33 Reading x 3

FIG. 3.3-30: Test C1-1 Data

ULTIMATE LOAD TESTS - PROTOTYPE ANCHORAGE COMPONENTS

SERIES C1 - 2 TEST 10 TEST DATE 3 MAY 67

DESCRIPTION 6" O.D. Thread - WITH SHIMS

COMPONENT DATA

COMPONENT NAME	SERIAL NUMBER	HARDNESS SCALE	 READING	UTS ① (ksi)
Washer (Solid)	011	R_c	41.0	113.0
Washer Nut	002	R_c	41.0	113.0
Split Shims	—	R_B	79	70.0

① From Fig. 3.2-6

PREDICTED FAILURE LOAD

$P_s' = \frac{F_{su} \times A_s'}{k_r} = 25.38\ F_{su} = 25.38 \times \underline{113.0} = \underline{2867.9}$ kips

$P_{br}' = F_{brs} \times A_{br}' = 8.79\ F_{tu} = 8.79 \times \underline{70.0} = \underline{615.3}$

$P' = P_s' + P_{br}' \qquad = \underline{3483.2}$ kips

where:
$A_s' = 27.92$ sq. in.
$k_r = 1.1$
F_{su} from Table 3.2-2
$A_{br}' = 3.42$ sq. in.
$F_{brs} = 2.57\ F_{tu}$ (shims)
F_{tu} = from Fig. 3.2-6

TEST PROCEDURE

Preload to approximately 400 kips; Return to zero;
Measure gap between components and punch;
Effective Ram Area (A_R) = 3 × 212.65 = 637.95 sq. in.

LOAD DATA

TEST GAUGE ① READING (psi)	 LOAD ② (kips)	TRANSDUCER ① ADX-38 READING Intended	 Actual	 LOAD ③ (kips)	REMARKS
					Preload. Gap = in.
960	612	200	195	585	
1870	1206	400	395	1185	
2830	1806	600	596	1788	
3760	2399	800	795	2385	
4380	2794	930	925	2775	
4700	2999	1000	995	2985	
5160	3292	1100	1075	3225	
5420	3458	1150	1145	3435	
5600	3573	1184	1183	3549	FAILURE - THREAD SHEAR

Notes: ① Hydraulic Test Gauge and Hydraulic Transducer plus ADX Digital Readout give redundant measurement of the same load.
② Load = Test Gauge Reading x 0.638
③ Load = ADX-38 Reading x 3 USE $P_s'' = 3541$ AVERAGE OF GAUGE & ADX

FIG. 3.3-31: Test C1-2 Data

Series C1 tests allow analysis of the total ultimate strength (P'_T) of an assembly of Washer-Washer Nut bearing on Split Shims, but, taken alone, give no information as to the relative portion of the total load taken by either shear in the 6" threads (P'_s) or by bearing on the shims (P'_{br}). When compared to results of Series C2, Series C1 allows the qualitative conclusion that shims increase the total load capacity (a conclusion further substantiated by design analysis) but still provide no accurate determination of the interaction between shear and bearing loads.

If we assume that the ultimate shear strength of the 6" threads has been setablished by Series C2 at 2810.6 kips (the $\overline{X}$ value of P'_T (min.) at F_{su} = 109 ksi per Table 3.3-14, then this value can be corrected to F_{su} (acutal) for the components tested in Series C1 and plugged for P'_s in Table 3.3-15. Continuing from this first premise, we can then assume that the actual ultimate bearing load (P''_{br}) is the difference between actual total load (P'') and P'_s. The above premise is not precise since actual shear ultimate (P''_s) for Series C1 is not necessarily the same as that established for Series C2. Still, there appears to be no better approach based on a limited series of tests and the error in conclusions so derived will be small. No real significance, however, should be attached to the actual numerical value of the Ultimate Bearing Strength Constant (C_{br}) derived from this analysis.

It can be seen from Table 3.3-15 that the variance of test results, as measured by the coefficient of variation (ν), is only 2.64%, a small value which gives a relatively high confidence in the values for total load (P'_T). The mean value for C_{br} of 2.41 is close to the approximate value of 2.57 arrived at in the design analysis of Section 3.2.6, which gives reasonable confidence in the design approach. However variance is relatively high (ν = 12.03%) and in future designs of similar mechanisms, a value C_{br} = 2.0 would seem both reasonable and conservative.

The value for P'_T (min.) is derived from correcting the values P'_s and P'_{br} to minimum values of F_u allowed by quality assurance procedures. Thus, corrected $P'_s = P'_s \times F_{su}$ (actual)/F_{su} (min.), and correct P'_{br} = corrected $C_{br} \times F_{tu}$ (min.) for shim material x A'_s. In accordance with this procedure, P'_T(min.) for each test of Series C1 becomes:

$$P'_T\ (\text{min}) = [\,2913.7 \times F_{su}\ (\text{actual})/109\,] + [\,C_{br} \times F_{tu}\ (\text{min.}) \times 3.42\,]$$

As an example, for test C1-1

$$P'_T(\text{min.}) = (2913.7 \times 109/113) + (2.12 \times 58 \times 3.42) = 3231.1 \text{ kips}$$

We then arrive at P'_T (min.) for the system at $\overline{X} - 3\sigma$ or 3116.0 kips which is 1.26 times the minimum value of 2472.6 per basic acceptance criteria. Numerical values derived above cannot be considered accurate as they are based on assumptions of questionable quantitiative accuracy. This is of no concern as the 6 inch thread with shims is not the critical failure mode in any event.

Photos of the components after being tested to failure are shown in Fig's. 3.3-32 and 33. Due to the relative magnitudes of the ultimate thread shear force (P'_s) and the ultimate bearing load on the split shims (P'_{br}), it can be assumed that the shim bearing failure which is clearly shown in Fig. 3.3-32 did not occur until after thread shear failure.

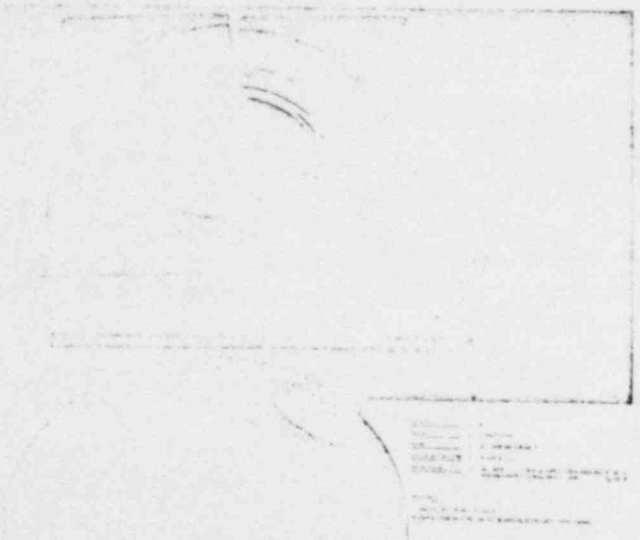


FIG. 3.3-32: Outer face of Washer Serial No. 014, Washer Nut Serial No. 008 and Split Shims after being loaded to ultimate as an assembly in test C1-1.

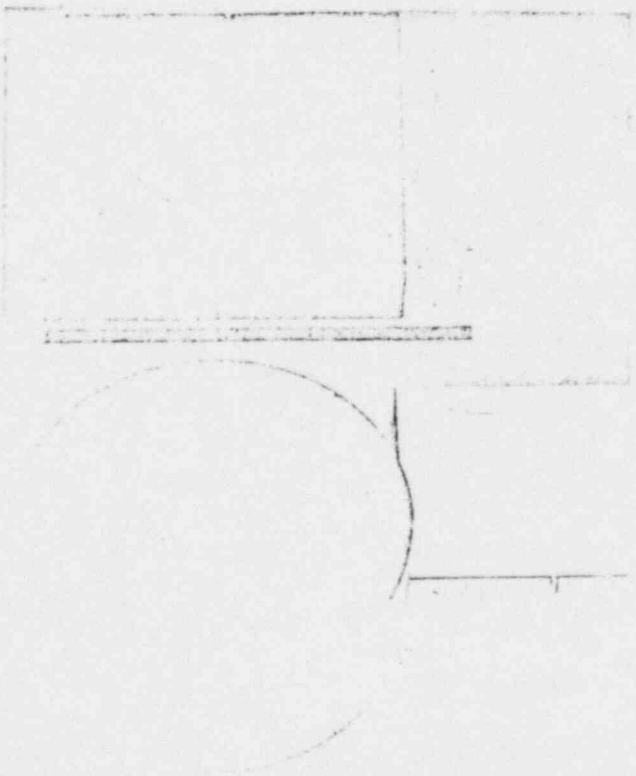


FIG. 3.3-33: Inner face of components shown in Fig. 3.3-32. Note that inner face of Washer - Washer Nut assembly bears on outer face of Split Shims.

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3.3.10 ANALYSIS OF FAILURE MODE FROM TESTS

A summary of failure loads for each mode of failure, based on Series B and C test results, is contained in Table 3.3-16. Failure load of the split shims at either the Bearing Plate or the more critical Composite Washer interface was not determined, but it must be in excess of the 3561 kip maximum load applied during the ten tests and must be due to bearing failure which is not a critical mode.

Wire hole web shear is shown to be slightly more critical than shear at the 6 inch diameter threads. Failure loads shown in Table 3.3-16 for both Wire Hole Web Shear and 6" Threads (with shims) are mean values.

As compared with the 6 inch threads of the same form, the 9-3/8 inch threads are subjected to a temporary load only, are unloaded in the structural condition, are subject to a maximum load which is 20% less and have a nominal area which is 57% greater. This thread is obviously not critical and was not tested.

To provide uniformity in dimensions (to facilitate inspection, shipping, field procedures etc.) it was decided to increase the thickness of both the Composite Washer and the Washer from 3-3/4 inches to 4 inches matching the required thickness of the Washer Nut. This increased thickness will provide additional strength for both the Wire Hole Web Shear and the 6 inch Thread Shear failure modes of production components. The increased strength, computed by linear increase of prototype component test results is shown in Fig. 3.3-16. The increased load capacity is not required for conformance to design or acceptance criteria and will not substantially increase the failure load for other (non-critical) modes of failure.

It should be noted that, by the time all test Series were completed, several specific components had been loaded several times to loads greater than the minimum guaranteed ultimate tendon strength of 2002.8 kips. As part of the overall test program, loads ≥ 2002.8 kips were applied five times to Washer - Serial No. 002, seven times to Washer Nut - Serial No. 004, nine times to Composite Washer - Serial No. 007, and several times to other components. While this number of cycles cannot be considered a fatigue test, the applied load is considerably higher than will ever be applied in the structure, and the number of times which many components withstood actual tendon ultimate, without failure, gives increased confidence in the basic criteria that the end anchorage be stronger than the tendon which it anchors.

3.3.11 SUMMARY CONCLUSIONS

The average error of predicted ultimate loads was - 0.61%, varying from -4.0 to +4.5 maximum error; therefore, it may be concluded that the design methods used are quite accurate and give predictable results.

The coefficient of variation of test results is small, having a mean value of 1.974% and varying between a low of 0.45% to a high of 2.98%, indicating that the combined effect of prototype production variables and testing variables is insignificant, therefore it may be concluded that both production methods and test procedures were satisfactory.

All test results were over acceptance minimums based on conservative basic critera; therefore it may be concluded that the end anchorage hardware as designed and tested will not be the weakest link in the tendon system.

Failure Mode	Type of Failure	Failure Load	
		Prototype	Production
Bearing Plate - Split Shim Interface	Bearing	>3561	>3561
Split Shim - Composite Washer Interface	Bearing	>3561	>3561
Wire Hole Web Shear	Shear	3062	3266
6" Threads (with shims)	Shear	3289	3542

TABLE 3.3-16: Summary of failure mode, type of failure and failure load for both prototype and production end anchorage hardware, based on Series B and C tests. Summary is for an anchorage consisting of a bearing plate, split shims, and a composite washer (or a washer-washer nut assembly).

[redacted]

4. "Dynamic test results of smaller tendon anchorage assemblies showing no loss of stress based on 500 cycles of rapid loading from stress level 0.70 f's to stress level 0.75 f's and return to 0.70 f's. One complete cycle shall take place in 0.1 seconds."

52,197-2
52,197-3
23,549-7
58,570-3
58,570-4

58,570-5
58,570-6
51,499-1
55,939-3
55,939-4

In addition to these tests, Item 2.4 reports on fatigue tests performed for WCS.

Additional tests are in process at Armco's laboratory in Middletown, Ohio. New tests on tendons up to 70 wires are scheduled in the future. Reports on these tests will be available soon after the tests are completed.

Eidgenössische Materialprüfungs- und Versuchsanstalt für Industrie,
Bauwesen und Gewerbe, 8600 Dübendorf

Laboratoire fédéral d'essai des matériaux et Institut de recherches — Industrie, Génie civil, Arts et Métiers — 8600 Dübendorf
Laboratorio federale di prova dei materiali ed Istituto sperimentale — Industria, Genio civile, Arti e Mestieri — 8600 Dübendorf

COPIE

Untersuchungsbericht

Procès-verbal / Processo verbale

EMPA No. 40'879.

Auftraggeber:
Commettant:
Committente:
BUREAU BBR, ZÜRICH
- Department A -

Gegenstand:
Objet:
Oggetto:
Eine Verankerung Typ A 703, bestehend aus: Grundplatte, Zeichnu
Proceq 4 - 107 693; Stützmutter, Zeic
nung Proceq 2 - 107 840; Versuchs-Gru
körper, Zeichnung Proceq 2 - 107 692.

Sägegewinde S 18o

- **Betrifft:** Schreiben 7764/A-Mä/zo vom 1. Februar 1966. -

- Angaben des Auftraggebers -

Einlieferung durch die Firma Mecana S. A., Schmerikon.

Datum des Eingangs:
Date de l'arrivée:
Data d'arrivo:
7. März 1966.

Ausführung der Untersuchung:
Exécution de l'essai:
Esecuzione della prova:
bis 24. März 1966.

Untersuchungsauftrag:

Durchführung eines Belastungsversuchs in Stufen von 50 to mit anschlies
sender Belastungssteigerung bis zum Bruch und Bestimmung der Härte nac
Brinell.

RESULTATE DER UNTERSUCHUNGEN.

1) Schema der Versuchsanordnung
   - Zeichnung EMPA-No. 4 - 91'400 -.
2) Resultate der Belastungsversuche.
3) Bestimmung der Härte nach Brinell.

[redacted]

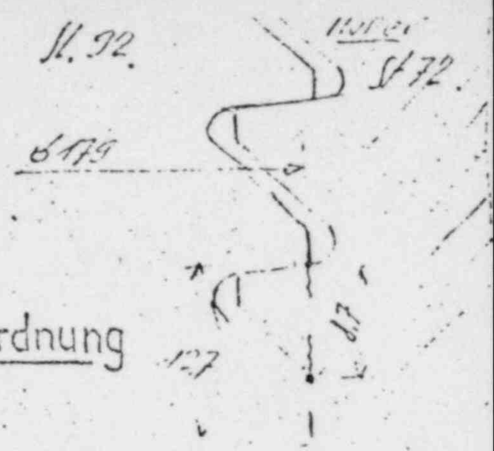
[illegible] Art, den blossen Hinweis auf diesen Bericht eingeschlossen, Bruchlast 13,76 t

Scherquerschnitt $F_s = \frac{11,0}{12,7} \cdot \pi \cdot 17,9 \cdot 0,87 = 4,62$ cm²

Bruchspannung für M 72

$\tau_B = \frac{13,76}{4,62} = \underline{3,0}$ t/cm²

(Max. Gebrauchsspannung $\tau_v = \frac{7,90}{4,62} = \underline{1,7}$ t/cm²)
(Bergener)

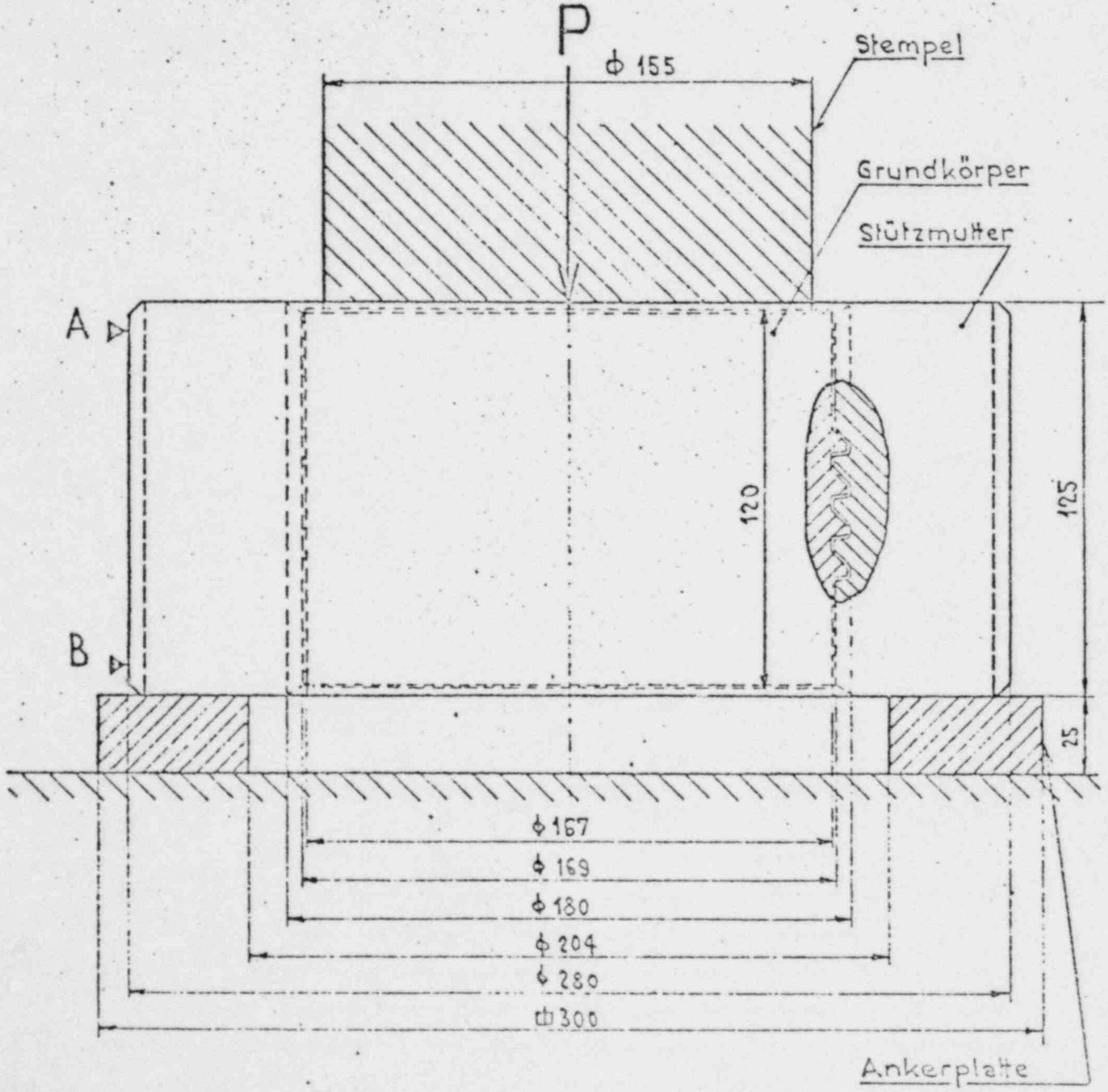


1) Schema der Versuchsanordnung

Sicherheit gegen Bruch (Bergener)

