APPENDIX 5B

INLAND-RYERSON'S REPORT ON

BBRV TENDON SYSTEMS

REPORT ON BBRV PRESTRESSING TENDONS

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REPORT ON BBRV PRESTRESSING TENDONS

Part
A. GENERAL INTRODUCTION, PURPOSE, SUMMARY

The 170 wire Inland-Ryerson BBRV Post-Tensioning System was developed specifically to post-tension the prestressed concrete reactor vessels of nuclear power plants and their secondary containments where total required force and/or spacing of tendons makes the use of large capacity tendons advantageous. In general the system utilized 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. The tests presented in the following section assure the integrity of the post-tensioning system in meeting the high quality control standards of the Three Mile Island station and the Atomic Energy Commission.

It was the purpose of the following tests to demonstrate the ability of the prestressed, post-tensioned system to fulfill the quality control specifications for this job. Part B. of this section presents a stress analysis of the anchorage components. Part C. deals with the dynamic and fatigue testing of the composite tendon system.

The static tests reported in Part D. dealt with subjecting anchorages to several levels of loading and analyzing failure modes. Part E. offers expert opinion

concerning possible deleterious effects of welding and flame cutting on the embedded steel bearing plates. The low temperature testing as detailed in Part F. shows the performance characteristics of the loaded tendon system under extreme environmental conditions.

A concensus of the results of these tests, indicates that the individual components of the system as well as the Inland-Ryerson BBRV Post-Tensioning System as a whole, performed above and beyond the minimum criteria of the job specifications. The results further indicate that the use of prestressed post-tensioned tendons as a critical structural member of this vessel was well justified.

Part
B. ECCENTRICITY AND STRESS ANALYSIS

Part
B. ECCENTRICITY AND STRESS ANALYSIS

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Part
B. ECCENTRICITY AND STRESS ANALYSIS

Introduction, Purpose, Summary

It was the purpose of this test to furnish a stress analysis on the anchorage components to determine "order of magnitude" stresses at applicable maximum loading conditions.

This report takes into consideration the conditions of maximum eccentricity and critical stress.

The analysis shows that the anchorage will perform as required with all allowable stress limits.

1.0 ECCENTRICITY ANALYSIS

1.1 — MAX. ECCENTRICITY, PULL ROD TO RAM:

MAX. RAM BORE = 6.015"
MIN. PULL ROD DIA. = 5.990
.025" = MAX. CLRNCE.

1.2 — MAX. ECC., RAM CHAIR HOLES TO RAM BASE:

IMPLIED DIMENSION = .031"

1.3 — CLEARANCE, CHAIR HOLES TO PINS:

NOM. HOLE DIA. = 1 1/16"
MAX. OVERSIZE IN NORMAL DRILLING OPERATIONS (MACHINERYS HANDBOOK, 17TH EDITION, PG 1428) = .005 + .0050 = .010"

MAX. HOLE DIA. = 1.073"
MIN. PIN SIZE = .990
.083" = MAX. CLRNCE.

1.4 — BEARING PLATE, STUD HOLES TO CENTER HOLE:

MAX. ECCENTRICITY = .031"

1.5 — BEARING PLATE, CENTER HOLE TO ℄. CENTER:

MAX. ECCENTRICITY = .094"

1.6 — TOTAL ECCENTRICITY (MAX.), TENDON TO BEARING ℄:

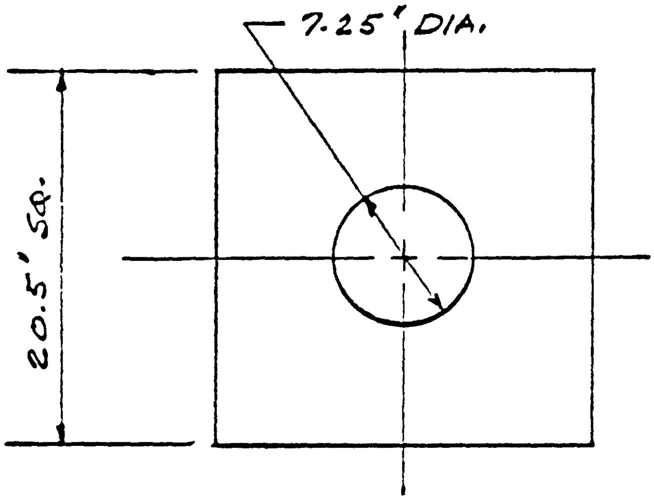
$\Sigma(1.0 - 5.0) = .264''$

NOTE: THIS ECCENTRICITY IS THE MAXIMUM THAT CAN EXIST BETWEEN THE CENTER OF PRESTRESSING FORCE AND CENTER OF BEARING PLATE. ECCENTRICITY FOR OTHER HARDWARE COMPONENTS IS ESSENTIALLY ZERO.

DATE	ECCENTRICITY & STRESS ANALYSIS	WESTERN CONCRETE STRUCTURES CO., INC	PROJ. NO.
DES. BY	2.0 Mep/170-W Post-Tensioning System	19113 SOUTH HAMILTON AVENUE GARDENA · CALIFORNIA · 321-1571	
DWN. BY			
CKD. BY			SHT 1 OF 8

2.0 – CONCRETE BEARING STRESS DUE TO ECCENTRICITY:

2.1 – BEARING AREA:



$$A_b = 20.5^2 - \frac{3.14}{4}(7.25)^2$$
$$= 379 \text{ IN.}^2$$

$$I_b = \frac{(20.5)^4}{12} - \frac{3.14(7.25)^4}{64}$$
$$= 14{,}582 \text{ IN.}^4$$

$$c = \frac{20.5}{2} = 10.25''$$

2.2. – ANCHORING FORCE:

$$F_i = 169(.70)(240)(.0491) = 1394^k$$

2.3 – CONCRETE STRESS:

$$f_{cb} = \frac{F_i}{A_b} \pm \frac{F_i e c}{I_b} = \frac{1394}{379} \pm \frac{1394(.264)(10.25)}{14{,}582}$$

$$= 3.678 \pm .259 = \begin{matrix} 3.937 \text{ KSI (MAX.)} \\ 3.419 \text{ " (MIN.)} \end{matrix}$$

2.4 – INCREASE DUE TO ECCENTRICITY:

$$\% = 100\left(\frac{.257}{3.678}\right) = 7\%$$

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3.0 - STRESS ANALYSIS, GENERAL:

3.1 - LOADING:

TENDON ULTIMATE = 169(.0491)(240) = 1991 K
MAX. JACKING LOAD = .80(1991) = 1593 K
MAX. ANCHORING LOAD = .70(1991) = 1394 K
MAX. EFFECTIVE LOAD = .60(1991) = 1195 K

3.2 - MATERIALS:

BEARING PLATE (P/N 100121): ASTM A-36, SILICON KILLED, FINE GRAIN PRACTICE.
F_{ty} = 36.0 KSI., MIN.
F_{tu} = 58.0 KSI., MIN.

SHIMS (P/N 101006): ASTM A-36 AS ABOVE.

WASHER (P/N 101003), WASHER-NUT (P/N 101004), COMP. WASHER (P/N 101005): AISI 4142, H.T. TO R_c = 40 MIN.
F_{ty} = 163 KSI. MIN.
F_{tu} = 180

(FOR OTHER MECHANICAL PROPERTIES REFER TO TABLE 3.2-2 & FIG. 3.2-6, CHAPTER 3, TR-8.)

3.3 - CRITERIA:

"ORDER OF MAGNITUDE" STRESSES WILL BE DETERMINED AT APPLICABLE MAXIMUM LOADING CONDITIONS AND COMPARED TO MECHANICAL PROPERTIES OF COMPONENT MATERIALS.

4.0 — WASHER:

4.1 WIRE HOLE WEB SHEAR:

CRITICAL CONDITION OCCURS DURING STRESSING WHEN LOAD MAY EQUAL 1593 K (REFER TO FIG. 3.2-8, TR-8)

FOR SHEAR PATH 2 (CRITICAL)

$$P = \frac{169 - 37}{169}(1593) = 1244^{K}$$

$$A_S = 40 \times 4(.397 - .264) = 21.28 \text{ IN.}$$

$$f_{SV} = \frac{P}{A_S} = \frac{1244}{21.28} = 58.46 \text{ KSI.}$$

PER TABLE 3.2-2, $F_{SU} = 109$ KSI

S.F. AT JACKING LOAD $= \frac{109}{58.46} = \underline{1.86}$

4.2 THREAD SHEAR:

CRITICAL CONDITION OCCURS AS ABOVE DURING STRESSING, $P = 1593^{K}$ (REFER TO PG. 12, TR-8)

PITCH DIA. = 6.00 − 0.3(.250) = 5.925"

$$A'_S = \frac{(L_e - p)\pi E}{2} = \frac{(3.25 - .25)(3.14)(5.925)}{2}$$

$$= 27.92 \text{ IN}^2$$

$$f_{SV} = \frac{P}{A'_S} = \frac{1593}{27.92} = 57.1 \text{ K/IN}^2$$

PER TABLE 3.2-2, $F_{SU} = 109$ KSI.

S.F. AT JACKING LOAD $= \frac{109}{57.1} = \underline{1.91}$

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5.0 - WASHER NUT:

5.1 - I.D. THREAD SHEAR:

SAME AS 4.2 FOR WASHER

5.2 - O.D. THREAD SHEAR:

CRITICAL CONDITION OCCURS DURING STRESSING, $P = 1593^K$
(REFER TO PG. 11, TR-8)

PITCH DIA. = 9.375 - 0.3(.250) = 9.300 IN.

$$A'_s = \frac{(Le - p)\pi E}{2} = \frac{(3.25 - .25)(3.14)(9.30)}{2}$$

$$= 43.83 \text{ IN}^2$$

$$f_{SV} = \frac{P}{A'_s} = \frac{1593}{43.83} = 36.35 \text{ KSI.}$$

PER TABLE 3.2-2, $F_{SU} = 109$ KSI.

S.F. AT JACKING LOAD $= \frac{109}{36.35} = \underline{\underline{3.00}}$

5.3 - TORSION DURING STRESSING:

CRITICAL CONDITION OCCURS DURING STRESSING, $P = 1593^K$
(REFER TO ROARK, PG. 220, CASE 14)

$$f_{ST} = -\frac{3W}{2\pi m t^2}\left[\frac{2a^2(m+1)}{a^2 - b^2}\log\frac{a}{b} + (m-1)\right]$$

$$a = \frac{9.30}{2} = 4.65''$$

$$b = \frac{5.925}{2} = 2.963''$$

$$W = P = 1593^K$$

$$m = \frac{1}{\mu} = \frac{1}{.27} = 3.70$$

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5.3 – CONT'D.

$$f_{st} = \frac{3(1593)}{2(3.14)(3.70)(160)}\left[\frac{2(4.65)^2(4.70)}{(4.65^2-2.963^2)}(.45066) + 2.70\right]$$

$$= 126.3 \text{ KSI.}$$

$$\text{S.F. AT JACKING LOAD} = \frac{180}{126.3} = \underline{\underline{1.43}}$$

6.0 – COMPOSITE WASHER:

6.1 – WIRE HOLE WEB SHEAR:

SAME AS 4.1 FOR WASHER

6.2 – THREAD SHEAR:

SAME AS 5.2 FOR WASHER NUT

7.0 – SPLIT SHIMS:

7.1 – BEARING AT BEARING PLATE:

(REFER TO 3.2.2, TR-8)

CRITICAL CONDITION AT ANCHORING LOAD, $P = 1394^K$

$$\text{AREA} = 10.0^2 - \frac{3.14}{4}(7.6625^2) = 60.83 \text{ IN.}^2$$

$$f_{sb} = \frac{P}{A} = \frac{1394}{60.83} = 22.9 \text{ KSI.}$$

PER TABLE 3.2-2, TR-8, ULTIMATE BEARING STRENGTH, $F_{bru} = 95.2$ KSI.

$$\text{S.F. AT ANCHORING LOAD} = \frac{95.2}{22.9} = \underline{\underline{4.16}}$$

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7.2 – BEARING AT COMPOSITE WASHER:

(REFER TO SECTION 3.2.3, TR-8)

CRITICAL CONDITION AT ANCHORING LOAD, $P = 1394^{k}$.

$$A = \frac{3.14}{4}(9.375^2 - 5.625^2) = 44.18 \text{ IN}^2$$

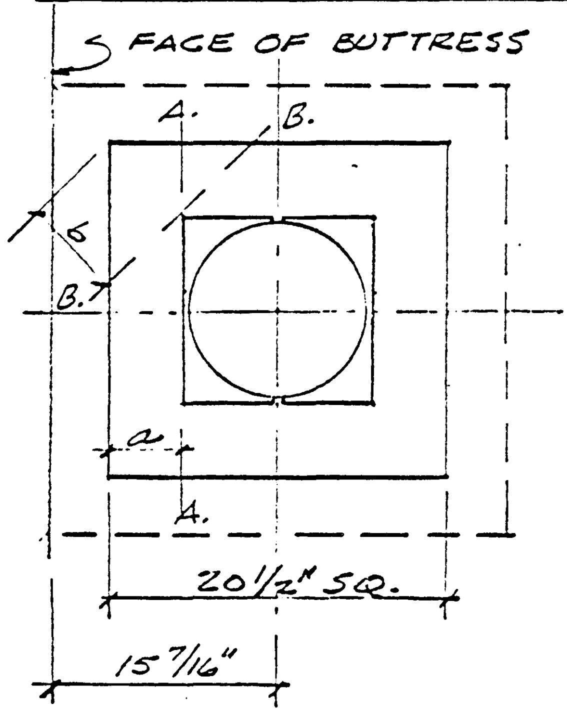
$$f_{sb} = \frac{P}{A} = \frac{1394}{44.18} = 31.55 \text{ KSI}$$

PER TABLE 3.2.2, TR-8, $F_{bru} = 95.2$ KSI.

$$\text{S.F. AT ANCHORING LOAD} = \frac{95.2}{31.55} = \underline{\underline{3.02}}$$

8.0 – BEARING PLATE:

8.1 – CONCRETE BEARING:



GROSS BEARING AREA:

$$A_{bG} = 20.5^2 = 420.25 \text{ IN}^2$$

CONCENTRIC CONC. AREA:

$$A_c = (2 \times 15.44)^2 = 953.57 \text{ IN}^2$$

CONCRETE STRENGTH:

$$f_c' = 5000 \text{ PSI}.$$

ALLOWABLE BEARING STRESS (PER A.C.I. 318-63)

$$f_{cb} = 0.6 f_c' \sqrt[3]{\frac{A_c}{A_{bG}}}$$

$$= 0.6(5.0)\sqrt[3]{\frac{953.57}{420.25}}$$

$$= 3.942 \text{ KSI}.$$

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8.1 – CONT'D.:

ACTUAL BEARING STRESS:

NET BEARING AREA,

$$A_{bN} = A_{bG} - \frac{3.14}{4}(7.0625)^2$$

$$= 420.25 - 39.17 = 381.1 \text{ IN}^2$$

$$f_c = \frac{P}{A_{bN}} = \frac{1394}{381.1} = 3.658 \text{ KSI.}$$

RATIO, ALLOWABLE TO ACTUAL $= \frac{3.942}{3.658} = \underline{\underline{1.08}}$

8.2 – BENDING AT A–A:

$$a = \tfrac{1}{2}(20.5 - 10.0) = 5.25 \text{ IN.}$$

$$M = \frac{f_c a^2}{2} = \frac{3.66(5.25)^2}{2} = 50.44 \text{ IN.}^K/\text{IN.}$$

$$f_s = \frac{6M}{bd^2} = \frac{6(50.44)}{1(3.75)^2} = 21.52 \text{ }^K/\text{IN}^2.$$

PER TABLE 3.2–2, TR-8, F_{tu} (MIN.) = 58 KSI.

S.F. AT ANCHORING LOAD $= \frac{58}{21.52} = \underline{\underline{2.70}}$

8.3 – BENDING AT B–B:

$$b = 1.414(a) = 1.414(5.25) = 7.424 \text{ IN.}$$

$$M = f_c(\tfrac{1}{2})(2a)^2(\tfrac{b}{3}) = 3.66(.5)(2 \times 5.25)^2(\tfrac{7.424}{3})$$

$$= 499.3 \text{ IN}^K.$$

$$f_s = \frac{6M}{2bd^2} = \frac{6(499.3)}{2(7.424)(3.75)^2} = 14.35 \text{ KSI.}$$

S.F. AT ANCHORING LOAD $= \frac{58}{14.35} = \underline{\underline{4.04}}$

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Part
C. DYNAMIC AND FATIGUE TESTS

Part
C. DYNAMIC AND FATIGUE TESTS

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Part
C. DYNAMIC AND FATIGUE TESTS

Introduction, Purpose, Summary

Based on specification requirements, it was necessary to test the full scale anchorage in as representative a test as possible. Inland-Ryerson contacted the Swiss Federal Laboratory for Testing Material and Research. They agreed to conduct the tests and the materials were forwarded to Switzerland. The results are noted in their tests 67'303/1, 67'303/2 and 67'303/3 following herein.

In the tests a free length of 4 meters was used and the tendon was anchored at both ends by means of small cold deformed buttonheads at each end and supported on a threaded ring at both anchor ends. The tendon system was cycled extensively by the test equipment and no significant defects or failures were observed.

In each test the tendon behaved as expected. The results proved the total reliability of the tendon system beyond the specification requirements.

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

Untersuchungsbericht
Procès-verbal
Processo verbale
TEST - REPORT

EMPA No. 67'303/2

Auftraggeber:
Commettant:
Committente:
Customer: STAHLTON AG ZUERICH

Gegenstand:
Objet:
Oggetto:
Object: A 4 meter long prestressing cable of 70 wires Ø 1/4"

Datum des Eingangs:
Date de l'arrivée:
Data d'arrivo:
Date of receipt: 12.5.1969

Ausführung der Untersuchung:
Exécution de l'essai:
Esecuzione della prova:
Execution of test: till 17.7.1969

FATIGUE TEST RESULTS

DESCRIPTION OF TEST

1. The presstressing cable

- Type: BBRV 70 Ø 1/4"
- Free length: 4 m
- 70 round and unprofiled steel wires Ø 1/4"
- Ultimate tensile strength $\beta_Z = 170\ kg/mm^2$ (According to data given by the customer. See also the experimental results of the tensile tests carried out on the steel wires in EMPA-Report No. 67'303/3).
- Anchorage: The cable was anchored at both ends by means of small cold deformed bottom heads at each wire end and supported on a threaded ring at both anchor heads (see appendix 2).

2. Equipment

The tested cable was mounted vertically in a testing frame with a weighing beam (see figures in appendices 1 & 3).

Lower and upper loading limits of 225 t and 250 t respectively could be achieved and kept constant during the test by using two hydraulic jacks which were connected to two coupled Amsler pulsators.

The applied loads were controlled by means of a "load cell" connecting the weighing beam with the lower anchor head of the tested cable.

A shock pickup was mounted on a plate fixed to the upper anchor head of the cable. To determine the number of the ruptured wires during the test, a recording unit was connected to the mentioned pickup.

3. Procedure

The cable was acted upon with a pulsating load, whose frequency was 250 cycles per minute, for six days. In spite of the failure of 6 wires during these $2{,}216 \cdot 10^6$ cycles the upper and lower loads were kept constant.

4. Results

The data concerning the failure of six wires are given in appendix 4. Due to these failures, the initial applied stress limits were raised from:

$$\sigma_{upper} = 112{,}8 \text{ kg/mm}^2 \text{ and } \sigma_{lower} = 101{,}5 \text{ kg/mm}^2$$

up to:

$$\sigma_{upper} = 123{,}4 \text{ kg/mm}^2 \text{ and } \sigma_{lower} = 111{,}1 \text{ kg/mm}^2$$

i.e.: at the end of the test, the applied stresses were:

$$\sigma_{upper} = 0{,}726 \cdot \beta_Z \quad \text{and} \quad \sigma_{lower} = 0{,}654 \cdot \beta_Z$$

The total elongation of the tested cable measured after $2{,}216 \cdot 10^6$ loading cycles was 3,2 mm. From this elongation 2 mm was a result of the excess stresses due to the failure of the six wires. This means that the actual elongation of the cable was 1,2 mm.

i.e.: The permanent strain after $2{,}216 \cdot 10^6$ loading cycles was 0,3 ‰.

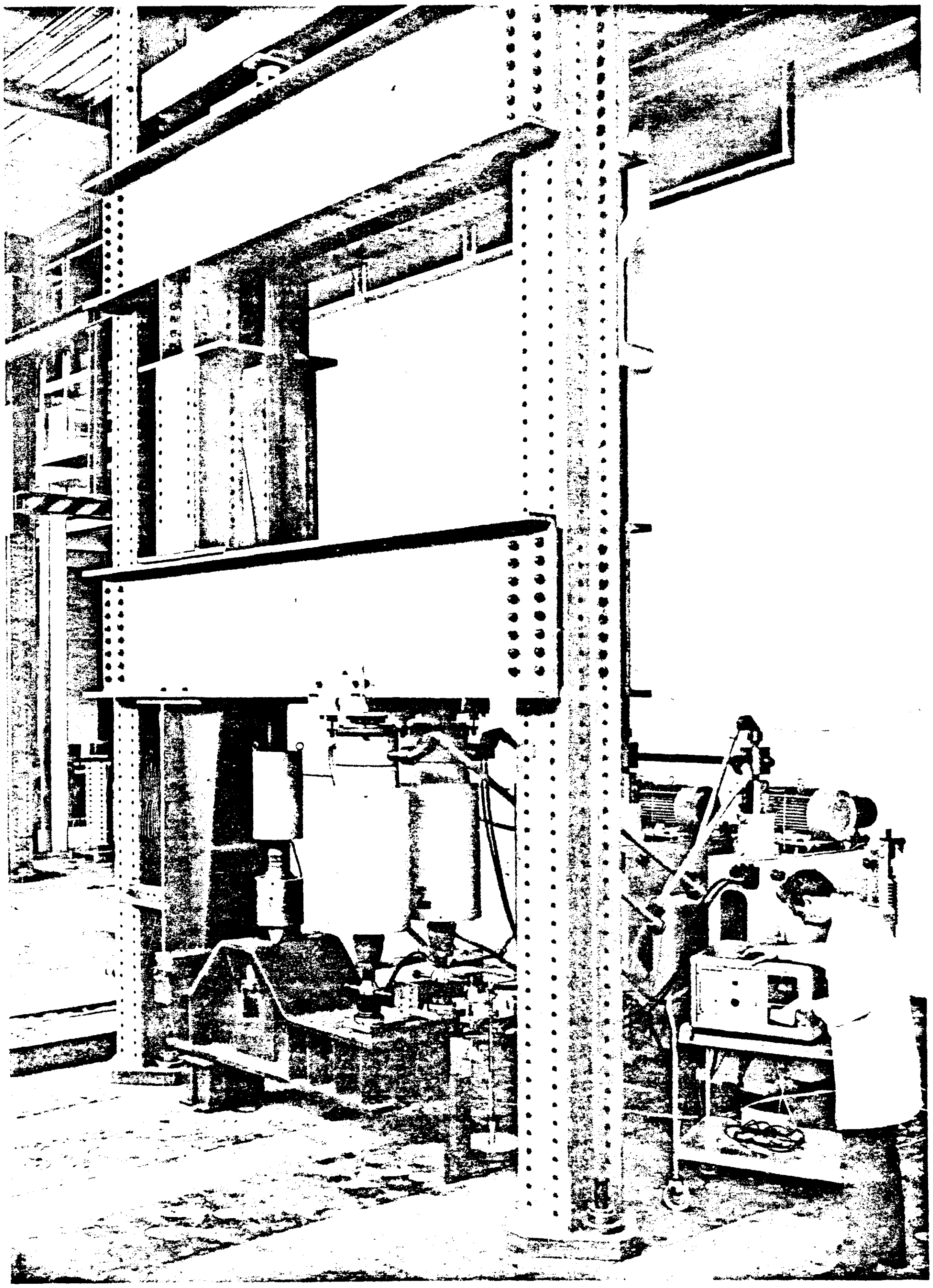
Dübendorf, 17th July,1969

Swiss Federal Laboratory for
Testing Materials and Research

A. Rösli

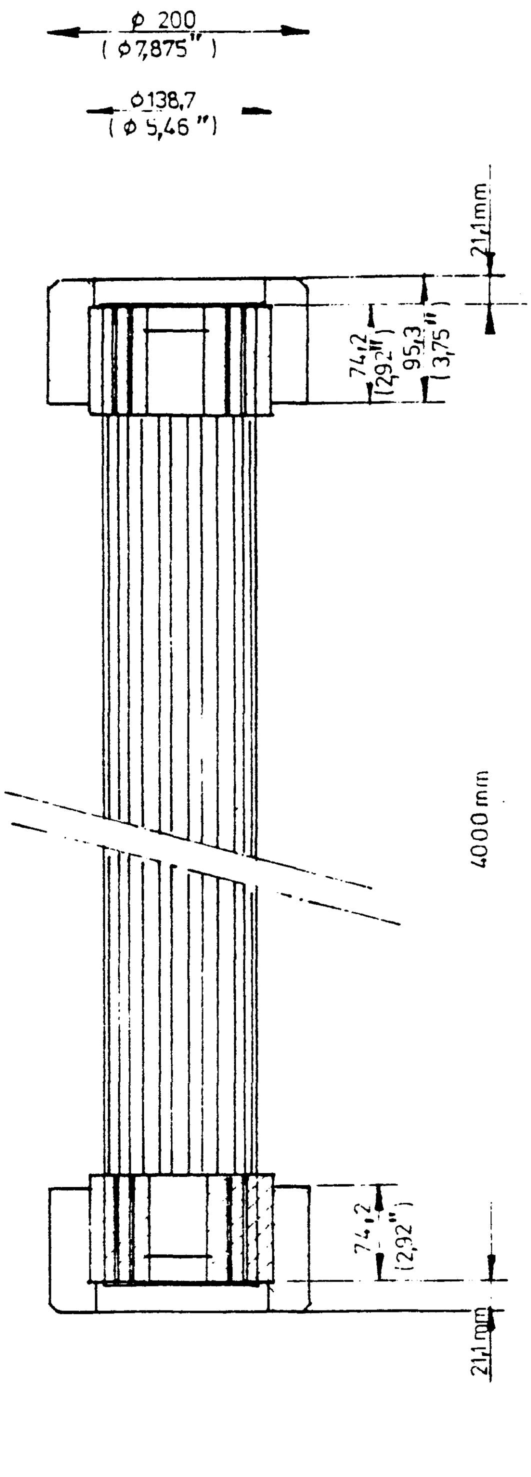
Engineer of test:

A. Ulrich



View of the test equipment with the mounted cable and the recording apparatus.

Cable for tension fatigue test at the " EMPA "

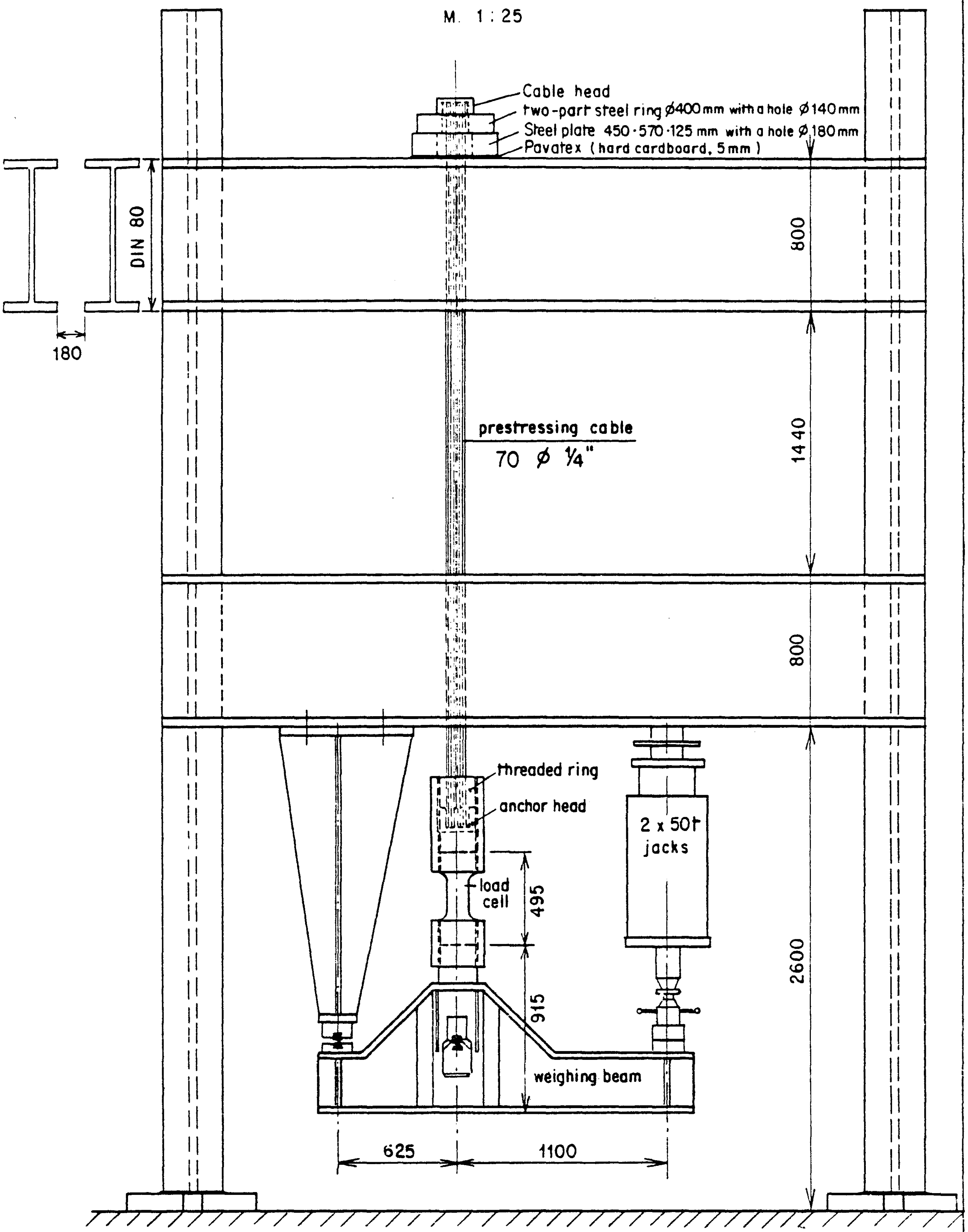


Inland_Ryerson Const. Prods. Co., Chicago

EMPA	Auftrags-Nr.	Auftraggeber:	Gezeichnet:	Zeichnungsnummer:
	67'303/2	Stahlton A.-G., Zürich	Juli 69	4 — 3409

Appendix 3

Experimental arrangement for a fatigue test on a prestressing cable



F. 95224	EMPA	Auftrags-Nr.: 67'303/2	Auftraggeber: Stahlton A.-G., Zürich 5B-23	Gezeichnet: Juli 69 se	Zeichnungsnummer: 4 — 3410

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TEST RESULTS

test specimen : BBRV prestressing cable 4m long

Nominal values : cross-sectional area : Fe = 70 Ø 1/4" = 70 · 31,65 mm^2 = 2216 mm^2
ultimate tensile strength : β_z = 170 kg / mm^2

Fatigue stage 1 : σ_{upper} = 0,663 · β_z = 112,8 kg/mm^2 ; P_{upper} = 250 t
σ_{lower} = 0,596 · β_z = 101,5 kg/mm^2 ; P_{lower} = 225 t

range of stress $\Delta \sigma$ = 11,3 kg/mm^2

FATIGUE STAGE No.	LOADING LIMITS		STRESSES (related to the remained cable cross-section at every fatigue-stage)			Total number of loading cycles after every fatigue-stage	REMARKS
	P_{upper} t	P_{lower} t	σ_{upper} kg/mm^2	σ_{lower} kg/mm^2	$\Delta\sigma$ kg / mm^2		
1	250,0	225,0	114,4	103,0	11,4	871'100	1. failure
2	"	"	116,1	104,5	11,6	1'216'900	2. "
3	"	"	117,9	106,1	11,8	1'877'700	3. "
4	"	"	119,7	107,7	12,0	1'885'700	4. "
5	"	"	121,5	109,3	12,2	1'946'900	5. "
6	"	"	123,4	111,1	12,3	2'198'900	6. "
7	"	"	123,4	111,1	12,3	2'216'300	End of test

Lower ancnorage
2 failures

Upper anchorage
4 failures

All of the six failures took place directly near the cold deformed small heads of the wires. During the 2,2 · 10^6 loading cycles and under lower and upper loading limits of 225t and 250 t respectively, the tested cable-including its both anchor heads-could remain without any other defects than these six failures.

TEST RESULTS

test specimen : BBRV prestressing cable 4m long

Nominal values : cross-sectional area : $Fe = 70\ \varnothing\ 1/4" = 70 \cdot 31{,}65\ mm^2 = 2216\ mm^2$
ultimate tensile strength : $\beta_z = 170\ kg/mm^2$

Fatigue stage 1 : $\sigma_{upper} = 0{,}663 \cdot \beta_z = 112{,}8\ kg/mm^2$; $P_{upper} = 250\ t$
$\sigma_{lower} = 0{,}596 \cdot \beta_z = 101{,}5\ kg/mm^2$; $P_{lower} = 225\ t$

range of stress $\Delta\sigma = 11{,}3\ kg/mm^2$

FATIGUE STAGE No.	LOADING LIMITS		STRESSES (related to the remained cable cross-section at every fatigue-stage)			Total number of loading cycles after every fatigue-stage	REMARKS
	P_{upper} t	P_{lower} t	σ_{upper} kg/mm²	σ_{lower} kg/mm²	$\Delta\sigma$ kg/mm²		
1	250,0	225,0	114,4	103,0	11,4	871'100	1. failure
2	"	"	116,1	104,5	11,6	1'216'900	2. "
3	"	"	117,9	106,1	11,8	1'877'700	3. "
4	"	"	119,7	107,7	12,0	1'885'700	4. "
5	"	"	121,5	109,3	12,2	1'946'900	5. "
6	"	"	123,4	111,1	12,3	2'198'900	6. "
7	"	"	123,4	111,1	12,3	2'216'300	End of test

Lower anchorage
2 failures

Upper anchorage
4 failures

All of the six failures took place directly near the cold deformed small heads of the wires. During the $2{,}2 \cdot 10^6$ loading cycles and under lower and upper loading limits of 225t and 250 t respectively, the tested cable-including its both anchor heads-could remain without any other defects than these six failures.

EMPA	Auftrags-Nr.	Auftraggeber:	Gezeichnet:	Zeichnungsnummer:
	67'303/2	Stahlton A.-G., Zürich 58-25	Juli 69 sc	4 — 3411

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

Untersuchungsbericht
Procès-verbal
Processo verbale
TEST - REPORT

EMPA No. 67'303/1

Auftraggeber:
Commettant:
Committente:
Customer: STAHLTON AG — Z U E R I C H

Gegenstand:
Objet:
Oggetto:
Object: A 4 meter long presstressing cable of 58 wires Ø 1/4"

Datum des Eingangs:
Date de l'arrivée:
Data d'arrivo:
Date of receipt: 2.5.1969

Ausführung der Untersuchung:
Exécution de l'essai:
Esecuzione della prova:
Execution of test: till 17.7.1969

DYNAMIC TEST RESULTS

15713/2

DESCRIPTION OF TEST

1. The prestressing cable

- Type: BBRV 58 Ø 1/4"
- Free length: 4 m
- 58 round and unprofiled steel wires Ø 1/4"
- Ultimate tensile strength β_z = 170 kg/mm^2 (According to data given by the customer. See also the experimental results of the tensile tests carried out on the steel wires in EMPA-Report No. 67'303/3).
- Anchorage: The cable was anchored at both ends by means of small cold deformed bottom heads at each wire end and supported on a threaded ring at both anchor heads.