$S = \frac{13,76}{7,90} = \underline{1,75}$

Masse in mm



[redacted] Diametrales Spiel 0,9 mm
Achsiales Spiel 0,48 mm

M. 1:2 0184

RESULTATE DER BELASTUNGSVERSUCHE

Durchmesser - Veränderungen in mm

Belastung P in t	Bei Belastung Stelle A	Bei Belastung Stelle B	$\varepsilon = \frac{\Delta d}{d}$	Bei Entlastung auf 10 t Stelle A	Bei Entlastung auf 10 t Stelle B	plastisch	Bemerkungen:
10	0	0		0	0		Nach vollständiger Entlastung:
800	- 0,32	+ 0,58	0,21 %	- 0,05	+ 0,18	0,06 %	Gewinde gängig.
900	+ 0,03	+ 0,79	0,28	- 0,09	+ 0,39	0,14	- do. -
950	+ 0,03	+ 0,90	0,32	- 0,11	+ 0,46	0,16	- do. -
1'000	- 0,02	+ 1,02	0,36	- 0,14	+ 0,60	0,21	[illegible] - do. -
1'050	- 0,03	+ 1,19	0,43	- 0,18	+ 0,73	0,26	- do. -
1'100	- 0,11	+ 1,41	0,51	- 0,24	+ 0,93	0,33	- do. -
1'150	- 0,15	+ 1,62	0,59	- 0,30	+ 1,14	0,41	- do. -
1'200	- 0,21	+ 1,90	0,68	- 0,36	+ 1,40	0,51	- do. -
1'250	- 0,27	+ 2,18	0,78	- 0,44	+ 1,67	0,6	- do. -
1'300	- 0,35	+ 2,52	0,91	- 0,52	+ 1,97	0,7	) Gewinde gängig, beginnt nach ungefäh) einer Umdrehung zu) klemmen.
1'350	- 0,46	+ 2,92	1,05	- 0,63	+ 2,36	0,85	

1'376 P_{max} Abscheren des Gewindes in der Mutter.

Bestimmung der Härte nach
Détermination de la dureté
Determinazione della durezza

[✓ Brinell HB]
Vickers HV
Rockwell HR

Belastung:
Charge:
Carico: 3'000 kg

Kugeldurchmesser:
Diamètre de la bille:
Diametro della biglia: 10 mm

Belastungsdauer:
Durée de charge:
Durata di carico: 30 sec.

Bezeichnung Désignation Designazione	Stelle Point Punto	Härtezahl Chiffre de dureté Grado di durezza kg/mm²			
		HB	HV	HR	
Versuchs-Grund-körper	1	274	--	--	
	2	262	--	--	268 92 kg/mm²
Stützmutter	1	198	--	--	
	2	203	--	--	201 72 kg/mm²
Anker-platte	1	112	--	--	119 43 kg/mm²
	2	127	--	--	

Dübendorf, 25. März 1966.

Eidg. Materialprüfungs- und Versuchsanstalt
Abteilung Metalle
Der Abteilungsvorsteher:

[redacted]

Eidgenössische Materialprüfungs- und Versuchsanstalt für Industrie, Bauwesen und Gewerbe, 8600 Dübendorf

Laboratoire fédéral d'essai des matériaux et Institut de recherches — Industrie, Génie civil, Arts et Métiers — 8600 Dübendorf
Laboratorio federale di prova dei materiali ed Istituto sperimentale — Industria, Genio civile, Arti e Mestieri — 8600 Dübendorf

Untersuchungsbericht

Procès-verbal / Processo verbale

EMPA No. 46'335.

Auftraggeber:
Commettant:
Committente: BUREAU BBR, - Department A - ZÜRICH

Gegenstand:
Objet:
Oggetto:

Ein	Grundkörper " C 220 ",	aus 42 Cr Mo 4, vergütet,	) bestimmt fü
Eine	Zughülse,	aus Marwe 176 M,	) Versuch mit
Ein	Stempel,	aus VCN 35,	) Wabe C 22
Ein	Stützring,	aus VCN 35,	)

Sämtliche Teile gemäss Zeichnung BBR - PQ - 4 - 108486.

- **Betrifft:** Schreiben A - Mä/ja vom 3. Oktober 1966. -

- Angaben des Auftraggebers -

Datum des Eingangs:
Date de l'arrivée:
Data d'arrivo: 5. Oktober 1966.

Ausführung der Untersuchung:
Exécution de l'essai:
Esecuzione della prova: bis 15. November 1966.

Untersuchungsauftrag:

Durchführung eines Bruchversuchs am Grundkörper C 220. - Bestimmung der Härte an sämtlichen Teilen.

RESULTATE DER UNTERSUCHUNGEN.

1) Bestimmung der Härte nach Brinell.
2) Schema der Versuchsanordnung.
3) Belastungsversuch mit Grundkörper " C 22 0 ".
4) Photographische Aufnahme.

Bestimmung der Härte nach Brinell HB
Détermination de la dureté Vickers HV
Determiniazione della durezza Rockwell HR

Belastung: Charge: Carico: 750 kg

Kugeldurchmesser: Diamètre de la bille: Diametro della biglia: 5 mm

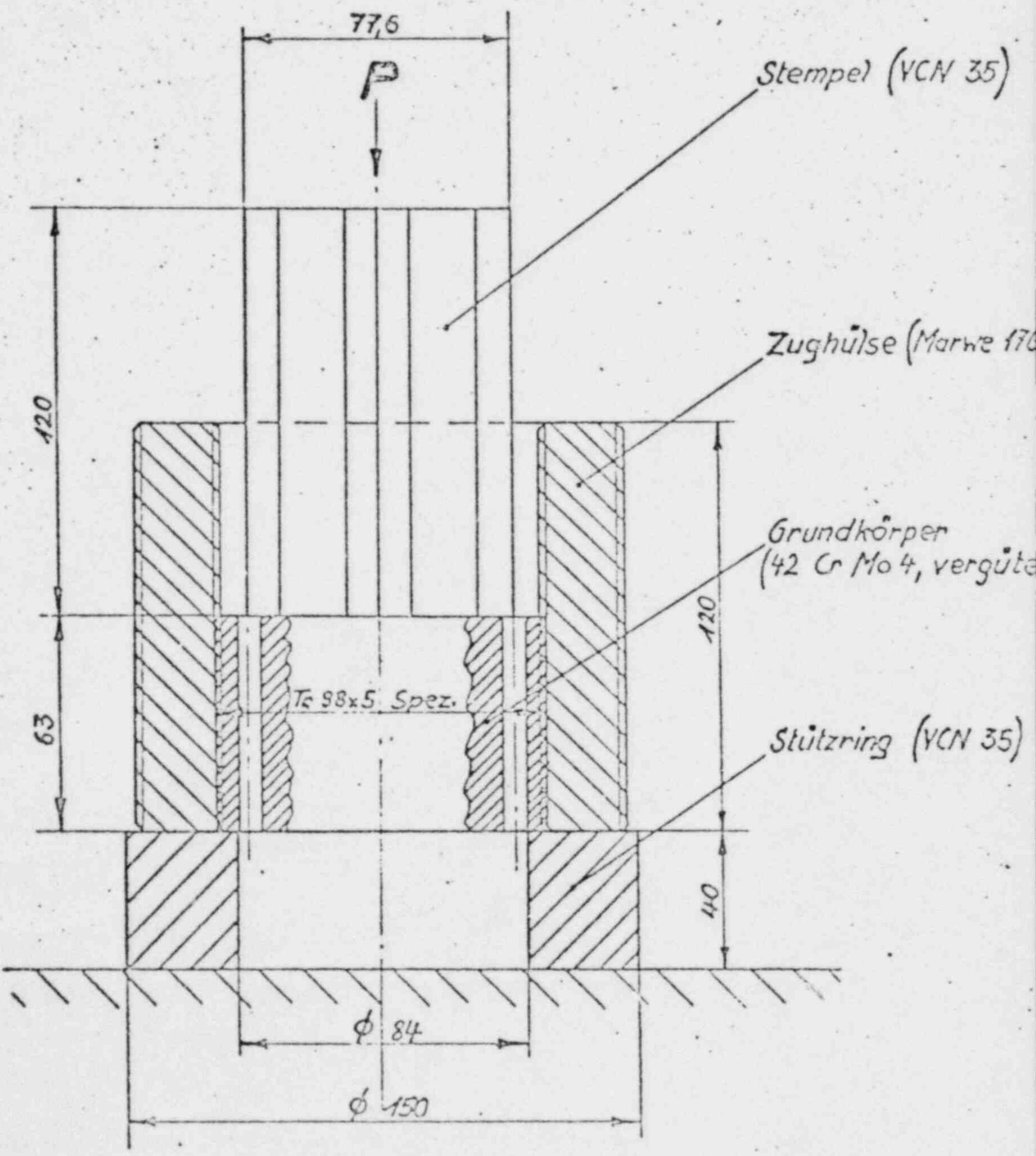
Belastungsdauer: Durée de charge: Durata di carico: 30 sec.

Bezeichnung Désignation Designazione	Stelle Point Punto	Härtezahl Chiffre de dureté Grado di durezza		
		HB kg/mm^2	HV kg/mm^2	HR
Grundkörper	1	293	--	--
	2	304	--	--
Zughülse	1	188	--	--
	2	192	--	--
Stempel	1	274	--	--
	2	275	--	--
Stützring	1	257	--	--
	2	260	--	--

Mittel
301 -> 102 kg/mm^2

[redacted]

Schema der Versuchsanordnung

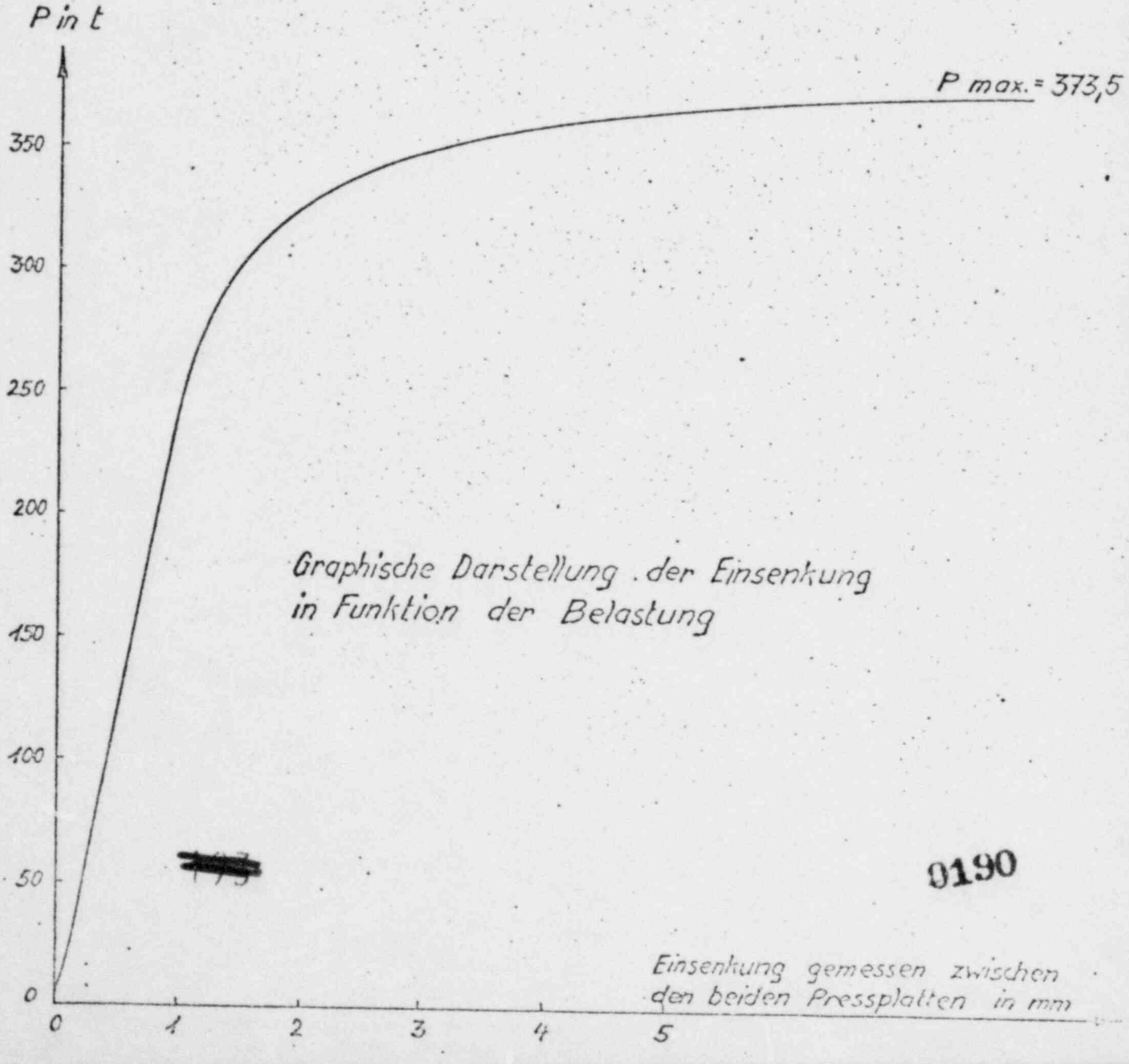


Maßstab 1:2

Belastungsversuch mit Messung der Einsenkung an Grundkörper C 220

Versuchsanordnung gemäss Zeichnung BBR-PQ-4-108 486

Erreichte Last beim Ausstanzen der Grundkörperwabe: 373,5 t
Grundkörper in der Zughülse verklemmt.

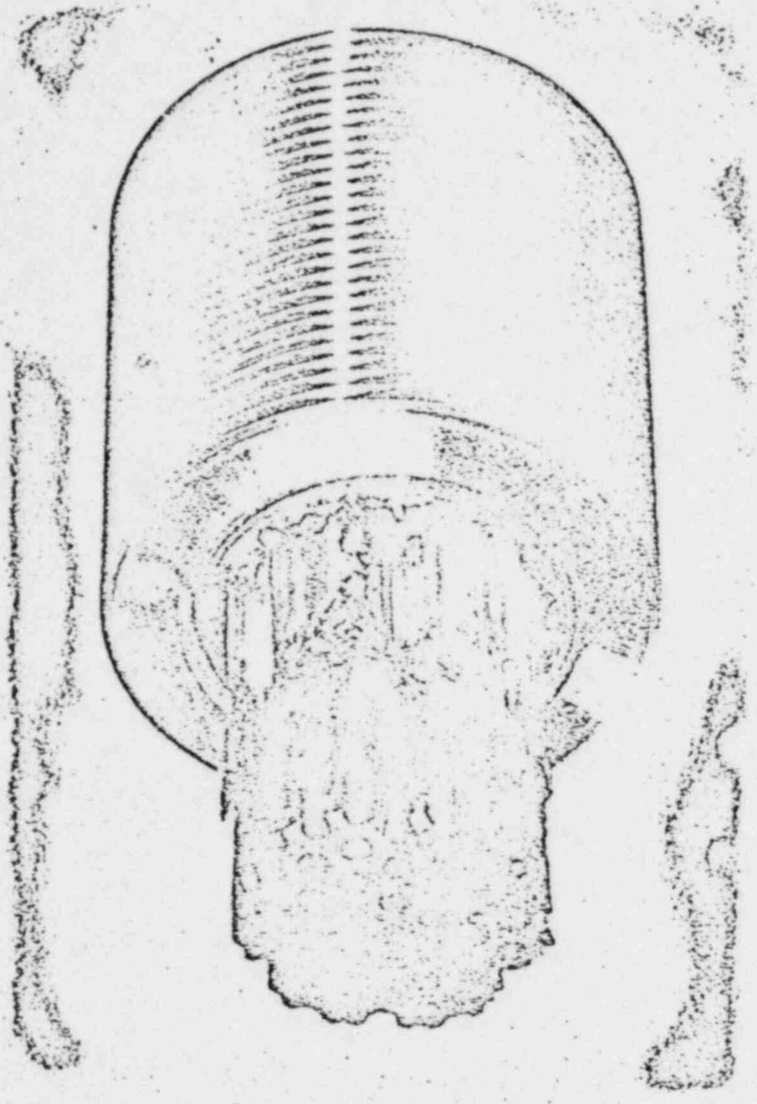


Graphische Darstellung der Einsenkung in Funktion der Belastung

~~173~~

PHOTOGRAPHISCHE AUFNAHME

Photo EMPA-No. 48'383



Ansicht von unten nach dem Ausstanzen der Grundkörperwabe.

Dübendorf, 15. November 1966.

Eidg. Materialprüfungs- und Versuchsanstalt
Abteilung Metalle
Der Abteilungsvorsteher

[redacted]

4

Eidgenössische Materialprüfungs- und Versuchsanstalt für Industrie,
Bauwesen und Gewerbe, 8600 Dübendorf
Laboratoire fédéral d'essai des matériaux et Institut de recherches — Industrie, Génie civil, Arts et Métiers — 8600 Dübendorf
Laboratorio federale di prova dei materiali ed Istituto sperimentale — Industria, Genio civile, Arti e Mestieri — 8600 Dübendorf

COPIE

Untersuchungsbericht
Procès-verbal / Processo verbale

EMPA No. 52'197/1

Auftraggeber: Commettant: Committente: P R O C E Q S. A., Z Ü R I C H

Gegenstand: Objet: Oggetto:

Zwei Grundkörper aus 42 Cr Mo 4, vergütet, Zeichnung Proceq No. 2 - 104 906 h:

Ein Stück, grau, gestempelt: Y 1074
Ein Stück, schwarz, gestempelt: Y 227.

Zwei Spannmuttern aus 40 Mn 4, Zeichnung Proceq No. 2 - 106 594 c, gestempelt: 49 U und 51 U.

- **Betrifft:** Schreiben Abt. A - Kü/sa vom 1. Juni 1967. -

- Angaben des Auftraggebers -

Datum des Eingangs: Date de l'arrivée: Data d'arrivo: 1. Juni 1967.

Ausführung der Untersuchung: Exécution de l'essai: Esecuzione della prova: bis 15. Juni 1967.

Untersuchungsauftrag:

Bestimmung der Härte nach Brinell - Durchstanzversuche - metallographische Untersuchung der Grundkörper.

RESULTATE DER UNTERSUCHUNGEN.

1) Bestimmung der Härte nach Brinell.
2) Versuchsanordnung
   Zeichnung EMPA-No. 4 - 96'608.
3) Bruchversuche mit Messung der Einsenkung am Spannglied 790 t
   Zeichnungen EMPA-No. 4 - 96'609
   und 4 - 96'610.

Anmerkung:

Die Resultate der metallographischen Untersuchung folgen später in einem separaten Untersuchungsbericht.

~~175~~

0192

Bestimmung der Härte nach Brinell HB
Détermination de la dureté Vickers HV
Determiniazione della durezza Rockwell HR

Belastung:
Charge:
Carico: 750 kg

Kugeldurchmesser:
Diamètre de la bille:
Diametro della biglia: 5 mm

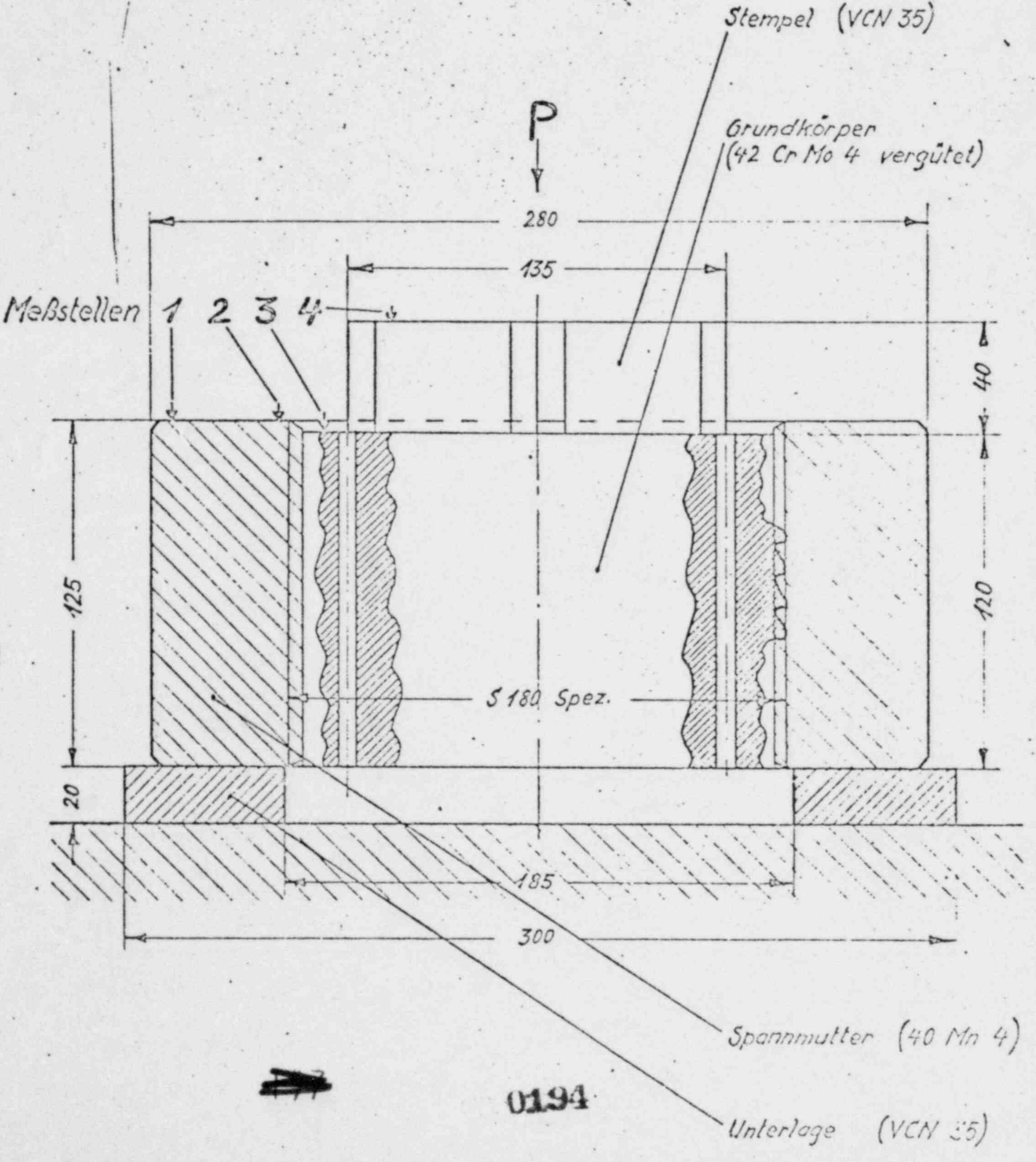
Belastungsdauer:
Durée de charge:
Durata di carico: 30 sec.

Bezeichnung Désignation Designazione	Stelle Point Punto	Härtezahl Chiffre de dureté Grado di durezza			
		HB kg/mm²	HV kg/mm²	HR	
Stempel	1	272			
	2	274			
Grundkörper					
Y 1074	1	306			
grau	2	302			
Y 227	1	298			
schwarz	2	298			
Spannmutter					
U 49	1	285			
	2	278			
U 51	1	221			
	2	235			
Unterlage	1	249			
	2	257			
		[redacted]			

0193

13163/6

Schema der Versuchsanordnung



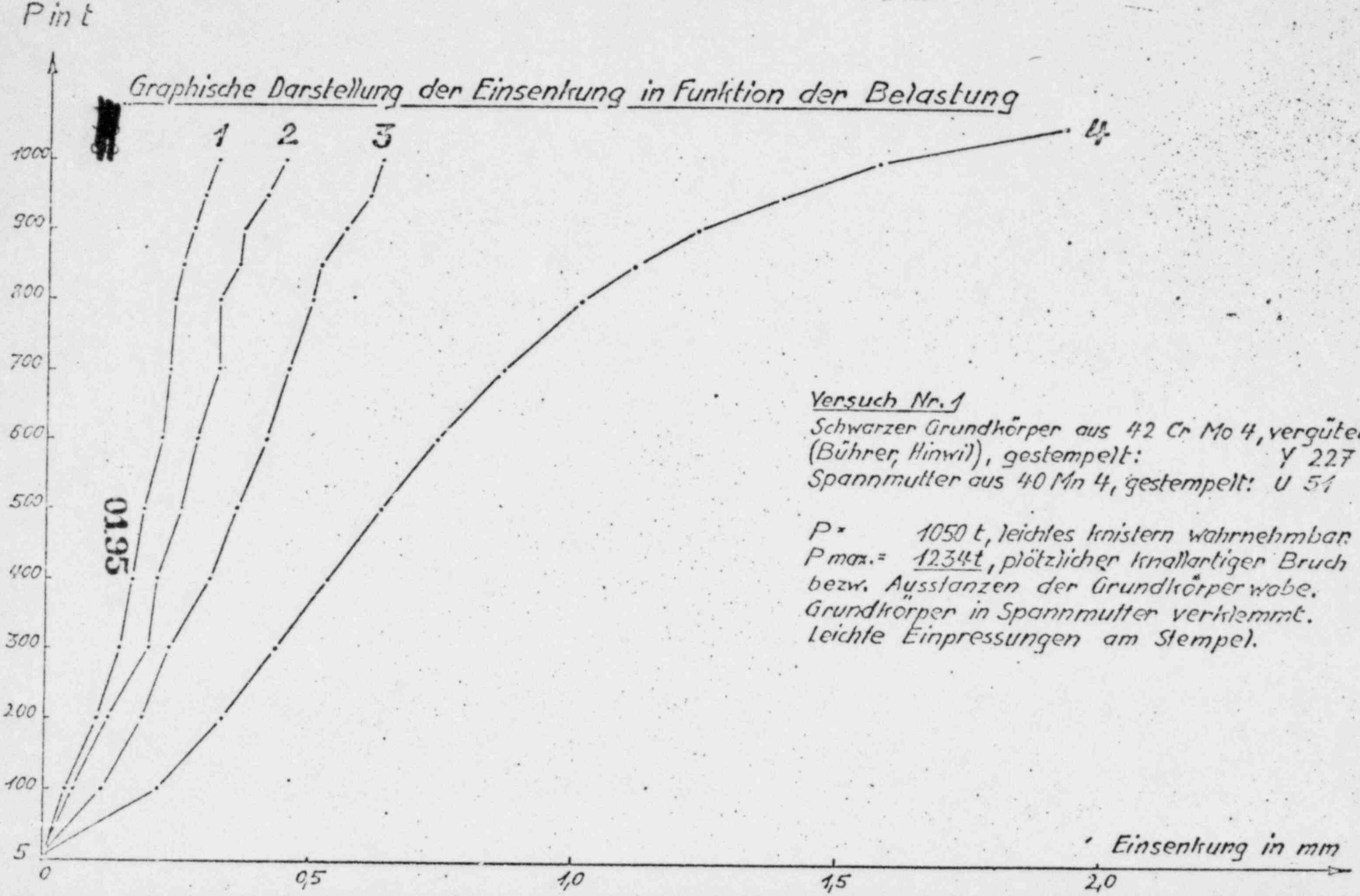
0194

Maßstab 1:2

Bruchversuch mit Messung der Einsenkung an Spannglied 790 t

(Mittelwerte aus je zwei Messungen)

Graphische Darstellung der Einsenkung in Funktion der Belastung



Versuch Nr. 1

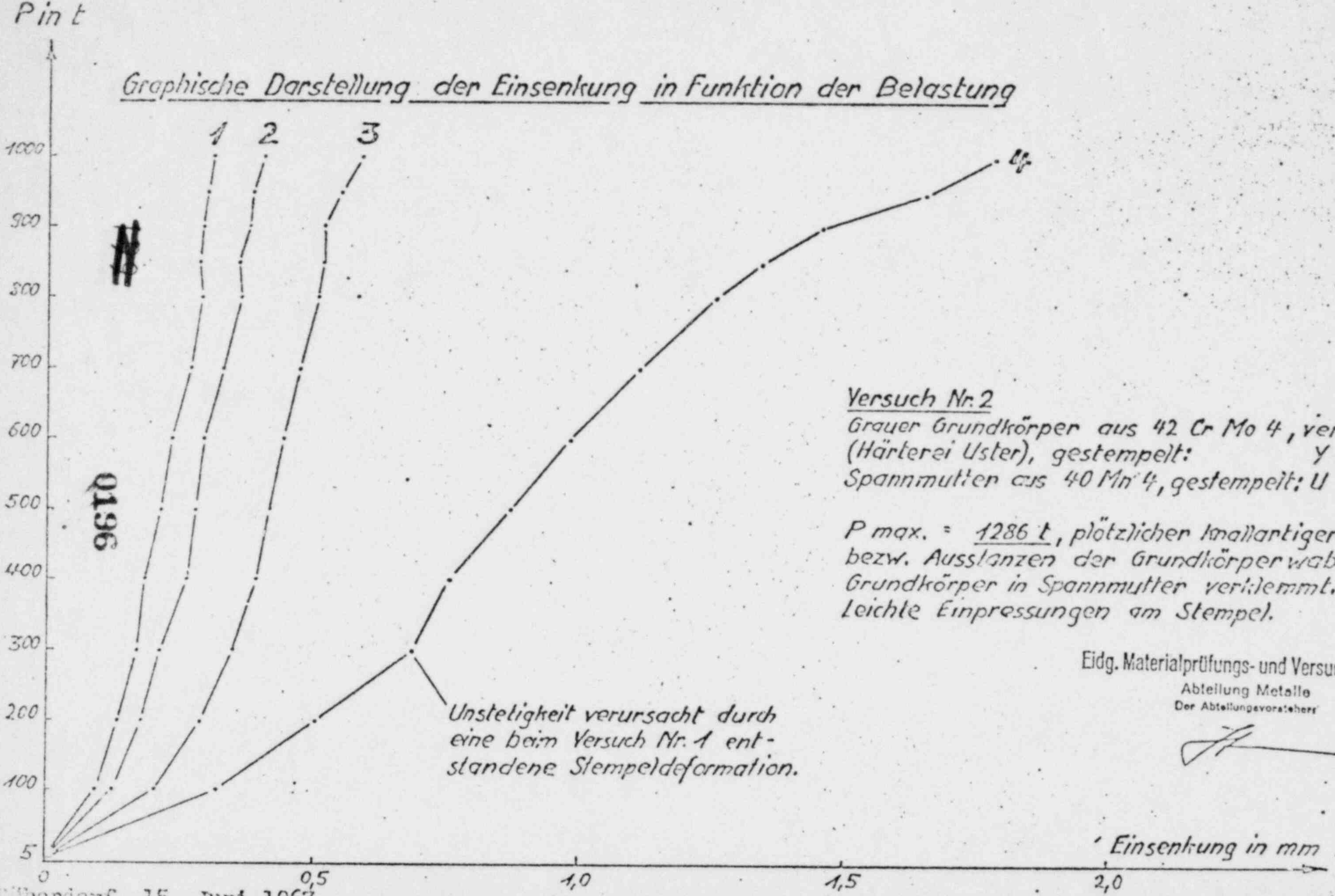
Schwarzer Grundkörper aus 42 Cr Mo 4, vergütet.
(Bührer, Hinwil), gestempelt: Y 227
Spannmutter aus 40 Mn 4, gestempelt: U 51

P = 1050 t, leichtes knistern wahrnehmbar.
P max. = 1234 t, plötzlicher knallartiger Bruch bezw. Ausstanzen der Grundkörperwabe.
Grundkörper in Spannmutter verklemmt.
Leichte Einpressungen am Stempel.

Bruchversuch mit Messung der Einsenkung an Spannglied 730 t

(Mittelwerte aus je 2 Messungen)

0196



Unstetigkeit verursacht durch eine beim Versuch Nr. 1 entstandene Stempeldeformation.

Versuch Nr. 2

Grauer Grundkörper aus 42 Cr Mo 4, vergütet (Härterei Uster), gestempelt: Y 1074

Spannmuttern aus 40 Mn 4, gestempelt: U 49

P max. = 1286 t, plötzlicher knallartiger Bruch bezw. Ausstanzen der Grundkörperwabe. Grundkörper in Spannmutter verklemmt. Leichte Einpressungen am Stempel.

Eidg. Materialprüfungs- und Versuchsanstalt
Abteilung Metalle
Der Abteilungsvorsteher:

Dübendorf, 15. Juni 1967.

Eidgenössische Materialprüfungs- und Versuchsanstalt für Industrie, Bauwesen und Gewerbe, 8600 Dübendorf

Laboratoire fédéral d'essai des matériaux et Institut de recherches — Industrie, Génie civil, Arts et Métiers — 8600 Dübendorf
Laboratorio federale di prova dei materiali ed Istituto sperimentale — Industria, Genio civile, Arti e Mestieri — 8600 Dübendorf

Untersuchungsbericht

Procès-verbal / Processo verbale

EMPA No. 52'197/3

Auftraggeber: / Commettant: / Committente: PROCEQ S.A., ZÜRICH

Gegenstand: / Objet: / Oggetto: Zwei Grundkörper aus 42 Cr Mo 4, vergütet, Zeichnung Proceq No. 2 - 104 906 h:

Ein Stück, grau, gestempelt: Y 1074
Ein Stück, schwarz, gestempelt: Y 227.

- **Betrifft:** Schreiben Abt. A - Kü/sa vom 1. Juni 1967. -

- Angaben des Auftraggebers -

Datum des Eingangs: / Date de l'arrivée: / Data d'arrivo: 1. Juni 1967.

Ausführung der Untersuchung: / Exécution de l'essai: / Esecuzione della prova: bis 10. August 1967

Untersuchungsauftrag: Bestimmung der Härte an Grundkörpern mit ausgestanzte Waben.