2. Equipment

The tested cable was mounted vertically in a testing frame with a weighing beam (see Figures in appendices 1 & 3).

Lower and upper loading limits of 125 t and 250 t respectively were achieved by using two hydraulic jacks, which were connected to a spring dynamometer. These loading limits could be kept constant during the test with the aid of the Amsler load and deformation regulating unit "The Hydro-Pacer".

Due to the high range of stress applied on the cable, the maximum possible frequency that could be reached was 0,5 cycles per minute.

3. Procedure

The required loading limits could be accurately adjusted by means of a "load cell" which connected the weighing beam with the lower anchor head of the tested cable.

The required 50 loading cycles were exceeded and the test was carried out up to 440 cycles.

4. <u>Results</u>

By visual inspection, after carrying out 440 loading cycles with stress limits of

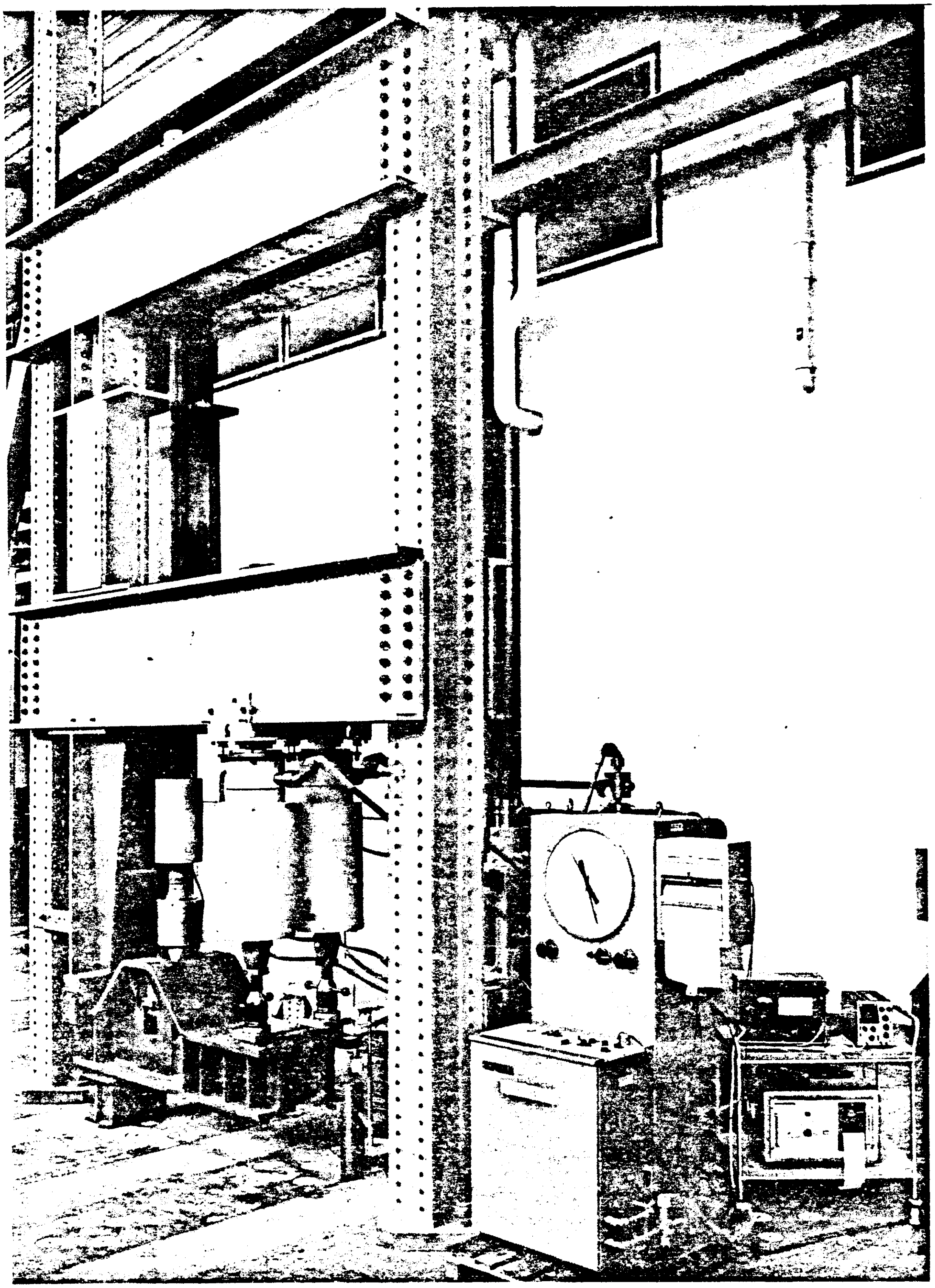
$$\sigma_{lower} = 0,4 \cdot \beta_Z \quad \text{and} \quad \sigma_{upper} = 0,8 \cdot \beta_Z \, ,$$

any defects could not be observed either in the prestressing wires or at the anchor heads (see appendix 4).

Dübendorf, 17th July 1969

Swiss Federal Laboratory for
Testing Materials and Research

Engineer of Test:

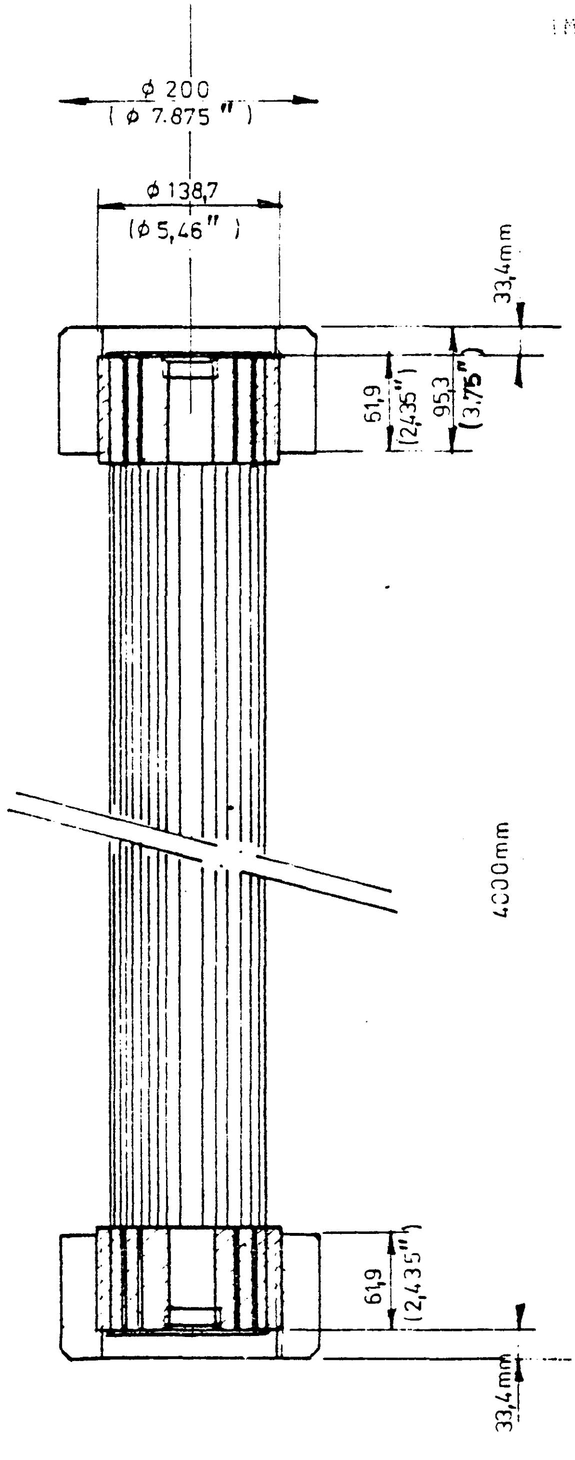


View of the test equipment with the mounted cable, the measuring instrument and the recording apparatus.

Appendix 2

Cable for tension fatigue test at the " EMPA "

IMI-1/FSAK



Inland_Ryerson Const. Prods Co , Chicago

EMPA	Auftrags-Nr.	Auftraggeber:	Gezeichnet:	Zeichnungsnummer:
	67'303/1	Stahlton A.-G., Zürich 58-30	Juli 69	4 — 3406

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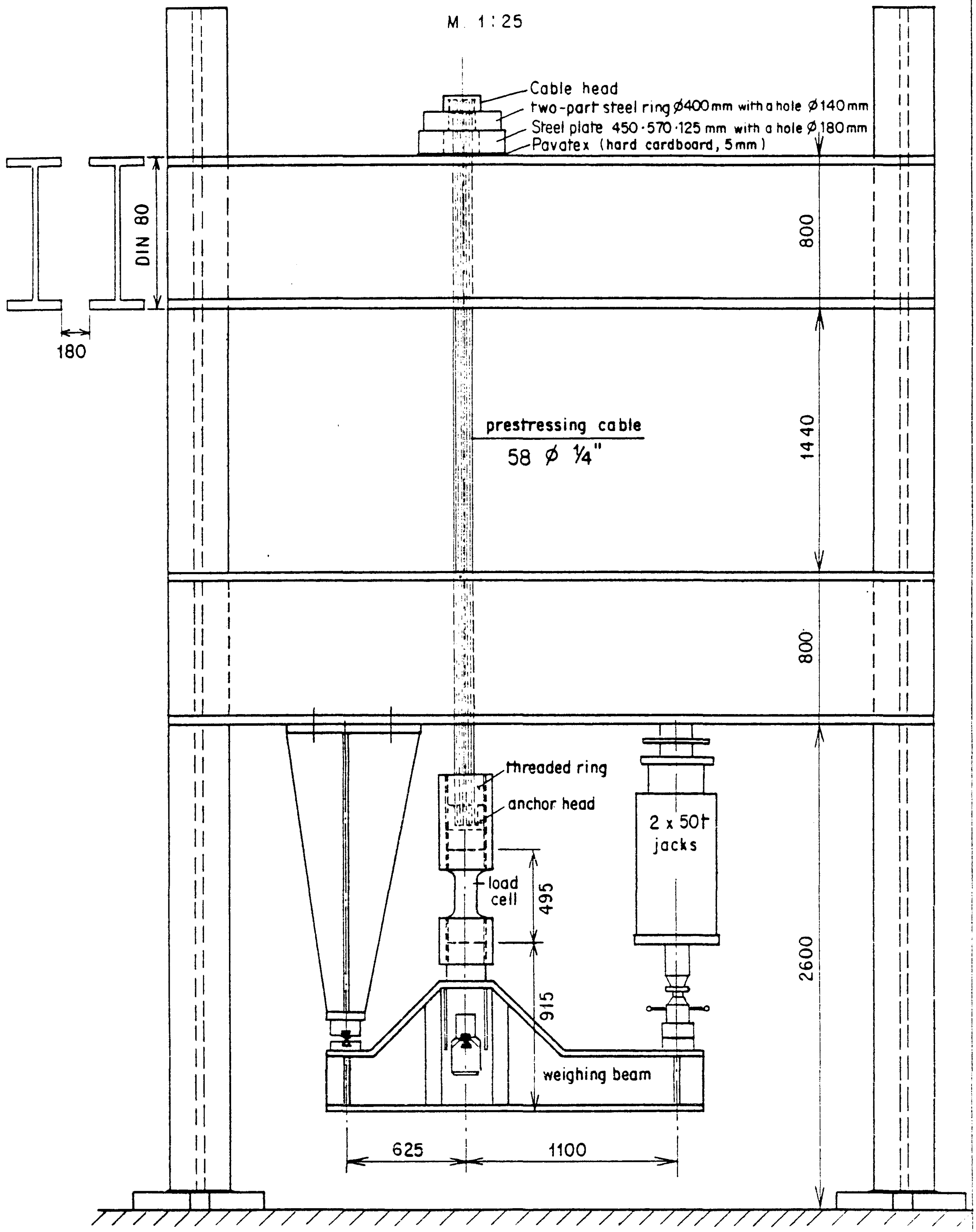
7/82

Appendix 3

Experimental arrangement for a fatigue test on a prestressing cable



F.95224	EMPA	Auftrags-Nr. 67'303/1	Auftraggeber: Stahlton A.-G., Zürich 5B-31	Gezeichnet: Juli 69 se	Zeichnungsnummer: 4 — 3407

UPDATE - 1
7/82

Appendix 4

TRI-17FSAR

TEST RESULTS

test specimen : BBRV prestressing cable 4m long

Nominal values : cross-sectional area : Fe = 58 Ø 1/4" = 58 · 31,65 mm² = 1836 mm²

ultimate tensile strength: β_z = 170 kg / mm²

$\sigma_{upper} = 0{,}80 \cdot \beta_z = 136{,}2\ kg/mm^2$; $P_{upper} = 250\ t$

$\sigma_{lower} = 0{,}40 \cdot \beta_z = 68{,}1\ kg/mm^2$; $P_{lower} = 125\ t$

range of stress $\Delta\sigma = 68{,}1\ kg/mm^2$

LOADING LIMITS		STRESSES			LOADING CYCLES	REMARKS
P_{upper} t	P_{lower} t	σ_{upper} kg/mm²	σ_{lower} kg/mm²	$\Delta\sigma$ kg/mm²		
250	125	136,2	68,1	68,1	440	End of test No defects could be observed either in wires or at anchor heads.

Lower anchorage

no failure of wires

Upper anchorage

no failure of wires

EMPA	Auftrags-Nr. 67'303/1	Auftraggeber: Stahlton A.-G., Zürich 5B-32	Gezeichnet: Juli 69 sc	Zeichnungsnummer: 4 — 3408

UPDATE - 1
7/82

IRI-1/FSAR COPY

Eidgenössische Materialprüfungs- und Versuchsanstalt für Industrie,
Bauwesen und Gewerbe, 8600 Dübendorf
Swiss Federal Laboratory for Testing Materials and Research
— 8600 Dübendorf —

Untersuchungsbericht

TEST-REPORT EMPA No. 67'303/3

Customer: S t a h l t o n AG, 8034 Zurich

Object: Prestressing wires Ø 1/4"

Date of receipt: 11th June 1969 Execution of investigation: till 31st July 1969

Tension and Fatigue Tests

1. Results of two tension tests

carried out on two prestressing wires

(b) (5)

[redacted]

(b) (5)

[redacted]

(b) (5)

[redacted]

(b) (5)

[redacted]

Part
D. STATIC TESTS - TECHNICAL REPORT #8

Part
D. STATIC TESTS - TR-8

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Part
D. STATIC TEST - TR #8

Introduction, Purpose, Summary

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

Testing was divided into four categories:

Series PL - ultimate load tests of 170 wire tendons and anchorages 4 feet long.
Series A - ultimate load and elongation tests of 170 wire tendons and anchorages 30 feet long.
Series B - ultimate shear load of web.
Series C - ultimate shear load of 6 inch diameter thread.

All test results were over acceptable minimums based on conservative basic critera. Therefore, the end anchorage hardware as designed and tested will not be the weakest link in the tendon system.

TECHNICAL REPORT NUMBER 8

THE WCS 2.0.Mep/170 W
POST-TENSIONING SYSTEM

INTERIM REPORT:

CHAPTER 3 - END ANCHORAGE, JANUARY, 1968

TABLE OF CONTENTS

for

CHAPTER 3.0 - END ANCHORAGE

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	REQUIRED FOR 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 ($\geq$ 30 feet) tendon composed of 170 individual ASTM A421 wires of 0.250 inch diameter can be expected to produce an ultimate load $\geq$ 2002.8 kips, and an ultimate elongation $\geq$ 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 ($\overline{\chi}$) 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: $P = (\overline{\chi} - 3\sigma) \times (F_y \div F_u) \geq 2002.8$ kips.

Since neither the mean ultimate load capacity ($\overline{\chi}$) 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:

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

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:

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

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 x 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 analytical 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 k/44 Post-Tensioning System Under Static Loads".

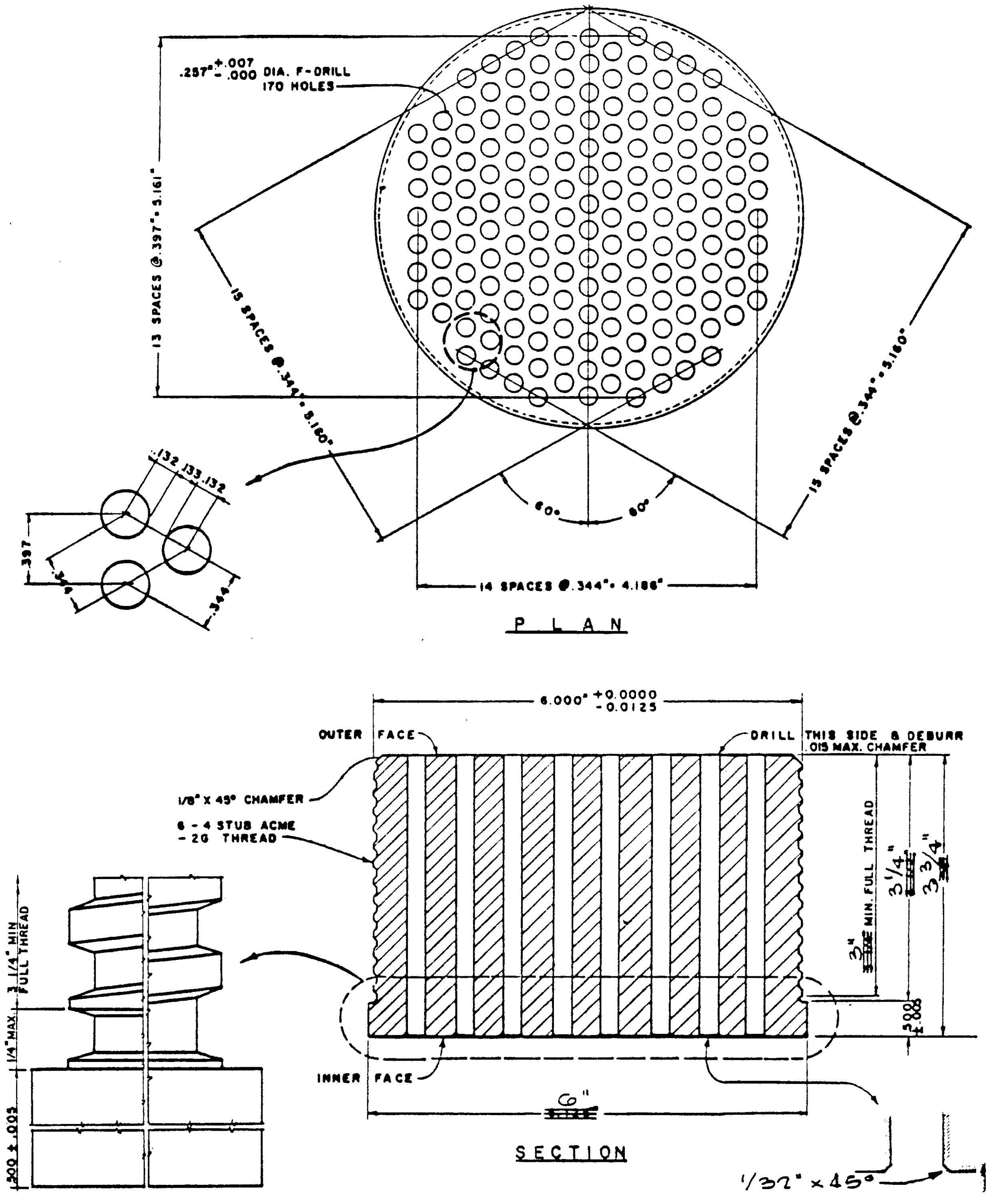
Mechanical properties for the various steels used in the prototype end anchorage components are shown in Table 3.2-2 for various strength levels. Strength levels are listed by equivalent hardness on the Rockwell B or C scales (R_B or R_C) since quality assurance is based upon determination and control 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

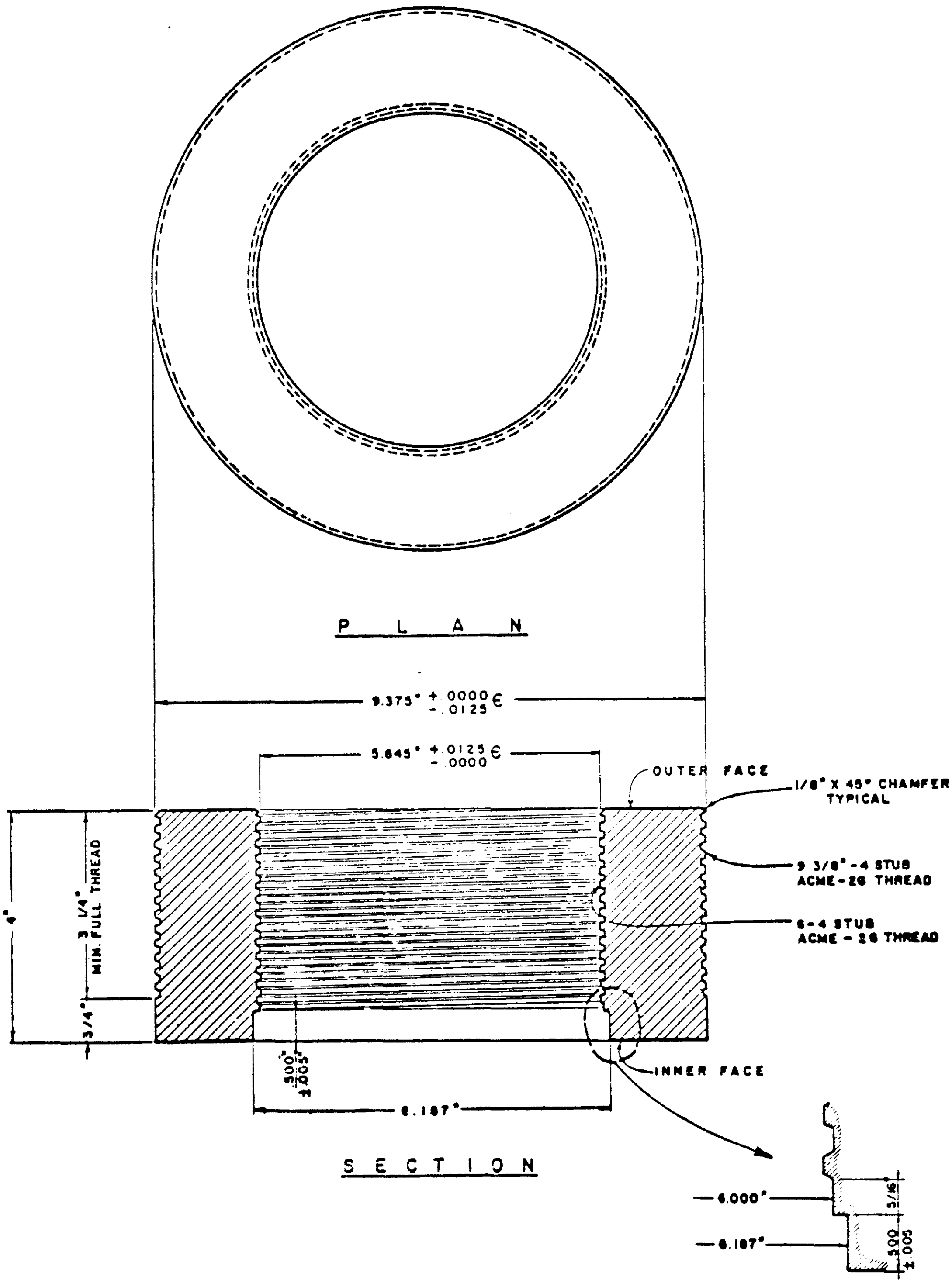
(2) Derived using ratio ($F_{bru} \div F_{tu}$) as indicated for AISI 1025 times F_{tu} for A7 or A36

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

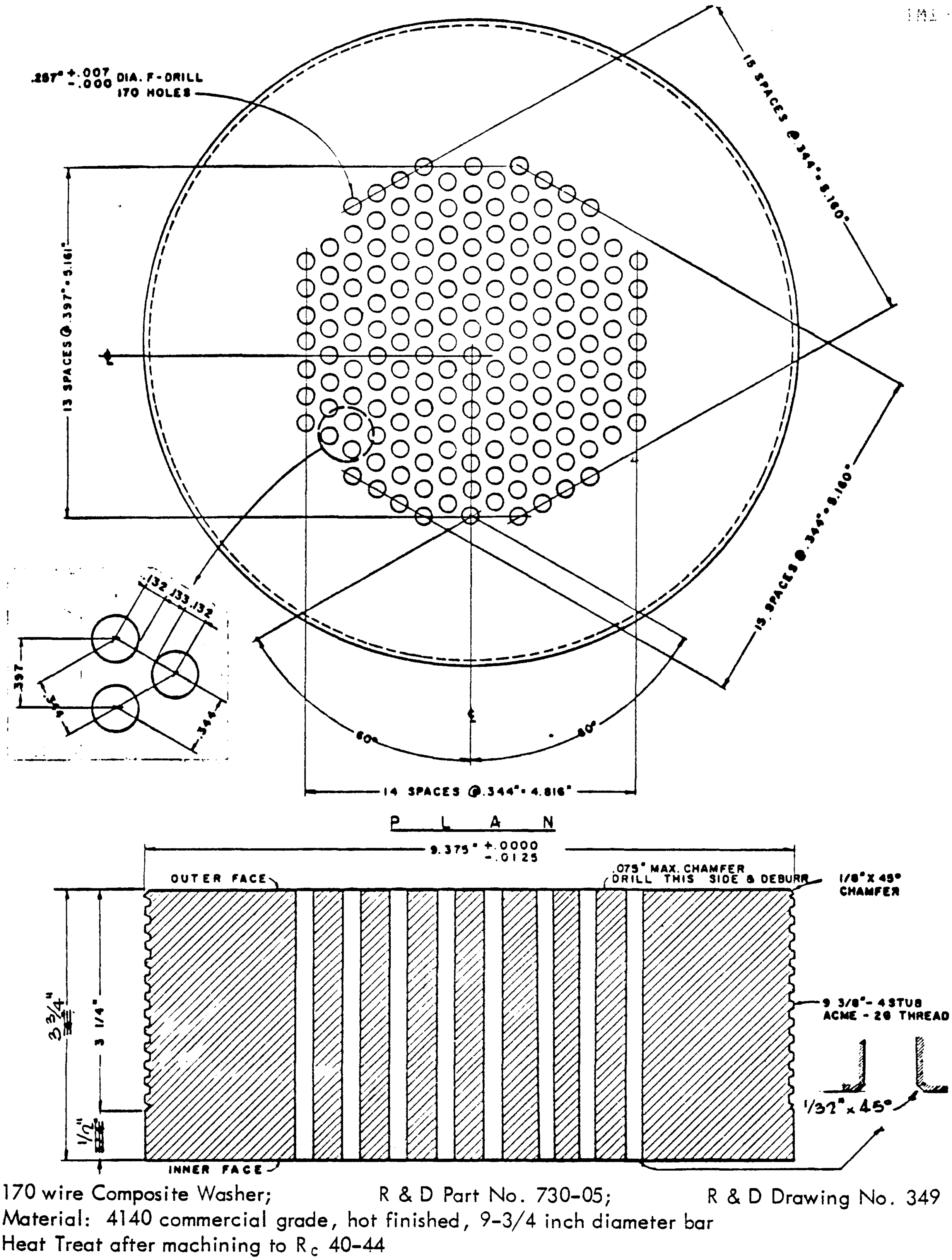


170 wire Washer Nut; R & D Part No. 730-04; R & D Drawing No. 348

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.

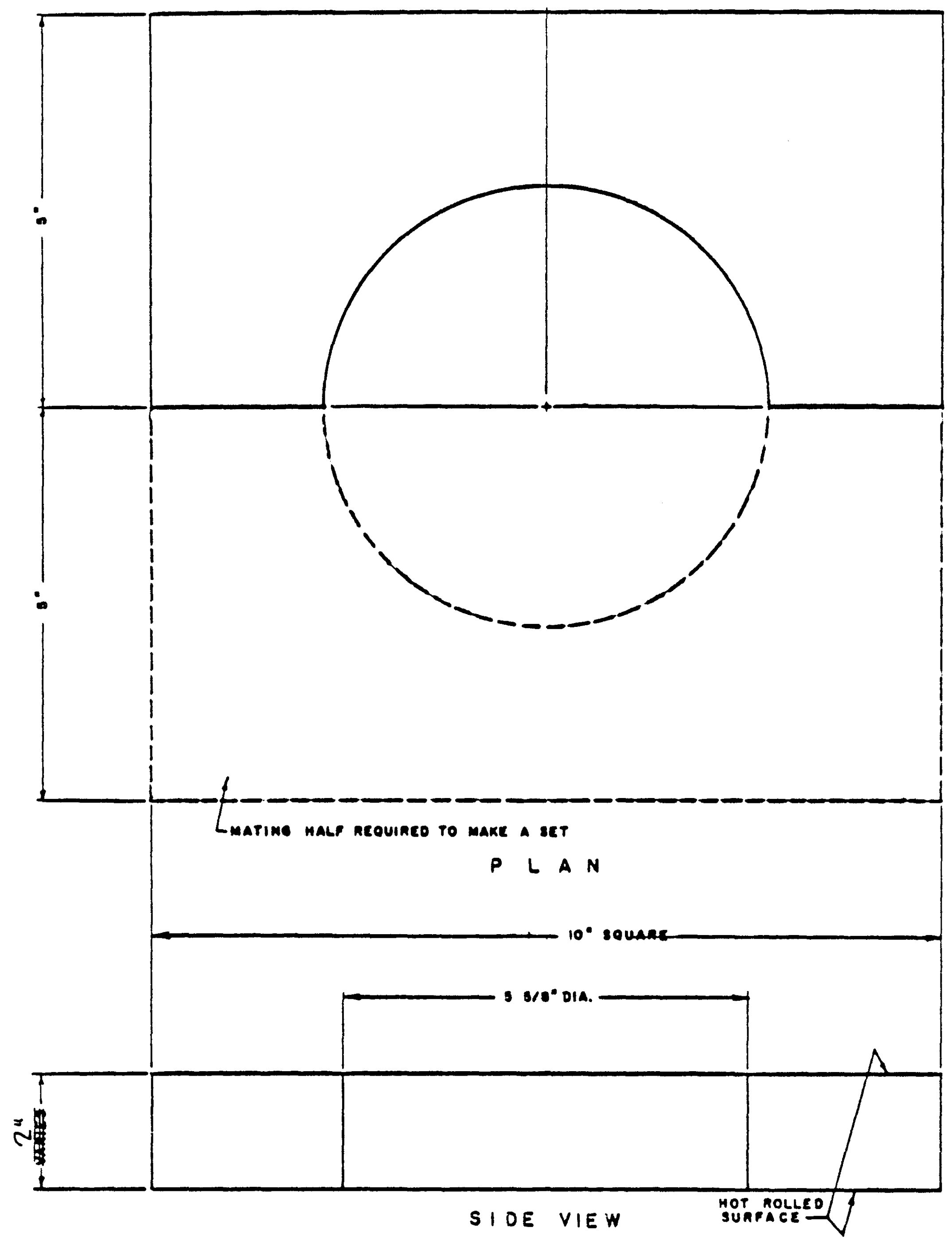
Heat Treat after machining to R_c 40-44

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



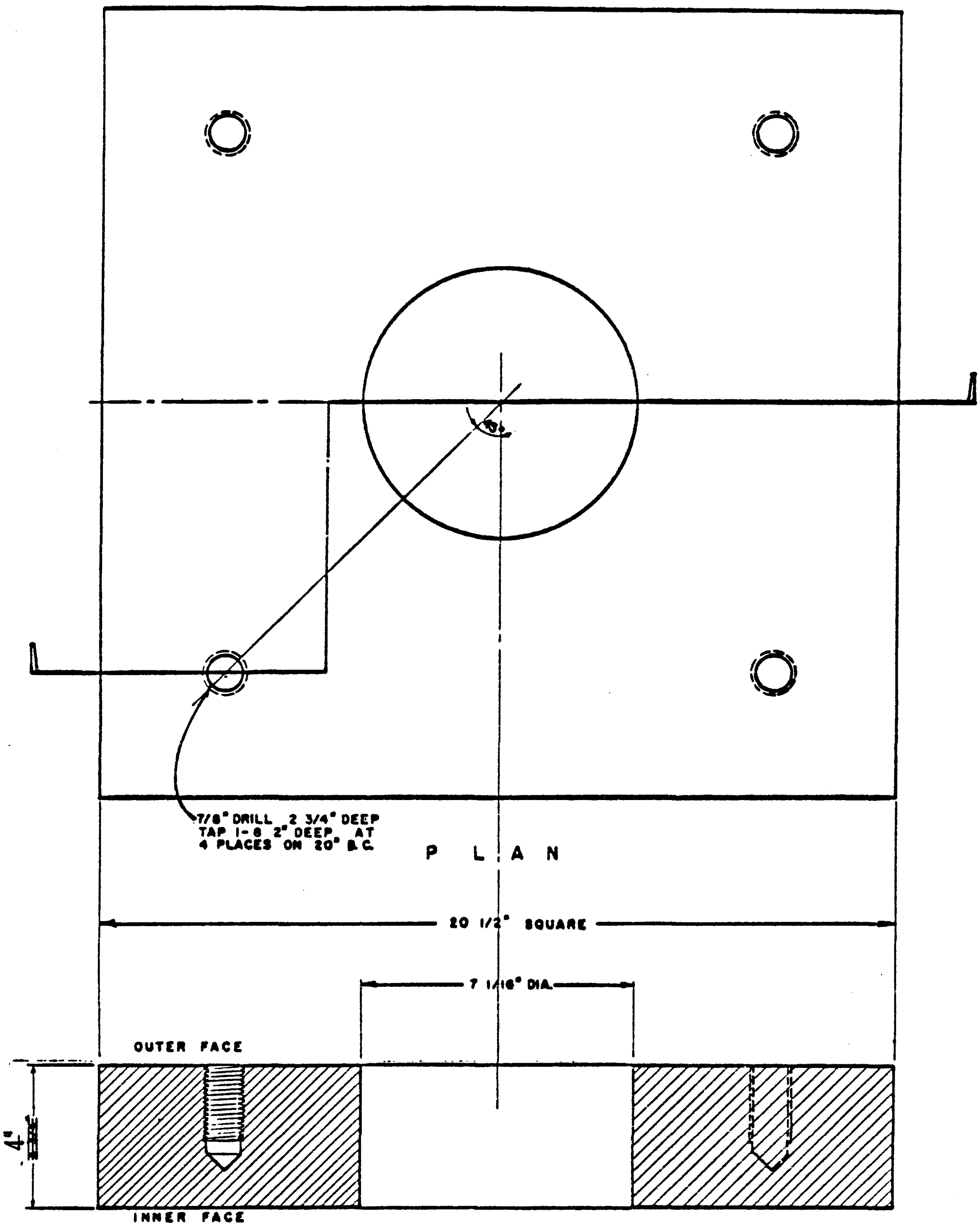
NOTE: THE SURFACES OF THE PLATES COMPRISING A SET SHALL NOT VARY MORE THAN .062".