RESULTATE

der

BESTIMMUNG DER HÄRTE NACH VICKERS

Bestimmung der Härte nach
Détermination de la dureté
Determinazione della durezza

Brinell HB
[✓ Vickers HV]
Rockwell HR

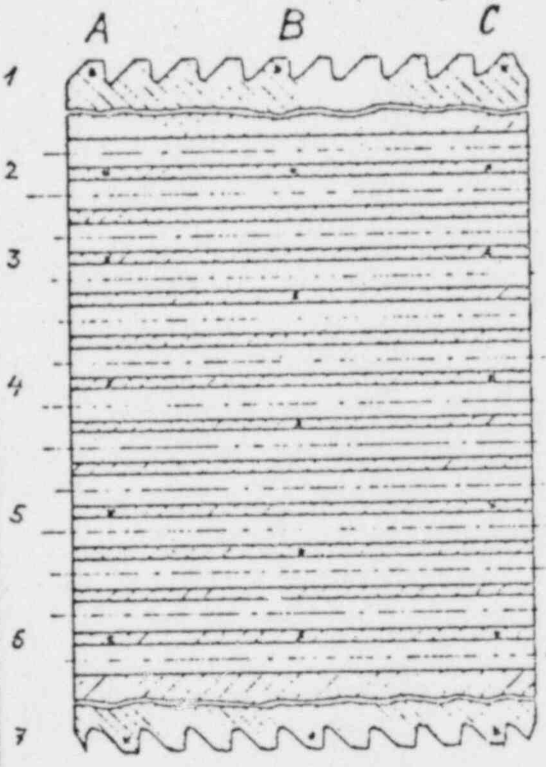
Belastung: / Charge: / Carico: 100 kg

Kugeldurchmesser: / Diamètre de la bille: / Diametro della biglia: --- mm

Belastungsdauer: / Durée de charge: / Durata di carico: --- sec.

Bezeichnung Désignation Designazione	Stelle Point Punto	Härtezahl HV in kg/mm²		
		Schnitte:		
		A	B	C
Y 227 (schwarz)	1	302	299	303
	2	300	304	310
	3	295	304	297
	4	303	310	311
	5	307	303	314
	6	301	302	307
	7	308	310	303
Y 1074 (grau)	1	304	303	302
	2	302	299	308
	3	301	307	307
	4	297	303	305
	5	303	302	302
	6	303	302	301
	7	305	306	306

Anordnung der Eindruckstellen



Dübendorf, 10. August 1967.

Eidg. Materialprüfungs- und Versuchsanstalt
Abteilung Metalle
Der Abteilungsvorsteher:

[redacted]

0198

70455

Eidgenössische Materialprüfungs- und Versuchsanstalt für Industrie, Bauwesen und Gewerbe, Dübendorf ZH

Untersuchungsbericht

EMPA No. 52'197/4

Auftraggeber: PROCEQ S. A., ZÜRICH

Gegenstand: Zwei Grundkörper aus 42 Cr Mo 4, vergütet, Zeichnung Proceq No. 2 - 104 906 h:
Ein Stück, grau, gestempelt: Y 1074; Ein Stück, schwarz, gestempelt: Y 227.

- Betrifft: Schreiben Abt. A - Kü/sa vom 1. Juni 1967. -

- Angaben des Auftraggebers -

Datum des Eingangs: 1. Juni 1967.

Ausführung der Untersuchung: bis 17. Oktober 1967.

Untersuchungsauftrag: Bestimmung der Zugfestigkeit an Grundkörpern mit ausgestanzten Waben.

Zugversuche mit Dehnungsmessung

ngaben über ersuchsmaterial: Zugproben, in axialer Richtung entnommen aus Mantelpartien von durchgestanzten Grundkörpern. (Die Probenentnahme erfolgte nach dem Bruchversuch, siehe Untersuchungsbericht EMPA-No. 52'197/1 vom 15. Juni 1967).

ersuchs-urchführung:
☒ σ_s aus Maschinen-Diagramm
☐ σ_s aus 2‰ bleib. Dehnung

Hinweis:
δ_{Gl} Gleichmassdehnung
$\frac{\sigma_s}{\sigma_B}$ Streckgrenzenverhält

Stab-zeichnung	Abmessungen mm ⌀	Quer-schnitt A_o mm²	Streck-grenze σ_s kg/mm²	Zug-Festigkeit σ_B kg/mm²	$\frac{\sigma_s}{\sigma_B}$	Kon-traktion ψ %	Dehnung nach Bruch δ_{10} %	δ_5 %	δ_{Gl} % ca.	Feststellungen
Y 227 chwarz)	5,92	27,5	86,5	97,3	0,89	63	10,7	17,0	4	Trichterbruch.
Y 1074 (grau)	5,91	27,4	85,4	98,4	0,87	61	10,0	15,7	4	Trichterbruch.

Eidg. Materialprüfungs- und Versuchsanstalt
Abteilung Metalle
Der Abteilungsvorsteher:

bendorf, 18. Oktober 1967.

Eidgenössische Materialprüfungs- und Versuchsanstalt für Industrie,
Bauwesen und Gewerbe, 8600 Dübendorf
Laboratoire fédéral d'essai des matériaux et Institut de recherches — Industrie, Génie civil, Arts et Métiers — 8600 Dübendorf
Laboratorio federale di prova dei materiali ed Istituto sperimentale — Industria, Genio civile, Arti e Mestieri — 8600 Dübendorf

COPIE

Untersuchungsbericht
Procès-verbal / Processo verbale

EMPA No. 52197/2

Auftraggeber:
Commettant:
Committente: PROCEQ S.A. **ZÜRICH**

Gegenstand:
Objet:
Oggetto: Zwei Grundkörper aus 42 Cr Mo 4, vergütet,
Zeichnung Proceq No. 2 - 104 906 h:

Ein Stück, "grau", gestempelt: Y 1074
Ein Stück , "schwarz", gestempelt: Y 227

Betrifft: Schreiben Abt. A-Kü/sa vom 1. Juni 1967

- Angaben des Auftraggebers -

Datum des Eingangs:
Date de l'arrivée:
Data d'arrivo: 1. Juni 1967

Ausführung der Untersuchung:
Exécution de l'essai:
Esecuzione della prova: bis 28. Juni 1967

Untersuchungsauftrag:

Bestimmung der Mikrohärte nach Vickers bei einer Belastung von 20 g und metallographische Untersuchung.

RESULTATE DER UNTERSUCHUNGEN

1. Bestimmung der Mikrohärte nach Vickers

2. Metallographische Untersuchung

o o o

[redacted]

1a. Bestimmung der Mikro-Härte nach | Brinell HB
Détermination de la dureté | Vickers HV
Determiniazione della durezza | Rockwell HR

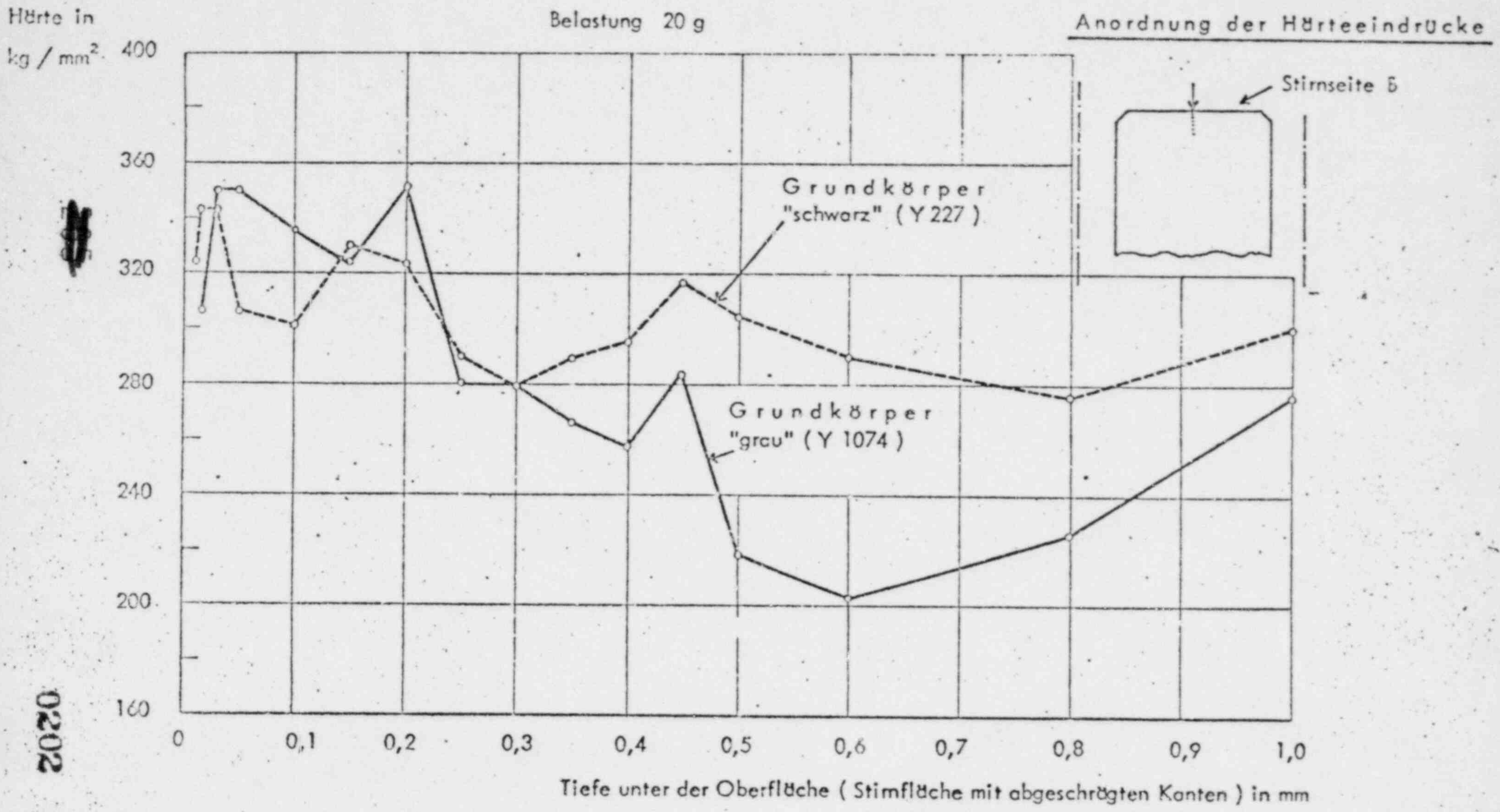
Belastung: Charge: Carico:	20 g XY	Kugeldurchmesser: Diamètre de la bille: Diametro della biglia:	/ mm	Belastungsdauer: Durée de charge: Durata di carico:	10 sec.

Bezeichnung Désignation Designazione	Stelle Point Punto Tiefe unter der Oberfläche	Härtezahl Chiffre de dureté Grado di durezza HB kg/mm²	 HV kg/mm²	 HR	Härteverlauf in der Randzone der Stirnseite mit abgeschrägten Kanten (Seite B).
		Grundkörper "grau"			
Y 1074	0,0125		306		
	0,015		306		
	0,03		350		
	0,05		350		
	0,10		336		
	0,15		324		
	0,20		253		
	0,25		280		
	0,30		280		
	0,35		266		
	0,40		258		
	0,45		285		
	0,50		219		
	0,60		203		
	0,80		226		
	1,00		276		Anordnung der Härteeindrücke und graphische Darstellung siehe Skizze EMPA-Nr. 4-93746.

0201

VERLAUF DER MIKROHÄRTE NACH VICKERS IN DER RANDZONE DER GRUNDKÖRPER

"grau" (Härterei Uster) und "schwarz" (Bührer Hinwil)



Mikro-
1b. Bestimmung der Härte nach — Brinell HB
Détermination de la dureté — ~~Vickers HV~~
Determiniazione della durezza — Rockweil HR

Belastung: / Charge / Carico: 20 G

Kugeldurchmesser: / Diamètre de la bille: / Diametro della biglia: / mm

Belastungsdauer: / Durée de charge: / Durata di carico: 10 sec.

Bezeichnung Désignation Designazione	Stelle Point Punto	Härtezahl Chiffre de dureté Grado di durezza			Härteverlauf in der Randzone der Stirnseite mit abgeschrägten Kanten (Seite D).
	Tiefe unter der Oberfläche	HB kg/mm²	HV kg/mm²	HR	
		Grundkörper "schwarz"			
Y 227	0,0125		324		
	0,015		343		
	0,03		343		
	0,05		306		
	0,10		301		
	0,15		330		
	0,20		324		
	0,25		290		
	0,30		280		
	0,35		290		
	0,40		296		
	0,45		318		
	0,50		306		
	0,60		290		
	0,80		276		
	1,00		301		

Anordnung der Härteeindrücke
und graphische Darstellung
siehe Skizze EMPA-Nr. 4-93746.

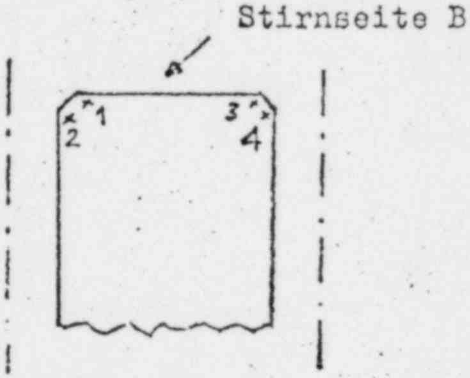
[redacted]

Mikro-
1c. Bestimmung der Härte nach Brinell HB
Détermination de la dureté Vickers HV
Determinazione della durezza Rockwell HR

Belastung: / Charge: / Carico: 20 g XX

Kugeldurchmesser: / Diamètre de la bille: / Diametro della biglia: / mm

Belastungsdauer: / Durée de charge: / Durata di carico: 10 sec.

Bezeichnung Désignation Designazione	Stelle Point Punto	Härtezahl Chiffre de dureté Grado di durezza			Anordnung der Härteeindrücke auf dem Mikroschliff.
		HB	HV kg/mm2	HR	
		Grundkörper "grau"			
Y 1074	1		266		
	2		285		
	3		285		
	4		306		
		Grundkörper "schwarz"			
Y 227	1		266		
	2		386		
	3		363		
	4		350		

2. METALLOGRAPHISCHE UNTERSUCHUNG

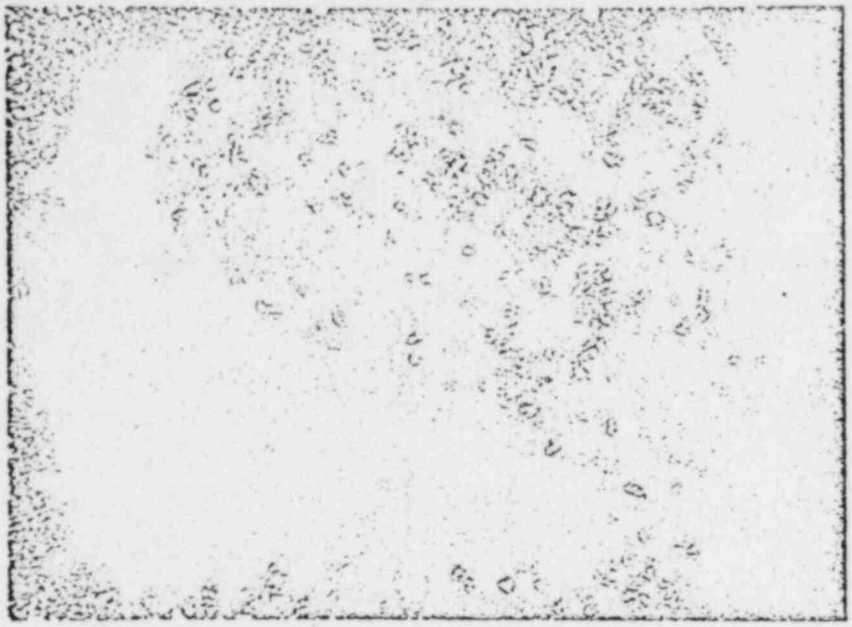
Für die Beurteilung der Gefügebeschaffenheit wurden beiden Grundkörpern bei der Stirnfläche B mit abgeschrägten Kanten und etwa in halber Höhe der Körper Schliffproben (Längsschliffe mit Schnitt in einer achsenparallelen Ebene) entnommen und einer vergleichenden, metallographischen Untersuchung unterzogen mit folgendem Ergebnis:

Beide Körper weisen ein feines Vergütungsgefüge auf, das mit ziemlich vielen, meist langgestreckten, nichtmetallischen Einschlüssen praktisch gleichmässig durchsetzt ist. Beim Grundkörper "grau" Y 1074 (Härterei Uster) unterscheidet sich das Gefüge der Randzone nicht nennenswert vom Gefüge der Kernzone der Wabenwandungen, sondern es zeigt durchwegs die gleiche Beschaffenheit. Hingegen ist beim Gefüge der Randzone des Körpers "schwarz" Y 227 (Bührer Hinwil) im Vergleich zu seinem Kerngefüge eine etwas stärkere Anätzbarkeit festzustellen. Dieser Unterschied ist sehr wahrscheinlich auf Differenzen in der Zusammensetzung der beim Härten der Grundkörper verwendeten Salzbäder zurückzuführen. Die Wärmebehandlung hat beim letztgenannten Grundkörper in der äussersten Randschicht bis in eine Tiefe von etwa 0,2 mm ein etwas dichteres Gefüge zur Folge gehabt (vgl. die Mikrobilder Nr. 33150 und 33151).

Im allgemeinen ist das Gefüge beider Grundkörper infolge von Seigerungsflecken etwas unausgeglichen, was auch in den relativ grossen Streuungen in der Mikrohärte beider Grundkörper, aber ganz besonders des Grundkörpers "grau" Y 1074 zum Ausdruck kommt (vgl. die Mikrohärtezahlen). Im übrigen zeigt das Gefüge im Innern der Körper praktisch die gleiche Beschaffenheit wie jenes an der besonders untersuchten Stirnseite B und es kann für relativ weich vergütete Stücke aus dem vorliegenden Stahl als normal bewertet werden.

Mikroaufnahme (Ringe)

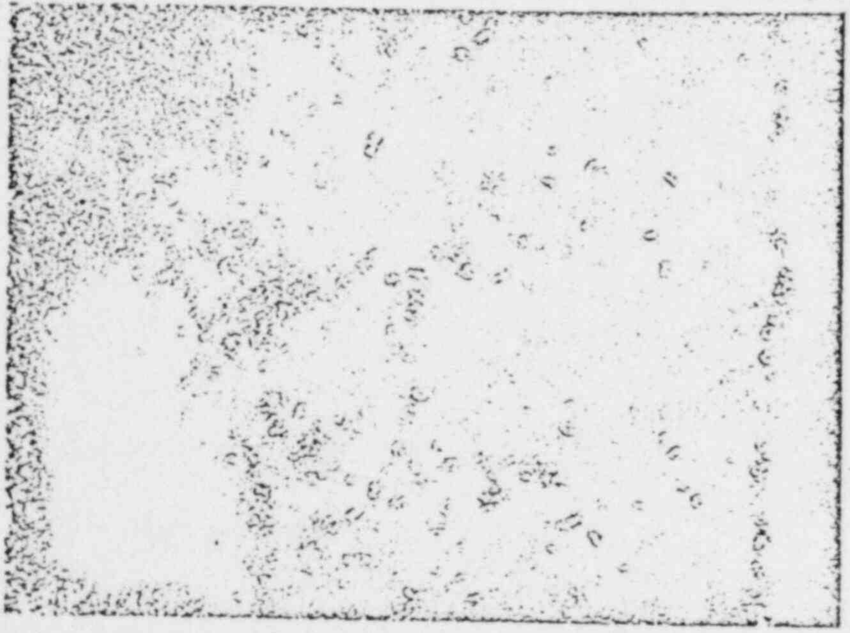
Nr. 33150 x 300



- Stirnfläche B

Grundkörper "grau" X 1074 (Härterei Uster)

Nr. 33151 x 300



Stirnfläche B

Grundkörper "schwarz" X 227 (Bührer Hinwil)

Dübendorf, 28. Juni 1957

Eidg. Materialprüfungs- und Versuchsanstalt
Abteilung Metallkunde und Metallographie
Der Abteilungsvorsteher:

~~207~~

Richter

Eidgenössische Materialprüfungs- und Versuchsanstalt für Industrie,
Bauwesen und Gewerbe, Dübendorf/ZH

Laboratoire fédéral d'essai des matériaux et Institut de recherches — Industrie, Génie civil, Arts et Métiers — Dübendorf/ZH
Laboratorio federale di prova dei materiali ed Istituto sperimentale — Industria, Genio civile, Arti e Mestieri — Dübendorf/ZH

COPIE

Untersuchungsbericht
Procès-verbal / Processo verbale

EMPA Nr. 23'549/7

Auftraggeber:
Commettant:
Committente:
STAHLTON AG, Zürich

Gegenstand:
Objet:
Oggetto:
1 Vorspannkabel BBRV CD 237

Datum des Eingangs:
Date de l'arrivée:
Data d'arrivo:
8.9.64

Ausführung der Untersuchung:
Exécution de l'essai:
Esecuzione della prova:
—

Resultate des Ermüdungsversuches

durchgeführt in der Versuchseinrichtung
auf dem Aufspannboden der EMPA.

[redacted]

/7

Vorspannkabel BBRV CD 237

- Angaben des Auftraggebers -

55 Drähte Ø 7 mm, glatt, Vereinigte Drahtwerke Biel,
$\beta_{z_{min.}} = 16o\ kg/mm^2$.

Verankerungen:

oben: Grundkörper Typ C
Gewindehülse, Stützmutter siehe Detail A, EMPA-Zeichnung Nr. 4-85'361

unten: Grundkörper Typ C
Gewindehülse als Kupplung zum Messtab

Köpfchen Typ II.

Länge des Kabels: 37o5 mm
F_e = 2117 mm^2 (nominell)

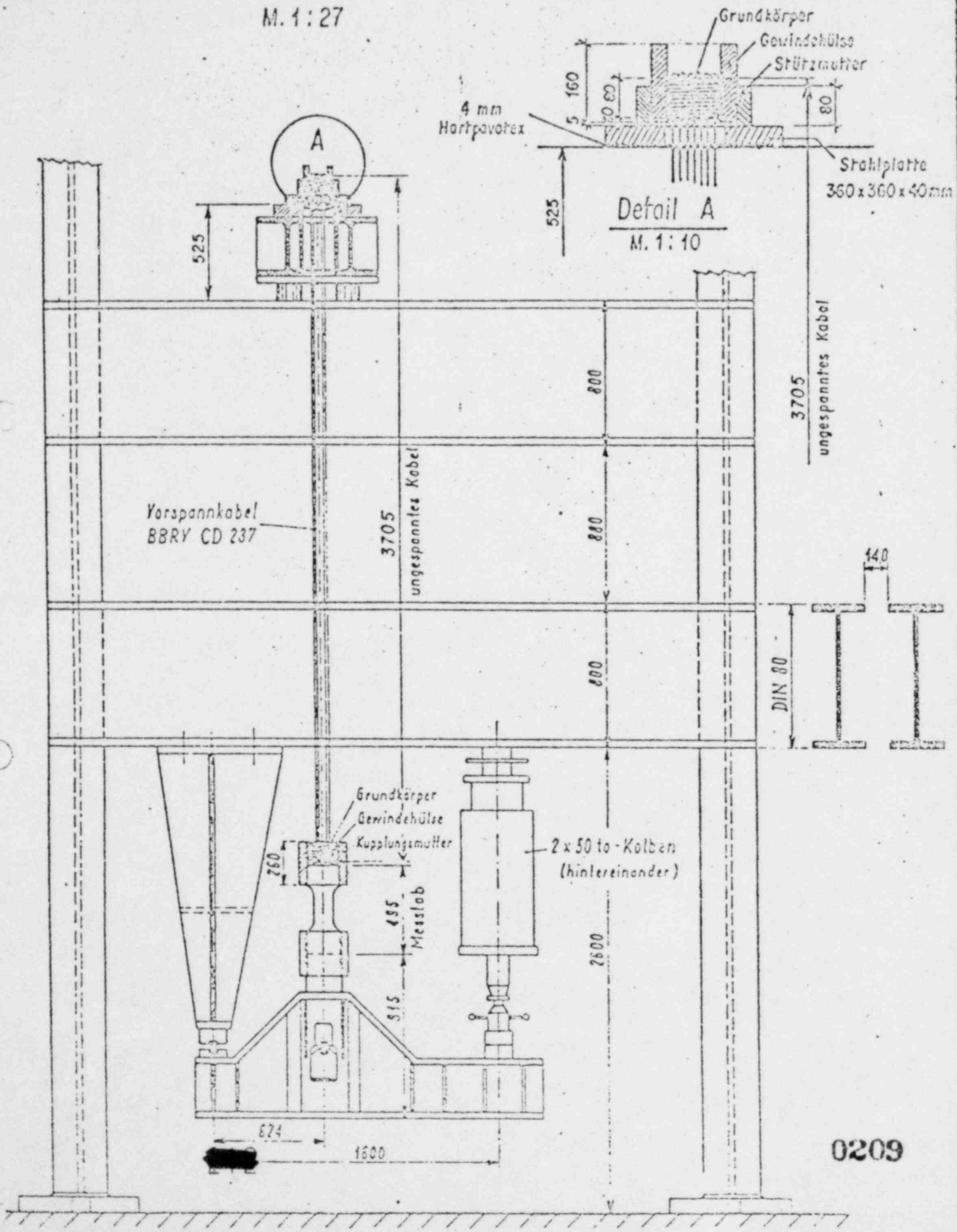
Prüfeinrichtung

2 Amsler Pulsatoren gekuppelt, ca. 27o Lastwechsel pro Minute,
2 Amsler 5o t Druckzylinder,
Prüfrahmen mit Wiegebalken auf dem Aufspannboden (siehe EMPA-Zeichnung Nr. 4-85'361).

Versuchsdurchführung

Bestimmung der Lastgrenzen mit Messtab gemäss Eichung der EMPA vom 3o./31. Januar 1964 (EMPA-Bericht Nr. 21'212).
Zeitliche Registrierung der Drahtbrüche mit Erschütterungsgeber.
Die Versuche fanden vom 1o.9.1964 bis 17.9.1964 statt.

Versuchsanordnung für Ermüdungsversuch mit Vorspannkabel BBRV CD 237



[redacted]

Resultate des Ermüdungsversuches

Kabel Typ BBRV CD 237, Grundkörper Typ C, Köpfchen Typ II
55 Drähte Ø 7 mm, F_e = 2117 mm² (nominell)

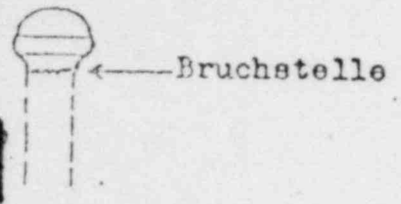
müdungs- stufe	Lastgrenzen		Spannungen *			Lastwechsel pro Ermüdungsstufe	Bemerkungen
	P_o t	P_u t	σ_o kg/mm²	σ_u kg/mm²	$\Delta\sigma$ kg/mm²		
1	237,1	215,9	112,o	1o2,o	1o,o	o	
					↓ **	1'755'ooo	1. Drahtbruch
						2'o36'ooo	2. Drahtbruch
						2'247'ooo	3. Drahtbruch
						2'327'ooo	4. Drahtbruch
	237,1	216,9	(12o,8)	(11o,5)	(1o,3)		
						2'6oo'ooo	Versuch abgebrochen

auf den nominellen Querschnitt bezogen

Klammern angegebene Werte sind auf den nach Drahtbrüchen verbliebenen Querschnitt bezogen:

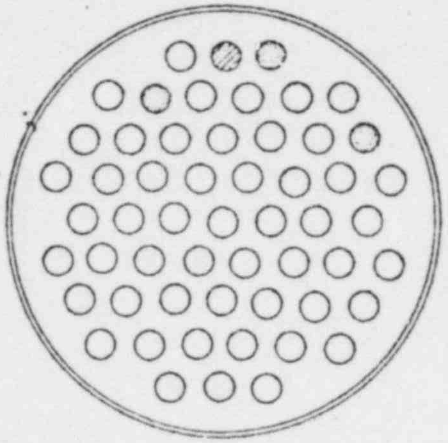
nach 4 Drahtbrüchen : F_o = 1963 mm², (51 Ø 7 mm) e der 4 Drahtbrüche

M. 1:1



[redacted]

Verteilung der Drahtbrüche



▨ Drahtbrüche in der unteren Verankerung (Anzahl 1)

○ Drahtbrüche in der oberen Verankerung (Anzahl 3)

35362

Dübendorf, den 3. November 1964

Eidg. Materialprüfungs- und Versuchsanstalt
Abteilung Stahlbeton und Betonbauten
Der Abteilungsvorsteher:

i. A. R. Sagelsdorff

Eidgenössische Materialprüfungs- und Versuchsanstalt für Industrie,
Bauwesen und Gewerbe, Zürich

Laboratoire fédéral d'essai des matériaux et Institut de recherches — Industrie, Génie civil, Arts et Métiers — Zurich
Laboratorio federale di prova dei materiali ed Istituto sperimentale — Industria, Genio civile, Arti e Mestieri — Zurigo

Kopie

StahlTon AG

Untersuchungsbericht

Procès-verbal / Processo verbale EMPA Nr. 58'570/3

Auftraggeber:
Commettant:
Committente: STAHLTON A.-G., ZÜRICH

Gegenstand:
Objet:
Oggetto: 7 Abschnitte Vorspanndraht Ø 7,0 mm, glatt, mit einseitig aufgestauchten Köpfchen, Typ rund, Drahtfabrikant : Vereinigte Drahtwerke Biel.

- **Betrifft:** Prüfung 150160; Schreiben Mü/cb v. 5. Februar 1960. -

- Angaben des Auftraggebers -

Datum des Eingangs:
Date de l'arrivée:
Data d'arrivo: 6. Februar 1960

Ausführung der Untersuchung:
Exécution de l'essai:
Esecuzione della prova: bis 24. Februar 1960

RESULTATE

der

ZUG - ERMÜDUNGSVERSUCHE IM HOCHFREQUENZ-PULSATOR

1. Bestimmung der Ursprungsfestigkeit.
2. Bestimmung der Wechselfestigkeit bei einer untern Spannungsgrenze von 95 kg/mm2.

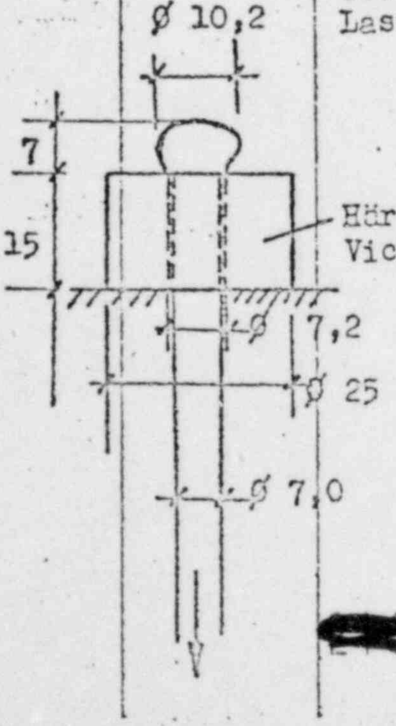
Zug-Ermüdungsversuche im Pulsator
Essais d'endurance par traction pulsatoire
Prove di fatica per trazione ripetuta nel pulsatore

Pulsator
Pulsateur
Pulsatore
2 t

7500 Lastwechsel pro Minute
Pulsations par minute
Pulsazioni per minuto

Bezeichnung Désignation Designazione	Querschnitt Section Sezione		Lastgrenzen Limites de charge Limiti di carico kg		Spannungsgrenzen Limites de tension Limiti di tensione kg/mm²		Anzahl der Lastwechsel Nombre de pulsations Numero delle pulsazioni	Bemerkungen Observations Osservazioni
	mm Ø	mm²	obere supérieure superiore	untere inférieure inferiore	obere supérieure superiore	untere inférieure inferiore		
	Bestimmung der Ursprungsfestigkeit							
1	7,02	38,7	850	20	22	0,5	1'010'000	Bruch beim Uebergang zum Köpfchen
2	7,02	38,7	780	20	20	0,5	868'000	do.
3	7,02	38,7	700	20	18	0,5	1'575'000	do.
4	7,02	38,7	620	20	16	0,5	2'000'000	intakt Last erhöht
			700	20	18	0,5	2'000'000	" " "
			780	20	20	0,5	163'000	Bruch wie Nr. 1

Ursprungsfestigkeit 1 < 21,5 kg/mm2
2 ≷ 19,5 "
bezügl. 2.10^6 3 < 17,5 "
Lastwechsel 4 = 17,7 "



Härte der Scheiben : 208 kg/mm²
Vickers Härte : 224 "
P = 20 kg : 214 "
Mittel 215 kg/mm²

[redacted]

3

Zug-Ermüdungsversuche im Pulsator
Essais d'endurance par traction pulsatoire
Prove di fatica per trazione ripetuta nel pulsatore

Pulsator
Pulsateur 10 t.
Pulsatore

7500 Lastwechsel pro Minute
Pulsations par minute
Pulsazioni per minuto

Bezeichnung Désignation Designazione	Querschnitt Section Sezione		Lastgrenzen Limites de charge Limiti di carico t.		Spannungsgrenzen Limites de tension Limiti di tensione kg/mm²		Anzahl der Lastwechsel Nombre de pulsations Numero delle pulsazioni	Bemerkungen Observations Osservazioni
	mm Ø	mm²	obere supérieure superiore	untere inférieure inferiore	obere supérieure superiore	untere inférieure inferiore		
	Bestimmung der Wechselfestigkeit bei einer untern Spannungsgrenze von 95 kg/mm²							
1	7,02	38,7	4,14	3,68	107	95	2'000'000	intakt Last erhöht
			4,22	3,68	109	95	2'000'000	do.
			4,30	3,68	111	95	2'000'000	do.
			4,37	3,68	113	95	325'000	Bruch beim Uebergang zum Köpfchen
2	7,02	38,7	4,30	3,68	111	95	2'000'000	intakt Last erhöht
			4,37	3,68	113	95	931'000	Bruch wie Nr. 1
3	7,02	38,7	4,30	3,68	111	95	2'000'000	intakt Last erhöht
			4,37	3,68	113	95	888'000	Bruch wie Nr. 1

Wechselfestigkeit Nr. 1 = 111,3 - 95 kg/mm²
2 = 111,9 - 95 "
bezügl. 2.10^6
Lastwechsel 3 = 111,9 - 95 "

Zürich, den 26. Februar 1960.