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 x 20-1/2 inches with 7-1/16 diameter center hole.
Drill and tap four holes for 1 inch diameter x 8 t.p.i. bolt on a 20 inch bolt circle.

Heat Treat: None

FIG. 3.2-5: . Prototype Bearing Plate Drawing

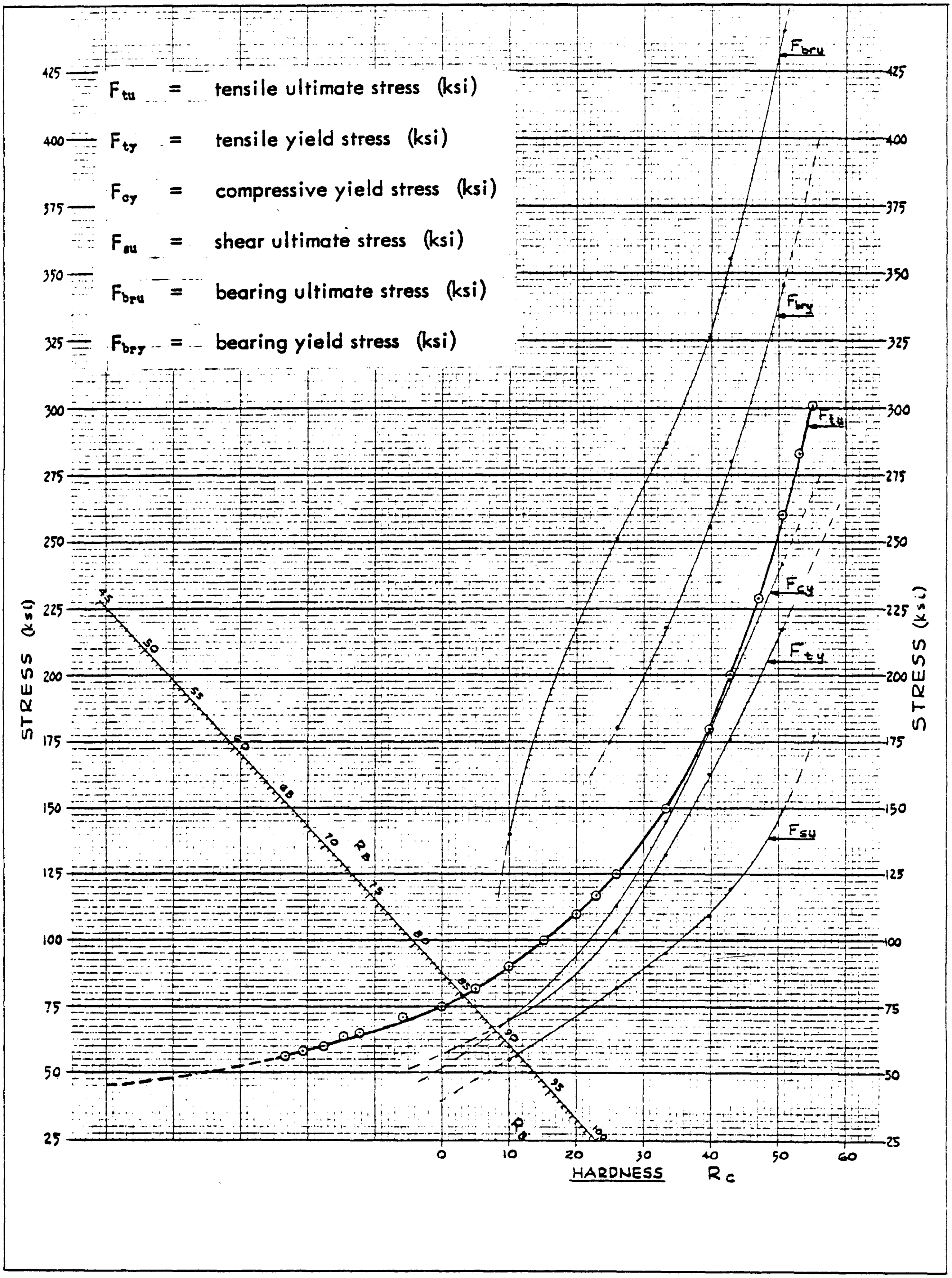


FIG. 3.2-6: Mechanical properties vs. hardness. The curve for tensile ultimate (F_{tu}), showing UTS plotted against Rockwell Hardness (R_B or R_C) is derived from information contained in the 1965 SEA Handbook, pages 107 and 109. Curves designated F_{bru}, F_{bry}, F_{cy}, F_{ty} and F_{su} show other 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 Shim Interface	Compression Flexural Bearing	 3527.9	 2002.8	 1.76	 1201.7	 2.94	
Split Shims	Bearing ℄ Interface* Washer Interface *	Bearing Bearing	3527.9 3357.7	2002.8 2002.8	1.76 1.68	1201.7 1201.7	2.94 2.79	No * Yes *
Composite Washer	Shim Interface * Web * 9-3/8" Threads	Bearing Shear and Flexure Shear	7908.2 2864.4 4342.7	2002.8 2002.8 1602.2	3.95 1.43 2.71	1201.7 1201.7 None	6.58 2.38 ∞	No * Yes * No
Washer Nut	Shim Interface * 9-3/8" Threads 6" Threads with Shims*	Bearing Shear Shear	7908.2 4342.7 3276.5	2002.8 1602.2 2002.8	3.95 2.71 1.64	1201.7 None 1201.7	6.58 ∞ 2.73	No * No Yes *
Washer	Web 6" Threads with Shims*	Shear and Flexure Shear	2864.4 3276.5	2002.8 2002.8	1.43 1.64	1201.7 1201.7	2.38 2.73	Yes 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	↓

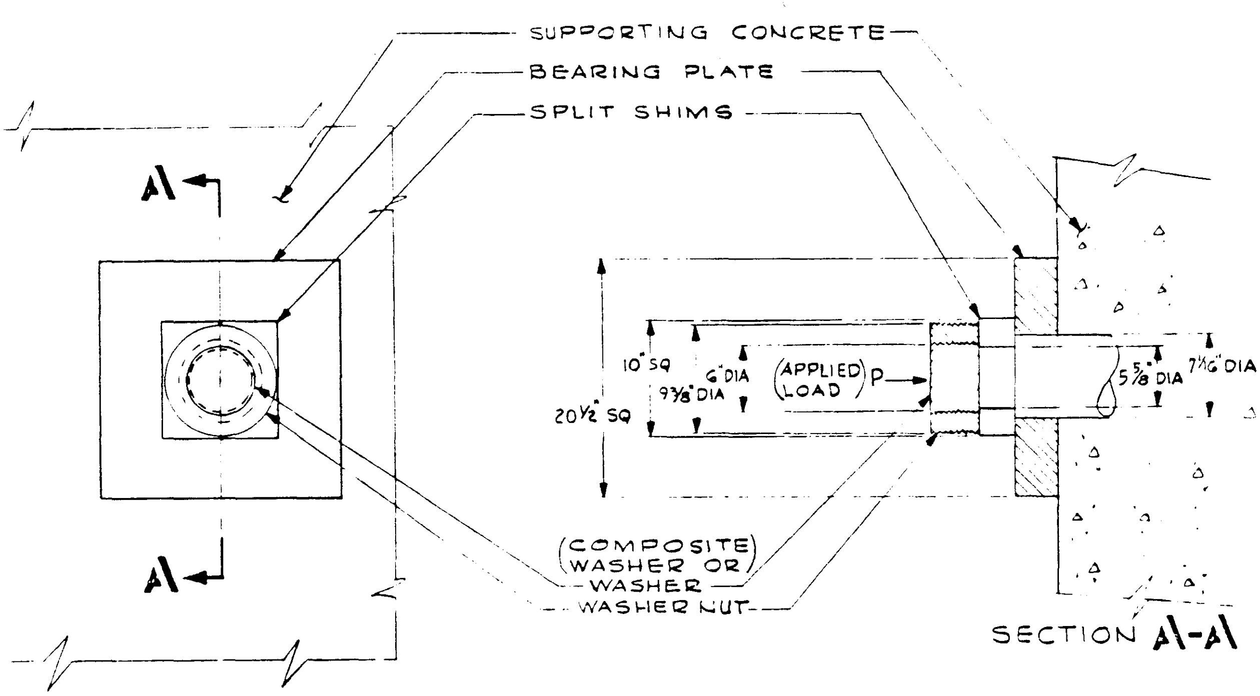


FIG. 3.2-7: Arrangement of Anchorage Components

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

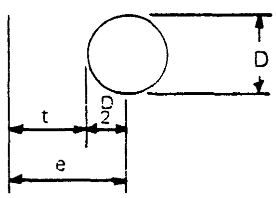
Nominal Area: $A'_s = \dfrac{\pi\,(9.375^2 - 5.625^2)}{4} = 44.18$ sq. in.

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 $D = \dfrac{9.375 - 5.625}{2} = 1.875$

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

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

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

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

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, ∴ $P_c = F_{su} \times A'_s$

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

3.2.5 6 INCH O.D. THREAD - WITHOUT SHIMS (REF. FIG. 3.2-7)

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

A_s' = nominal shear area

L_e = length of thread engagement = 3.250 inches

n = number of threads per inch = 4

p = pitch = l ÷ 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

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

Calculated Ultimate Load:

$$P_c = P_s = F_{su} \times A_s'$$

Predicted Ultimate Loads and Stresses:

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

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 ↓

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:

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

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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.

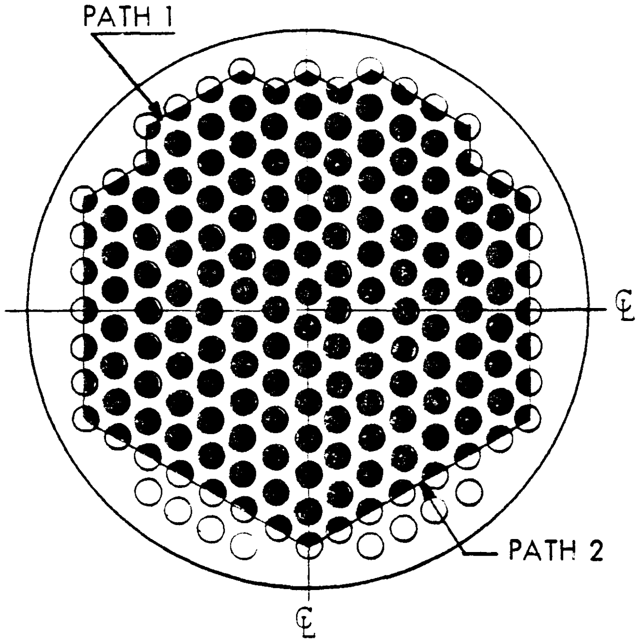

FIG. 3.2-8: Alternate shear paths for wire hole web shear failure with Path 1 shown above horizontal ℄ and Path 2 below. Path 2 is slightly more critical than Path 1.

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:

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

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

N = number of webs along Path 2 = 40

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

$w_{min.}$ = 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.

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:

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

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

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

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.

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[illegible] ; 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

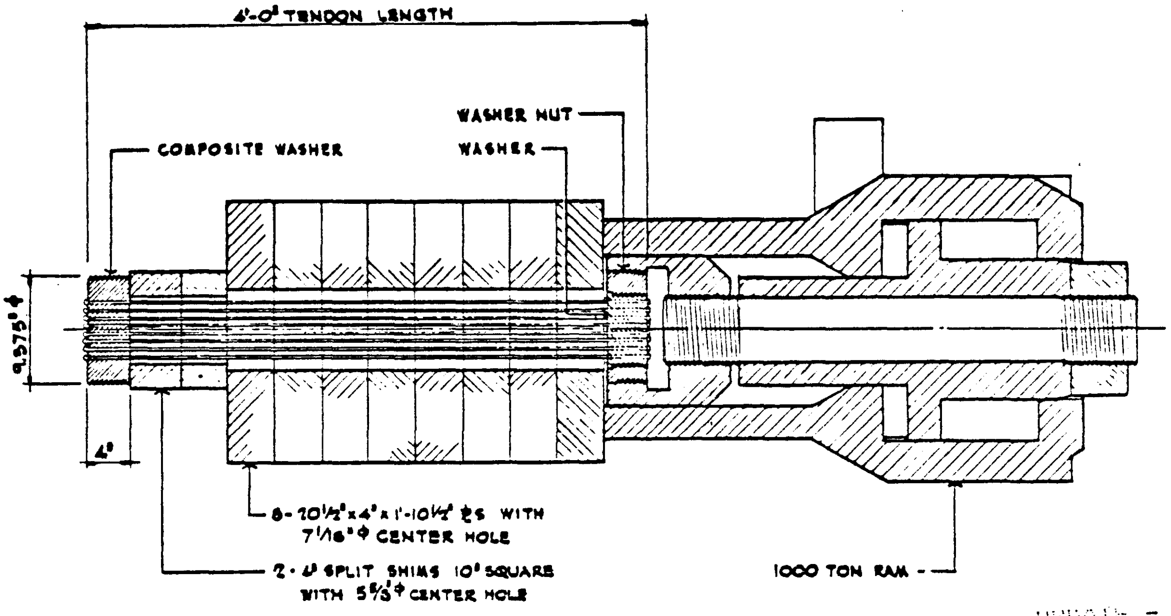

FIG. 3.3-1: Setup for Series PL tests.

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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 .42 ; Mn .83 ; P .008 ; S .020 ; Si .27 ; Cr .92 ; Mo .18 ; Pb .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

	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	≈ 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	53.6	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 .38 ; Mn .76 ; P .008 ; S .025 ; Si .240 ; Cr .90 ; Mo .15 ; Pb -
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.

	Measured Dimensions										Load History						
	External Thread				Internal Thread												
Serial Number	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	.085	.028	.029	5.860	.021	.010	40.5	385	388	PL-4					C2-9	
002	9.372	.088	.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	5.392	.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	.0878	.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					
			Clearance		Hardness								
Serial Number	Major Diameter	Thread Depth	Pitch Dia.	Axial	R_c	≈ BHN	Lab.	Series PL	Series A		Test Bed	Series B & C	General Atomic Tests
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	-						
n	15	15	15	15	15	15	5						
$\overline{X}$	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.

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								
			Part Serial Numbers					
			Left			Right		
Test Number	Test Date	Max. Load (kips)	Washer	Nut	Compo	Washer	Nut	Remarks
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

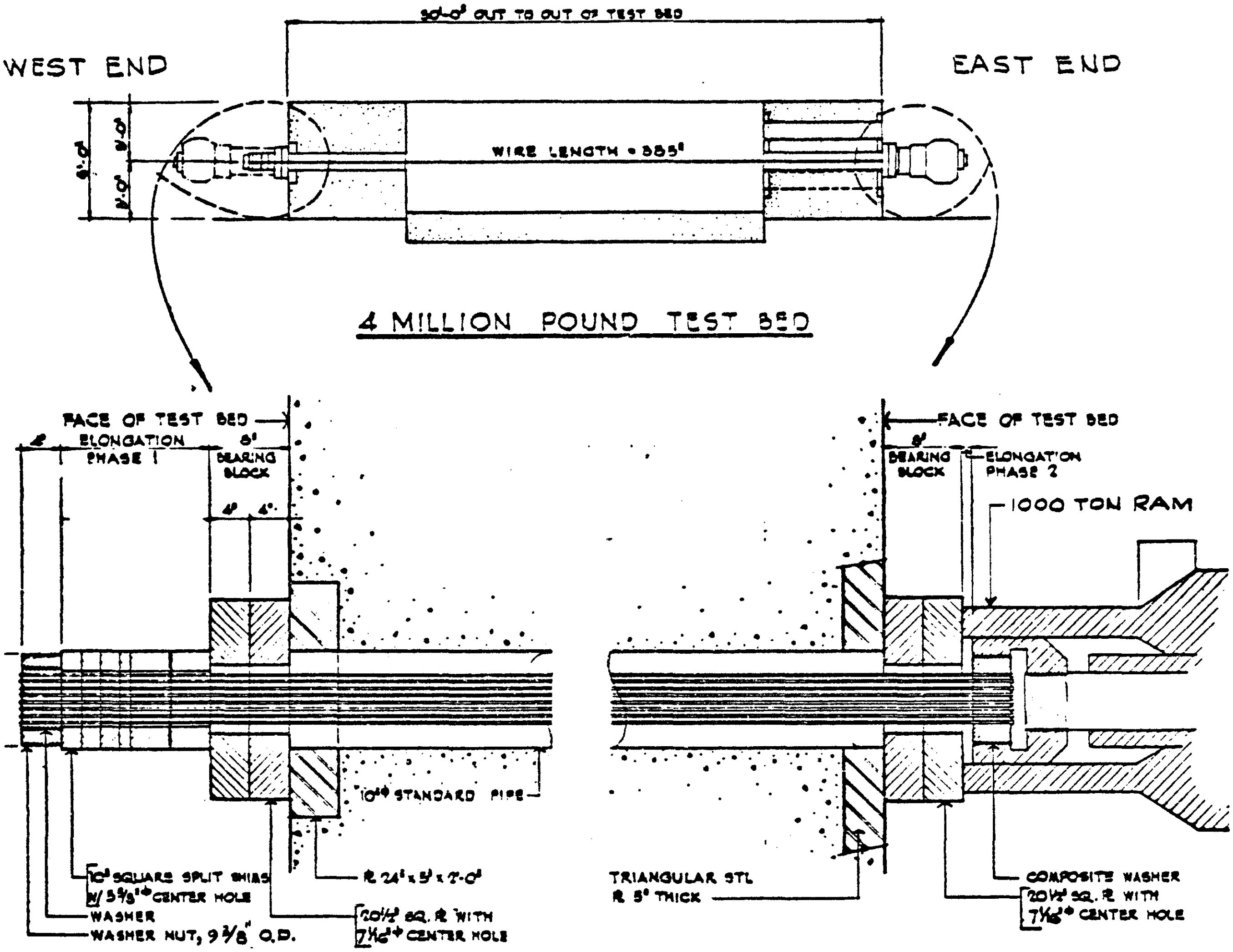


FIG. 3.3-2: Test setup for Series A tests.

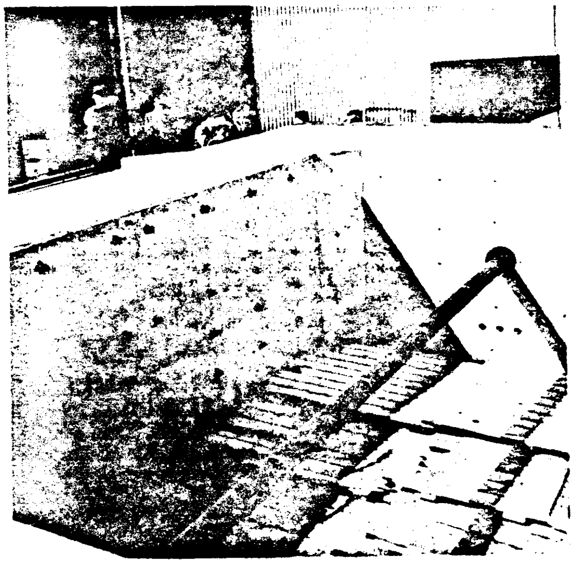


FIG. 3.3-3: Series A. 170 wire banded tendon installed through center hole of 4.0 Mep test bed.

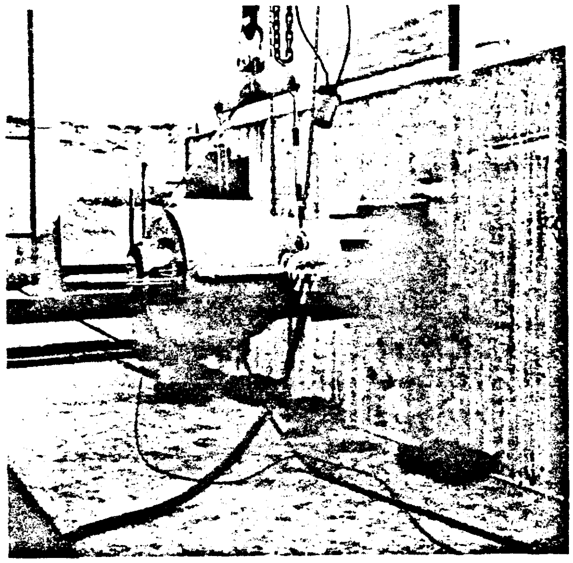


FIG. 3.3-4 Series A. Stressing jack attached to tendon at west end for Phase I elongation.

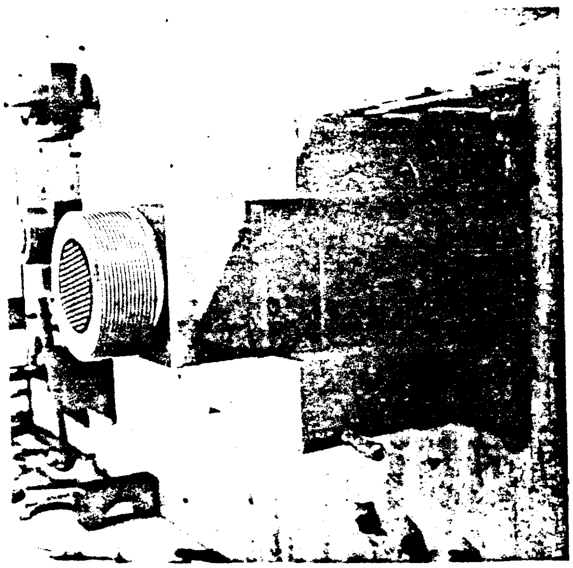


FIG. 3.3-5: Series A. West end after Phase I elongation, showing 14" to 16" shims is place retaining elongation of prototype washer - washer nut anchorage hardware.

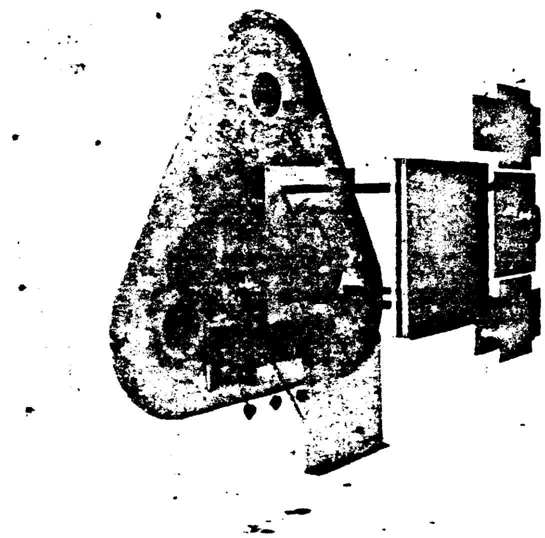


FIG. 3.3-6: Series A. Prototype composite washer at east end at the same test stage as that shown in Fig. 3.3-5. The wire deflector plate, shown in place, is removed prior to installation of 1,000-ton Stressing Ram for Phase II elongation.

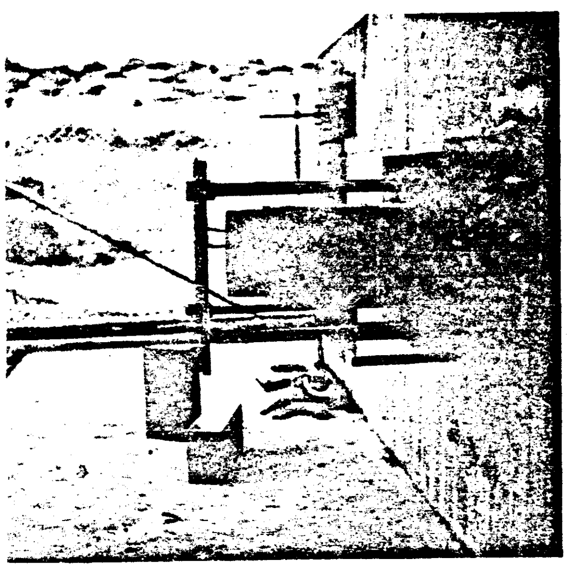


FIG. 3.3-7: Series A. West end during test A-2. Two wires have failed at a force of 2,054k at an elongation of 17.0 inches and can be seen against the deflector plates. At this stage of the test, Phase II elongation is being applied at the opposite (east) end of the tendon.

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.

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.

WIRE FOR TEST A-1

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

E_s : 29.3 x 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_{tu} (kips)	F_{ty} (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	5.05
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

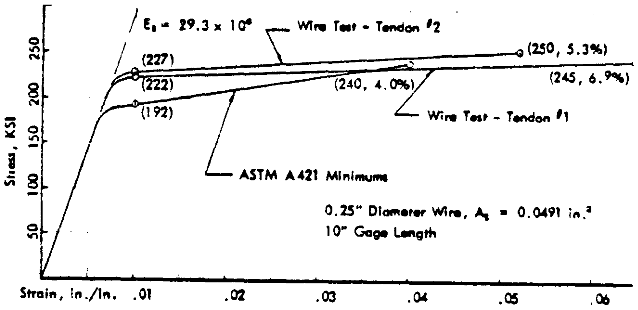
Source: United States Steel Corporation
Heat Number 87 B756
Coil Number 63

E_s : 29.3 x 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_{tu} (kips)	F_{ty} (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.



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 ADX (kips)	Load Hydraulic Gauge (psi)	Load Hydraulic Gauge (kips)	Elong. (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	
2030	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	
2000	9400	1999	14.90	
-	9800	2084	16.00	ADX indicator off scale.
-	9800	2084	16.20	2 wires failed at heads.
-	9750	2073	16.65	2 wires failed at heads.

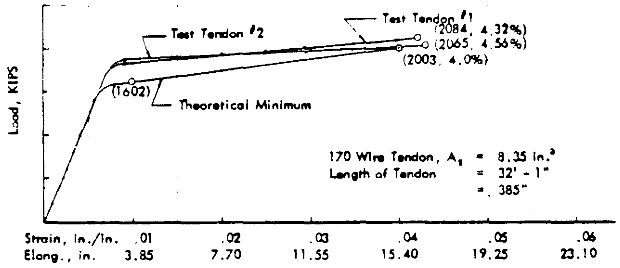
TABLE 3.3-8: Test data for Series A, test A-1.

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 ADX (kips)	Load Hydraulic Gauge (psi)	Load Hydraulic Gauge (kips)	Elong. (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	2065	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.



TEST RESULTS

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 theoretcally 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 East Compo.	Part Serial Number West Washer	Part Serial Number West Nut	Test Results Load (P_t'') (kips)	Test Results Elong (E_t'') (inches)	Gauge Length (inches)	Elong. (%)	Analysis of Ultimate Force Results P'_{170} ⑤ (kips)	P''_{170} ⑥ (kips)	nR_p ⑦	tR_p ⑧	Analysis of Ultimate Elongation Results E'_t ⑨ (inches)	E''_t ⑩ (inches)	nR_E ⑪	tR_E ⑫
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	0.964			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'_{170} = 170 × P'_w = 170 × 11.781 = 2002.8 kips
⑥ P''_{170} = 170 × P''_w = 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_t'' / P'_{170}
⑧ tR_p = P_t'' / P''_{170}
⑨ E'_t = nominal elongation of tendon = nominal elongation of wire (E'_w) × gauge length. E'_w = 4.0%.
⑩ E''_t = theoretical actual elongation of tendon = actual elongation of wire (E''_w) × gauge length.
For A-1, E''_w = $\bar{X}$ (elongation) = 6.9% ③. Therefore E''_t = 0.069 × 385 = 26.57 inches.
For A-2, E''_w = $\bar{X}$ (elongation) = 5.28% ④. Therefore E''_t = 0.0528 × 384 = 20.28 inches.
⑪ nR_E = E''_t / E'_t
⑫ tR_E = E''_t / E''_t

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

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.

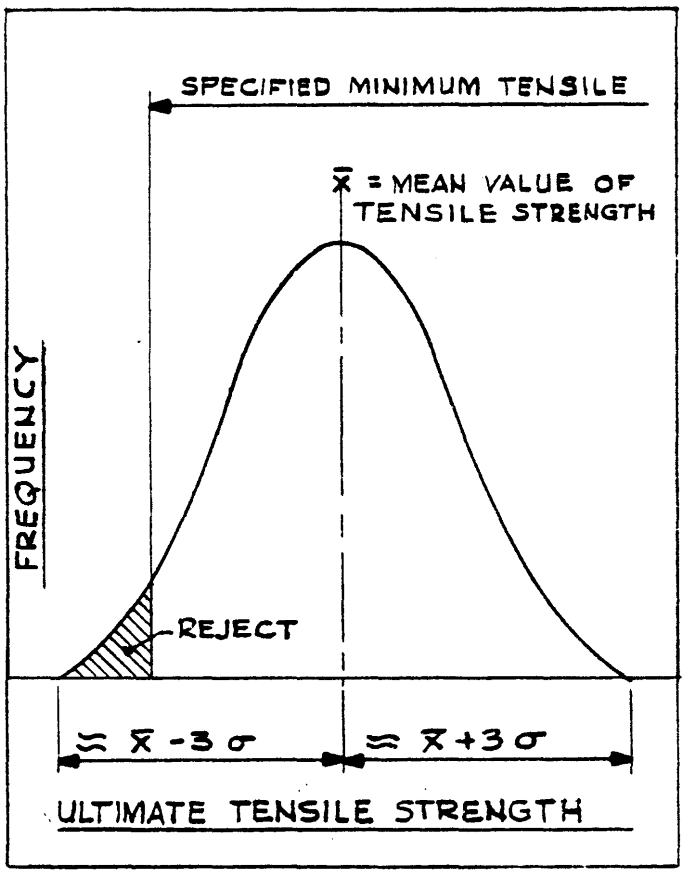


FIG. 3.3-10: Frequency distribution of ultimate tensile strength for all coils of a mill heat of 0.250 inch diameter ASTM: A421 wire.

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-

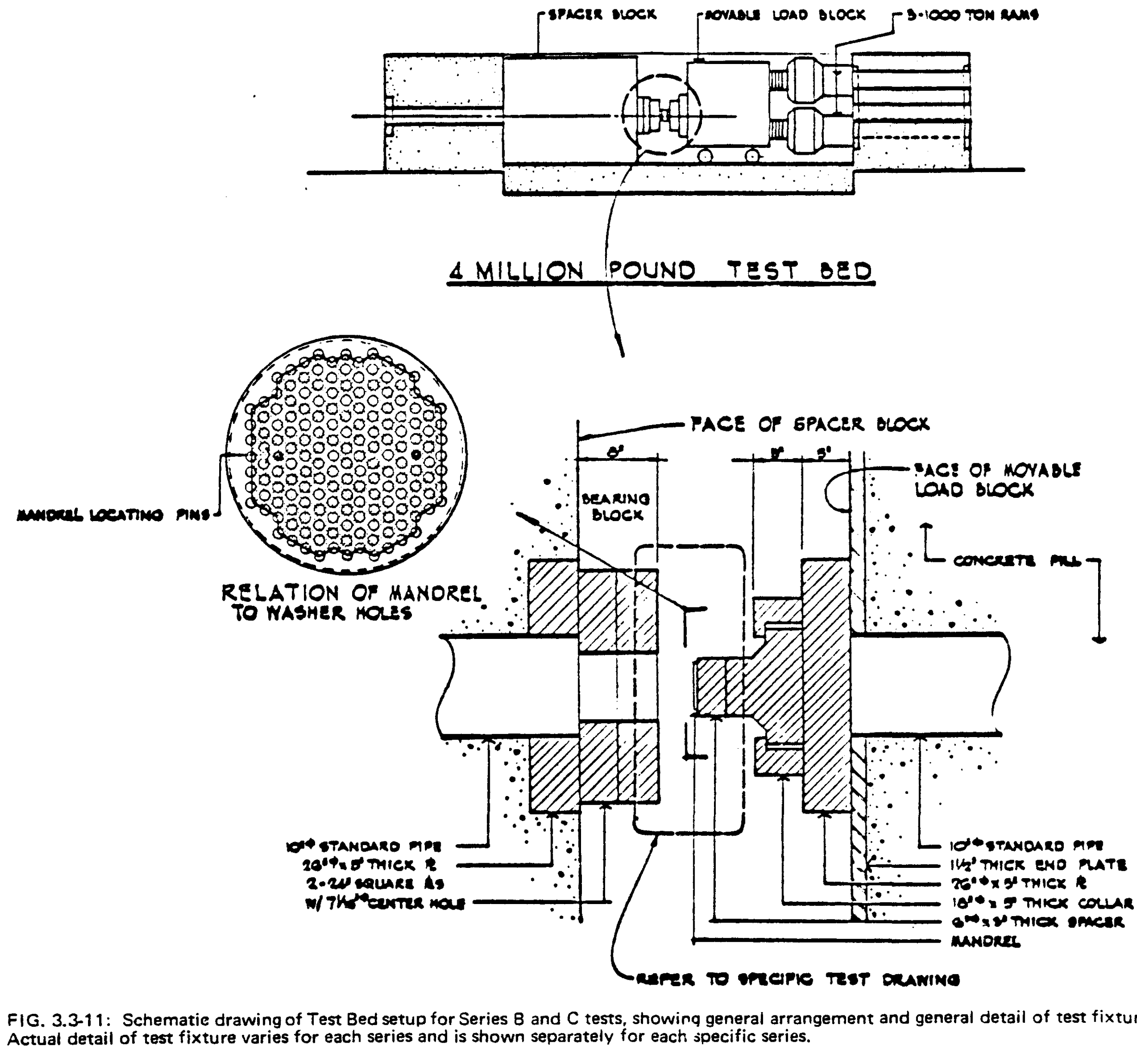


FIG. 3.3-11: Schematic drawing of Test Bed setup for Series B and C tests, showing general arrangement and general detail of test fixture. Actual detail of test fixture varies for each series and is shown separately for each specific series.

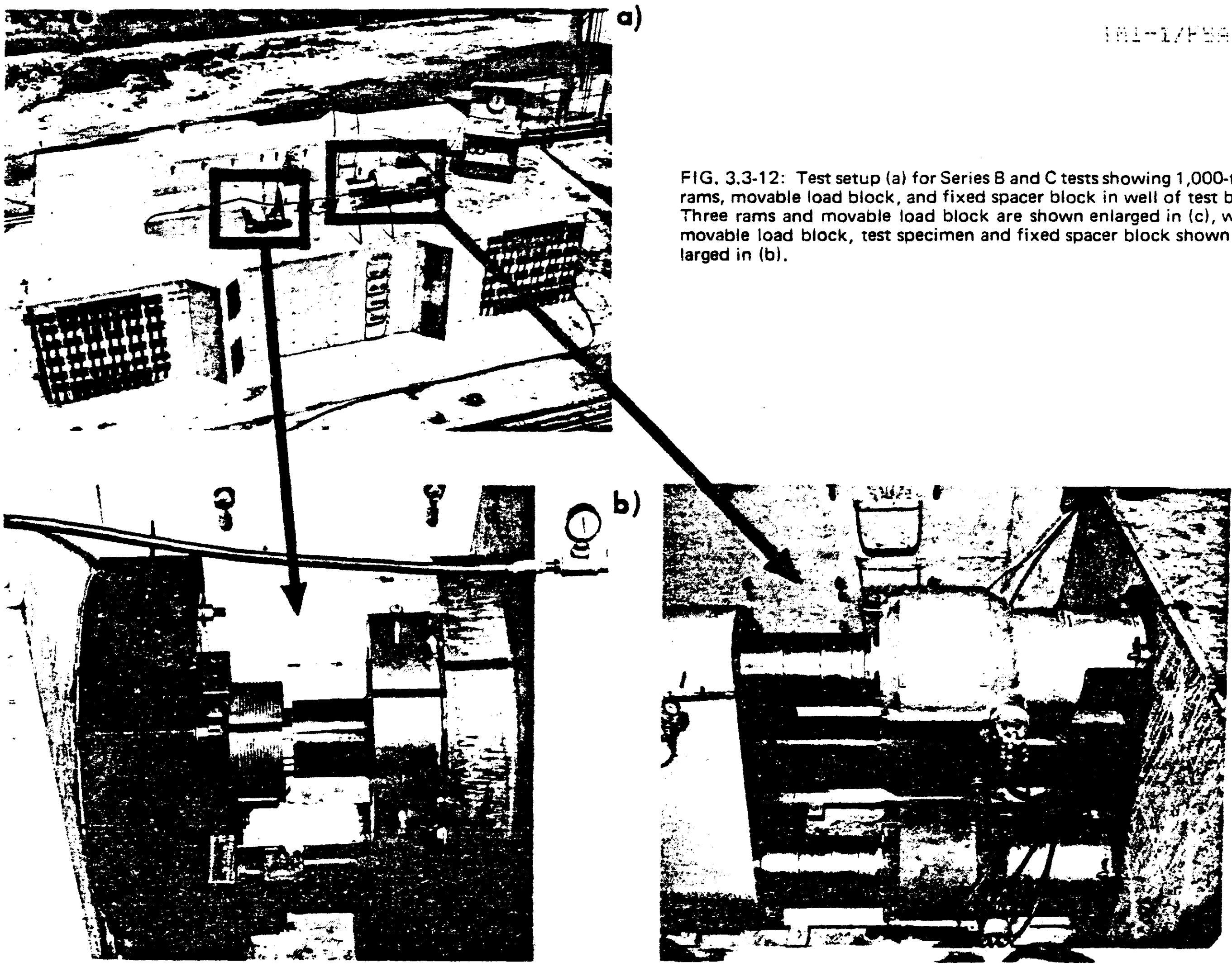


FIG. 3.3-12: Test setup (a) for Series B and C tests showing 1,000-ton rams, movable load block, and fixed spacer block in well of test bed. Three rams and movable load block are shown enlarged in (c), with movable load block, test specimen and fixed spacer block shown enlarged in (b).

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 ($38.2 \div 40.5 = 0.943$) is quite close to the ratio of predicted ultimate to actual ultimate ($2509.7 \div 2613 = 0.9605$), 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.

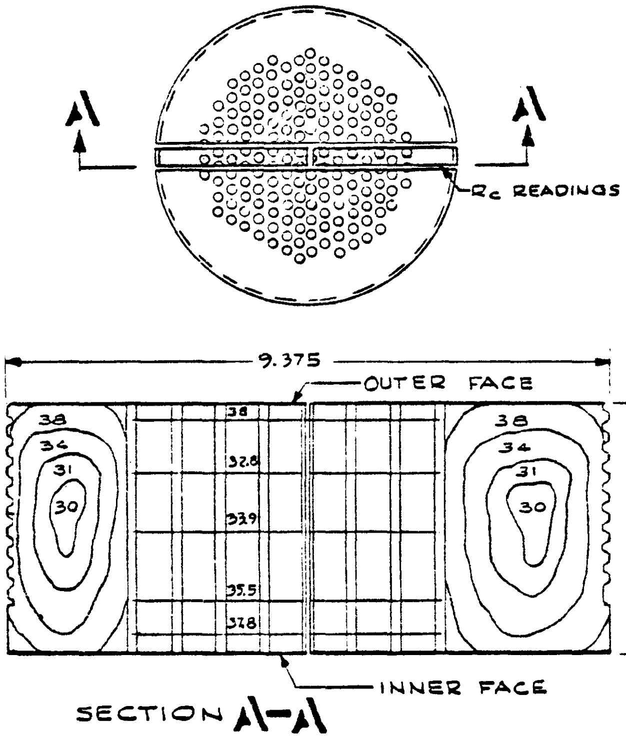


FIG. 3.3-13: Schematic drawing of section cut from Composite Washer Serial No. 002 after having been loaded to web failure in test B1-1. R_C hardness values were measured for approximately 100 points. Distribution of material hardness throughout the cross section is as shown by the schematic iso-hardness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

Test Designation Series	No.	Description	Test Date	Components (with Serial No.) Washer	Washer Nut	Compo Washer	Split Shims	Failure Load Predicted (kips)	Actual (kips)	Error (Note 1) = (%)	Equiv Tendon UTS (Note 2)	Safety Factor (Note 3)	Remarks
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.

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.

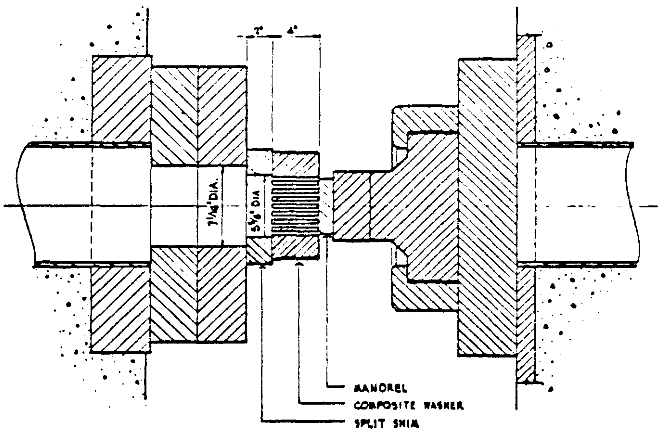


FIG. 3.3-14: Fixture for Series B1 tests. Components being tested are shown shaded. Mandrel conforms to shape illustrated in Fig. 3.3-11 for Path 1 shear failure mode.

Test 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
v	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	3197.9	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} × A'_s)/k_r; k_r = 1.0
3. Error = (P'_c - 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'_T (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'_T (min.)/P'_{270} = P'_T (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_e) = 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 = 0.024 in.
480	306	100	95	285	
1900	1212	400	375	1185	
2830	1806	600	595	1785	
3760	2399	804	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_e) = 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 = 0.012 in.
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	FAILURE { SHEAR THRU WEB
4220	2692	896±	891	2673	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

$= \frac{P_i'}{R_e} = \frac{2564.0}{0.829} = 3092.8$ 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_e) = 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	870±	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

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.

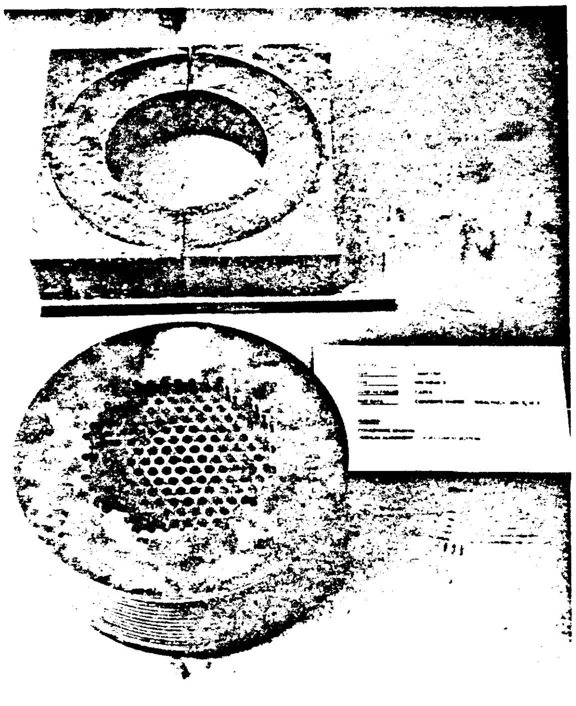


FIG. 3.3-18: Outer face of Composite Washer and Split Shims of test B1-3 after being loaded to ultimate. Note that shear failure is along Path 1 only. Photos here and in Fig. 3.3-19 are typical for all tests in Series B1.

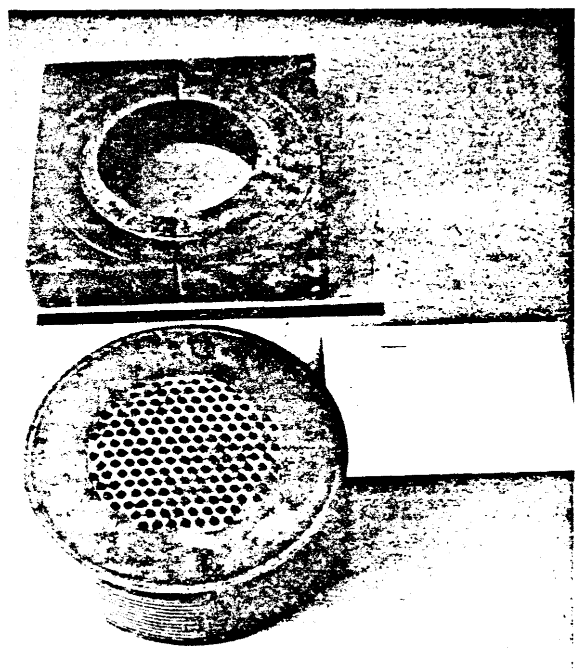


FIG. 3.3-19: Inner face of Composite Washer and Split Shims of test B1-2 after being loaded to ultimate. Note that shear failure is along both Paths 1 and 2.

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.

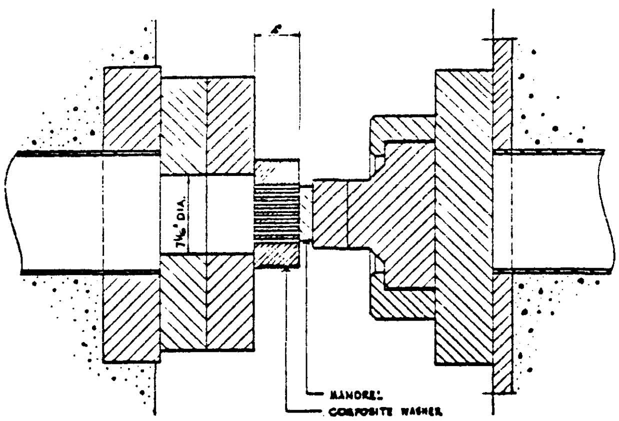


FIG. 3.3-20: Test setup for the two tests in Series B2.

Test Desig.	Calculated UTS (P_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
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_c') = F_{su} x 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_c' - P'') x 100 ÷ P'' (percent)
4. Revised Rupture Factor: k_r = P_c'/P''
5. Minimum Equivalent Tendon UTS: P'' corrected to minimum F_{su}
   P_T' (min.) = (P''/R_p) x (min. F_{su} @ R_c 40/F_{su} of Specimen)
   For failure along shear Path 1, R_p = 0.829
   For the specified minimum R_c = 40, F_{su} = 109 ksi
6. Safety Factor: SF = P_T' (min.)/P_{ISA}' = P_T' (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	Rc	42.6	117.4
~~Split Shims~~				

① From Fig. 3.2-6

PREDICTED FAILURE LOAD

$P_s' = \frac{F_{su} \times A_s'}{k_r} = \frac{117.4 \times 22.61}{} = 2654.4$ kips

P' = equivalent tendon load

$= \frac{P_s'}{R_p} = \frac{2654.4}{0.829} = 3201.9$ kips

where:

		PATH 1	PATH 2
F_{su}	from Table 3.2-2		
A_s'	=	22.61	20.55
R_p	=	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 = 0.016 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_s'' =				(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 x 0.638
③ Load = ADX-38 Reading x 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	Rc	42.0	115.0
~~Split Shims~~				

① From Fig. 3.2-6

PREDICTED FAILURE LOAD

$P_s' = \frac{F_{su} \times A_s'}{k_r} = \frac{115 \times 22.61}{} = 2600.2$ kips

P' = equivalent tendon load

$= \frac{P_s'}{R_p} = \frac{2600.2}{0.829} = 3136.5$ kips

where:

		PATH 1	PATH 2
F_{su}	from Table 3.2-2		
A_s'	=	22.61	20.55
R_p	=	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 = 0.017 in.
930	593	200	195	585	
1860	1187	400	395	1185	
2800	1786	600	595	1785	
3740	2386	800	795	2385	
3960	2526	842	837	2511	FAILURE - SHEAR THRU WEB
					ALONG PATH 1 PRIMARILY
P_s'' =				(2518)	
P'' =	2518 ÷	0.829		3038	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. 3.3-22: 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 $\bar{X}$ 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.

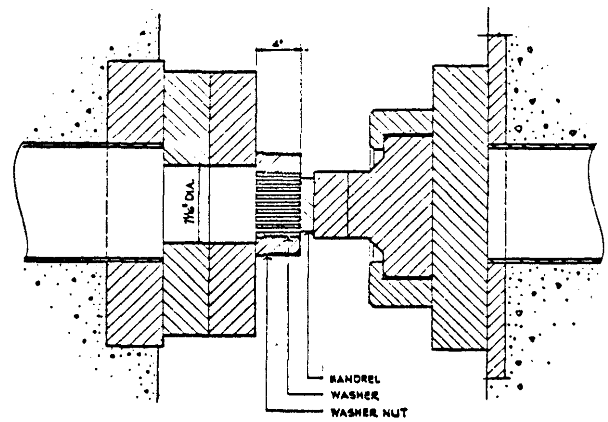


FIG. 3.3-23: Test setup for the three tests in Series C2.

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 SCALE	HARDNESS READING	UTS ① (ksi)
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

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

$P'_{br} = F_{bru} \times A'_{br} = 8.79\,F_{tu} = 8.79 \times$ ____ = –0–

$P' = P'_s + P'_{br} = 2903.5$ 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_{bru} = 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 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 = in.
980	625	200	195	585	
1860	1187	400	395	1185	
2800	1786	600	595	1785	
3740	2386	800	795	2385	
4140	2641	930	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 Reading 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 SCALE	HARDNESS READING	UTS ① (ksi)
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

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

$P'_{br} = F_{bru} \times A'_{br} = 8.79\,F_{tu} = 8.79 \times$ ____ = –0–

$P' = P'_s + P'_{br} = 2817.2$ 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_{bru} = 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 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 = 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 SCALE	HARDNESS READING	UTS ① (ksi)
Washer (Solid)	013	Rc	39.0	108.0
Washer Nut	001	Rc	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

$P'_{br} = F_{bru} \times A'_{br} = 8.79 F_{tu} = 8.79 \times$ ____ = -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_{bru} = 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 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 = in.
960	612	200	195	585	
1880	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 x 0.638
③ Load = ADX-38 Reading x 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
$\bar{X}$ + 3σ	3321.6	3019.7	3121.8	- 6.42	1.13	2952.9	1.48
$\bar{X}$ - 3σ	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) x 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) x 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'' x F_{su}(min) / F_{su} (actual) = P'' x 109/F_{su} (actual).
6. Safety Factor (S.F.) = P'_T (min.)/min. guaranteed tendon UTS S.F. = P'_T (min.)/ 2002.8

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 σ 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 σ 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.

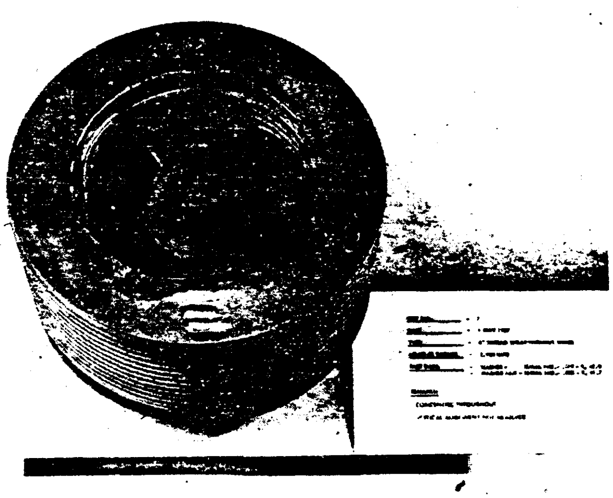


FIG. 3.3-27: Outer face of Washer Serial No. 010 and Washer Nut Serial No. 005 after being loaded to ultimate in Test C2-1.

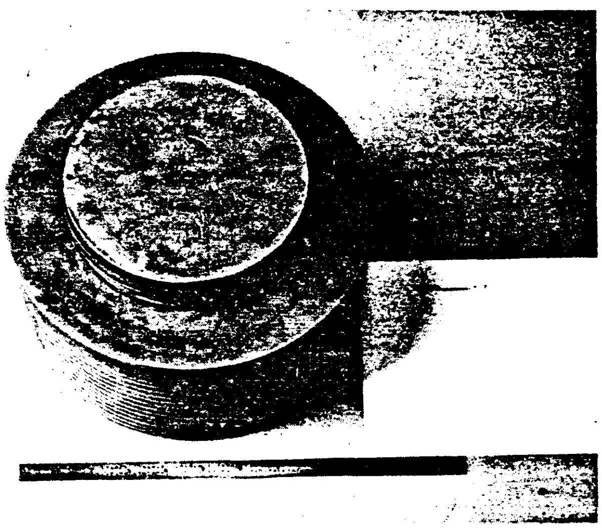


FIG. 3.3-28: Inner face of components shown in Fig. 3.3-27. Both photos are typical for Series C2 components after failure.

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.

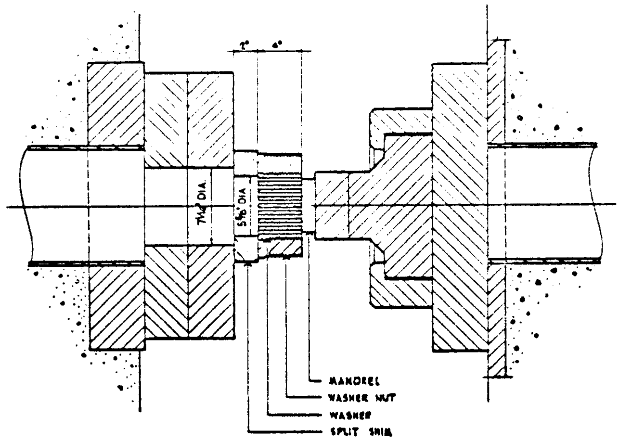


FIG. 3.3-29: Test setup for the two tests of Series C1.

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_f' 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
$\bar{X}$ + 3σ	2913.7	668.0	3581.7	3744.0	6.72	3.28	3461.3	1.73
$\bar{X}$ - 3σ	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_f' (min.) from Table 3.3-14 x 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}') = $F_{bru} \times A_{br}' = C_{br} \times F_{tu}$ (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_f' (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	HARDNESS READING	UTS (1) (ksi)
Washer (Solid)	014	Rc	41.0	113.0
Washer Nut	008	Rc	42.0	113.0
Split Shims	—	RB	77	64.0

(1) From Fig. 3.2-6

PREDICTED FAILURE LOAD

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

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

$P' = P_s' + P_{br}' = 3430.5$ 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.
$F_{bru} = 2.57\ F_{tu}$ (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 x 212.65 = 637.95 sq. in.

LOAD DATA

TEST GAUGE (1) READING (psi)	TEST GAUGE LOAD (2) (kips)	TRANSDUCER (1) ADX-38 READING Intended	ADX-38 READING 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-38 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	HARDNESS READING	UTS (1) (ksi)
Washer (Solid)	011	Rc	41.0	113.0
Washer Nut	002	Rc	41.0	113.0
Split Shims	—	RB	79	70.0

(1) From Fig. 3.2-6

PREDICTED FAILURE LOAD

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

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

$P' = P_s' + P_{br}' = 3483.2$ 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.
$F_{bru} = 2.57\ F_{tu}$ (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 x 212.65 = 637.95 sq. in.

LOAD DATA

TEST GAUGE (1) READING (psi)	TEST GAUGE LOAD (2) (kips)	TRANSDUCER (1) ADX-38 READING Intended	ADX-38 READING Actual	LOAD (3) (kips)	REMARKS
					Preload. Gap = in.
960	612	200	195	565	
1890	1206	400	395	1185	
2830	1806	601	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	1188	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'' = 3561 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 $\bar{\chi}$ 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 $\bar{\chi} - 3\sigma$ 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.

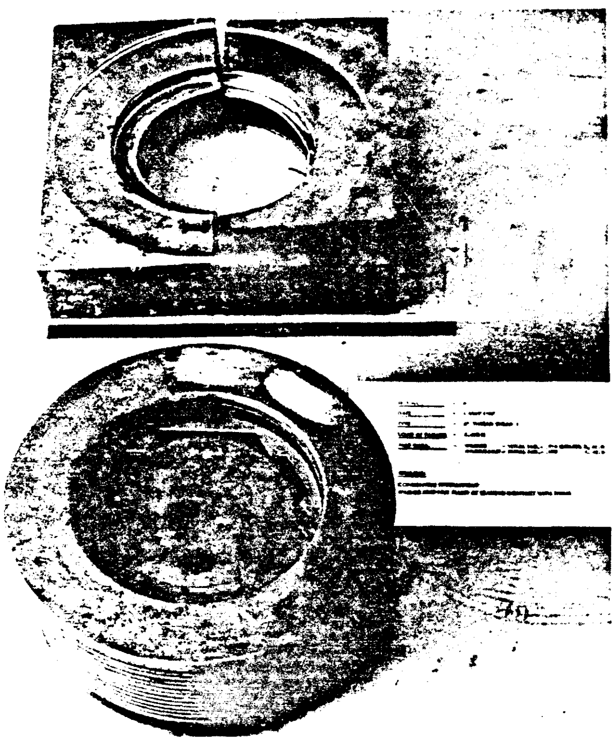


FIG. 3.3-32: Outer face of Washer Serial No. 014, Washer Nut Serial No. 008 and Split Shims after being loaded to ultimate as an assembly in test C1-1.

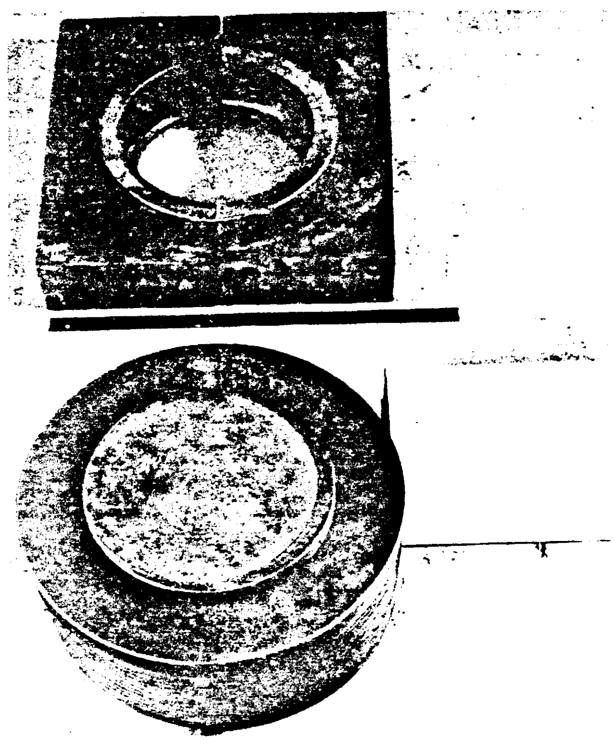


FIG. 3.3-33: Inner face of components shown in Fig. 3.3-32 Note that inner face of Washer - Washer Nut assembly bears on outer face of Split Shims.

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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).

Gulf General Atomic
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GA-9155

TESTING LARGE TENDONS FOR A NUCLEAR REACTOR VESSEL

by

T. E. Northup, G. S. Chow, and J. F. Hildebrand

December 27, 1968

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Work supported by U.S. Atomic Energy Commission,
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Gulf General Atomic Project 901 December 27, 1968

ABSTRACT

Prestressing tendons with a minimum guaranteed ultimate tensile strength (GUTS) of 1000 tons have been sucessfully developed for use on the first prestressed concrete reactor vessel (PCRV) being constructed in the U.S. Measured values for modulus of elasticity, yield and ultimate strength, friction, and short-term relaxation, for both straight and curved tendons, are presented. Short-term relaxation tests on long tendons made with stress-relieved wire show significantly higher relaxation losses than tendons made with low-relaxation wire. A cyclic test on a large curved tendon had no effect on the ultimate capacity of the system. A tendon corrosion-protection system, and various corrosion- and radiation-test results obtained to establish the adequacy of the system, are presented.

APPENDIX TO CHAPTER 3

TECHNICAL REPORT NUMBER 8

CONTENTS

FIGURES

TABLES

TESTING LARGE TENDONS FOR A NUCLEAR REACTOR VESSEL[a]

By Tharold E. Northup,[1] Fellow ASCE, George S. Chow,[2]
and John F. Hildebrand[3]

INTRODUCTION

Several prestressing systems have been used successfully on PCRVs built in France and England. The capacity of the different tendons has ranged from 146 tons for the EDF-3 vessel to 2460 tons for the Marcoule G-2 and G-3 vessels. The capacity of all systems used to date is shown in Table 1.

The prestressing systems shown in Table 1 were either being tested or developed for nuclear reactor vessel application when the Fort St. Vrain vessel was being designed for the Public Service Company of Colorado by Gulf General Atomic Incorporated. This PCRV will contain the entire primary system for a 330 MW(e) high-temperature gas-cooled reactor (HTGR)near Platteville, Colorado, under the AEC power-reactor demonstration program.

A single tendon, with an ultimate capacity of 1000 tons ("tons" refers to short tons in this report) was judged to produce the lowest capital cost in-place prestressing system. Lower-capacity tendons of similar design were also judged to

[a]Presented at the February 3-7, 1969, ASCE Conference at New Orleans, La.

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TABLE 1.–PRESTRESSING SYSTEMS USED ON PCRVs[a]

System	Ultimate Capacity, in tons	Type
Marcoule G-2 Marcoule G-3	2460	Special design, multiple wires
Oldbury	273	Freyssinet, multiple 7-wire strands
Wylfa	820	Freyssinet, multiple 7-wire strands
Dungeness B	1020	BBRV, multiple wires
EDF-3	146	SEEE, single 61-wire strand
St. Laurent I	325	SEEE, multiple 7-wire strands

[a]Taken from "Prestressed Concrete in Nuclear Pressure Vessels - A Critical Review of Current Literature," by Chen Pang Tan, Oak Ridge National Laboratory Report ORNL-4227, dated May 1, 1968.

be feasible. All cost evaluations included the expected research and development costs associated with each system. The research and development programs were necessary to demonstrate the efficiency of the selected prestressing system.

The development of anchor hardware and tendon fabrication, installation, and stressing equipment was contracted to Western Concrete Structures, Incorporated, Gardena, California, and is not reported in this paper. This paper summarizes the development of system data for use in the PCRV design.

TENDON SYSTEM

The prestressing system selected consists of up to one-hundred and seventy 1/4-in.-diam high-strength wires with stressing washer assemblies at each end to support the buttonheaded wire anchorages. This system, manufactured by Western Concrete, is similar to the BBRV system used on the Dungeness B vessel (Table 1). A schematic view of the 1000-ton tendon anchor assembly as it will appear on the PCRV is shown in Fig. 1. The covers shown protect the tendon from corrosion and mechanical damage.

The system is partially shop-fabricated from straight wires with one end-anchor assembly attached. Each tendon consists of two concentric bundles of counter-twisting wire. The counter-twisting effect prevents the wires from unravelling and minimizes the variation of wire lengths in a curved tendon. All wires of the tendon are coated, bound, and coiled for shipment to the site. A coiled test tendon is shown in Fig. 2.

The partially fabricated tendons are pulled through tendon tubes embedded in the PCRV and each wire is then threaded through the second anchor assembly and buttonheaded. Prestressing is accomplished with high-capacity jacks from both ends on curved tendons and from one end on straight tendons. The high-capacity jacks developed for the 1000-ton tendons are shown in Fig. 3.

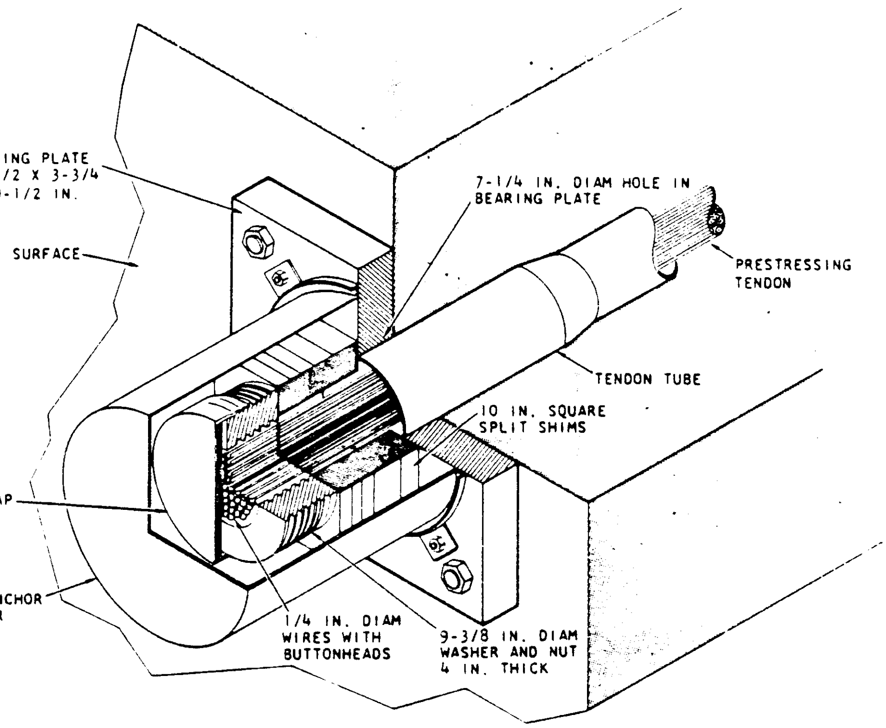

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FIG. 1.–TENDON END-ANCHOR ASSEMBLY ARRANGEMENT

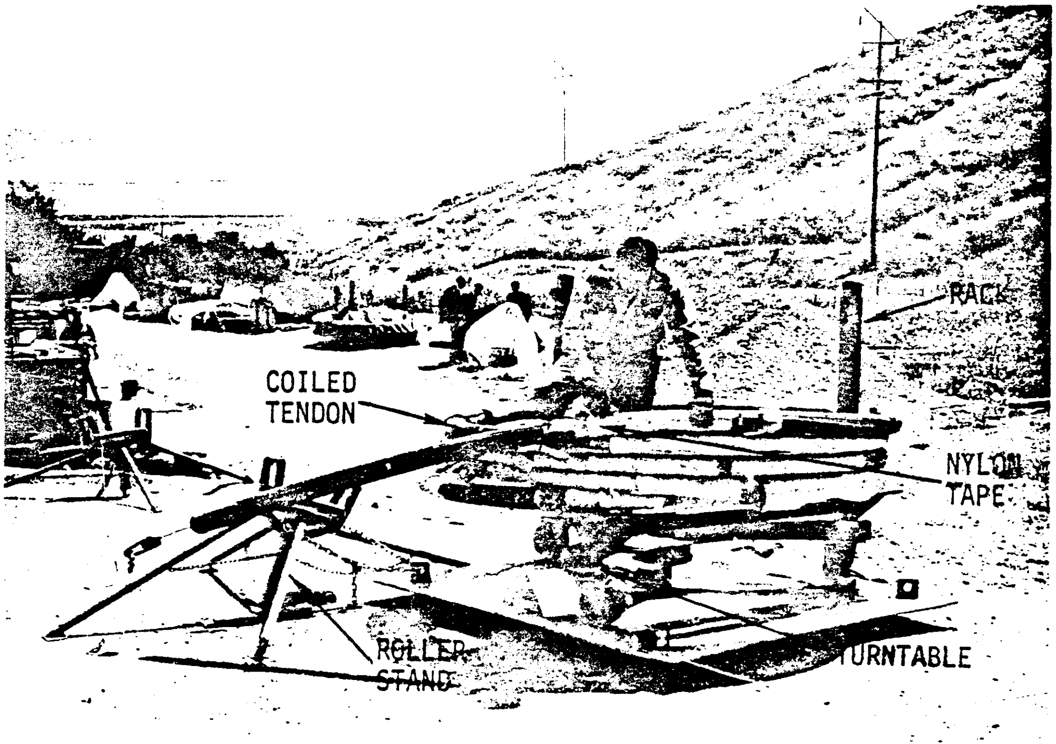

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FIG. 2.–PARTIALLY FABRICATED COILED TENDON

HT54973

FIG. 3.—1000-TON TENDON PRESTRESSING JACK

RESEARCH AND DEVELOPMENT SCOPE

The prestressing system was tested by GGA to determine: (1) modulus of elasticity, (2) friction, (3) yield strength, (4) ultimate strength, (5) cyclic load effect, (6) short-term relaxation, and (7) corrosion protection.

TEST FACILITY

The facility for testing full-size tendons in their expected environment and load conditions is shown in Fig. 4. The test bed consists of a 90-ft-long straight test section and variable curved test sections with maximum radius of 16 ft and minimum radius of 10 ft. These dimensions provide the full range of vertical tendon lengths and horizontal curves required by the Fort St. Vrain vessel.

The straight part of the test bed contains five tubes. The center tube (No. 5) is 7 in. OD throughout its 90-ft length. The outer four tubes (Nos. 1 through 4) are 4-1/2 in. OD with temperature regulation for relaxation tests at temperatures from ambient up to 150 F.

The semicircular portion of the test bed permits testing a variety of curved tendons. Each curved tendon-tube can be removed and replaced as required. This feature enables several friction-reducing or corrosion-protection materials to be investigated, starting with clean tubes for each test phase. Provisions for measuring the tendon tangential shear force and radial force at several points around the 180° curves are also provided. The two smaller curved (No. 9 with 10-ft radius and No. 8 with 16-ft radius) tendons are truly semicircular. These short tendons simulate the range of curvature of the crosshead tendons of the Fort St. Vrain vessel. The longer curved tubes (Nos. 6 and 7) are a series of flat-curved sections with the radius of the curved sections being 16 ft maximum. These tendons simulate the circumferential wall tendons of the Fort St. Vrain vessel. All tubes are ASTM A-513, Grade 1010 HREW, having splice details as shown typically in Fig. 5.