Eidg. Materialprüfungs- und Versuchsanstalt
Abteilung Messtechnik und besondere
Untersuchungen an Metallen
Der Abteilungsvorsteher:

[redacted]

0214

Eidgenössische Materialprüfungs- und Versuchsanstalt für Industrie,
Bauwesen und Gewerbe, Zürich

Laboratoire fédéral d'essai des matériaux et Institut de recherches — Industrie, Génie civil, Arts et Métiers — Zurich
Laboratorio federale di prova dei materiali ed Istituto sperimentale — Industria, Genio civile, Arti e Mestieri — Zurigo

Kopie

Untersuchungsbericht

Procès-verbal / Processo verbale

Stahlton AG

EMPA Nr. 58'570/4

Auftraggeber: / Commettant: / Committente: **STAHLTON A.-G., ZÜRICH**

Gegenstand: / Objet: / Oggetto:
9 Abschnitte Vorspanndraht Ø 7,0 mm glatt
Drahtfabrikant : Vereinigte Drahtwerke Biel

- **Betrifft:** Prüfung 150160; Schreiben Mü/cb v. 5. Februar 1960. -
- Angaben des Auftraggebers -

Datum des Eingangs: / Date de l'arrivée: / Data d'arrivo: 6. Februar 1960

Ausführung der Untersuchung: / Exécution de l'essai: / Esecuzione della prova: bis 24. Februar 1960

RESULTATE

der

ZUG - ERMÜDUNGSVERSUCHE IM HOCHFREQUENZ-PULSATOR

1. Bestimmung der Ursprungsfestigkeit.
2. Bestimmung der Wechselfestigkeit bei einer untern Spannungsgrenze von 95 kg/mm².

2430

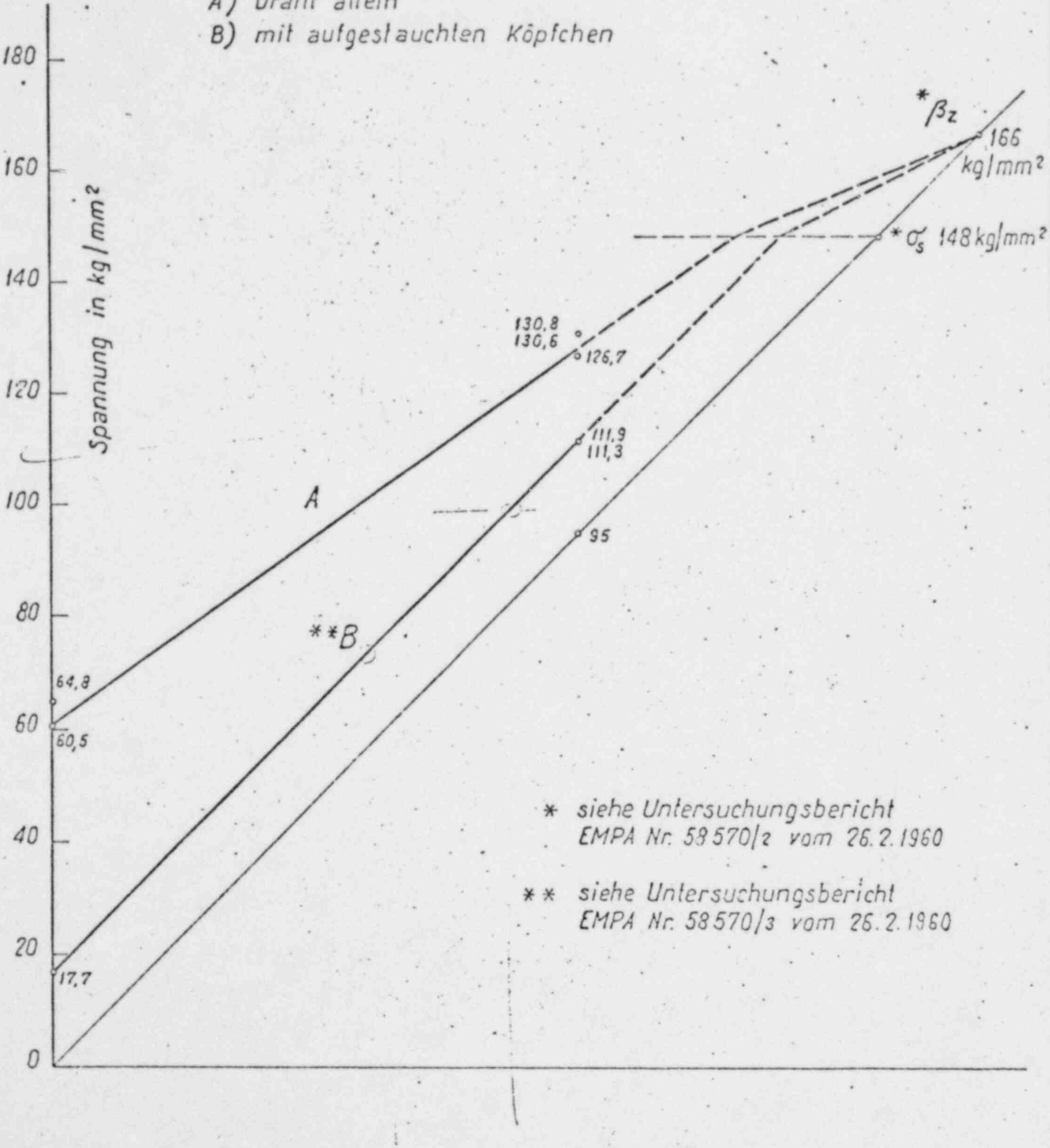
[redacted]

Anmerkung: Eine Verwendung dieses Berichtes zu Werbezwecken irgendwelcher Art, den blossen Hinweis auf diesen Bericht eingeschlossen, bedarf der [illegible]

Zug-Ermüdungs-Diagramme bezügl. $2 \cdot 10^6$ Lastwechsel

Vorspanndraht ⌀ 7,0 mm glatt
Anzahl Lastwechsel 7500/min
freie Prüflänge ~ 170 mm

A) Draht allein
B) mit aufgestauchten Köpfchen



* siehe Untersuchungsbericht EMPA Nr. 58 570/2 vom 26.2.1960

** siehe Untersuchungsbericht EMPA Nr. 58 570/3 vom 26.2.1960

[redacted]

0216

Zug-Ermüdungsversuche im Pulsator
Essais d'endurance par traction pulsatoire
Prove di fatica per trazione ripetuta nel pulsatore

Pulsator
Pulsateur 10 t.
Pulsatore

7500 Lastwechsel pro Minute
Pulsations par minute
Pulsazioni per minuto

Bezeichnung Désignation Designazione	Querschnitt Section Sezione		Lastgrenzen Limites de charge Limiti di carico t.		Spannungsgrenzen Limites de tension Limiti di tensione kg/mm²		Anzahl der Lastwechsel Nombre de pulsations Numero delle pulsazioni	Bemerkungen Observations Osservazioni
	mm Ø	mm²	obere supérieure superiore	untere inférieure inferiore	obere supérieure superiore	untere inférieure inferiore		
	Bestimmung der Ursprungsfestigkeit							
1	7,02	38,7	2,71	0	70	0	184'000	Bruch freier Teil
2	7,02	38,7	2,32	0	60	0	196'000	do.
3	7,02	38,7	2,32	0	60	0	2'000'000	intakt Last erhöh
			2,48	0	64	0	2'000'000	do.
			2,64	0	68	0	394'000	Bruch freier Teil
4	7,02	38,7	2,32	0	60	0	184'000	Bruch freier Teil
5	7,02	38,7	2,16	0	56	0	176'000	do.
6	7,02	38,7	2,01	0	52	0	2'000'000	intakt Last erhöh
			2,32	0	60	0	2'000'000	do.
			2,48	0	64	0	238'000	Bruch freier Teil

Ursprungsfestigkeit Nr. 1 < 70,0 kg/mm²

2 < 60,0 "

bezügl. 2.10^6 Lastwechsel 3 = 64,8 "

4 < 60,0 "

5 < 56,0 "

6 = 60,5 "

4

Zug-Ermüdungsversuche im Pulsator
Essais d'endurance par traction pulsatoire
Prove di fatica per trazione ripetuta nel pulsatore

Pulsator
Pulsateur
Pulsatore 10 t

7500 Lastwechsel pro Minute
Pulsations par minute
Pulsazioni per minuto

Bezeichnung Désignation Designazione	Querschnitt Section Sezione		Lastgrenzen Limites de charge Limiti di carico t		Spannungsgrenzen Limites de tension Limiti di tensione kg/mm'		Anzahl der Lastwechsel Nombre de pulsations Numero delle pulsazioni	Bemerkungen Observations Osservazioni
	mm ∅	mm'	obere supérieure superiore	untere inférieure inferiore	obere supérieure superiore	untere inférieure inferiore		
Bestimmung der Wechselfestigkeit bei einer untern Spannungsgrenze von 95 kg/mm²								
1	7,02	38,7	5,03	3,67	130	95	2'000'000	intakt Last erhöht
			5,22	3,67	135	95	250'000	Bruch im Kopf
2	7,02	38,7	4,88	3,67	126	95	2'000'000	intakt Last erhöht
			5,03	3,67	130	95	347'000	Bruch freier Teil
3	7,02	38,7	4,88	3,67	126	95	2'000'000	intakt Last erhöht
			5,03	3,67	130	95	2'000'000	do.
			5,19	3,67	134	95	408'000	Bruch freier Teil

Wechselfestigkeit bezügl. 2.10^6 Lastwechsel

Nr 1 = 130,6 - 95 kg/mm²
2 = 126,7 - 95 "
3 = 130,8 - 95 "

Zürich, den 26. Februar 1960.

Eidg. Materialprüfungs- und Versuchsanstalt
Abteilung Messtechnik und besondere
Untersuchungen an Metallen
Der Abteilungsvorsteher:

[redacted]

Eidgenössische Materialprüfungs- und Versuchsanstalt für Industrie,
Bauwesen und Gewerbe, Zürich

Laboratoire fédéral d'essai des matériaux et Institut de recherches — Industrie, Génie civil, Arts et Métiers — Zurich
Laboratorio federale di prova dei materiali ed Istituto sperimentale — Industria, Genio civile, Arti e Mestieri — Zurigo

Kopie

Stahlton AG

Untersuchungsbericht

Procès-verbal / Processo verbale

EMPA-No. 58'570/5

Auftraggeber: / Commettant: / Committente: STAHLTON A.-G., ZÜRICH

Gegenstand: / Objet: / Oggetto: 1 Vorspannkabel " BBRV ", Type CC 90, bestehend aus 2 Ankerköp und 22 Drähten Ø 7 mm, glatt, verankert mit beidseitig aufgestauchten Köpfchen, Type rund; Drahtfabrikant: Vereinigte Dr werke A.-G., Biel.

- **Betrifft:** Prüfung 150160, Schreiben Mü/cb vom 5. Februar 1960. -

- Angaben des Auftraggebers -

Datum des Eingangs: / Date de l'arrivée: / Data d'arrivo: 6. Februar 1960.

Ausführung der Untersuchung: / Exécution de l'essai: / Esecuzione della prova: bis 2. Mai 1960.

RESULTATE DER UNTERSUCHUNGEN.

1) Statischer Versuch.
2) Dynamischer Versuch.

[redacted]

5
5

Zug-Ermüdungsversuche im Pulsator
Essais d'endurance par traction pulsatoire
Prove di fatica per trazione ripetuta nel pulsatore

Pulsator
Pulsateur 100 t.
Pulsatore

350 Lastwechsel pro Minute
Pulsations par minute
Pulsazioni per minuto

Bezeichnung Désignation Designazione	Querschnitt Section Sezione		Lastgrenzen Limites de charge Limiti di carico t.		Spannungsgrenzen Limites de tension Limiti di tensione kg/mm²		Anzahl der Lastwechsel Nombre de pulsations Numero delle pulsazioni	Bemerkungen Observations Osservazioni
	mm	mm²	obere supérieure superiore	untere inférieure inferiore	obere supérieure superiore	untere inférieure inferiore	total	
	1) STATISCHER VERSUCH							
	*) 18 × Ø 7,02	697	3		4,3			Kabellänge von Köpfchen zu Köpfchen: 2,387 m
			85		122			8 Minuten konstant
			3		4,3			Kabellänge von Köpfchen zu Köpfchen: 2,387 m
	2) DYNAMISCHER VERSUCH							
	18 × Ø 7,02	697	75,9	64,9	109	93	962'600	Bruch erster Draht ca. 48 mm vom Köpfchen entfernt, in der Nähe Austritt Grundkörper (Scheuerstelle).
	17 × Ø 7,02	658	71,7	61,3	109	93	1'584'800	Bruch zweiter Draht beim Uebergang zum Köpfchen; entlastet
			3		4,3			Kabellänge von Köpfchen zu Köpfchen: 2,387 m

Nach den Versuchen:

Stützmutter-Zughülse-Grundkörper noch gut drehbar.

Anmerkungen:

*) = Kabelquerschnitt reduziert von 851 mm² (22 Drähte) auf 697 mm² (18 Drähte), da die untere Lastgrenze von 80,7 t nicht genügend genau konstant gehalten werden kann.

Zürich, 5. Mai 1960.

Eidg. Materialprüfungs- und Versuchsanstalt
Abteilung Messtechnik und besondere Untersuchungen an Metallen
Der Abteilungsvorsteher:

[redacted]

0220

Eidgenössische Materialprüfungs- und Versuchsanstalt für Industrie,
Bauwesen und Gewerbe, Zürich

Laboratoire fédéral d'essai des matériaux et Institut de recherches — Industrie, Génie civil, Arts et Métiers — Zurich
Laboratorio federale di prova dei materiali ed Istituto sperimentale — Industria, Genio civile, Arti e Mestieri — Zurigo

Stahlton AG

Untersuchungsbericht

Procès-verbal / Processo verbale

EMPA-No. 58'570/6

COPIE

Auftraggeber:
Commettant:
Committente: STAHLTON A.-G., ZÜRICH

Gegenstand:
Objet:
Oggetto: 1 Vorspannkabel " BBRV ", Type CC 90, bestehend aus 2 Ankerköpf
und 22 Drähten Ø 7 mm, glatt, verankert mit beidseitig aufge-
stauchten Köpfchen, Type rund, Drahtfabrikant: Vereinigte Dra
werke A.-G., Biel.

- **Betrifft:** Prüfung 150160, Schreiben Mü/cb vom 5. Februar 1960. -

- Angaben des Auftraggebers -

Datum des Eingangs:
Date de l'arrivée:
Data d'arrivo: 13. Februar 1960.

Ausführung der Untersuchung:
Exécution de l'essai:
Esecuzione della prova: bis 2. Mai 1960.

- 7. MAI 1960
.V
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RESULTATE DER UNTERSUCHUNGEN.

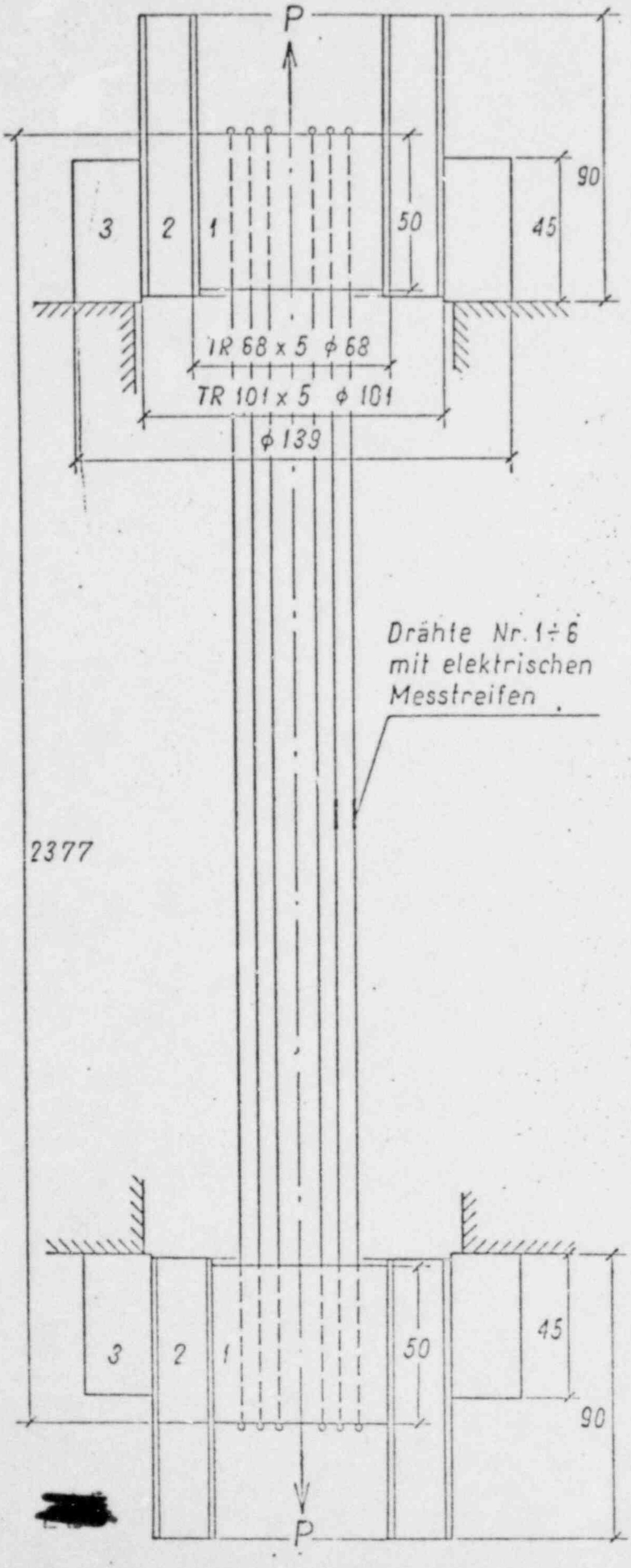
1) Statische Dehnungsmessungen.
2) Dynamischer Versuch.