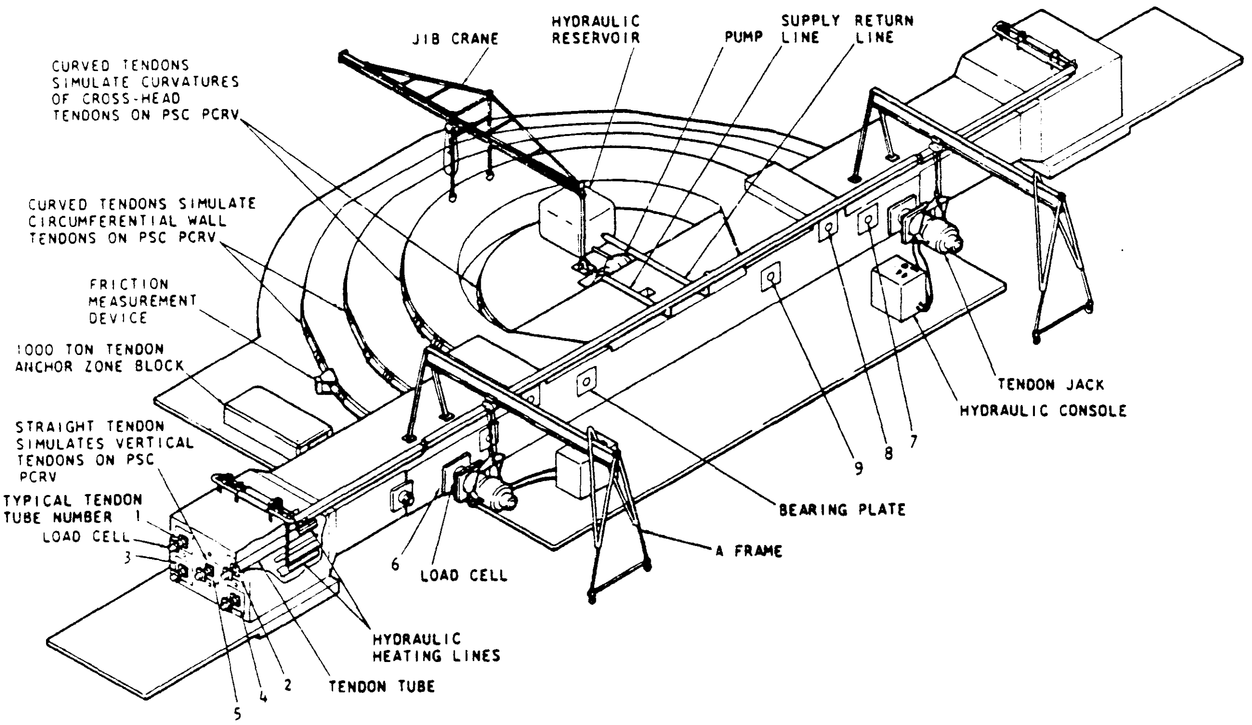

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FIG. 4.–PRESTRESSING SYSTEM RESEARCH AND DEVELOPMENT TEST BED

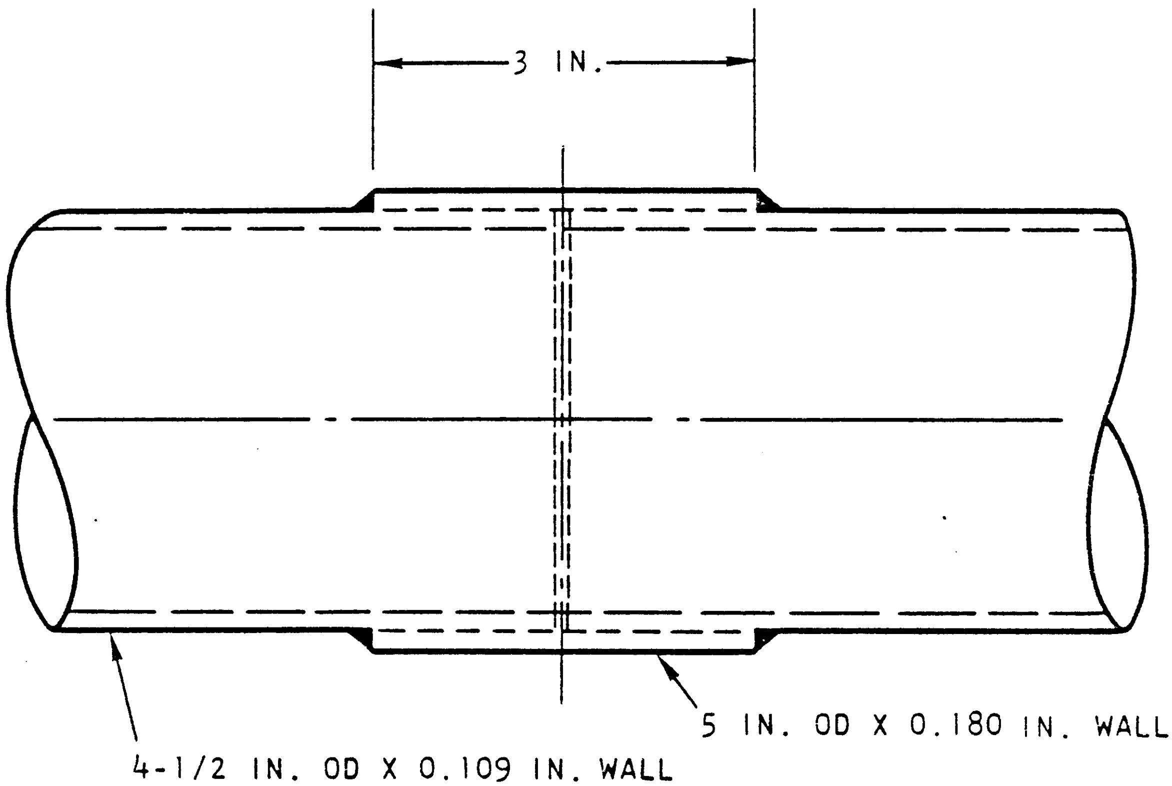

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FIG. 5.–TYPICAL TENDON TUBE SPLICE

The completed test facility is shown in Fig. 6. The dimensional changes of this bed were measured with Invar rods. Tendons were heated by flowing oil into small tubes attached to the outside of the embedded tendon tubes. Jack pressure, tendon force, and tendon elongation measurements were also made.

TEST PROGRAM AND RESULTS

The tendon system test program was started with ASTM A-421 stress-relieved wire. After the initial high results on tendon relaxations at ambient temperature were obtained, the program was reoriented to use only Thermalized (trademark of Richard Johnson and Nephew, Ltd., Manchester, England) wire because of its low relaxation property. Thermalized wire meets the requirements of ASTM A-421, including a minimum GUTS of 240,000 psi.

Table 2 summarizes the physical tests performed on the tendon system. Test parameters, including test type, number, duration, tendon makeup, environment, and material, are given. Table 3 summarizes the corrosion tests performed to establish the adequacy of the corrosion-protection system selected for the tendon system. Further discussion of these tables is given later.

STRESS-STRAIN BEHAVIOR

A typical stress-strain curve for a full-size straight tendon is shown in Fig. 7. The tendon system exhibits good ductility. The initial individual wire failures have an insigificant effect on the ultimate capacity of the tendon. The yield strength of the tendon system at 1% elongation meets the requirement of not being less than 75% of the minimum ultimate strength. An ultimate strain at failure of greater than 4% provides considerable reserve above the 1 to 1.5% predicted maximum capability required by PCRV designers.

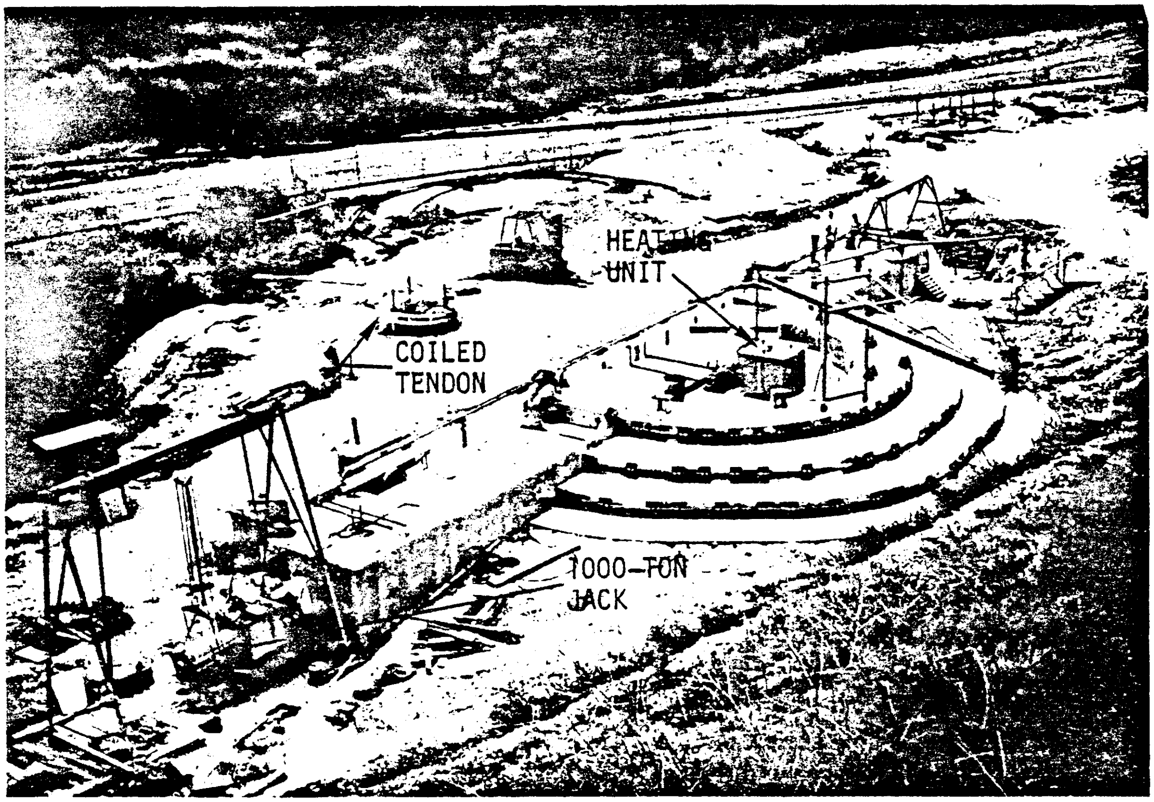

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FIG. 6.–PRESTRESSING SYSTEM TEST-BED FACILITY

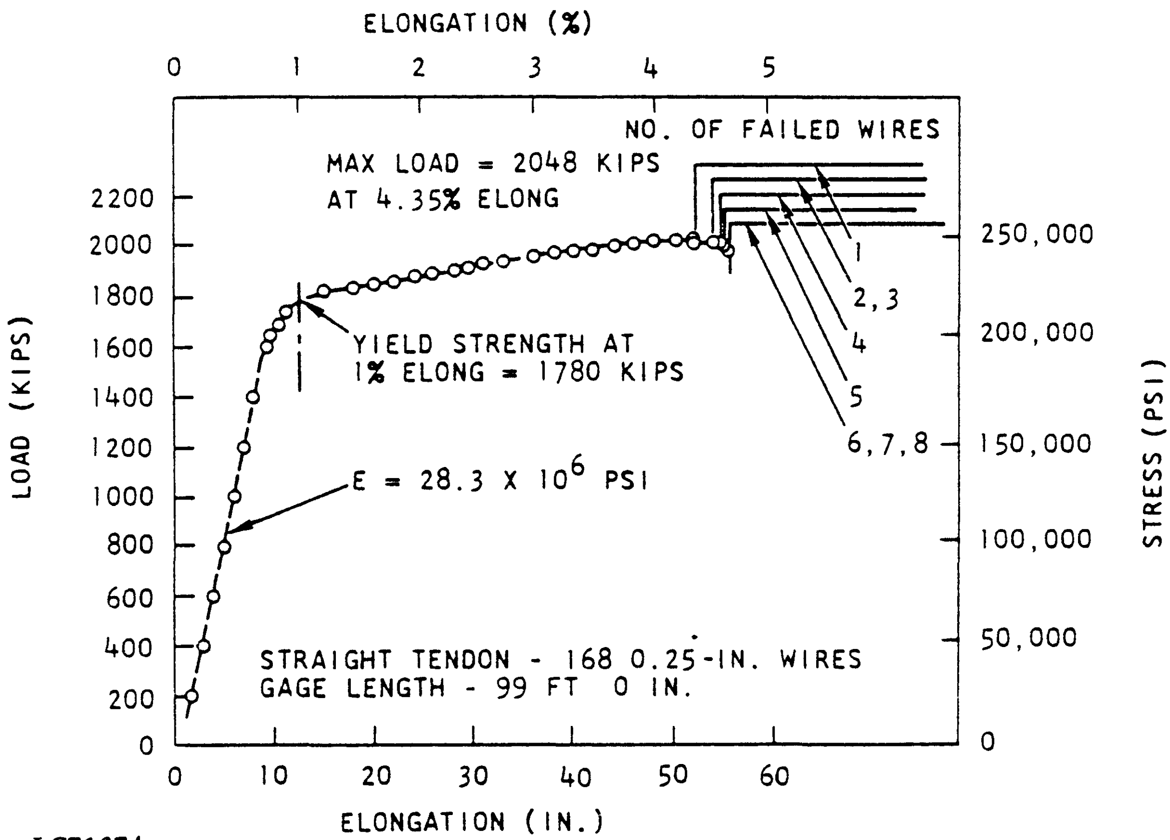

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FIG. 7.–TENDON STRESS-STRAIN CURVE

TABLE 2.—SUMMARY OF PRESTRESSING TENDON MECHANICAL TESTS

Test Type	Tendon Number	Length (ft-in.)	Shape [a]	Number of Wires	Wire Material	Lubricant	% Elongation at Maximum Tendon Load	Maximum Load, in kips	Number of Wires Failed	E, Modulus of Elasticity, 10^6 psi	Average Coefficient of Friction: Tensioning	Average Coefficient of Friction: Detensioning
Ultimate	5A	98-11	Straight	168	Stress-relieved	---	4.13	2075	7	27.4	---	---
	5B	99-0	Straight	168	Stress-relieved	---	4.35	2048	8	28.3	---	---
	5C	99-0	Straight	168	Stress-relieved	---	3.90	2050	9	28.4	---	---
Friction and Ultimate	6A	99-8	Curved	168	Stress-relieved	No-Ox-Id-CM	2.80	1963	25	----	0.138	0.165
	6B	99-6 1/2	Curved	168	Stress-relieved	No-Ox-Id-CM	2.06	1900	15	23.9 [b]	0.136	0.190
	6C	100-0	Curved	168	Stress-relieved	No-Ox-Id-CM + Paraffin	2.84	1970	38	24.8 [b]	0.150	0.172
	8A	70-4	Curved	168	Stress-relieved	No-Ox-Id-CM	2.82	1966	8	25.2 [b]	0.135	0.169
	8B	70-4	Curved	168	Stress-relieved	No-Ox-Id-CM	----	----	--	25.2 [b]	0.145	0.164
	9A	51-6	Curved	168	Stress-relieved	No-Ox-Id-CM	2.80	1962	18	25.1 [b]	0.154	0.169
	9B	51-6	Curved	168	Stress-relieved	No-Ox-Id-CM	2.84	1970	15	23.9 [b]	0.146	0.164
	9C	51-6	Curved	168	Thermalized	No-Ox-Id-500 +No-Ox-Id-CM	----	2035	15	----	0.187	---

Test Type	Tendon Number	Length (ft-in.)	Shape [a]	Number of Wires	Wire Material	Temperature, in degrees Fahrenheit	Initial Load, in % GUTS Nominal	Tensioning History	Test Duration in hours	% Relaxation Loss [c] at 1000 hours
Relaxation	1B	91-1 1/2	Straight	25	Stress-relieved	68	70	1st tensioning	1180	10.5
						68	70	2nd tensioning	2690	3.4
						120	70	3rd tensioning	1130	4.4
	1C	91-1 1/2	Straight	25	Thermalized	120	70	1st tensioning	In progress	3.0
	2B	91-1 1/2	Straight	25	Stress-relieved	68	70	1st tensioning	1180	10.2
						68	70	2nd tensioning	2690	6.2
						120	70	3rd tensioning	In progress	6.1
	3B	91-1 1/2	Straight	25	Stress-relieved	68	70	1st tensioning	1180	9.8
						68	70	2nd tensioning	2690	3.8
						68	70	3rd tensioning	1130	3.0
	3C	91-1 1/2	Straight	25	Thermalized	68	70	1st tensioning	In progress	0.7
	4B	91-1 1/2	Straight	25	Stress-relieved	68	70	1st tensioning	1180	10.0
						68	70	2nd tensioning	In progress	3.8
	8C	73-0	Curved	168	Thermalized	120	70	1st tensioning	In progress	2.2

[a] All 168-wire tendons are gently spiralled to equalize their length within the tendon. All curved tendons include 180° of curvature.

[b] Apparent modulus.

[c] Relaxation loss is obtained as % of initial load at anchor.

TABLE 3.–SUMMARY OF TENDON WIRE-CORROSION TESTS

Type of Test	Purpose	Material	Coating	Test Conditions	Results
General corrosion	Corrosion effect on tensile properties	Stress-relieved wire	None	La Jolla[a] coastal environment exposure 30, 180,365 days, tensile test	No loss of tensile strength in 30-, 180-, and 365-day tests
General corrosion	Protection by phosphate coatings	Stress-relieved wire	Auto Bond[b] (lead phosphate) Meta Bond (zinc phosphate)	La Jolla coastal environment	Both provide some protection. Meta Bond rated more protective than Auto Bond, 132-day exposure
General corrosion	Protection by Kephos[c] coating by RJ&N[d]	Thermalized wire	Kephos[c] (Organic phosphate treatment)	La Jolla coastal environment	Coated wire corroded, equivalent to bare wire, 30-day exposure
General corrosion	Protection by No-Ox-Id-CM	Stress-relieved wire	No-Ox-Id-CM[e] casing filler	La Jolla coastal environment	No corrosion after 2-yr exposure
General corrosion	Protection of wire by coating at WCS[f]	Thermalized wire	Meta Bond	La Jolla coastal environment	Moderate protection for 90-day exposure
General corrosion	Protection by Meta Bond	Thermalized wire	Meta Bond, Meta Bond and Rustarest 452	La Jolla coastal environment at 75% F_{ntu}[g]	Exposure continuing, no failures at 6 mo
General corrosion	Stress relaxation test and corrosion protection	Stress-relieved wire	Chassis black[h]	25-wire tendon (2B), 120 F, 1-yr test	Exposure at test site continuing. No corrosion attack observed
General corrosion	Stress relaxation test and corrosion protection	Stress-relieved wire	No-Ox-Id-CM casing filler	25-wire tendon (4B)	Exposure at test site continuing. No corrosion attack observed
General Corrosion	Stress relaxation test and corrosion protection	Thermalized wire	No-Ox-Id-CM casing filler	25-wire tendon (1C)	Exposure at test site continuing. No corrosion attack observed
General corrosion	Stress relaxation test and corrosion protection	Thermalized wire	No-Ox-Id-CM casing filler	25-wire tendon (3C)	Exposure at test site continuing. No corrosion attack observed
General corrosion	Stress relaxation test and corrosion	Thermalized wire	No-Ox-Id-CM casing filler	168-wire tendon (8C)	Exposure at test site continuing. No corrosion attack observed
General corrosion	Bearing plate reinforcing and corrosion protection	Thermalized wire	No-Ox-Id-CM casing filler	Short-beam 168-wire tendon	Exposure at test site continuing. No corrosion attack observed
General corrosion	Selection of overseas shipping method	Thermalized wire	A1 - Bare wire A2 - Kephos B1 - Unwrapped B2 - VPI-Hessian burlap paper and tape B3 - VPI-Hessian burlap paper and more Hessian burlap paper B4 - VPI-Hessian burlap paper	Ocean shipment in unsealed steel containers	A1 B1 - Light rust haze A2 B1 - No rust A1 B4 - Light rust haze on bottom coil A2 B2 - No rust A2 B3 - No rust A2 B4 - No rust
Runoff	Effect of temperature on tenacity of grease	Stress-relieved wire	No-Ox-Id-CM casing filler	Coated wire held at 120 F for 100 hr, La Jolla environmental exposure	Film of grease covered wire after 100 hr at temperature. No visible rust 90 days
Runoff	Effect of temperature on tenacity of grease	Stress-relieved wire	No-Ox-Id-CM casing filler	Coated wire held at 160 F for 1000 hr, La Jolla environmental exposure	Film of grease covered wire after 1000 hr at temperature. Moderate protection for 90-day exposure
Self-healing	Ability of grease to cover bare wire	Thermalized wire	No-Ox-Id-CM casing filler	Horizontal wire partially covered with grease heated in humid air	No corrosion on wire after 480 hr in humid air. No corrosion after 90-day La Jolla exposure
Hydrogen embrittlement	Hydrogen embrittlement caused by WCS Meta Bond	Stress-relieved wire	Meta Bond and Rustarest	Sustained load at 75% F_{ntu}	Survived 312 hr without failure
Hydrogen embrittlement	Susceptibility hydrogen embrittlement of wire	Stress-relieved wire	None	Notched specimen cathodically charged and sustained load at 75% F_{ntu}	Specimens survived over 200 hr without failure
Radiolysis	Effect of irradiated grease on wire	Stress-relieved wire	No-Ox-Id-CM casing filler	Irradiated 4 $(10)^8$ rads, 1.7 $(10)^{17}$ nvt (> 1.0 MeV) stressed 75% F_{ntu}	All specimens survived exposure, no embrittlement
Radiolysis	Effect of irradiated grease on wire	Thermalized wire	Meta Bond plus No-Ox-Id-CM	Stressed wire at 75% F_{ntu} exposure 14 days 4 $(10)^9$ rads, 1.5 $(10)^{17}$ nvt (> 1.0 MeV)	All specimens survived exposure, no embrittlement

[a]La Jolla, California
[b]Auto Bond and Meta Bond: Trade names of International Rustproof Company, Cleveland, Ohio
[c]Kephos: Trade name of AMCHEM Products, Inc., Ambler, Pennsylvania
[d]Richard Johnson and Nephew, Manchester, England
[e]No-Ox-Id-CM: Trade name of product of Dearborn Chemical Division of W. R. Grace, Chicago, Illinois
[f]Western Concrete Structures, Gardena, California
[g]The Subscript ntu equals notch tensile ultimate strength
[h]Electro Paint Company, Gardena, California

It is impossible to directly measure the modulus of elasticity for full-size curved tendons because of the variation in stress between the two anchor points. The effects of transverse load, ovaling of the tendon wire bundle, friction, and actual stress in each wire all make the determination of E, as shown in Table 2, approximate.

The ultimate load of a tendon test specimen is reached only in the straight portion between the anchors for a straight tendon and in the first point of tangency for a curved tendon. Beyond the tangent point, friction reduces the tendon load. Therefore, the measured total elongation is mainly influenced by the length of the straight portion. A meaningful test result interpretation is required to relate the measured ultimate load to the strain in the wires at the failure point. Since the wire failures always occur close to the tangent point within the curved part, it is valid to equate the measured failure load to the tendon load at the point of failure. The percent elongation at maximum curved tendon load is determined by averaging the percent elongations of the straight tendons (5A, 5B, and 5C) at the corresponding maximum curved tendon load. The percent elongation at maximum curved-tendon load is about one-half to two-thirds of that exhibited by straight tendons.

The stress in each wire of a curved tendon depends upon the actual length of each wire. If the tendon wires are parallel, the inner wires of a curved tendon will project approximately 6 in. further than the outer wires at each anchor. To compensate for this, all curved test tendons were fabricated as follows: the center 80 wires were gradually twisted 10 turns clockwise while being greased and combed into position, the remaining outer wires were then greased and combed into position, and finally the whole tendon was twisted four turns counterclockwise. This operation reduced the variation in wire projections at anchors to ± 3/4 in. Test tendon 6B (Table 2) was specially treated in an effort to further study wire-length variations. In this case, the wires were cut parallel to the bearing plate after insertion to remove the ± 3/4-in. variation. This operation,

however, actually increased the wire variation in total length and resulted in a lower ultimate strain and strength for this tendon. As the result of these tests, the Fort St. Vrain counter-twisted tendon wires projecting through the stressing washer will be buttonheaded without field-cutting the wires.

CYCLIC-LOAD EFFECT

Tendon 9C was tested by cyclic loading 1000 times between a load range of 1275 kips and 1525 kips (i.e., 0.7 GUTS ± 15,000 psi) prior to the ultimate load test. The cycles and stress range are at least double those expected to occur in a PCRV. The jacks shown in Fig. 3 were used to apply the cyclic load and thus also provide experience on jack reliability.

FRICTION

Coefficient-of-friction values were determined for all full-sized curved tendons after a series of tests were performed on small, 7-wire tendons. In this series of tests, the friction-reducing characteristics of various materials were considered along with their ability to provide corrosion protection for the wire. A petroleum-base compound containing microcrystalline wax, No-Ox-Id-CM, was selected for use on all of the full-size tendon tests.

Friction values were determined by recording the load at one end of the tendon while jacking at the other. Friction coefficients were computed using an average wobble effect of K = 0.00027. Typical friction coefficients determined during tensioning and detensioning are shown in Fig. 8. The lower value obtained during tensioning is attributed to the fact that the tendon wires slid more freely during tensioning than detensioning because sliding friction is less than static friction. (Friction at tensioning resembles sliding friction and friction at detensioning resembles static friction.) A factor of 0.15 during tensioning is believed to be an adequate design value, but a value of 0.19 was used for the Fort St. Vrain design to allow for construction variables.

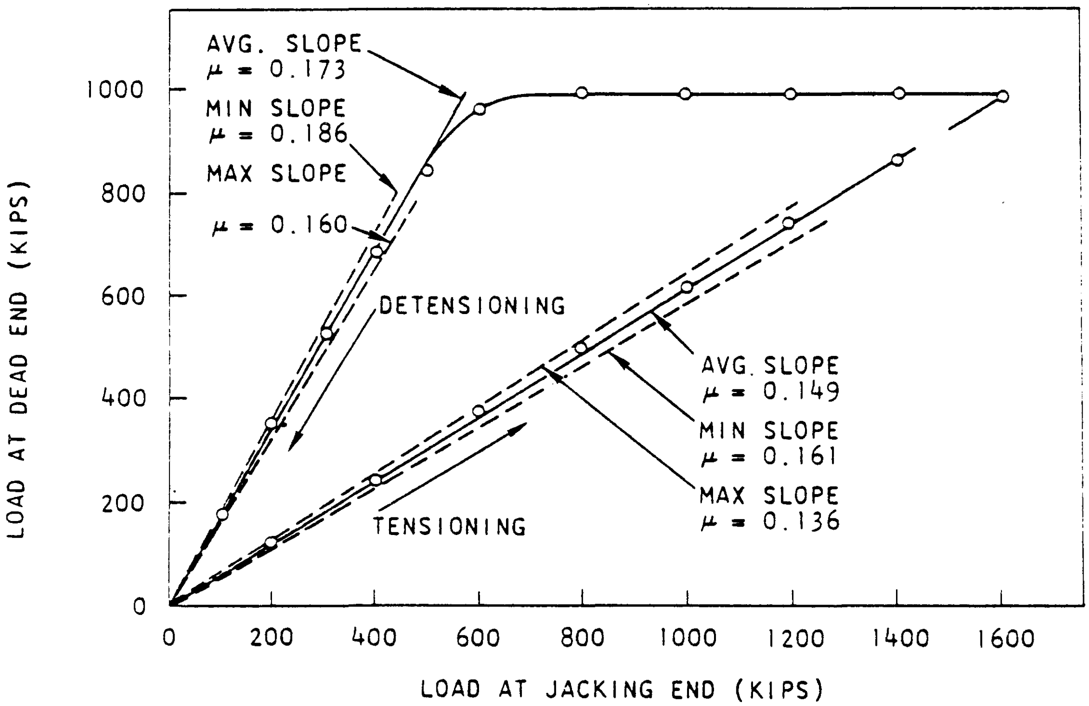

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FIG. 8.–TYPICAL COEFFICIENT-OF-FRICTION CURVES

Coefficient-of-friction values determined along the curved tendons are shown in Table 4. Tube Nos. 8 and 9 are completely circular and little variation in friction value occurs. Tube No. 6 is made up of straight and curved sections with high values of friction occurring in the curved portions (60° and 150°). The average friction values determined by load cells are consistently higher than those determined along the curved segment. The addition of paraffin or No-Ox-Id-500 to No-Ox-Id-CM for lubricating tendons 6C and 9C did not reduce friction below values obtained using No-Ox-Id-CM alone.

RELAXATION

Relaxation tests require considerable time to accomplish if a basis for 30-yr predictions is expected to be established. Many relaxation tests on prestressing steel have been performed by others, extrapolating the long-term relaxation loss from a minimum of 1000-hr (approximately 42-day) test data. Relaxation tests on the test bed have ranged from 1000 hr to approximately 1 yr. The test results to date on Thermalized wire tendons indicated only a slight rate of change of relaxation loss between the period of 1000 hr and less than 1 yr.

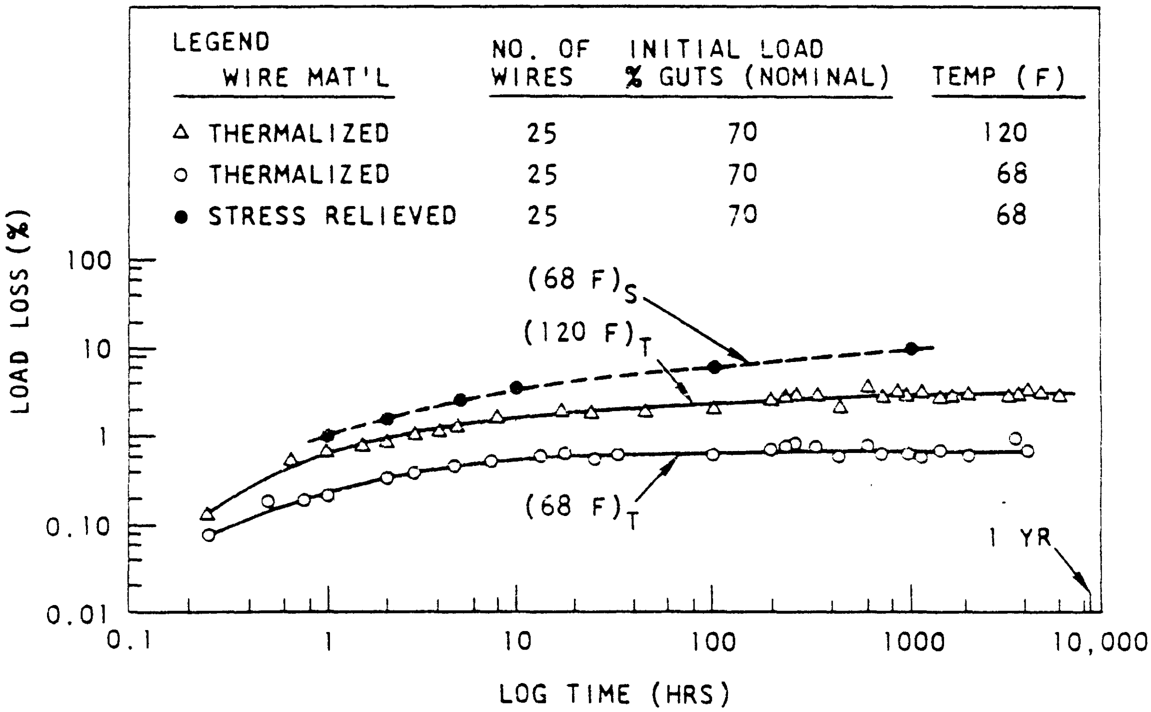
Relaxation loss was obtained as a percentage of initial prestress at anchor. Tendon loads were measured with spool-type load cells calibrated to ± 0.5% accuracy at rated load. Applied tendon loads and number of wires per tendon are shown in Table 2. Temperature of each tendon is maintained within ± 5 F of the stated values. Temperature-change adjustment was included in the test data.

A comparison of load loss vs log time is shown in Fig. 9 for straight tendons made up of stress-relieved and Thermalized wires. Only ambient-temperature tests were performed on stress-relieved wire units initially stressed to 0.7 GUTS, and the results shown in Fig. 9 as $(68\ F)_S$ are the average of four 25-wire tendons. Retensioning after various periods of time reduced the relaxation of stress-relieved wire tendons to about one-third to two-thirds of its initial value as shown in

TABLE 4.—COEFFICIENT OF FRICTION MEASURED ALONG THE CURVED TENDONS AT VARIOUS DEGREES OF TURN

	Lubricant		
	No-Ox-Id-CM plus paraffin	No-Ox-Id-CM	
Degree of turn	Tube 6	Tube 8	Tube 9
10		0.142[a]	0.146[a]
30	0.109[a]		
50			0.126[a]
60	0.176[a]		
90		0.133[a]	
120	0.107[a]		
130			0.127[a]
150	0.147[a]		
170		0.132[a]	0.125[a]
Mean	0.135	0.136	0.131
1 Std deviation	±0.029	±0.005	±0.008
Avg values by load cells at anchors	0.150	0.140	0.150

[a]Coefficients of friction are derived from normal load and shear load measured along the curved tendons at various degrees of turn.



LC71372

FIG. 9.–TENDON RELAXATION TEST DATA

Table 2. The test duration reported is related to the period following each tensioning operation. The percent relaxation reported at 1000 hr is also related to each tensioning operation.

CORROSION PROTECTION

The development of a satisfactory corrosion-protection system requires a broad knowledge of all the steps in the preparation and use of a prestressing system. This is essential since continuous corrosion protection must be provided on all tendon components from the point of manufacture to final installation. The total corrosion-protection system for the Fort St. Vrain prestressing tendons consists of the following:

1. The tendon wire is coated with a zinc-phosphate (Meta Bond), which is then sealed with an oil film of Rustarest, both of which are applied just after the Thermalizing process.

2. The wire coils, spiral-wrapped in VPI Hessian burlap paper, are shipped from England to point of fabrication in unsealed steel containers.

3. No-Ox-Id-CM is applied to the individual wires and anchor hardware during tendon fabrication.

4. Fabricated tendons are banded and placed in protective tendon racks for shipment and site storage.

5. No-Ox-Id-CM is applied to the interior of the tendon tubes prior to tendon installation.

6. After tendon installation, the ends of each anchor assembly are covered with caps until the stressing operation is performed. These caps are

removed for tendon stressing and then reinstalled after the anchor assembly is thoroughly coated with No-Ox-Id-CM. The tendon tube and end caps form a protective chamber for the prestressing tendons.

The selection of this corrosion-protection system is based on the test program summarized in Table 3. The most significant results show that:

1. The strength loss and elongation loss on bare wire from corrosion was insignificant in wire after 1 yr of continuous coastal exposure. The wire samples exhibited fine scaling corrosion.

2. The zinc-phosphate coating (Meta Bond) produced no hydrogen embrittlement even at stress levels of 75% of the notched wire ultimate strength. Neither the coating nor cathodic charging caused failure of stressed wire.

3. No-Ox-Id-CM is self-healing and does not uncover the wire at 120 F, the maximum temperature expected to be experienced by PCRV tendons.

4. Irradiation to levels recorded does not cause delayed failure of stressed and coated wire.

5. Stress-corrosion cracking and hydrogen embrittlement have not caused failure of these wires, which have a pearlitic microstructure.

Corrosion tests on full-size stressed tendons in the test bed (Fig. 6) were performed to verify the adequacy of the protectants selected on the basis of the specimen tests summarized in Table 3. These tests are continuing and no signs of corrosive attack have appeared.

CONCLUSIONS

It is apparent from the test results that counter-twisting of tendon wires is essential for large-capacity curved tendons. The counter-twisting effect prevents multiple tendon wires from unravelling after tendon fabrication and during tendon installation, and minimizes the total wire length variation. It is important that the wire bundle not be cut parallel to the bearing plate after curved tendon insertion. If the wire bundle is cut, a 3 to 4% reduction of the tendon ultimate load capacity can be expected for tendon configurations described in this report.

As expected from the curved tendon ultimate load tests, most of the wire failures occurred in the curved segment close to the first point of tangency on the curve. This is the region where the simultaneous action of high-tensile, bending, and transverse stresses localize as a result of the effects of friction and sudden change in curvature in the tendon profile.

Thermalized wires used in this test program meet all the mechanical properties of ASTM A-421 wire. Thermalized wire is characterized by its low relaxation property. The relaxation loss for Thermalized wire tendon was only approximately 7% of the relaxation loss that was measured for the stress-relieved wire tendons tested under similar test conditions at 68 F after 1000 hr and after initial anchor load of 70% GUTS.