0221

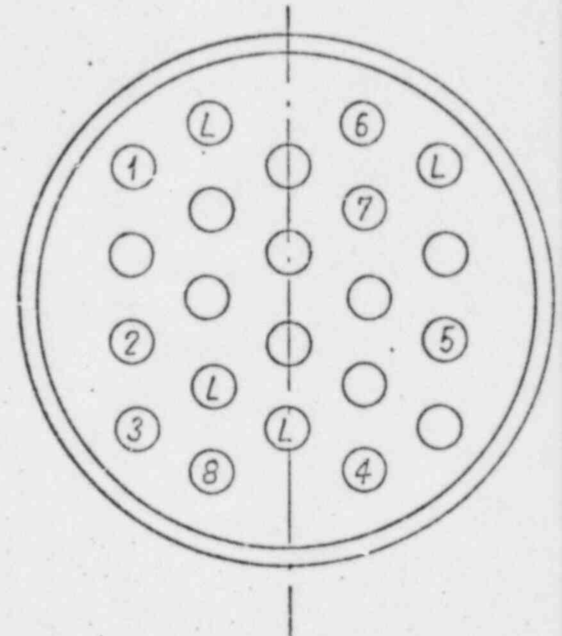
[redacted]

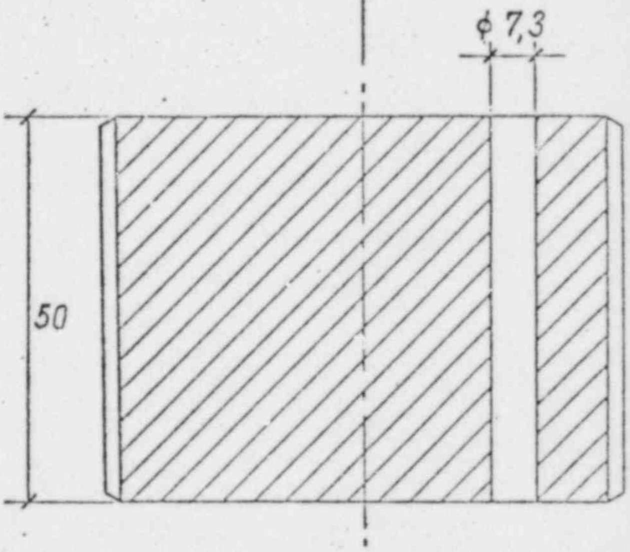
Anmerkung: Eine Verwendung dieses Berichtes zu Werbezwecken irgendwelcher Art, den blossen Hinweis auf diesen Bericht eingeschlossen, bedarf der

Versuchsanordnung



Drahtanzahl von 22 auf 18
reduziert (Löcher mit L bez.)
wegen Leistungsgrenze des
Pulsators.





1 Grundkörper
2 Zughülse
3 Stützmutter

STATISCHE DEHNUNGSMESSUNGEN

spannkabel, bestehend aus 18 Drähten; Draht-Ø 7,02 mm, Drahtquerschnitt 38,7 mm²; Kabelquerschnitt F = 697 mm
mungen, gemessen mit elektrischen Dehnungsmessstreifen, Messlänge 20 mm; Versuchsanordnung gemäss Zeichnung
EMPA-No.: 70'465

teinsteig am Penmanometer in t	Spannung $\frac{P}{F}$ kg/mm²	Dehnungen ε in °/oo					
		Draht No. 1	Draht No. 2	Draht No. 3	Draht No. 4	Draht No. 5	Draht No. 6
4,0	5,7	0	0	0	0	0	0
16,0	23,0	0,840	0,836	0,845	0,829	0,816	0,814
28,0	40,2	1,665	1,657	1,669	1,655	1,635	1,632
40,0	57,4	2,492	2,484	2,502	2,481	2,461	2,457
52,0	74,6	3,324	3,310	3,331	3,305	3,285	3,285
64,0	91,8	4,147	4,133	4,159	4,126	4,108	4,108
70,0	100,5	4,563	4,540	4,576	4,542	4,521	4,523
75,9	109,0	4,971	4,952	4,982	4,945	4,930	4,933
66,2	95,0	4,294	4,276	4,303	4,270	4,254	4,284
75,9	109,0	4,974	4,960	4,988	4,953	4,936	4,935
66,2	95,0	4,292	4,276	4,302	4,268	4,253	4,248
75,9	109,0	4,976	4,957	4,988	4,948	4,934	4,934
66,2	95,0	4,301	4,283	4,312	4,277	4,263	4,261

Zug-Ermüdungsversuche im Pulsator
Essais d'endurance par traction pulsatoire
Prove di fatica per trazione ripetuta nel pulsatore

Pulsator
Pulsateur 100 t.
Pulsatore

350 Lastwechsel pro Minute
Pulsations par minute
Pulsazioni per minuto

Bezeichnung Désignation Designazione	Querschnitt Section Sezione		Lastgrenzen Limites de charge Limiti di carico t.		Spannungsgrenzen Limites de tension Limiti di tensione kg/mm^2		Anzahl der Lastwechsel Nombre de pulsations Numero delle pulsazioni total	Bemerkungen Observations Osservazioni
	mm	mm^2	obere supérieure superiore	untere inférieure inferiore	obere supérieure superiore	untere inférieure inferiore		
	*) 18 x 7,02	697	77,4	66,2	111	95	2'040'000	intakt, Last erhöht
			78,7	66,2	113	95	113'000	Bruch des Drahts No. 2 beim Uebergang zum Köpfchen
	17 x Ø 7,02	658	74,3	62,6	113	95	452'400	Bruch des Drahts No. 1 wie oben.
	16 x Ø 7,02	619	70,0	58,2	113	95	1'523'000	Bruch des Drahts No. 4 im freien Teil, beim elektrischen Messstreifen, Oberfläche leicht angeschmirgelt.
	15 x Ø 7,02	580	65,5	55,1	113	95	1'583'000	Bruch des Drahts No. 7 beim Uebergang zum Köpfchen
	14 x Ø 7,02	542	61,3	51,5	113	95	1'854'700	Bruch des Drahts No. 8 wie Draht No. 7.

Nach den Versuchen:

Stützmutter-Zughülse-Grundkörper noch gut drehbar.

Anmerkungen:

*) = Kabelquerschnitt reduziert von 851 mm^2 (22 Drähte) auf 697 mm^2 (18 Drähte), da die untere Lastgrenze von 80,7 t nicht genügend genau konstant gehalten werden kann.

Zürich, 5. Mai 1960.

Eidg. Materialprüfungs- und Versuchsanstalt
Abteilung Messtechnik und besondere
Untersuchungen an Metallen
Der Abteilungsvorsteher:

[redacted]

0224

i. V. Güntert

Swiss Federal Laboratories for Testing Materials.
Eidgenössische Materialprüfungs- und Versuchsanstalt für Industrie,
Bauwesen und Gewerbe, Zürich

Laboratoire fédéral d'essai des matériaux et Institut de recherches - Industrie, Génie civil, Arts et Métiers, Zurich
Laboratorio federale di prova dei materiali ed Istituto sperimentale - Industria, Genio civile, Arti e Mestieri - Zurigo

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VORLÄUFIGE BENACHRICHTIGUNG

Untersuchungsbericht

Procès-verbal Processo verbale

EMPA-No. 51'449/

Auftraggeber: / Commettant: / Committente: STAHLTON A.-G., ZÜRICH

3 Sections of prestressing wire, ∅ 0.276", smooth, buttonhead on one side.

Gegenstand: / Objet: / Oggetto: 3 Abschnitte Spannbetondraht ∅ 7 mm, glatt, mit einseitig aufgestauchten Köpfchen; Draht-Fabrikant: Vereinigte Drahtwerke A.-G., Biel.

Betrifft: Drahtversuche 160759, dynamisch - Schreiben Mü/cb vom 16. Juli 1959.

\- Angaben des Auftraggebers -

Datum des Eingangs: / Date de l'arrivée: / Data d'arrivo: 22. Juli 1959.

Ausführung der Untersuchung: / Exécution de l'essai: / Esecuzione della prova: bis 18. Dezember 1959.

Date of Test

RESULTATE

der

ZUG - ERMÜDUNGSVERSUCHE IM HOCHFREQUENZ - PULSATOR

Results of tensil fatigue tests in high frequency pulsator.

[redacted]

Anmerkung: Eine Verwendung dieses Berichtes zu Werbezwecken irgendwelcher Art [illegible]

1

Zug-Ermüdungsversuche im Pulsator (Hochfrequenz-Pulsator)
Essais d'endurance par traction pulsatoire
Prove di fatica per trazione ripetuta nel pulsatore

Pulsator
Pulsateur 10 t.
Pulsatore

7'500 Lastwechsel pro Minute
Pulsations per minute
Pulsazione pro minuto
Pulsation per minute

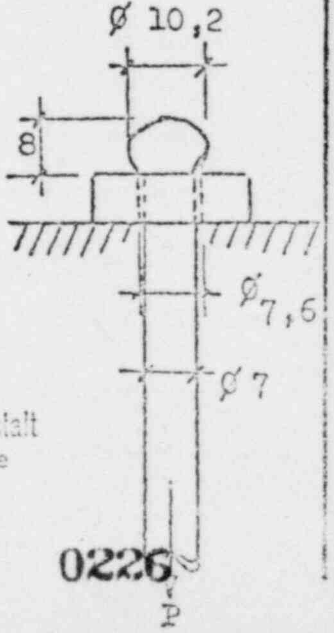
Determination of Dynamic Strength, botton stress = 95 Kg/mm2 (135 Ksi)
Bestimmung der Wechselfestigkeit bei einer unteren Spannungsgrenze von 95 kg/mm²

Design. Bezeichnung Désignation Designazione F	Cross Section Querschnitt Section Sezione Ø mm	mm²	Lastgrenzen Limites de charge Limiti di carico Load limits t. obere supérieure superiore	untere inférieure inferiore	Spannungsgrenzen Limites de tension Limiti di tensione Stress limits kg/mm² obere supérieure superiore	untere inférieure inferiore	Nr. of pulsat. Anzahl der Lastwechsel Nombre de pulsations Numero delle pulsazioni	Remarks Bemerkungen Observations Osservazioni
1	7,01	38,6	4,25 4,40	3,67 3,67	110 114	95 95	2'000'000 797'000	Intact, load increased intakt, Last erhöht Bruch beim Uebergang zum Köpfchen. Fract. at transition to buttonhead.
2	7,01	38,6	4,25 4,40	3,67 3,67	110 114	95 95	2'000'000 620'000	intakt, Last erhöht Bruch beim Uebergang zum Köpfchen. as above.
3	7,01	38,6	4,32	3,67	112	95	1'296'000	Bruch beim Uebergang zum Köpfchen. Fract. at transition to buttonhead.

Wechselfestigkeit bezüglich 2×10^6 Lastwechseln
Dynamic Strength relative to $2 \cdot 10^6$ pulsations.

1 = 111,6 - 95 kg/mm² 158 - 135 Ksi
2 = 111,2 - 95 kg/mm² 158 - 135 Ksi
3 < 112,0 - 95 kg/mm² 159 - 135 Ksi

Skizze:
Sketch



Zürich, 21. Dezember 1959.

Eidg. Materialprüfungs- und Versuchsanstalt
Abteilung Maschinentechnik und besondere Untersuchungen an Metallen
Der Abteilungsvorsteher:

[redacted]

Swiss Federal Laboratories for testing materials

Eidgenössische Materialprüfungs- und Versuchsanstalt für Industrie,
Bauwesen und Gewerbe, Zürich

Laboratoire fédéral d'essai des matériaux et Institut de recherches — Industrie, Génie civil, Arts et Métiers — Zurich
Laboratorio federale di prova dei materiali ed Istituto sperimentale — Industria, Genio civile, Arti e Mestieri — Zurigo

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Untersuchungsbericht

Procès-verbal / Processo verbale

EMPA-No. 55'939/3

Auftraggeber: / Commettant: / Committente: STAHLTON A.-G., ZÜRICH

2 pieces of prestressing wire ∅ 0.237" with upset head on one side, type round, Wire manufacturer: F+G.

Gegenstand: / Objet: / Oggetto: 2 Abschnitte Spannbetondraht ∅ 6 mm, glatt, mit einseitig aufgestauchten Köpfchen, Typ rund; Drahtfabrikant: F + G, Ring Nr. 325.

- Betrifft: Schreiben Mü/ed vom 11. November 1959. -

- Angaben des Auftraggebers -

Datum des Eingangs: / Date de l'arrivée: / Data d'arrivo: 12. November 1959.

Ausführung der Untersuchung: / Exécution de l'essai: / Esecuzione della prova: bis 12. Februar 1960.
Date of test.

RESULTATE

der

ZUG - ERMÜDUNGSVERSUCHE IM HOCHFREQUENZ - PULSATOR.

Results of tensil fatigue tests in high frequency pulsator.

[redacted]

Zug-Ermüdungsversuche im Pulsator (Hochfrequenz-Pulsator)
Essais d'endurance par traction pulsatoire
Prove di fatica per trazione ripetuta nel pulsatore

Determination of dynamic strength with bottom stress = 0

Pulsator
Pulsateur
Pulsatore
2 t.

6'500 Lastwechsel pro Minute
Pulsations par minute
Pulsazioni per minuto
Pulsations per minute

Bestimmung der Ursprungsfestigkeit.

Bezeichnung Désignation Designazione	cross-section Querschnitt Section Sezione		load limits Lastgrenzen Limites de charge Limiti di carico t.		stress limits Spannungsgrenzen Limites de tension Limiti di tensione kg/mm'		Nr. of pulsat. Anzahl der Lastwechsel Nombre de pulsations Numero delle pulsazioni	Observations Bemerkungen Observations Osservazioni
	Ø mm	mm'	Top obere supérieure superiore	Bott. untere inférieure inferiore	Top obere supérieure superiore	Bott. untere inférieure inferiore		
1	5,98	28,1	0,56	0,02	20	0,7	2'000'000	intact, load increase intakt,Last erhöht
			0,67	0,02	24	0,7	988'000 failure at buttonhead	Bruch beim Uebergang zum Köpfchen.
2	5,98	28,1	0,56	0,02	20	0,7	2'000'000	intact, load increase intakt,Last erhöht
			0,62	0,02	22	0,7	2'000'000	- do. -
			0,67	0,02	24	0,7	788'000 failure at buttonhead	Bruch beim Uebergang zum Köpfchen.

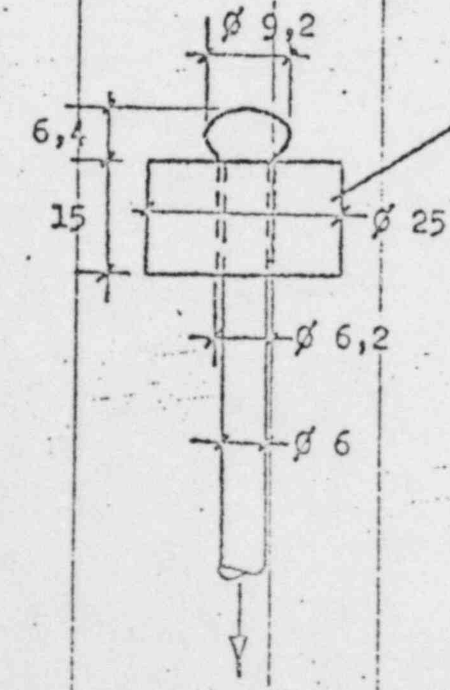
dynamic strength, bottom stress = 0, relatif to 2×10⁶ pulsations

Ursprungsfestigkeit bezüglich 2×10^6 Lastwechseln:

Nr. 1 = 21,3 kg/mm² 0 - 30300 psi

Nr. 2 = 22,1 kg/mm² 0 - 31'500 psi

Skizze:



Härte der Scheiben (Vickers-Härte: P = 20 kg)
Hardness of washers

210 kg/mm²
298 000 psi

Eidg. Materialprüfungs- und Versuchsanstalt
Abteilung Messtechnik und besondere
Untersuchungen an Metallen
Der Abteilungsvorsteher:

[redacted]

0228

Zürich, 15. Februar 1960.

Swiss Federal Laboratories for testing materials

Eidgenössische Materialprüfungs- und Versuchsanstalt für Industrie,
Bauwesen und Gewerbe, Zürich

Laboratoire fédéral d'essai des matériaux et Institut de recherches — Industrie, Génie civil, Arts et Métiers — Zurich
Laboratorio federale di prova dei materiali ed Istituto sperimentale — Industria, Genio civile, Arti e Mestieri — Zurigo

Kopie

Untersuchungsbericht

Procès-verbal / Processo verbale

EMPA-No. 55'939/4

Auftraggeber:
Committant:
Committente: S T A H L T O N A. - G., Z Ü R I C H

9 pieces of prestressing wire, ∅ 0.237" , smooth, wire manufacturer F+G.

Gegenstand:
Objet:
Oggetto: 9 Abschnitte Spannbetondraht ∅ 6 mm, glatt; Drahtfabrikant: F
Ring Nr. 325.

- Betrifft: Schreiben Mü/ed vom 11. November 1959. -

- Angaben des Auftraggebers -

Datum des Eingangs:
Date de l'arrivée:
Data d'arrivo: 12. November 1959.

Ausführung der Untersuchung:
Exécution de l'essai:
Esecuzione della prova: bis 12. Februar 1960.
Date of Test

R E S U L T A T E

d e r

ZUG - ERMÜDUNGSVERSUCHE IM HOCHFREQUENZ - PULSATOR.

1) Bestimmung der Ursprungsfestigkeit.
2) Bestimmung der Wechselfestigkeit $\sigma_{w\ 4/5}$.

Results of tensil fatigue tests in high frequency pulsator.