The casing-filler material No-Ox-Id-CM provided dual functions in this test program. It was used for a friction-reducing agent and for corrosion protection of the tendon system. The No-Ox-Id-CM material is self-healing and does not uncover the wire at 120 F, which is the maximum temperature expected to be experienced by PCRV tendons. The self-healing effect of No-Ox-Id-CM permits tendons to be protected without resorting to completely filling the tendon tubes with protectant.

The 1000-ton prestressing system developed for the Fort St. Vrain PCRV has been subjected to service loads and environmental conditions far in excess of those required to satisfy design requirements. Mechanical properties required by the design have been established by testing full-size tendons in configurations simulating those of the actual vessel. Tendon-relaxation values have been shown to be small for Thermalized wire, and a complete corrosion-protection system has been developed to ensure tendon stability throughout the design life of a PCRV.

ACKNOWLEDGMENT

This work was supported by the U.S. Atomic Energy Commission under Contract AT(04-3)-633.

Part
E. TRUMPLATE WELDING EFFECTS

Part
E. TRUMPLATE WELDING EFFECTS

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Part
E. TRUMPLATE WELDING EFFECTS

Introduction, Purpose, Summary

A question had been raised regarding the integrity of the Three Mile Island bearing plate because of the possible weakening effect of flame cut or welded areas at normal environmental temperatures.

In addition to actual low temperature testing covered within, it was requested we provide a professional opinion.

Mr. Hildebrand's work with Gulf General Atomics on similar questions well qualifies his opinion and experience.

There is no question in the author's mind that the proposed prestressing system will function properly.

John F. Hildebrand
6124 Terryhill Drive
La Jolla, California 92037

27 October 1969

Inland-Ryerson Construction Products Co.
Box 5532
Chicago, Illinois 60680

Attention: Mr. William A. Corson

Re: Bearing Plate Serviceability

Gentlemen:

Following recent discussions with Western Concrete Structures, I felt it was necessary to prepare a brief statement clarifying our position relative to the metallurgical serviceability of the bearing plates for the Three Mile Island containment. Flame cutting the bearing plate and attaching the trumpet by welding are not expected to detrimentally affect the functionality of the prestressing system at normal environmental temperatures. A test program is in the final stages of preparation at this time to assess the effects of these fabrication procedures at an extreme low temperature.

At normal temperatures it is recognized that the mass of the bearing plate represents a substantial heat sink. As such - the mass acts to drastically quench steel heated locally above the transition temperature. Mild steels with 0.25% or more carbon may form zones of brittle martensite, but for the A36 plate in question, the low (less than 0.2%) carbon precludes the formation of embrittling martensite. The microstructure of the plate is simply modified by zones of less desirable coarse grains and coarse pearlite. These microstructural variations are not likely to act as metallurgical notches. The same conditions are produced by both cuts and welds. If the welding procedure did cause cracks in the bearing plate, they would most likely follow the contour of the weld metal/base metal interface, that is within the hardened structure of the heat affected zone. In effect the weld bead would remain attached to the trumpet and leave a chamfer-shaped edge on the bearing plate. It is true that branch cracks might form but their propagation depends on both the notch sensitivity of the plate and a high strain rate loading.

Inland-Ryerson Construction Products Co. 27 October 1969

The Welding Handbook points out that almost all carbon steels are notch sensitive below a certain temperature or above a certain strain rate. The sensitivity of the steel varies considerably with the composition, thickness and rigidity of the structure; it is related to the general toughness of the steel or the ability to withstand impact or shock loads. In this regard the thickness of the bearing plates is a detriment, the composition is favorable (low carbon) and the rigidity of the structure is an asset. Since cupping of the bearing plate is resisted by the back-up concrete, the peripheral tensile stress at the edge of the hole is kept at a relatively low level. And finally, tendons and anchor hardware are a static system, not subject to impact or high strain rate loadings.

It is also important to point out that the weld holding the trumpet to the plate has two functions; 1) it maintains the axis of the trumpet perpendicular to the face of the bearing plate and 2) it prevents leakage of the grout/concrete during construction. Once the concrete has set, the weld has no further function; as an example, in one concrete structure, the plate is placed and grouted after the trumpets are embedded and the gap between the tube and plate are simply calked.

By the way of demonstration that the proposed prestressing system will function properly at normal temperatures, several buildings and bridges using a similar system with similar materials, have been built during the past decade and none of these has experienced degradation such as cracking or failure of any of the components. Some of the bridges have also endured extremely low temperatures.

Sincerely,

John F. Hildebrand

John F. Hildebrand, Metallurgical Engineer

JFH:ko

LOW TEMPERATURE TEST

LOW TEMPERATURE TESTS
TABLE OF CONTENTS

LOW TEMPERATURE BEHAVIOR

OF

THE WCS 2.0 Mep/170-W

POST-TENSIONING SYSTEM

1.0 INTRODUCTION AND SUMMARY

The WCS 2.0 Mep/170-W Post-Tensioning System has been developed primarily for use in post-tensioned concrete reactor vessels and containment structures in which massive concrete sections and large required prestressing forces dictate the need for tendons of high capacity. In some of these applications the end anchorages may be exposed to very low ambient temperatures which may exist at the exterior of the structure. Because of the critical nature and function of these structures, it was felt necessary to prove the adequacy of the system when subjected to these low temperatures. The following report covers the procedures and results of a test conducted to demonstrate this adequacy.

A reinforced concrete test specimen was constructed utilizing materials and components typical of those used in actual practice. The cross section of the specimen was square and the size was selected to represent, on four sides, the conditions of minimum concrete cover that would exist on one side of the tendon anchorage buttress in a typical containment structure. When the concrete had achieved strength a 169-wire tendon was installed and stressed to a load equivalent to seventy percent of its guaranteed ultimate tensile strength. An insulating enclosure was placed around the test specimen and using liquid nitrogen, the assembly was cooled to a temperature of approximately minus eighty degrees, Farenheit. This temperature was selected arbitrarily as being significantly lower than the lowest expected outdoor temperature for most areas of the country. The cooling period required approximately twenty-four hours to reach and stabilize at the selected temperature.

At this point the load-test phase was commenced while maintaining the reduced temperature. The load on the tendon was increased to 80% G.U.T.S. and held for fifteen minutes. At this point the load was then cycled between 60% and 80% G.U.T.S. for 500 cycles. Following the cyclic loading, the force in the tendon was increased to 100% of its guaranteed ultimate load.

At no time during the test was there any failure or evident distress in any component of the system. Post-test examination of the wire, bearing plate and anchorage hardware revealed no cracking or permanent damaging distortion.

2.0 PURPOSE

The purpose of this test was to demonstrate the low temperature serviceability of the 170-wire, BBR-type buttonhead anchorage post-tensioning system, including shims and bearing plate and to determine the crack sensitivity of tendon anchorage components when stressed to 0.7 G.U.T.S. cooled to a temperature of approximately - 80°F., subjected to 500 cycles of loading between 0.6 and 0.8 G.U.T.S., and then subjected to a static load of 1.0 G.U.T.S.

3.0 MATERIALS

With the exception of the bearing plates, all of the components of the test anchorage assembly represent an essentially random selection of material or fabricated items from stock.

a. Wire: Domestic stress-relieved wire conforming to the requirements of ASTM A 421 Grade BA was used to fabricate the tendon . Certificates of the chemical analysis and tensile properties are included in Appendix A2.0.

The buttonhead anchorage produced by cold upsetting the shear-cut end of the wire conformed to the requirements of the WCS 1.5 FS Head-Seat Systems.

b. Shims (Part No. 101006): Hot rolled plate conforming to the requirements of ASTM A 36 were torch-cut to the shape and dimensions shown by Figure A1-1.

All loose mill scale was removed by chipping and wire-brushing; all edges were deburred to assure full surface contact with adjacent shims, stressing washer and bearing plate. The cut edges were not machined, ground, or otherwise finished from the torch-cut condition.

c. Stressing Washer (Part No. 101003): Rod stock (6-1/2" dia.) of AISI 4142 steel was rough turned, drilled and heat treated to a hardness of R_c 42 ± 2 and then threaded. The serial number of the stressing washer used in the test was number 1024 and details are shown on Figure A1-2 which is included together with mill chemical analysis and heat treat certification in Appendix A1.0.

d. Washer Nut (Part No. 101004): Tube stock of AISI 4142 steel was machined and then heat treated to a hardness of R_c 42 ± 2. The washer nut was finished to the dimensions shown on Figure A1-3, which is included in Appendix A1.0 along with the mill chemical analysis and heat treat certifications. Threading was performed after heat treat. The serial number of the part used in the test was #561.

e. Bearing Plate (Part No. 100121): Hot rolled plate conforming to the requirements of ASTM A 36 (silicon killed, fine grain practice) was torch-cut to the shape and dimensions shown on Figure A1-4, which is included in Appendix A1.0 together with the certified chemical and physical analysis.

3.0 MATERIALS (continued)

f. Reinforcing Steel: Intermediate grade deformed reinforcing bars conforming to the requirements of ASTM A15 were placed in the concrete supporting the bearing plate in the manner shown on Figure 3-1 and 3-2. Mill certificates for the reinforcing steel are contained in Appendix A2.0.

g. Concrete: The concrete used in the test specimen conformed to the mix design prepared by Twining Laboratories, a copy of which is included in Appendix A2.0. The criteria for the mix design were: 1) compressive strength of 5,000 psi in 5 - 10 days, 2) 3/4-inch maximum size hardrock aggregate, 3) 2-1/2% entrained air, 4) 4-in. maximum slump. Twining Laboratories also inspected placement of bearing plates, reinforcing steel and concrete, and made cylinder tests as reported by them in Appendix A2.0. At the time of the cyclic loading and ultimate load test the concrete strength was 5,078 psi as indicated by two test cylinders. The age of the concrete at this time was 12 days. The modulus of elasticity was determined to be 3,383,000 psi.

4.0 PREPARATION OF TEST SPECIMEN

4.1 Plate Size and Preparation: In order to obtain plates for the test specimen with as high a carbon content as has been utilized to date in construction; it was necessary to produce the test samples from 4-inch thick plate, the only material available with a carbon content of approximately 0.2%. Consequently, a 4-inch thick piece, 2' - 0" x 4' - 0", was obtained and ground on one face to a thickness of 3-3/4inches. The plate was then torch-cut into eight pieces as shown in Fig. 4-1. All cutting was started on the unground side and this side of the bearing plate, piece No. P1, was placed against the concrete so that any harmful effects of the mill rolled surface would be on the tensile surface.

4.2 Mechanical Faults: In an attempt to make the test more severe than any condition that would occur in practice, several artificial flaws were added in addition to whatever metallurgical notches might be produced by torch-cutting the tendon tube hole. These mechanical faults, shown in Figures 4-1, through 4-5, consisted of 1) a V notch produced with a cold-chisel and intended to simulate a case where the edge of a plate is dropped across the hole edge of another plate, 2) a 1/2 inch long radially directed torch-cut slot intended to simulate the case of an overlooked, misdirected torch-cut and 3) a hook-shaped, torch-cut slot intended to simulate the case of an overlooked starting cut that had been made on the incorrect side of the opening. In addition, during the welding of the trumpet tube to the bearing plate, the welding rod was deliberately dragged away from the joint for a distance of one inch onto the plate and on completion the rod was grounded-out to the plate and then broken off to simulate an accidental weld strike. While the faults may be realistic, it is considered inconceivable that a bearing plate containing any one of them would escape detection and be installed on a concrete structure.

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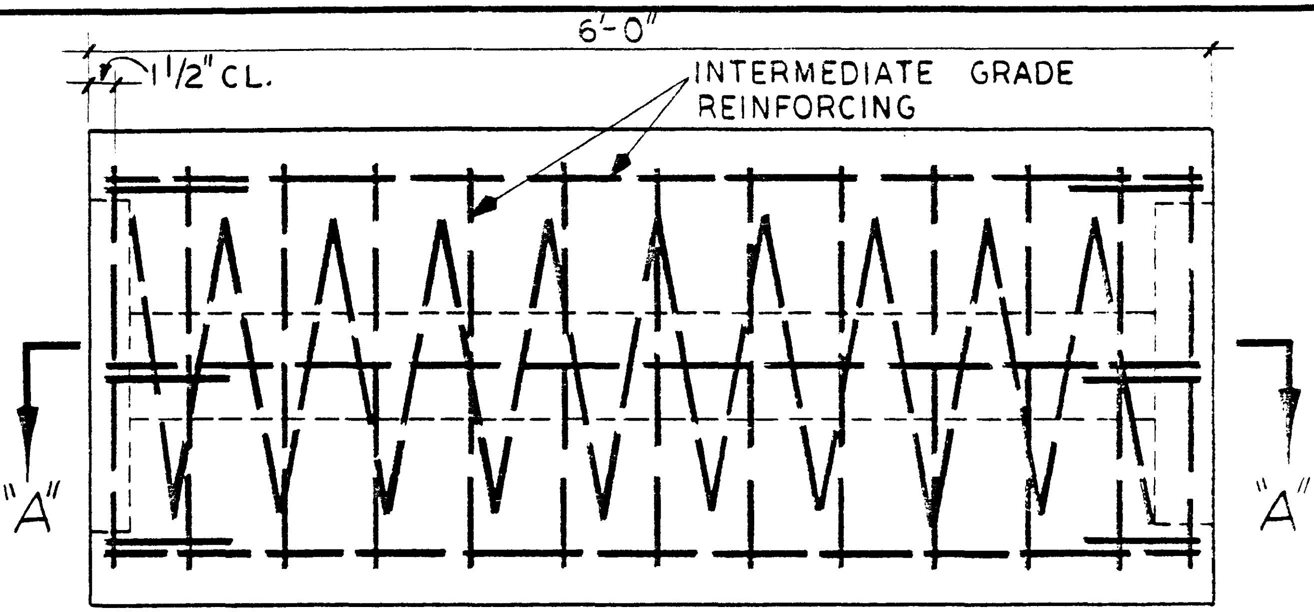
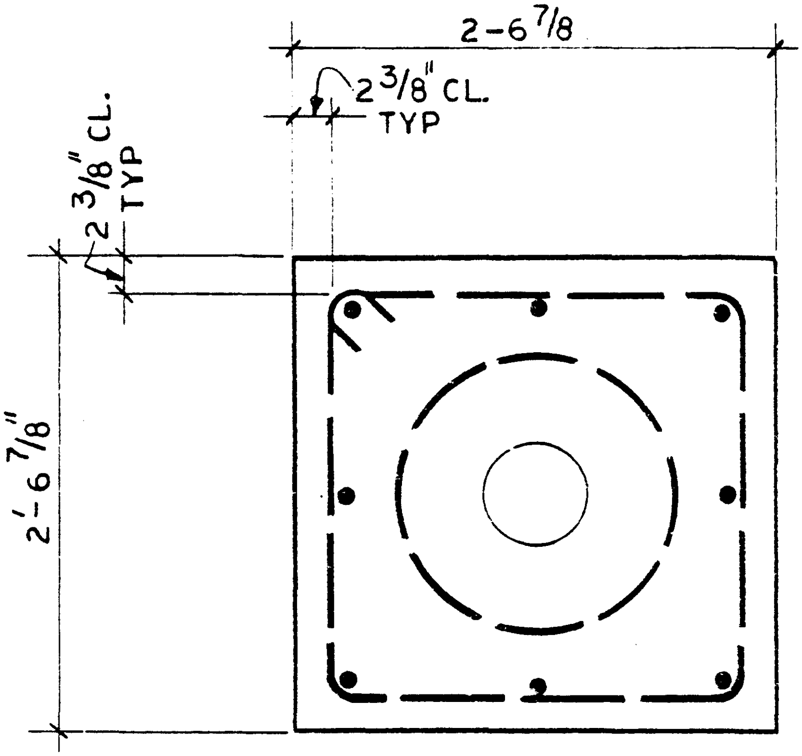


PLAN



END VIEW

DATE	LOW TEMPERATURE BEHAVIOR OF THE WCS 2.0 Mep/170-W POST-TENSIONING SYSTEM	WCS 19113 SOUTH HAMILTON AVENUE GARDENA · CALIFORNIA · 321-1571	PROJ. NO. 1-445
DES. BY			Fig. 3-1
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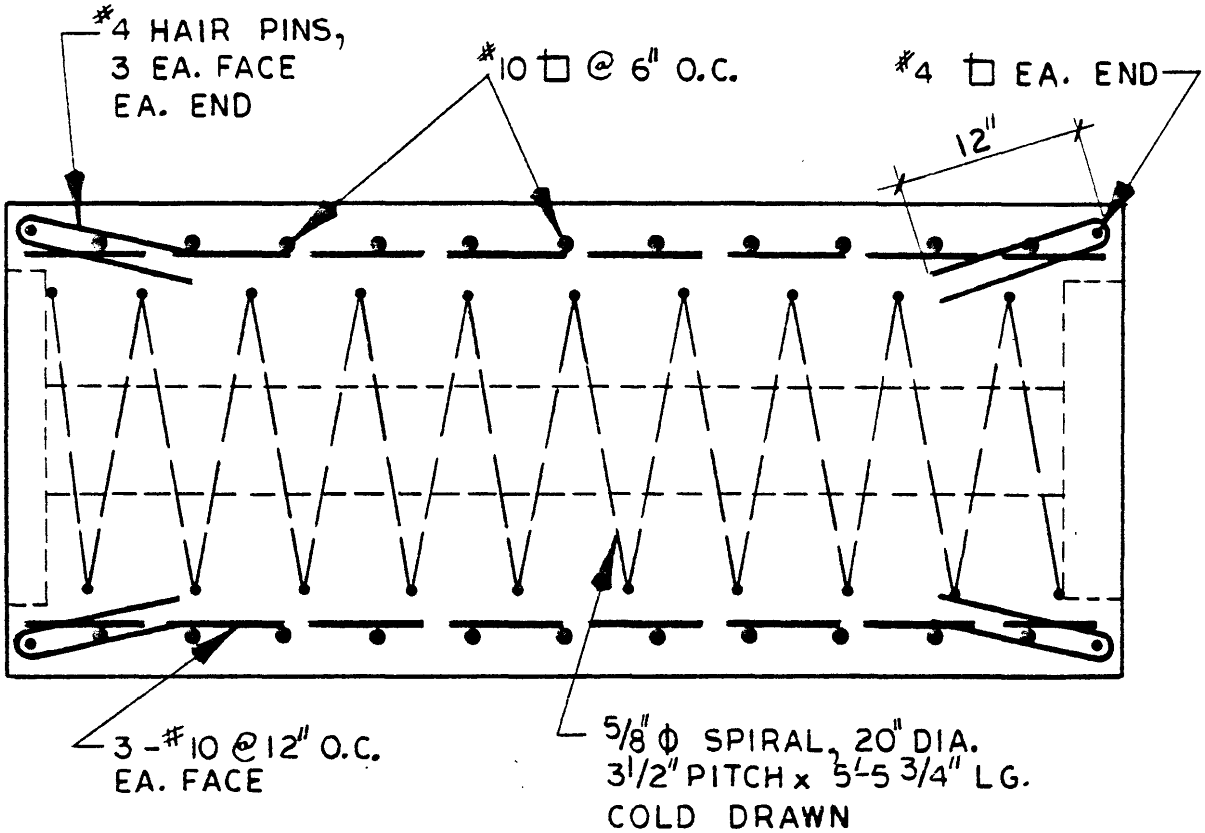

SECTION "A-A"

INTERMEDIATE GRADE REINFORCING

DATE	LOW TEMPERATURE BEHAVIOR OF THE WCS 2.0 Mep/170-W POST-TENSIONING SYSTEM	WCS	PROJ. NO. 1-445
DES. BY			Fig. 3-2
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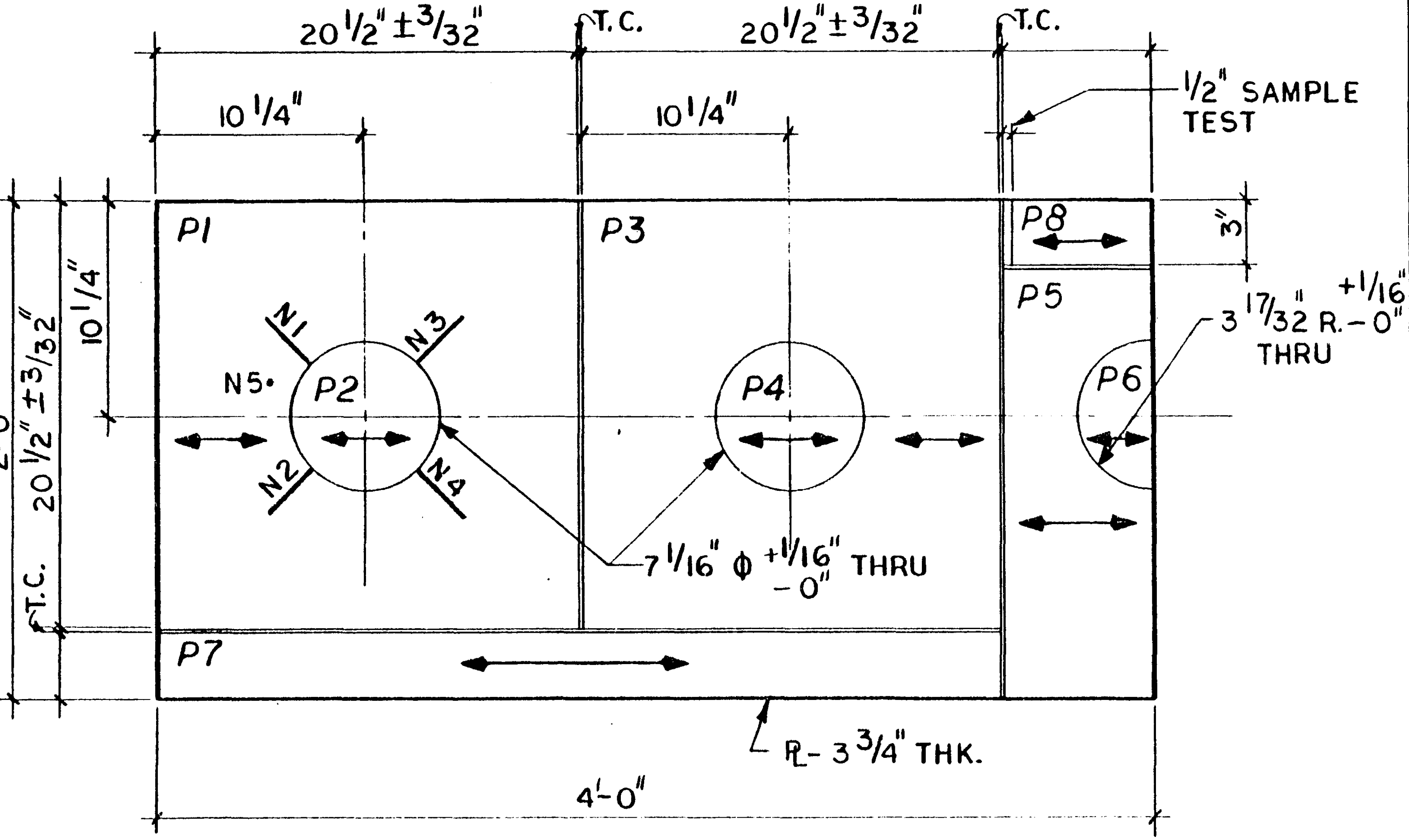

CUTTING LAYOUT

NOTES:

1- SAVE ALL SCRAPS.
2- INDENTIFY ALL PIECES (P1, P2, ETC)
3- INDENTIFY WITH ARROWS TO MATCH PIECES.
4- N-1 = 1" LG. DRAG WELD
   N-2 = 1/2" LG. (THRU) TORCH CUT
   N-3 = 1/2" LG. "J" START TORCH CUT
   N-4 = 1/8" COLD CHISEL "V" NOTCH
   N-5 = WELD STRIKE

LOW TEMPERATURE BEHAVIOR OF THE WCS 2.0 Mep/170-W POST-TENSIONING SYSTEM

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Fig. 4-1

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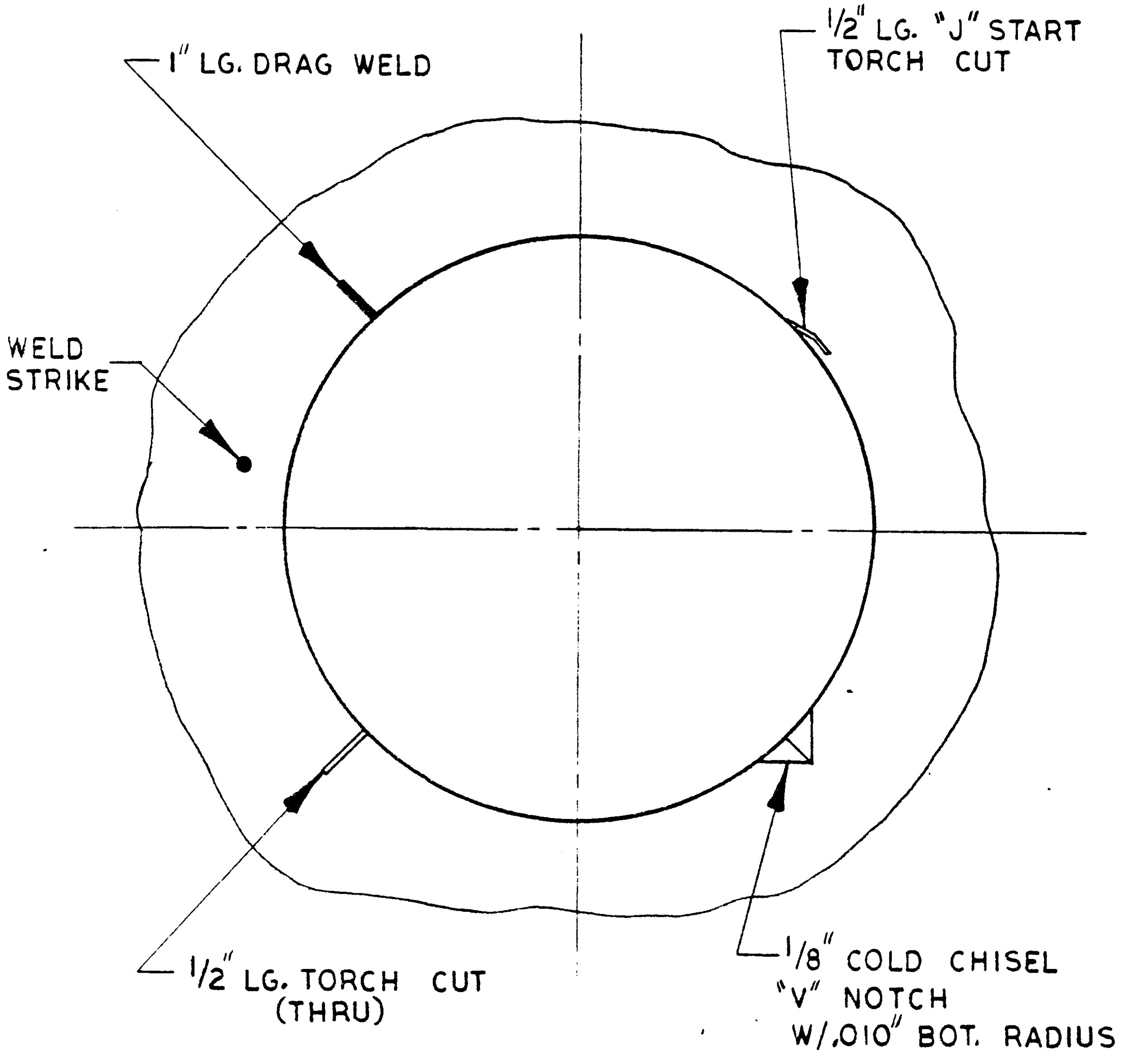

TEST DETAIL

DATE	LOW TEMPERATURE BEHAVIOR OF THE WCS 2.0 Mep/170-W POST-TENSIONING SYSTEM	WCS	PROJ. NO. 1-445
DES. BY		19113 SOUTH HAMILTON AVENUE GARDENA · CALIFORNIA · 321-157	Fig. 4-2
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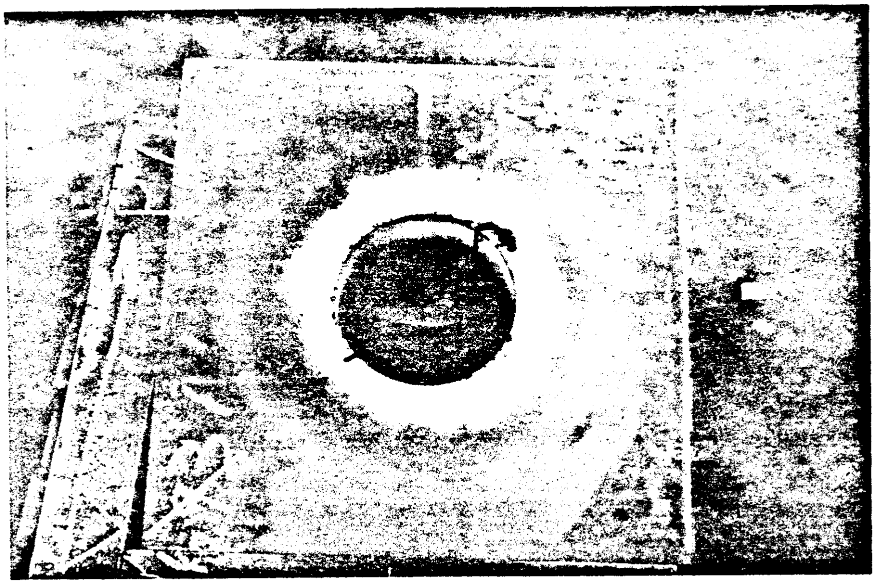


Figure 4-3 Test bearing plate after dye penetrant inspection for cracks around center hole and intentional torch-cut flaws.

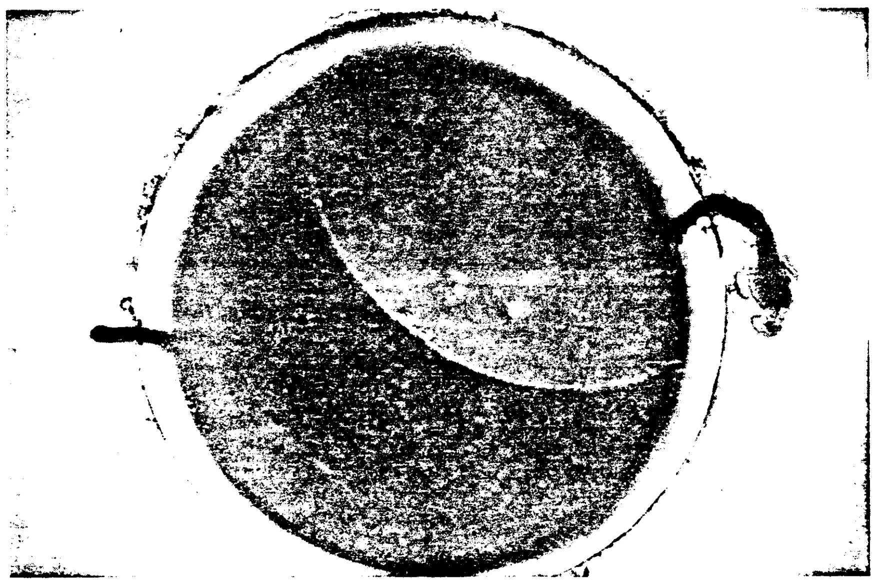


Figure 4-4 Close-up of torch-cut flaws.

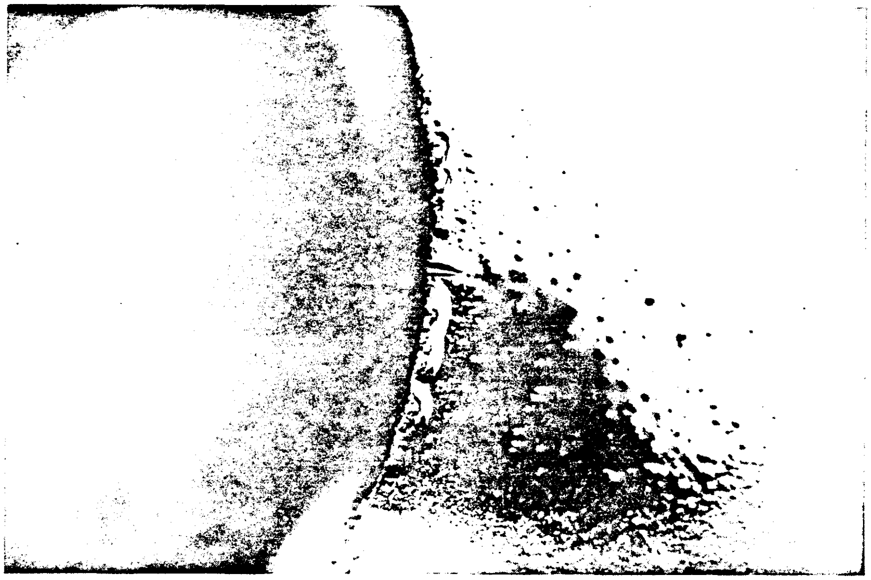


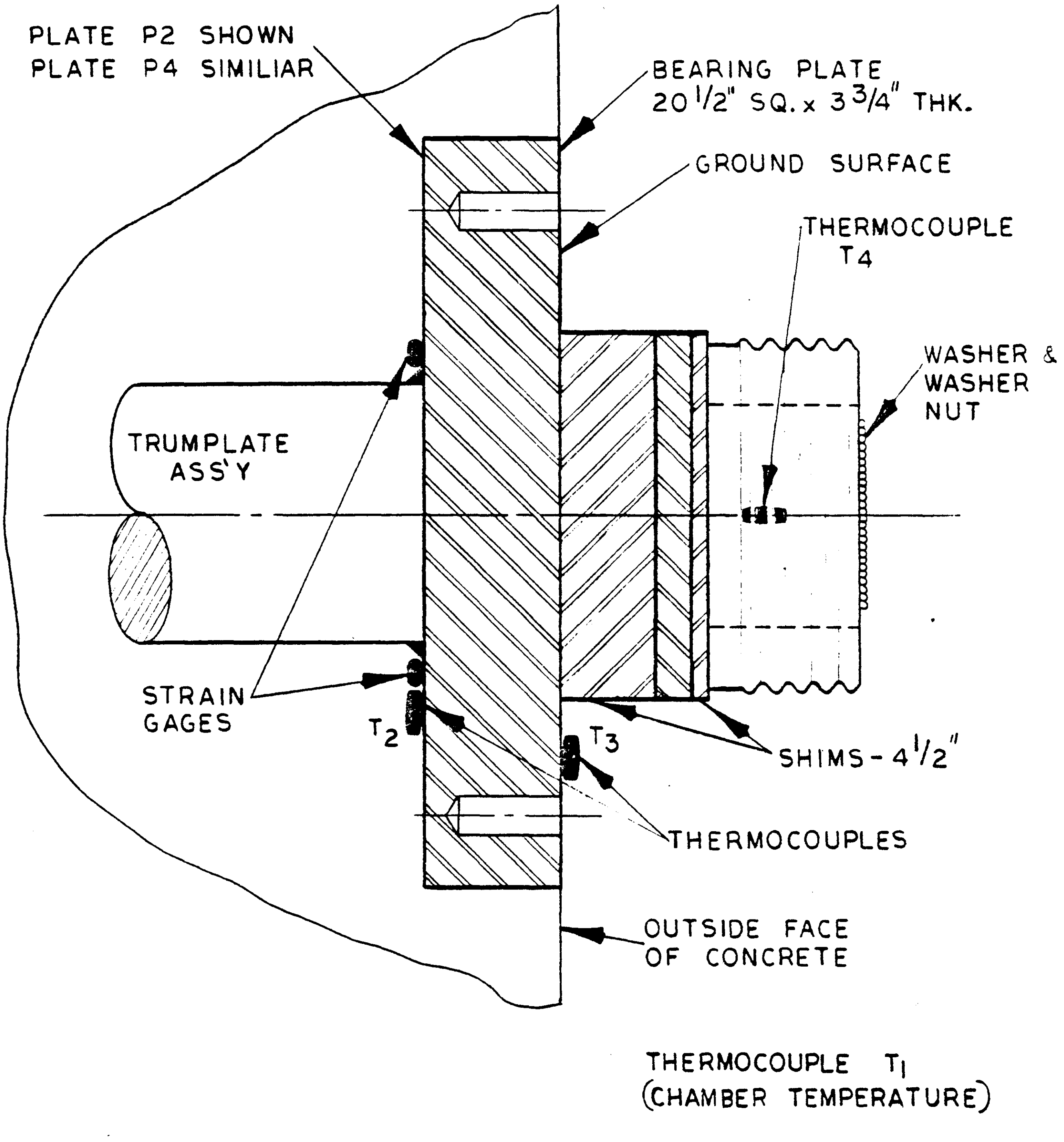
Figure 4-5 Close-up of cold chisel notch on edge of bearing plate center hole.

4.0 PREPARATION OF TEST SPECIMEN (continued)

4.3 Inspection: The bearing plate was inspected for cracks or other surface defects using dye penetrant. This inspection was made on both sides of the plate in an area approximately six inches wide surrounding the center hole. The surface of the hole was also checked.

This inspection was repeated after the trumpet tube was welded to the bearing plate. No evidence of cracking was detected as a result of these inspections.

4.4 Instrumentation Placement: Copper-constantan thermocouples and strain gage rosettes were attached to the bearing plate. The strain gages were placed as close as practical to the weld between the trumpet tube and bearing plate; the center of the gage was approximately 1/2" from the toe of the weld. The position and orientation of the gage axes are shown in Figs. 4-6 and 4-7. The thermocouple on the outside of the plate was installed after the concrete was cast and the forms stripped. Thermocouple readout was by a Leeds and Northrop Model 8662 temperature potentiometer while strain gages were read with a Baldwin SR4 strain gage readout.



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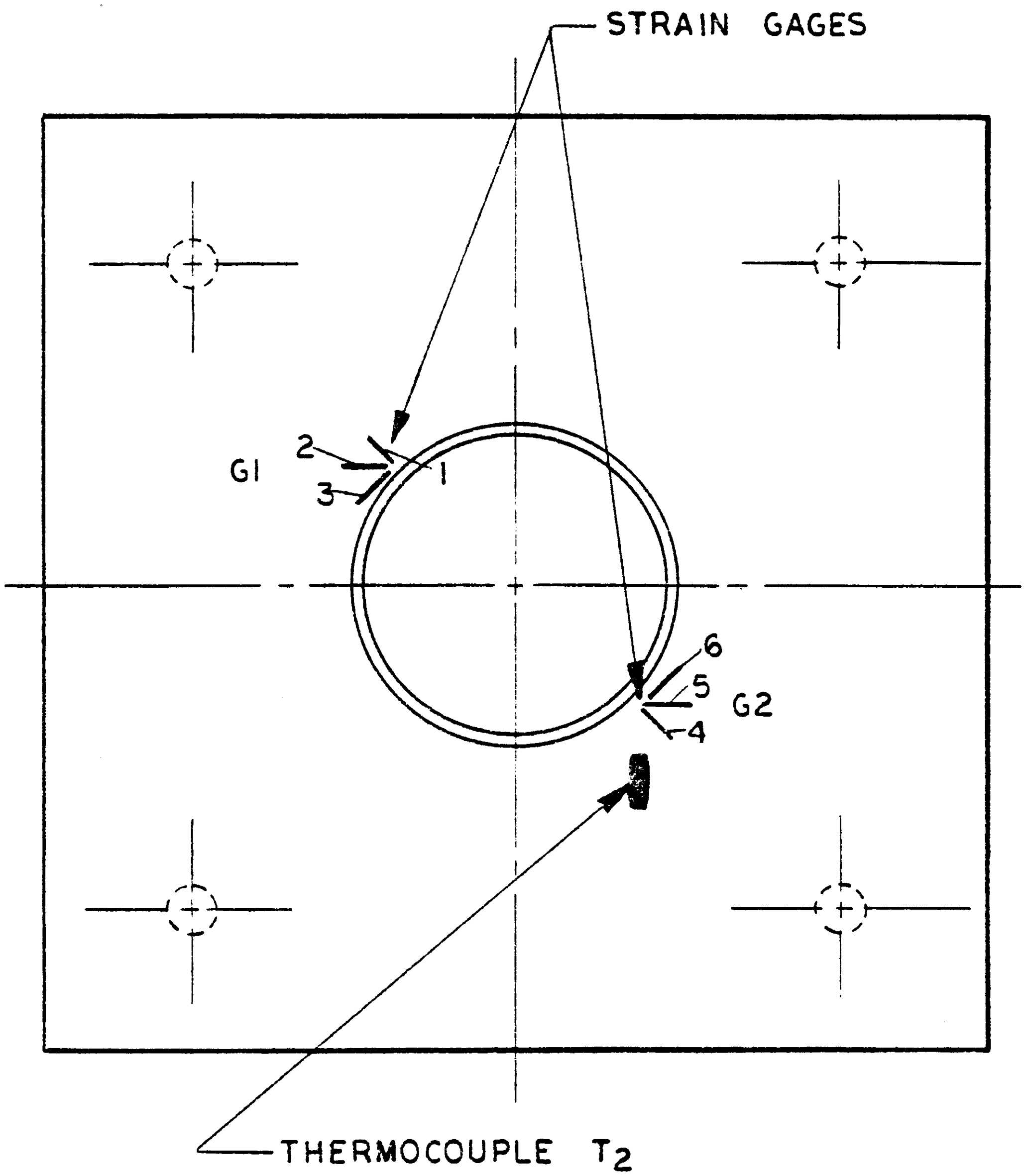

CONCRETE SIDE OF BEARING PL

DATE	LOW TEMPERATURE BEHAVIOR OF THE WCS 2.0 Mep/170-W POST-TENSIONING SYSTEM	WCS	PROJ. NO. 1-445
DES. BY			Fig. 4-7
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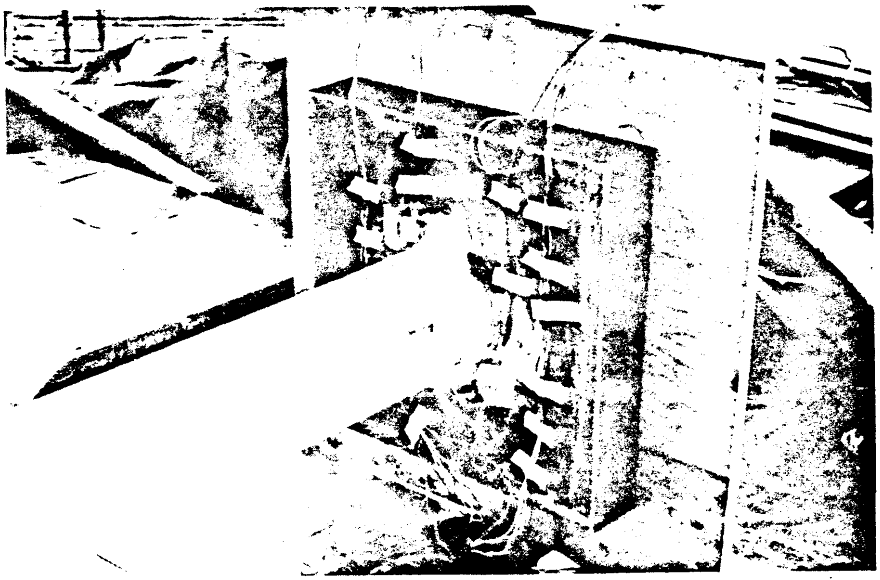


Figure 4-8 Bearing plate and trumpet assembly with instrumentation in place.

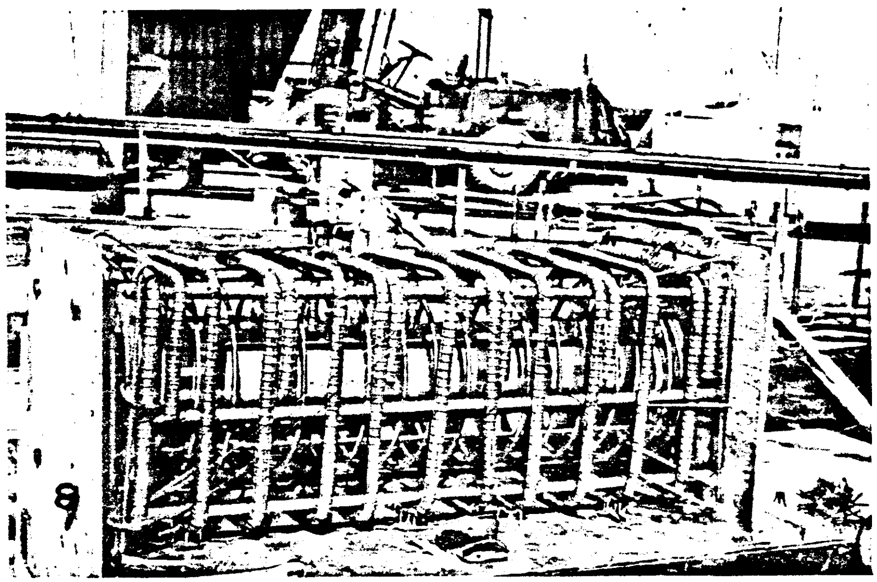


Figure 4-9 Preparation of test specimen with reinforcement in place.

5.0 BEARING PLATE METALLURGICAL EVALUATION

5.1 Tensile Properties: The tensile properties of the bearing plate steel were determined by Atlas Testing Laboratories for all three directions; longitudinal, transverse and short transverse, as shown in Appendix A2.0. The tests were performed in accordance with ASTM - E8 and the specimens were cut from Piece P8 as shown by Figure 5-1. Subsequent to preparation of Figure 5-1 and the test specimens, metallographic examination revealed that the 4' - 0" dimension of the plate was in fact oriented transverse to the rolling direction. The actual average tensile properties are as shown below:

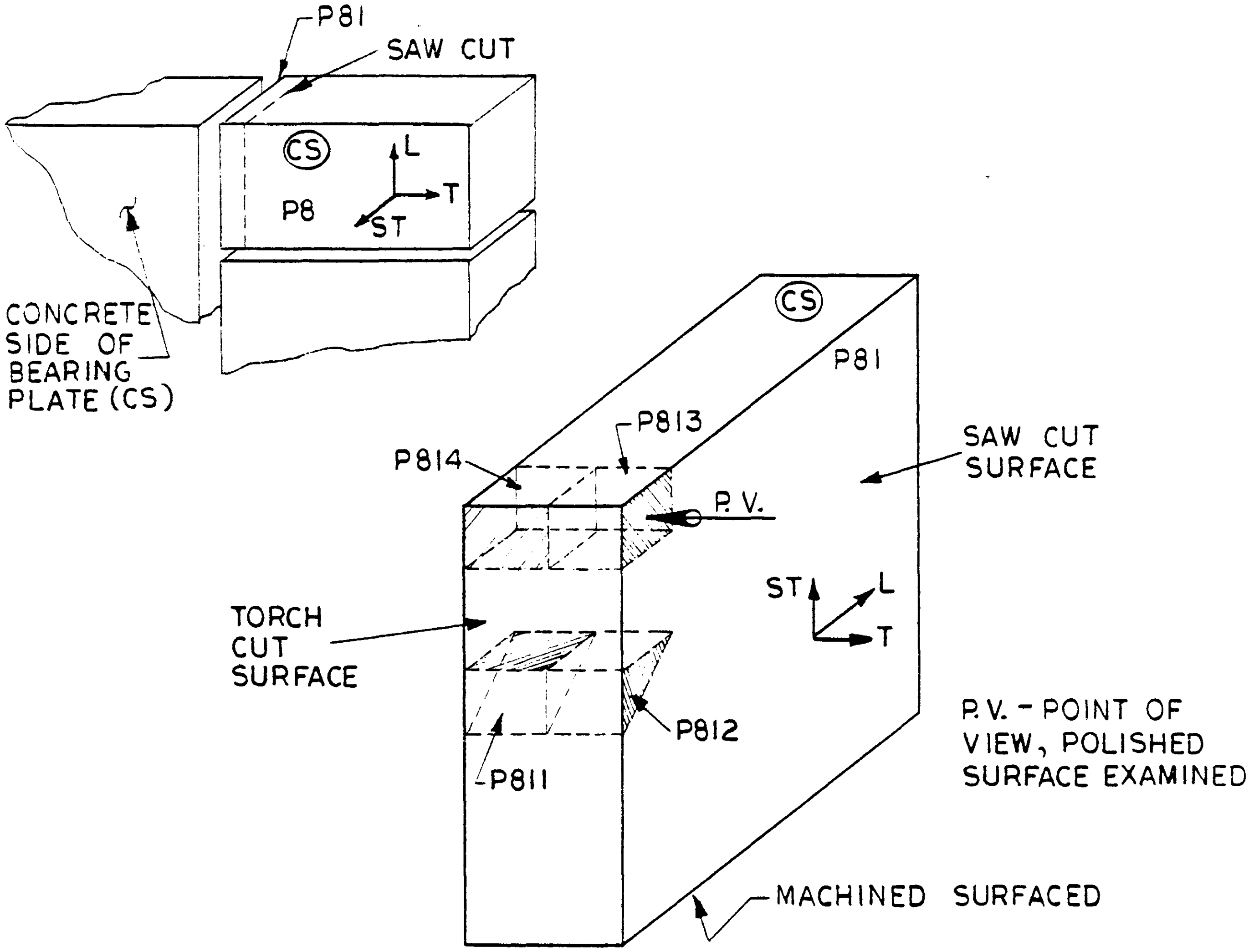
	Tensile Strength (ksi)	Yield Point (ksi)	Elong. % in 4 D	Reduction in Area %
Longitudinal	65.8	35.0	34.1	64.3
Long Transverse	65.8	32.7	30.5	46.0
Short Transverse	63.17	39.2	9.8	18.9

It should be noted that some of the properties listed above are below the minimums specified by ASTM-A 36.

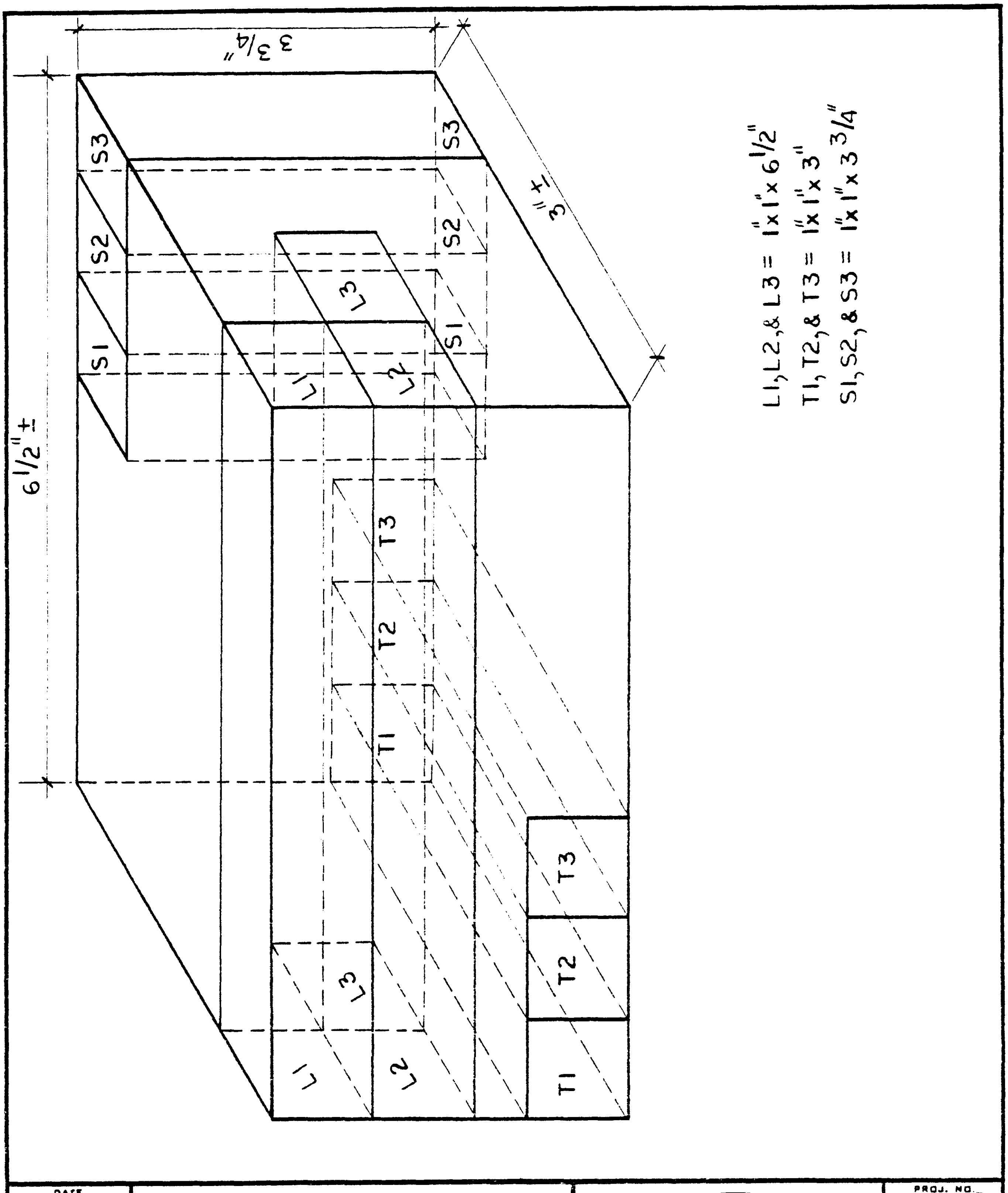
A chemical analysis was also made by Atlas Testing Laboratories, Inc., a copy of which is included in Appendix A2.0.

5.2 Metallography: The bearing plate was sectioned for a metallographic examination of the microstructure associated with a torch-cut and with the bearing plate trumpet weld. The location of these sections is shown on Figures 5-1 and 5-2.

The 1/2-inch slice from piece P8 of the plate material was resectioned as shown by the following sketches:



P811	T-L	Surface - check rolling direction.
P812	ST-L	Surface - check inclusions to compare with P813.
P813	ST-L	Surface - check effect of torch - cut at edge simulating BP hole edge; grain size.
P814	ST-T	Surface - check rolling direction and grain size.



DATE	LOW TEMPERATURE BEHAVIOR OF THE WCS 2.0 Mep/170-W POST-TENSIONING SYSTEM	WCS	PROJ. NO. 1-445
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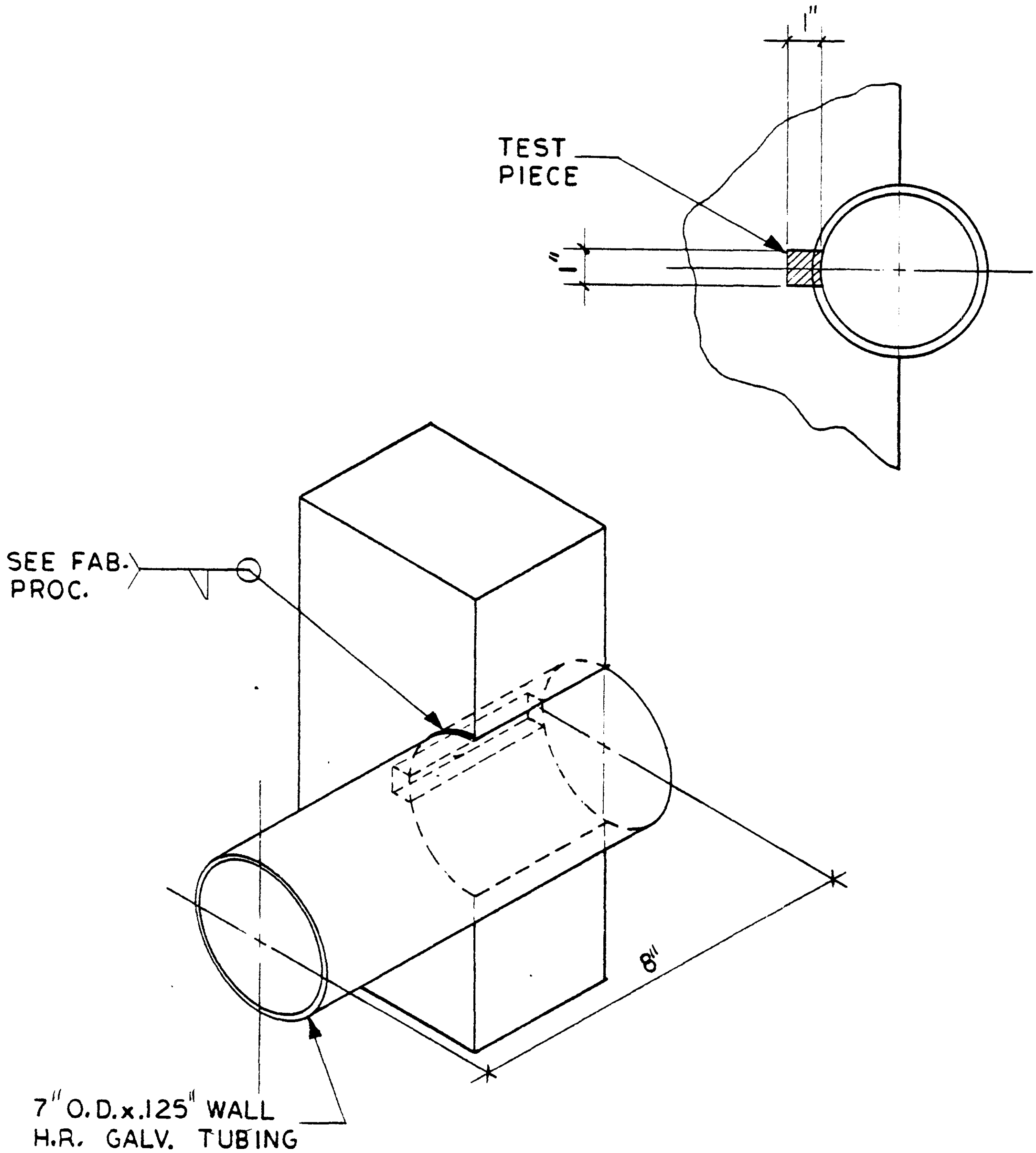

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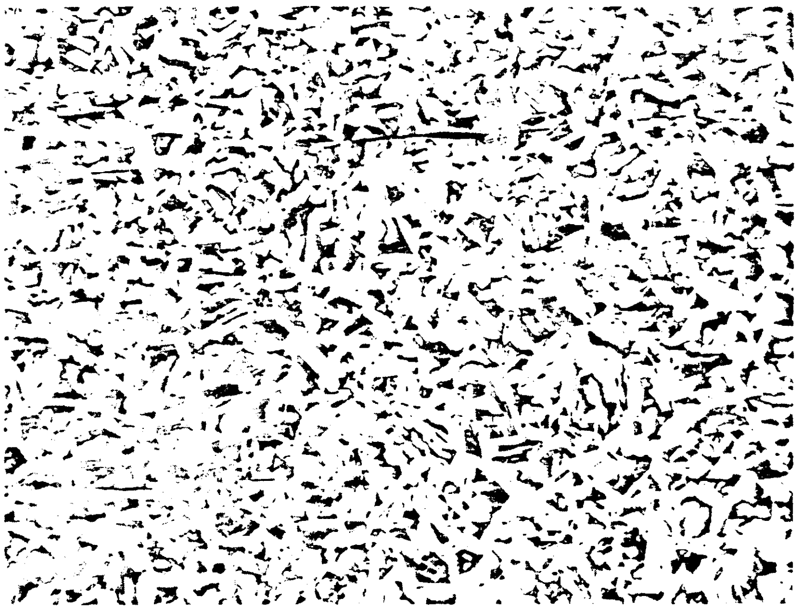


Figure 5-3 General microstructure of the bearing plate is normal, pearlite in a matrix of ferrite; an inclusion is shown at the top center. The grain size was estimated at ASTM 6. Piece P813, Neg. No. LTH 645-2 (50x.)

Figure 5-4 Microstructure at the rolled surface of the plate is normal. Piece P813, Neg No. LTH 645-4 (200x.)

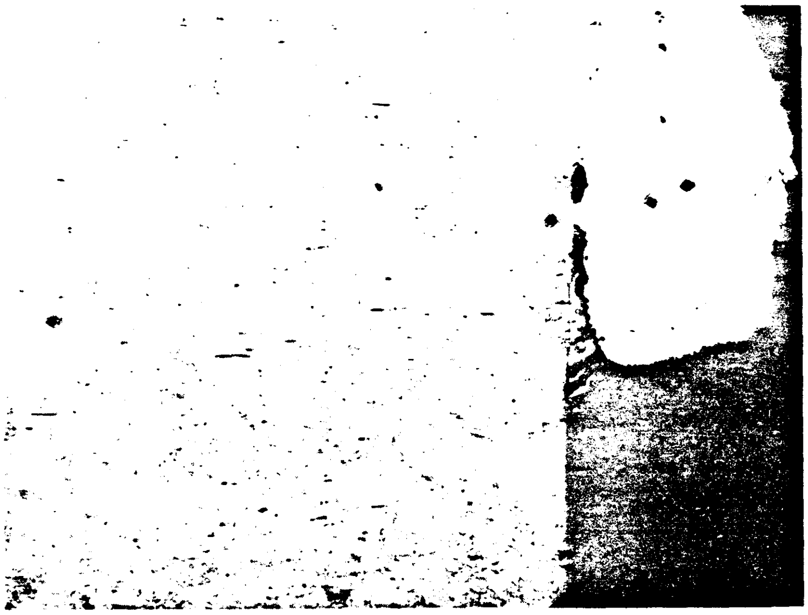
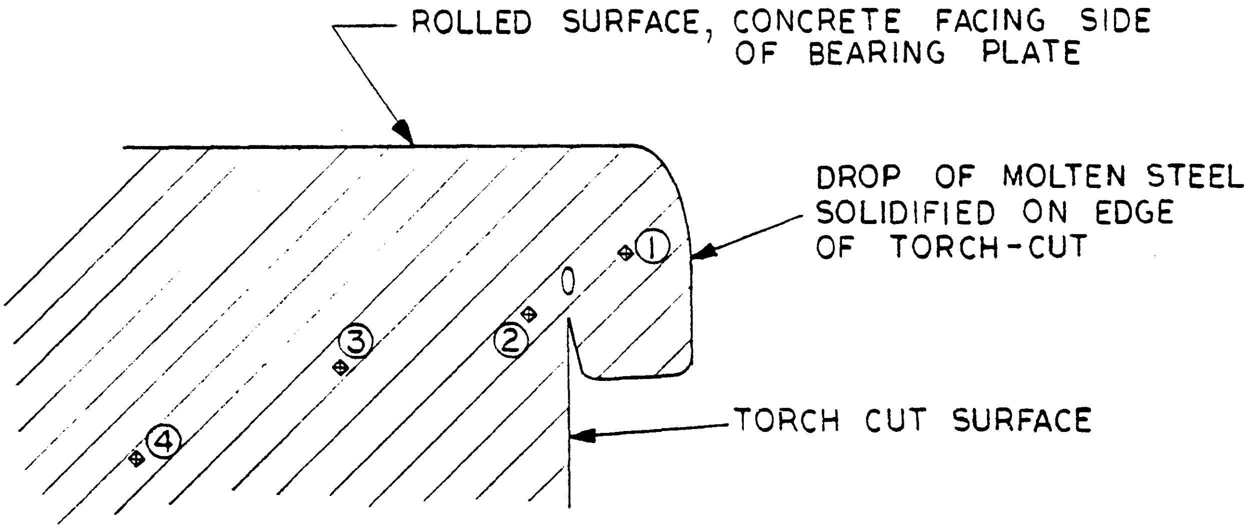


Figure 5-5 A torch-cut surface (right) near rolled surface of bearing plate (see sketch below.) Piece P813, Neg. No. LTH 645-3 (50x).



HARDNESS - ① 155 DPH = RB 82
② 202 DPH = RB 92
③ 227 DPH = RB 97
④ 247 DPH = RB 100 = RC 22

BASE METAL=RB 92

Figure 5-6 Hardness and microstructure on a mid-thickness section of the bearing plate hole. A thin dark-grey layer at the edge is scale, the white layer (0.001" thick) is a hard (R_c - 67) martinsite, the subsurface Widmanstatten structure is relatively soft (R_c - 22) and becomes softer further from the surface. This structure may have poor ductility. Neg. No. LTH 645-10 (250x).

5.3 Weld Metallography: The weld joint was good; there was no evidence of gas porsity of cracks at the toe or root of the weld. The microstructure of the heat affected zone was normal as shown in the following photo-micrographs.

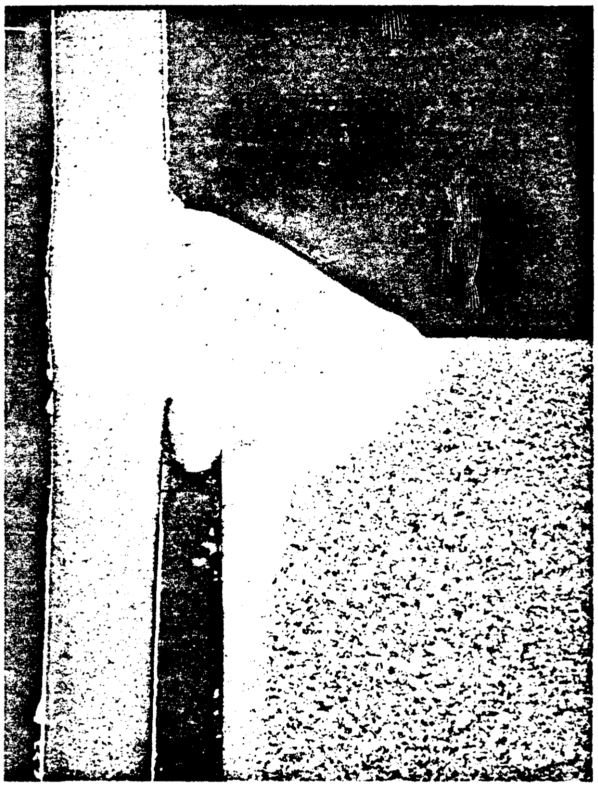


Figure 5-7 The microstructure of the trumpet/bearing plate fillet weld. No cracks or porosity were seen Neg. No. LTH 719-1 (4.5x).

	DPH	R_B
1.	222	95
2.	230	97
3.	274	(103)
4.	221	95
5.	181	87
6.	186	88
7.	207	93
		(bearing Plate)
8.	266	(101.5)

Figure 5-8 The toe of the weld at the bearing plate showed no hardened layer in the heat affect zone, see Table above. Neg. No. LTH 719-3 (100x).

	DPH	R_B
1.	242	98
2.	230	97
3.	168	85
4.	221	95
5	203	92

Figure 5-9 The root of the weld showing the edge of the bearing plate hole (arrow) and the martensitic layer, see table above for hardnesses. Neg. No. 719-2 (100x).

UPDATE - 1 7/82

6.0 TEST PROCEDURE

6.1 Test Set Up: The test set up is shown schematically in Figures 6-1 and 6-2. Figure 6-4 is a photograph of the actual test installation.

Liquid nitrogen was used for chamber cooling. Loading was accomplished by means of a WCS 1,000 Ton stressing jack.

6.2 Stressing Jack Calibration: The jack was calibrated using a short tendon and a compression type load cell. Jack output force was obtained as a function of hydraulic pressure at 100 kip increments from 100 to 1100 kips. This data was plotted and extrapolated to 2000 kips, as shown by the data sheet and calibration contained in Appendix A 3.0.

6.3 Cool Down: The tendon was installed in the test block, with shims at the test end, after the concrete reached 4000 psi, and the insulated chamber placed over the test assembly as shown in Figure 6-1 and 6-4.

When concrete strength reached 4,845 psi the tendon was stressed to 1,393 kips (70% of G.U.T.S.) and the cooldown started. Cooling was by means of liquid nitrogen bled into the chamber. Upon entry into the chamber the nitrogen vaporized to a gas and was circulated by the notch driven fan.

Temperature on both faces of the bearing plate, on the inside surface of the washer and in the chamber was monitored and recorded at one-half hour intervals during the cooldown period. Also recorded were the strains registered by the two rosettes. These data are contained in Appendix A3.0. Cooldown required approximately 24 hours. At the end of this period, the temperature at the concrete face and exposed face of the bearing plate were – 73°F and – 81°F. respectively. Lowest chamber temperature during cooldown was – 128° F.

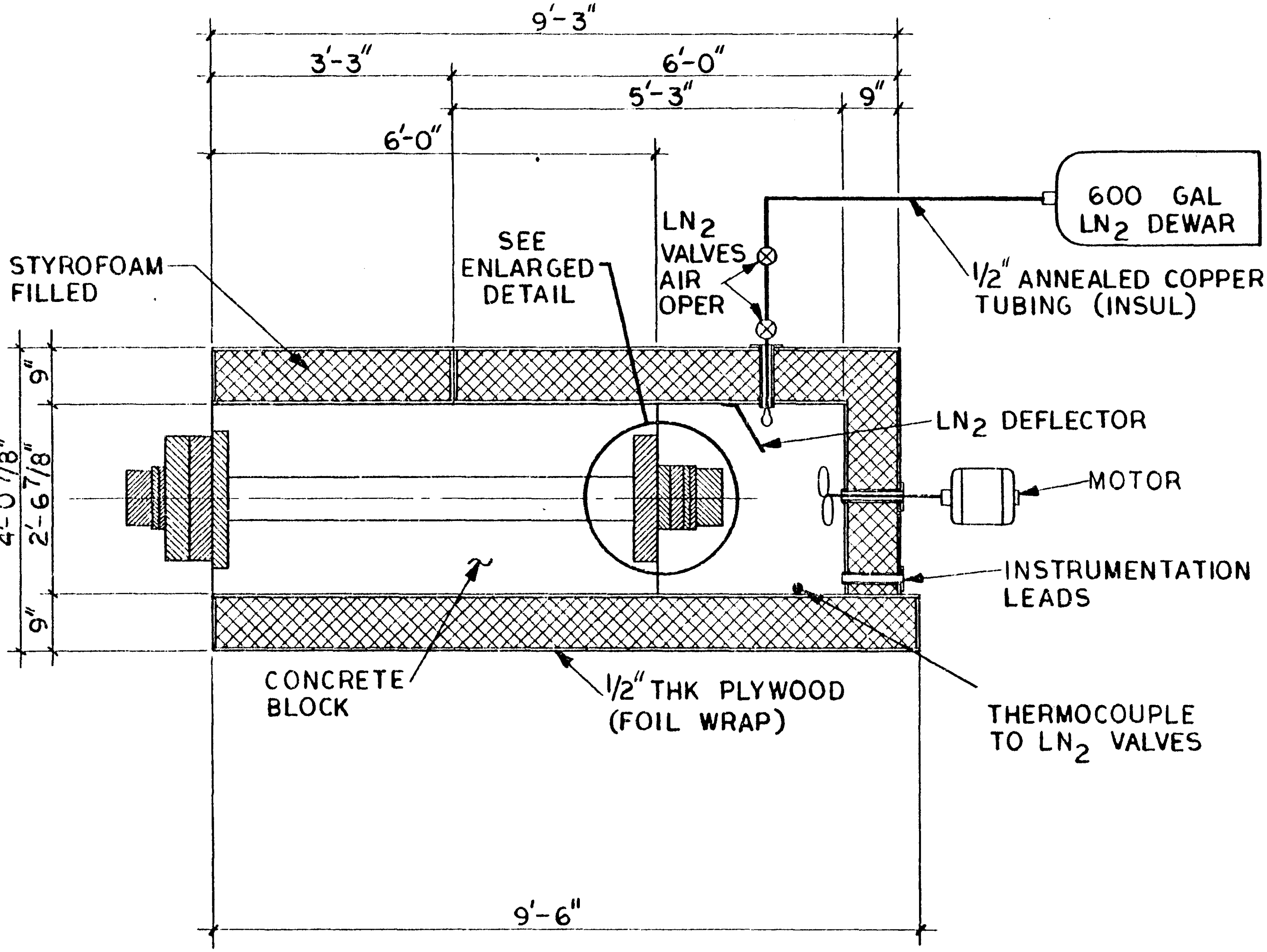
6.4 Cyclic Loading: Immediately following the cooldown period the tendon was stressed to a hydraulic pressure of 7728 psi (80% G.U.T.S.) and held at this load for 15 minutes.