1) Determination of dynamic strength, bottom stress = 0
2) Determination of dynamic strength, bottom stress = 4/5 top stress

[redacted]

Zug-Ermüdungsversuche im Pulsator(Hochfrequenz-Pulsato
Essais d'endurance par traction pulsatoire
Prove di fatica per trazione ripetuta nel pulsatore

1) Bestimmung der Ursprungsfestigkeit

Pulsator
Pulsateur 10 t.
Pulsatore

6'500 Lastwechsel pro Minute / Pulsations par minute / Pulsazioni per minuto / Pulsations p minute

1) Determination of dynamic strength, botton stress = 0

Designation Bezeichnung Désignation Designazione	Cross-section Querschnitt Section Sezione		Lastgrenzen Limites de charge Limiti di carico Load t. limits		Spannungsgrenzen Limites de tension Limiti di tensione kg/mm' Stress limits		Nr. of pulsat Anzahl der Lastwechsel Nombre de pulsations Numero delle pulsazioni	Observations Bemerkungen Observations Osservazioni
	Ø mm	mm'	obere supérieure superiore	untere inférieure inferiore	obere supérieure superiore	untere inférieure inferiore		
1	5,98	28,1	1,97	0	70	0	2'000'000	Intact,Load increased intakt,Last erhöht
			2,08	0	74	0	2'000'000	- do. -
			2,19	0	78	0	358'000	Bruch freier Teil Failure in free part
2	5,98	28,1	2,02	0	72	0	2'000'000	intact,load increased intakt,Last erhöh
			2,14	0	76	0	528'000	Bruch freier Teil. failure in free part
3	5,98	28,1	2,08	0	74	0	1'103'000	Bruch freier Teil. failure in free part
4	5,98	28,1	2,02	0	72	0	575'000	Bruch freier Teil. failure in free part
5	5,98	28,1	1,97	0	70	0	2'000'000	intact, load increase intakt,Last erhöh
			2,08	0	74	0	268'000	Bruch freier Teil. failure in free part

Dynamic strength, botton stress = 0, relativ to 2x10^6 pulsations

Ursprungsfestigkeit bezüglich 2 x 10^6 Lastwechseln:

106 000 psi
Nr. 1 = 74,7 kg/mm²

Nr. 2 = 73,0 kg/mm²
103 600 psi

105 000 psi
Nr. 3 < 74,0 kg/mm²

Nr. 4 < 72,0 kg/mm²
102 300 psi

Nr. 5 = 70,5 kg/mm²
100 000 psi

[redacted]

/4

Zug-Ermüdungsversuche im Pulsator(Hochfrequenz-Pulsato
Essais d'endurance par traction pulsatoire
Prove di fatica per trazione ripetuta nel pulsatore
2) Bestimmung der Wechselfestigkeit σ_W 4/5

Pulsator Pulsateur Pulsatore	10 t.	6'500	Lastwechsel pro Minute Pulsations par minute Pulsazioni per minuto Pulsations pe minute

2) Determination of dynamic strength, botton stress = 4/5 top stress.

Designat. Bezeichnung Désignation Designazione	Cross-section Querschnitt Section Sezione		load Lastgrenzen Limites de charge Limiti di carico t. limits		stress limits Spannungsgrenzen Limites de tension Limiti di tensione kg/mm²		nr. of pulsat. Anzahl der Lastwechsel Nombre de pulsations Numero delle pulsazioni	Observations Bemerkungen Observations Osservazioni
	Ø mm	mm^2	obere supérieure superiore	untere inférieure inferiore	obere supérieure superiore	untere inférieure inferiore		
1	5,98	28,1	4,07	3,26	145	116	2'000'000	intact, load increased intakt, Last erhöht
			4,35	3,48	155	124	2'000'000	- do. -
			4,50	3,60	160	128	764'000	Bruch freier Teil. failure in free part
2	5,98	28,1	4,35	3,48	155	124	2'000'000	intact, load increased intakt, Last erhöht
			4,50	3,60	160	128	1'988'000	Bruch freier Teil. failure in free part
3	5,98	28,1	4,35	3,48	155	124	2'000'000	intact, load increased intakt, Last erhöht
			4,50	3,60	160	128	2'000'000	- do. -
			4,64	3,71	165	132	926'000	Bruch freier Teil. failure in free part
4	5,98	28,1	4,50	3,60	160	128	1'652'000	failure in free part Bruch freier Teil.

Dynamic strength, botton stress = 4/5 top stress, relativ to $2x10^6$ pulsations.

Wechselfestigkeit σ_W 4/5 bezüglich 2×10^6 Lastwechseln:

220 300 - 179 000 psi
Nr. 1 = 157 - 126 kg/mm^2

Nr. 2 = 160 - 128 kg/mm^2
227 000 - 182 000 psi

230 000 - 184 500 psi
Nr. 3 = 162 - 130 kg/mm^2

Nr. 4 < 160 - 128 kg/mm^2
227 000 - 182 000 psi

Zürich, 15. Februar 1960.

Eidg. Materialprüfungs- und Versuchsanstalt
Abteilung Messtechnik und besondere
Untersuchungen an Metallen
Der Abteilungsvorsteher:

[redacted]

Zug - Ermüdungs - Diagramme Tensil fatigue diagram

bezügl. $2 \cdot 10^6$ Lastwechsel for $2 \cdot 10^6$ pulsations

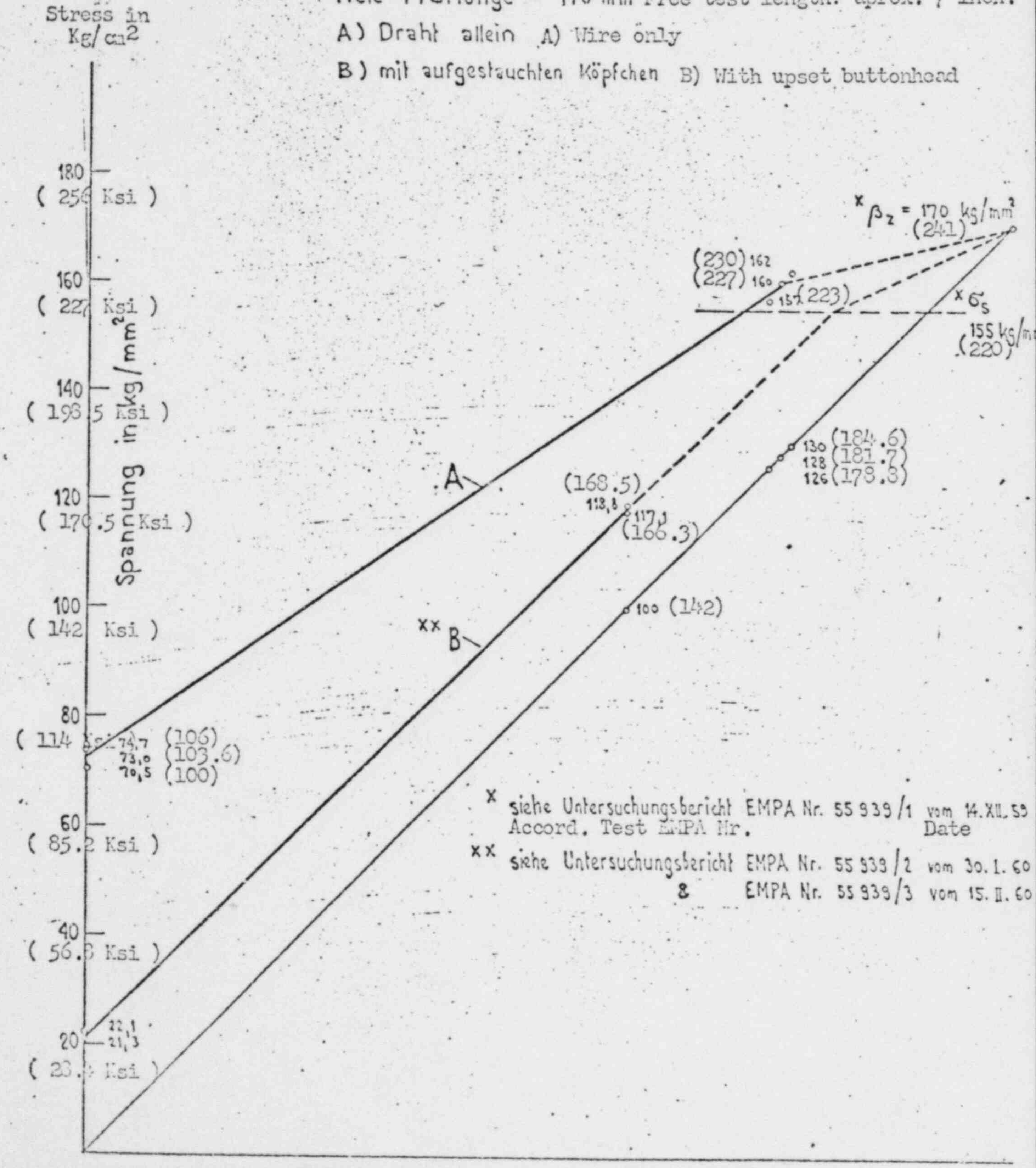
Spannbetondraht ϕ 6 mm glatt Prestressing wire ϕ 0.237" smoot

Anzahl Lastwechsel 6 500/min Pulsations: 6500 / min.

Freie Prüflänge ~ 170 mm Free test length: aprox. 7 inch.

A) Draht allein A) Wire only

B) mit aufgestauchten Köpfchen B) With upset buttonhead



x siehe Untersuchungsbericht EMPA Nr. 55 939/1 vom 14.XII.59
Accord. Test EMPA Nr. Date

xx siehe Untersuchungsbericht EMPA Nr. 55 939/2 vom 30.I.60
& EMPA Nr. 55 939/3 vom 15.II.60

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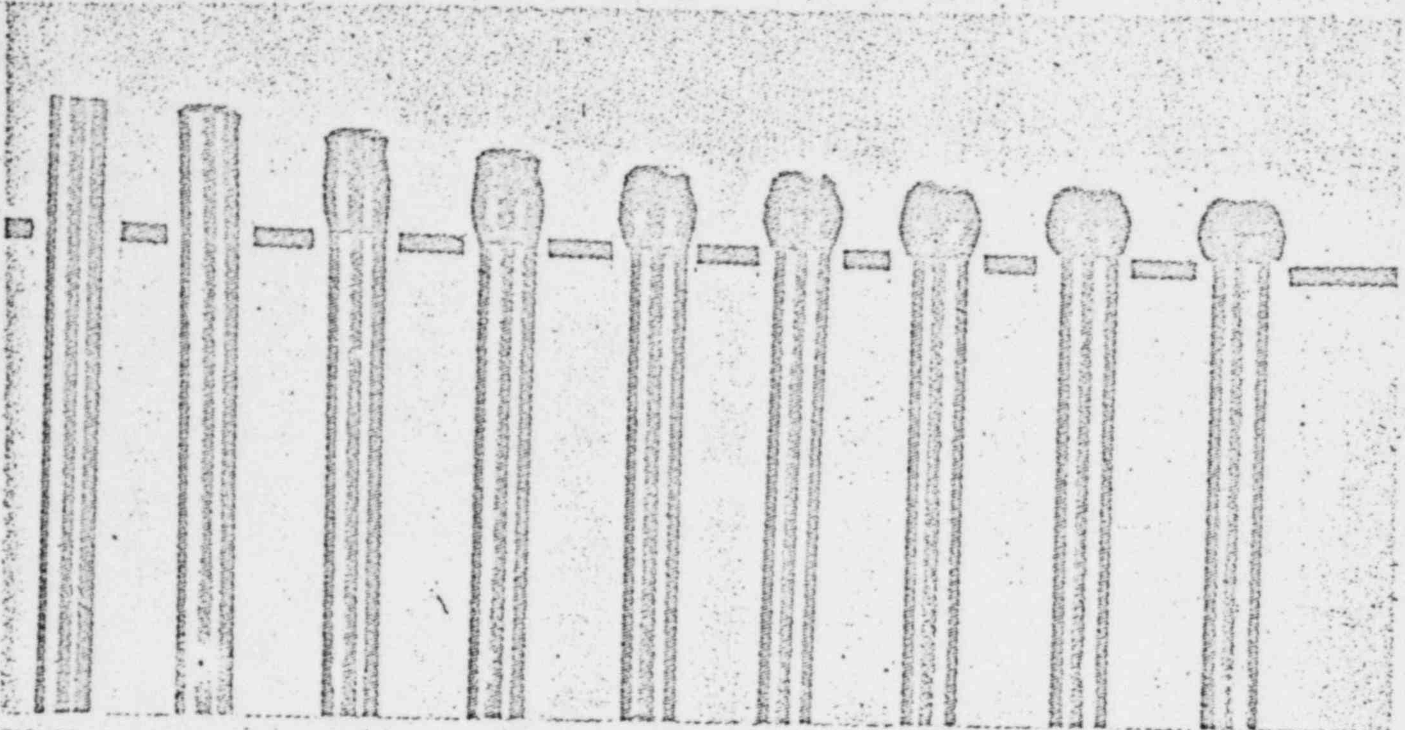

FIG. 22: Actual size photos of nine stages in the progressive forming of a button-head, showing assymetrical forming of the head. Actual heading is a continuous process but was interrupted in nine stages, as shown here, for illustration.

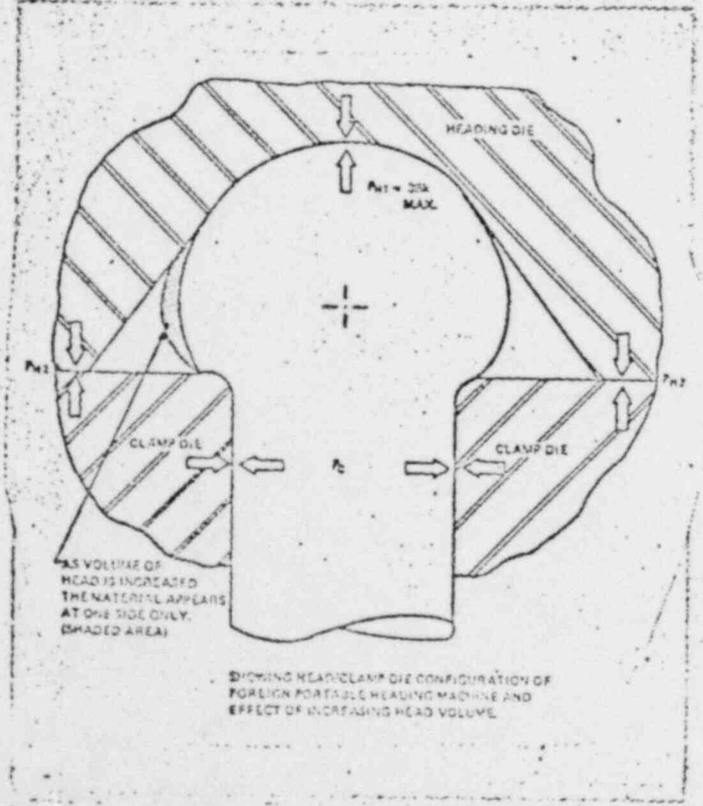

FIG. 21: Heading die and clamp die configuration of the foreign manufactured portable Heading Machine showing effect of increasing the indexed length of wire on head form.

2.4 FATIGUE TESTS

2.4.1 GENERAL

Fatigue tests on the Western 1.5 FS Head-Seat System (see Section 4.3 for description) were conducted

Fatigue tests were divided into five Series (designated Series No. 1 thru Series No. 5) having seven test specimens (designated A thru G) in each series. Variable loads were applied by an Amsler HF Vibrophore Fatigue - Testing Machine operating at 6500 cycles per minute.

Complete test data, description of each Series, description of the test equipment and procedures, and summary of results are contained in Appendix II.

2.4.2 SAMPLING

Ninety-six samples of wire 16 inches long were cut by Western from Coil No. 5, Heat No. 798615, Layout No. 563-6 of wire manufacutred by United States Steel Corporation. Thirty-five samples were selected at random for fatigue tests. Of these, twenty-eight were fabricated into fatigue test specimens using head-seat conditions conforming to criteria for the Western 1.5 FS Head-Seat System described in Fig. 25. By random selection, these headed test specimens were separated into groups of seven and designated Series 2 thru 5. Heads were formed by Western laboratory personnel using Heading Machine No. 6 and identical techniques used to form heads for the static test specimens of Phase I. All specimens were submitted "as headed" with no selection or rejection of heads.

[redacted]

2.4.3 SELECTION OF STRESS LEVELS

Fatigue test specimens were initially loaded to .8 x f''_s , and held at that load for two minutes in order to: 1) duplicate the actual conditions in a tendon which is stressed to that load in order to overcome stressing friction and is held while shims are installed, and 2) to prevent minor head seating during the fatigue test.

Initial stress was selected at 0.6 x actual ultimate stress. A stress of 0.6 g.u.t.s. (144 kis) is the maximum long term stress, after all losses, allowed by the ACI code and is therefore the highest permanent stress in the wire in a structure. Although 0.6 a.u.t.s. is a higher stress (153.2 ksi) than 0.6 g.u.t.s. (144 ksi), it was selected as giving a better representation of fatigue properties of an actual sample of wire as related to static properties of that same sample.

The stress range of ± 15,000 psi used in Series Nos. 3 and 4 was selected as being the maximum conceivable stress change in wire in an actual structure subjected to overload forces of a cyclic nature.

The stress range of ± 3,000 psi used for Series No. 5 was selected as being the maximum stress change in the wire of a Prestressed Concrete Reactor Vessel (PCRV) resulting from actual operating conditions.

2.4.4 SUMMARY OF RESULTS

In Series No. 3, where the load on the heads was 0.6 f''_s (153.2 ksi) ± 15,000 psi, five of the seven specimens had no failure after 10 million cycles. One speciman (3-C) had a fatigue failure in the wire at 4,681,000 cycles. One speciman (3-B) had a fatigue failure in one head at 3,504,000 cycles.

Static tests to failure were conducted on seven specimens in Series No. 2 and in nineteen specimens in Series Nos. 3-5 after fatigue loading (note that specimen 3-[illegible] and 3-C failed in fatigue and could not therefore have subsequent static tests). Out of 52 heads tested to ultimate in static tests - none failed. 38 heads sustained 10 million cycles without failure and 3 others could not be taken to that number of cycles because failure occurred elsewhere.

Neither the forming of Western 1.5 FS Heads nor fatigue loading of headed samples had any significant effect on the static properties of unheaded wire as determined by Series No. 1, except that test data indicates that fatigue cycling may have raised the static yield point slightly.