The load on the tendon was then cycled between 60% and 80% of guaranteed ultimate tensile strength (1,194,600 lbs. and 1,592,000 lbs. respectively) a total of five hundred times. Each cycle consisted of an increase in load from 60% to 80% of G.U.T.S. and then back to 60%. Cycling rate was approximately 100 cycles per hour.

Load was determined by means of the stressing jack hydraulic pressure, measured using the same gage that had been used for jack calibration.

After each 100 cycles, strain gage data was read at 60% and 80% load and recorded along with bearing plate and anchor head temperature. These data may be found in Appendix A3.0.

UPDATE - 1
7/82



SECTION - COOLANT HOUSING

LOW TEMPERATURE BEHAVIOR OF THE WCS 2.0 Mep/170-W POST-TENSIONING SYSTEM

SECTION 5E

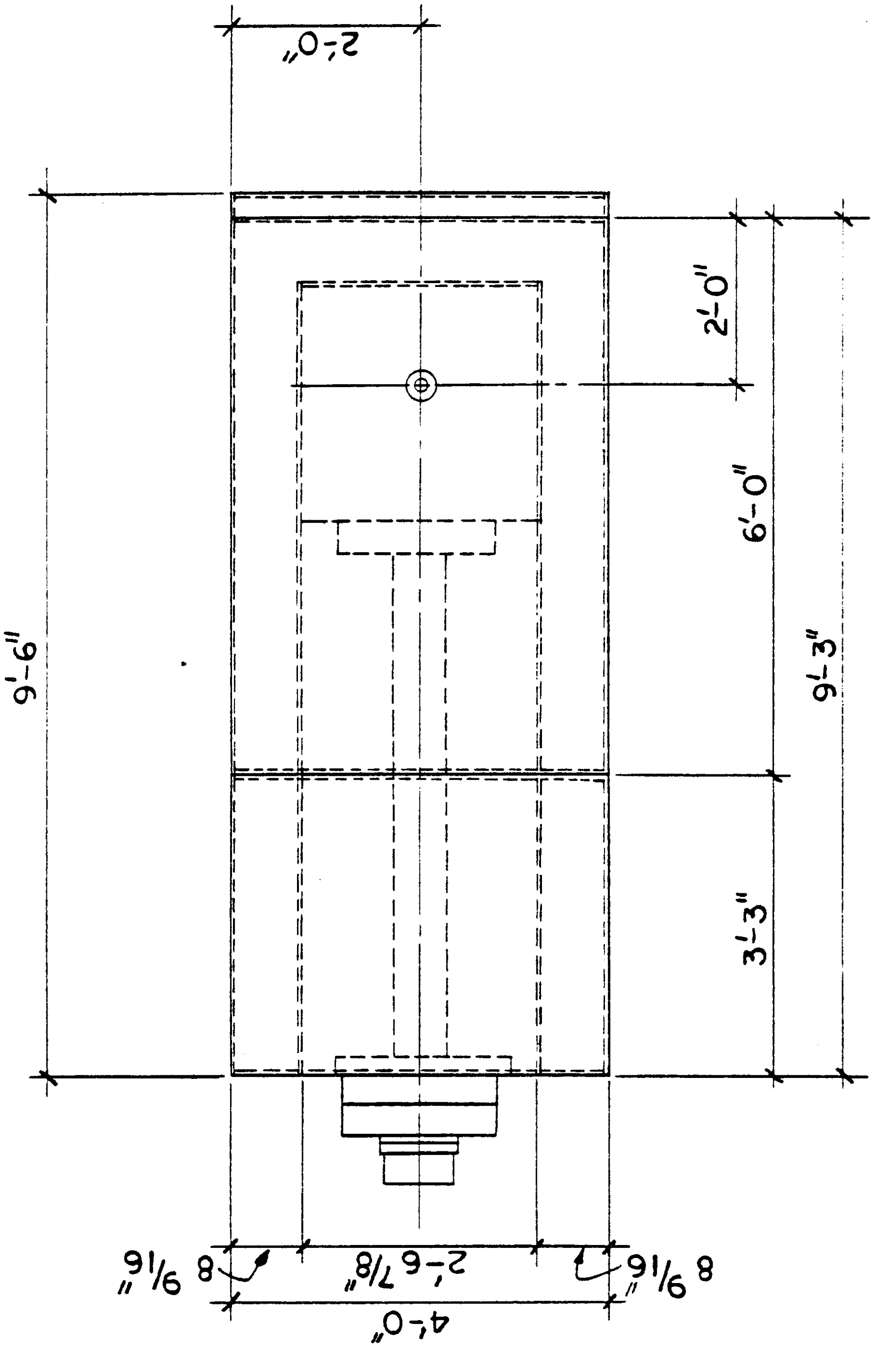
5B-138

1913 SOUTH HAMILTON AVENUE
GARDENA · CALIFORNIA · 321-1571

PROJ. NO. 1-445

Fig. 6-1

SEPT. 69



PLAN - COOLANT HOUSING

DATE			PROJ. NO. 1-445
DES. BY	LOW TEMPERATURE BEHAVIOR OF THE WCS 2.0 Mep/170-W POST-TENSIONING SYSTEM	WCS	Fig. 6-2
DWN. BY			
CKD. BY	SECTION 5B 5B-139	19113 SOUTH HAMILTON AVENUE GARDENA · CALIFORNIA · 321-1571	SHT ____ OF ____

SEPT - 69

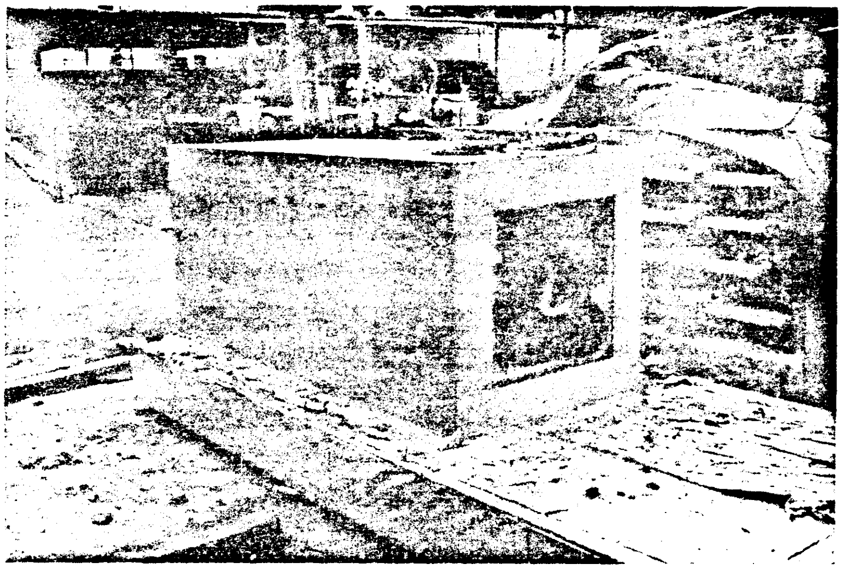


Figure 6-3 Test specimen after concrete cast and forms removed.

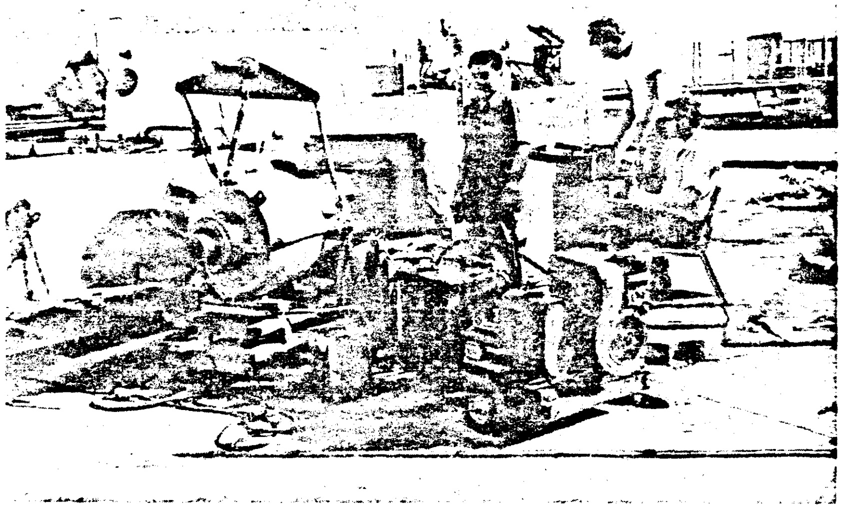


Figure 6-4 Test set-up during cyclic loading. Load applied using 1000-Ton hydraulic ram.

6.0 TEST PROCEDURE (continued)

6.5 Tendon Guaranteed Ultimate Load: Following the cyclical loading, the tendon was loaded to guaranteed ultimate tensile strength 1,990,000 lbs. in the increments shown on DS-3, contained in Appendix A3.0. Strain gage data was recorded at each increment.

Temperatures during this test were – 76°F. at the concrete face of the bearing plate, and – 87°F. at the front face .

6.6 Post Test Inspection: Upon completion of testing, the tendon was removed from the test assembly, the wires cut, and the anchorage hardware removed for inspection. The washer and washer nut were checked for distortion and dye penetrant inspected for cracks.

The outer face of the bearing plate, a ground surface was check for flatness.

The bearing plate was then removed from the concrete and dye penetrant inspected.

7.0 RESULTS

7.1 Chemical and physical properties of the material used in the bearing plate tested was determined by Atlas Testing Laboratories of Los Angeles. Copies of their reports are included in Appendix A.

Tensile yield in the longitudinal direction as determined from the average of three tests was 35,000 psi. This is almost 3% lower than the value of 36,000 psi minimum specified in A-36. Ultimate tensile strength was in the low end of the allowable range. Chemical composition was undistinguished with a carbon content of .21%. This is higher than any of the plates used in production.

7.2 The plate tested showed no visible signs of damage after being loaded to tendon guaranteed ultimate tensile strength, following 500 cycles of loading from 60% to 80% of tendon guaranteed ultimate tensile strength, all at temperatures between – 70°F. and – 90°F.

7.3 Post test inspection revealed no deformation or cracks on either the anchorage hardware or bearing plate.

7.4 Strain gage data indicated that strains were linear throughout the cyclic and ultimate load test phases showing that the bearing plate stresses remained below the yield point of the material at ultimate tendon load.

8.0 CONCLUSIONS

8.1 Due to the comparatively higher carbon content and low yield strength, it may be concluded that, in terms of material properties, this test represented a more severe condition than would be expected on the job.

8.2 Deliberate damage to the plate, as described in Section 4.2 was severe. These defects would ordinarily be cause for rejection. It may therefore be stated, that in terms of material condition, the plate tested represented an extreme case.

8.3 The serviceability of the bearing plate at temperatures well below normal ambient conditions has been demonstrated.

8.4 In view of this test, wherein a defective bearing plate with unacceptably low physical properties was loaded to values which will not be encountered in actual use, under temperatures lower than ever expected, without failure; it may concluded that the bearing plate design is suitable for the use intended.

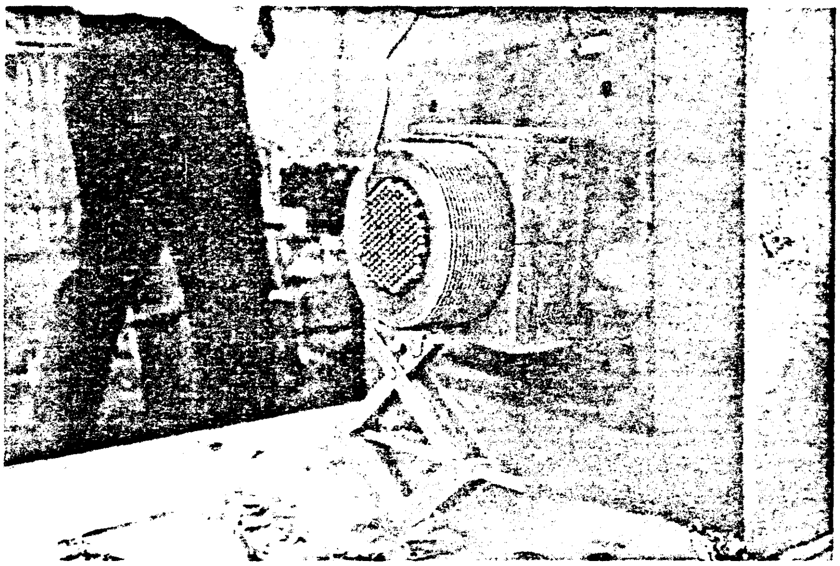


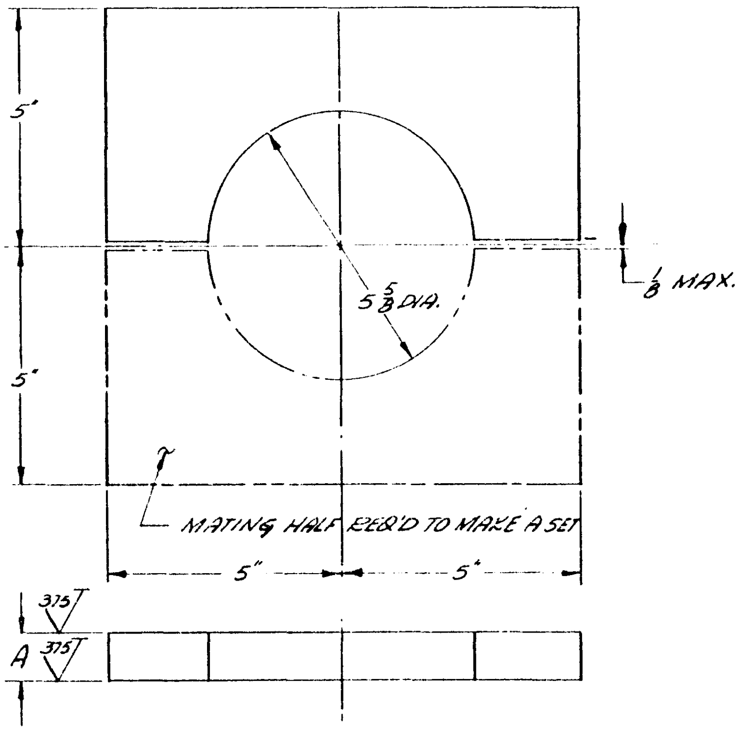
Figure 8-1 Test specimen anchorage immediately after conclusion of test and removal of insulated enclosure.

APPENDIX A1.0

ANCHORAGE DETAILS AND PROPERTIES

NOTES: UNLESS OTHERWISE SPECIFIED

1. SEE L.M. FOR QUALITY ASSURANCE AND PROCESSING REQUIREMENTS
2. MATERIAL PER ASTM A-36, SILICON KILLED FINE GRADE PRACTICE. SEE L.M. FOR PROCUREMENT SPECIFICATIONS
3. REMOVE SLAG & BURRS FROM ALL EDGES
4. DIMENSIONS SHOWN ARE FOR TOP EDGE, 1/2 DEG. BEVEL ALLOWABLE FOR FLAME CUTTING

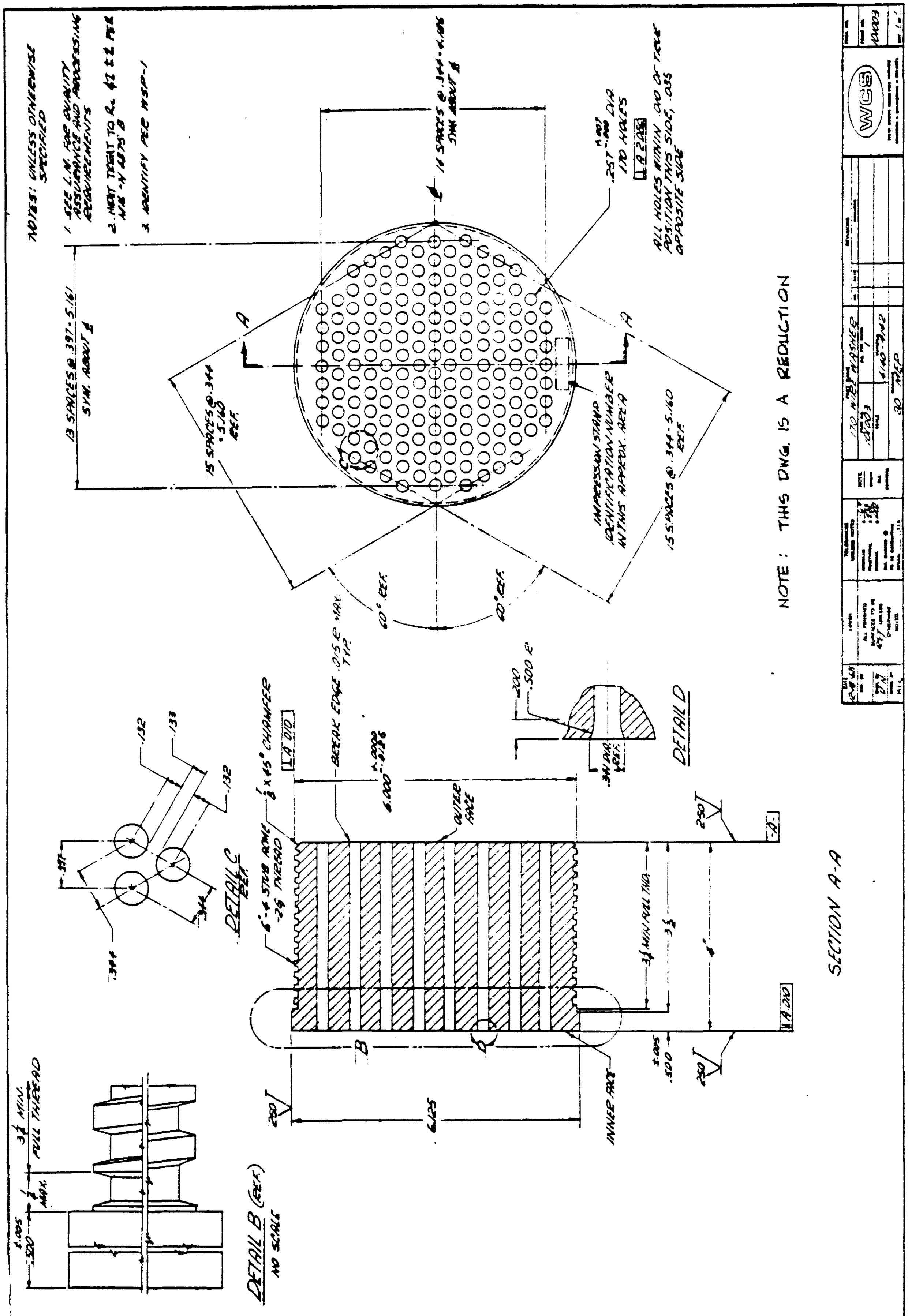


SHIM THICKNESS		STOCK TOL	
PART NO.	A	+	-
101006 - 1	1"	.035	.010
101006 - 2	2"	.070	.010
101006 - 3	3"	.105	.010
101006 - 4	4"	.120	.010
101006 - 5	1/4"	.015	.010
101006 - 6	1/2"	.020	.010
101006 - 7	3/4"	.026	.010

DATE 12-19-68	FINISH	TOLERANCES UNLESS NOTED	NOTE: BREAK ALL CORNERS	PART NAME 170 WIRE SPLIT SHIM	REVISIONS (NO / DATE / REMARKS)	WCS 19113 SOUTH HAMILTON AVENUE GARDENA • CALIFORNIA • 321-1971	PROJ. NO.
DES BY	ALL FINISHED SURFACES TO BE 500 UNLESS OTHERWISE NOTED	ANGULAR ±1/2° FRACTIONAL ±1/32 DECIMAL ±.010" DIA MARKED ⊕ TO BE CONCENTRIC WITHIN T.I.R.		PART NO 101006 / NO PER MACH.			PRINT NO. 101006
DWN BY U.N.				SCALE NONE / MATERIAL NOTED			
CHKD BY MLC				MACHINE 20 MEP			SHT ___ OF ___

6-68 DIETRICH POST CLEARPRINT 1000H

FIG. A1-1


NOTES: UNLESS OTHERWISE SPECIFIED
NOTE: THIS DWG. IS A REDUCTION
SECTION A-A
DETAIL B (REF.) NO SCALE
DETAIL C REF.
DETAIL D
WCS

UPDATE - 1

LIST OF MATERIALS

TITLE: 170 WIRE WASHER — DWG NO: 101003

Item No.	Qty	Nomenclature or Description	Material Description	Material Spec	Stock Size & Ordering Instructions
1	1	Washer	Alloy Bar, Hot Rolled, Vacuum Degassed, Machine Straightened, Open Hearth, 4142 H, Annealed, Commercial Quality.	ASTM A-322	6 1/2" x 4 1/8" Stock Mill Material Chemical and Physical Certification Required. Color Code each blank with full length stripe and record Heat Number - color relation on Mill Certification.

Quality Assurance Provisions

A) Each material heat to be processed separately.

B) Serial Number to be placed on parts prior to removal of color coding, or as soon as practicable thereafter.

C) 10 % thread inspection to be performed by vendor using WCS "Go"-"No"-"Go" gauges, inspection certification required.

D) Heat Treat Certification required for each furnace batch. Vapor-hone to remove scale after heat treat.

E) Vendor to provide Serial Number traceability to material and heat treat certifications per WCS Form 100.

Sym	Date	Revisions		
A	4/9	Added Q./C. Approval Block	MLC	Q.C.

DATE: 30 Dec 68 — DWN BY: MBH — CKD BY: HRR

Western Concrete Structures Co., Inc.
1913 South Hamilton Avenue, Gardena, California 9?2?5

PROJ NO: LM 101003 — 1 of 1

RYERSON CERTIFIED TEST REPORT

DATE	INVOICE NUMBER	CUSTOMER'S ORDER NUMBER	SHIP TO	TEST	HEAT NO
9-12-69	12-AX-500164A	5377			71153H

WESTERN CONCRETE STRUCTURES CO., INC.
19113 SO. HAMILTON ST.
GARDENA, CALIF. 90247

RYERSON SPEC
STOCK SIZE 6-1/2" RD

80 BARS 6-1/2" RD X 0'4-1/8" 3120#

DESCRIPTION OF MATERIAL AND SPECIFICATIONS

STRIPE FULL LENGTH OF BAR - BROWN & BLACK
HR 4142 ANNLD "H" VACUUM DEGASSED MS OH GRAIN 5-8 PER ASTM E112 & ASTM A-322

CHEMICAL ANALYSIS

HEAT NO	CARBON	MANG	PHOS	SULPHUR	SILICON	NICKEL	CHROME	MOLY.	COPPER	TI.	ALUM.	LEAD	OTHER
71153H	.42	.97	.011	.022	.28		1.02	.18					

MECHANICAL PROPERTIES AND TESTS

TENSILE PSI	YIELD PSI	% ELONGATION	REDUCTION OF AREA %	HARDNESS	BEND	GRAIN	EMB	COR.	HARDENABILITY
						6-8			/16— /16—

MANUFACTURED
COPPERWELD STEEL CORP.

OTHER MECHANICAL PROPERTIES AND TESTS
1/59 2/58 3/58 4/58 5/57 7/57 8/57 10/56 12/55
14/52 16/52 20/50 24/48 28/47 32/46

THE ABOVE TESTS CONFORM TO THE REQUIREMENTS OF THE SPECIFICATIONS LISTED.
THIS IS A FACSIMILE COPY OF THE NOTARIZED MASTER IN OUR FILES.

I RUSSELL D. YOUNG, a Notary Public do hereby certify that the affidavit was subscribed and sworn to before me by a duly authorized agent of Joseph T. Ryerson & Son, Inc., this 12TH day of SEPT., 1969

Russell D. Young

MY COMMISSION EXPIRES

We hereby certify that the foregoing data is a true copy of the data furnished us by the producing mill or the data resulting from tests performed in the Ryerson Laboratory.

JOSEPH T. RYERSON & SON, INC.

By K. Wagner
Authorized Agent

NOTARY PUBLIC
OFFICIAL SEAL
RUSSELL D. YOUNG
NOTARY PUBLIC - CALIFORNIA
PRINCIPAL OFFICE
LOS ANGELES COUNTY
My Commission Expires Jan. 23, 1973

JOSEPH T. RYERSON & SON, INC.

5B-147

UPDATE - 1
7/82

ACCURATE STEEL TREATING, INC.
10008 MILLER WAY • SOUTH GATE, CALIF. 90280 • 869-3385

PROCESS CERTIFICATION

TO: WESTERN CONCRETE STRUCTURES, INC. DATE 11-7-69
19113 S. HAMILTON AVE.
GARDENA, CALIF. 90247

ORDER NO. 2769---378 PART NO. 101003

CONTRACT NO. OUR SHOP NO. 72891

MATERIAL 4142 NO. OF PCS. 40

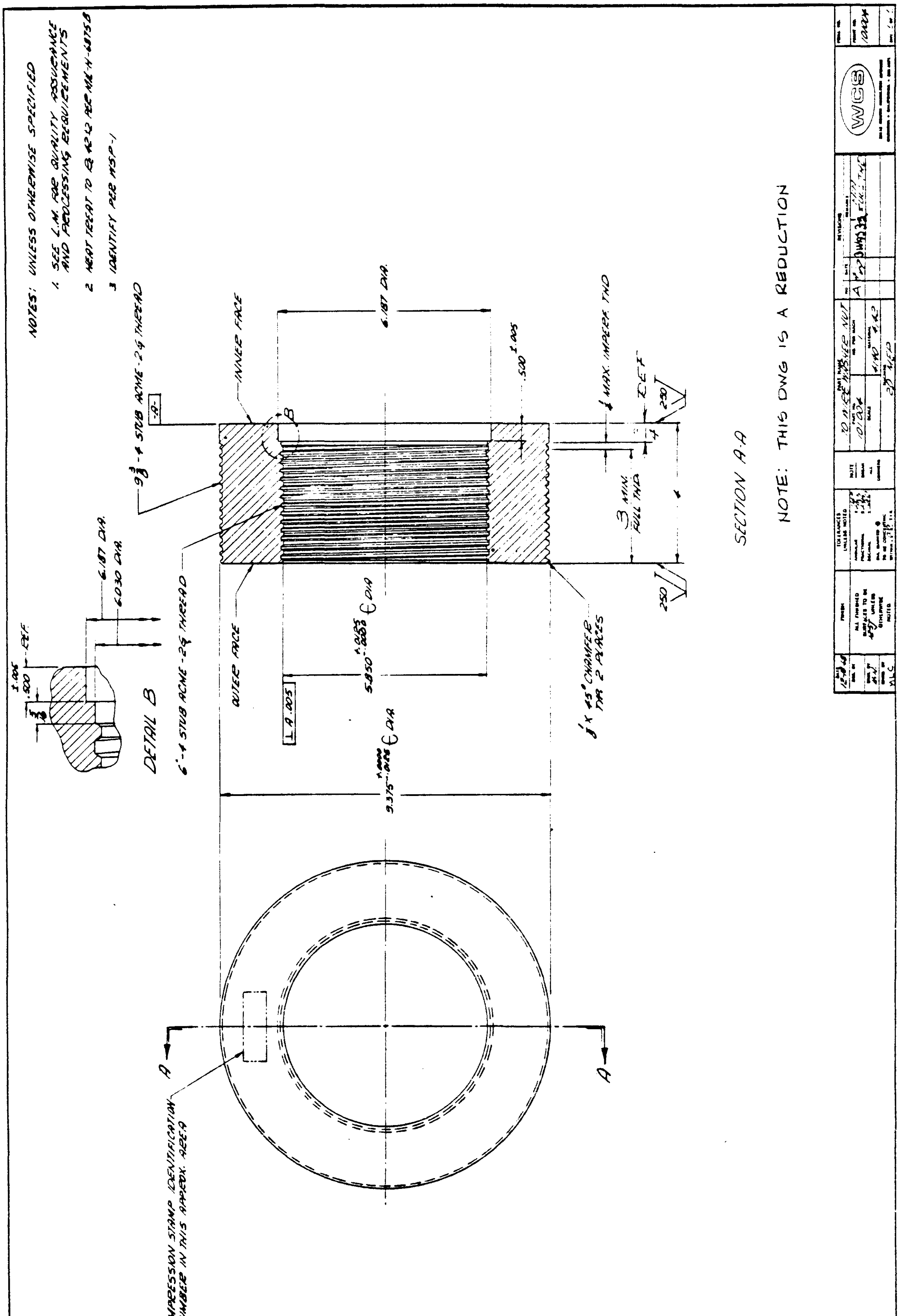
WE HEREBY CERTIFY THAT THE MATERIALS DESCRIBED WERE PROCESSED AS INDICATED BELOW:

HARDENED & TEMPERED TO R/C 42-2 PER MIL H 6875B
SERIAL NOS. 1053-1032-1029-1039-1034-1014-1001-1027-1024-1023-
1000-1003-1007-1002-1030-1005-10171006-1010-1021-
1057-1040-998-993-997-1041-1056-979-996-974-1043-
1044-995-1045-1059-1054-1051-1042-1055-1052

ACCURATE STEEL TREATING

BY Paul Lunghofer

All processes involved requiring Government Process approval have been so approved and certifications are on file subject to examination


NOTES: UNLESS OTHERWISE SPECIFIED
NOTE: THIS DWG IS A REDUCTION
SECTION A-A
DETAIL B
INNER FACE
OUTER FACE
6.187 DIA.
6.030 DIA.
IMPRESSION STAMP IDENTIFICATION NUMBER IN THIS APPROX. AREA

LIST OF MATERIALS

TITLE: 170 WIRE WASHER NUT — DWG NO: 101004

ITEM NO	QTY	NOMENCLATURE OR DESCRIPTION	MATERIAL DESCRIPTION	MATERIAL SPEC	STOCK SIZE & ORDERING INSTRUCTIONS
1	1	Washer Nut	Hot Finished, Seamless, Mechanical Tubing, 4142 H, Open Hearth, Vacuum Degassed, Annealed, Pickled, Oiled, Machine Straightened.	ASTM-A-519	9 3/4" O.D. x 5 1/3" I.D. x 4 1/3" stock. Mill material chemical and physical certifications required. Color code each blank with full length strip and record Heat Number - color relation on Mill Certification.

Quality Assurance Provisions

A) Each material heat to be processed separately.

B) Serial Number to be placed on parts prior to removal of Color Coding, or as soon as practicable thereafter.

C) 10 % thread inspection to be performed by vendor using WCS "Go"-"No"-"Go" gauges, inspection certification required.

D) Heat Treat Certification required for each furnace batch. Vapor-hone to remove scale after heat treat.

E) Vendor to provide Serial Number traceability to material and Heat Treat Certifications per WCS Form 100.

SYM	DATE	REVISIONS		
A	4-9	Added Q./C. Approval Block	MLC	Q.C.

DATE: 30 Dec 63 — DWN BY: MBH — CKD BY: HRR

WESTERN CONCRETE STRUCTURES CO. INC.

1913 SOUTH HAMILTON AVENUE, GARDENA, CALIFORNIA

PROJ NO

LM 101004

RYERSON CERTIFIED TEST REPORT

DATE	INVOICE NUMBER	CUSTOMER'S ORDER NUMBER	ST/TR	TEST	HEAT NO.
4-21-69	12-AX-505370-B	4927			57758

WESTERN CONCRETE STRUCTURES
19113 S. HAMILTON AVE.
GARDENA, CALIF. 90247

RYERSON SPEC.

STOCK SIZE 9-3/4" OD

~~149~~ 48 TUBES 9-3/4"OD X 5-1/8"ID X 0'4-1/8"

COLOR CODE WHITE

DESCRIPTION OF MATERIAL AND SPECIFICATIONS

HFSM TUBING AISI 4142-H OH QUAL VACUUM DEGASSED ANN

CHEMICAL ANALYSIS

HEAT NO	CARBON	MANG	PHOS	SULPHUR	SILICON	NICKEL	CHROME	MOLY	COPPER	TI.	ALUM.	LEAD	OTHER
57758	.42	.90	.013	.015	.28	.11	.97	.22	.08				

MECHANICAL PROPERTIES AND TESTS

TENSILE PSI	YIELD PSI	% ELONGATION	REDUCTION OF AREA %	HARDNESS	BEND	GRAIN	EMB.	COR.	HARDENABILITY
						FINE			/16— /16—

MANUFACTURER

TIMKEN ROLLER BEARING

OTHER MECHANICAL PROPERTIES AND TESTS

1/58 2/58 4/57 6/57 8/56 10/55 12/54 14/52
16/50 20/47 24/45 28/42 32/40 40/38

THE ABOVE TESTS CONFORM TO THE REQUIREMENTS OF THE SPECIFICATIONS LISTED.
THIS IS A FACSIMILE COPY OF THE NOTARIZED MASTER IN OUR FILES.

RUSSELL D. YOUNG, a Notary Public do hereby certify that affidavit was subscribed and sworn to before me by a duly authorized agent of Joseph T. Ryerson & Son, Inc., this 25TH day of MARCH, 1969

Russell D. Young

MY COMMISSION EXPIRES

NOTARY PUBLIC
RUSSELL D. YOUNG

We hereby certify that the foregoing data is a true copy of the data furnished us by the producing mill or the data resulting from tests performed in the Ryerson Laboratory.

JOSEPH T. RYERSON & SON, INC.
By *R.C. Wagner*
Authorized Agent

JOSEPH T. RYERSON & SON, INC.
FORM 230 ... AUG. 68 COPYRIGHT

UPDATE - 1
7/82

ACCURATE STEEL TREATING INC.
10008 MILLER WAY • SOUTH GATE, CALIF. 90280 • 869-3385

PROCESS CERTIFICATION

TO: WESTERN CONCRETE STRUCTURES, INC. DATE 11-14-69
19113 S. HAMILTON AVE.
GARDENA, CALIF. 90247

ORDER NO. 2777---378 PART NO. 101004

CONTRACT NO. OUR SHOP NO. 73149

MATERIAL 4142 NO. OF PCS. 28

WE HEREBY CERTIFY THAT THE MATERIALS DESCRIBED WERE PROCESSED AS INDICATED BELOW:

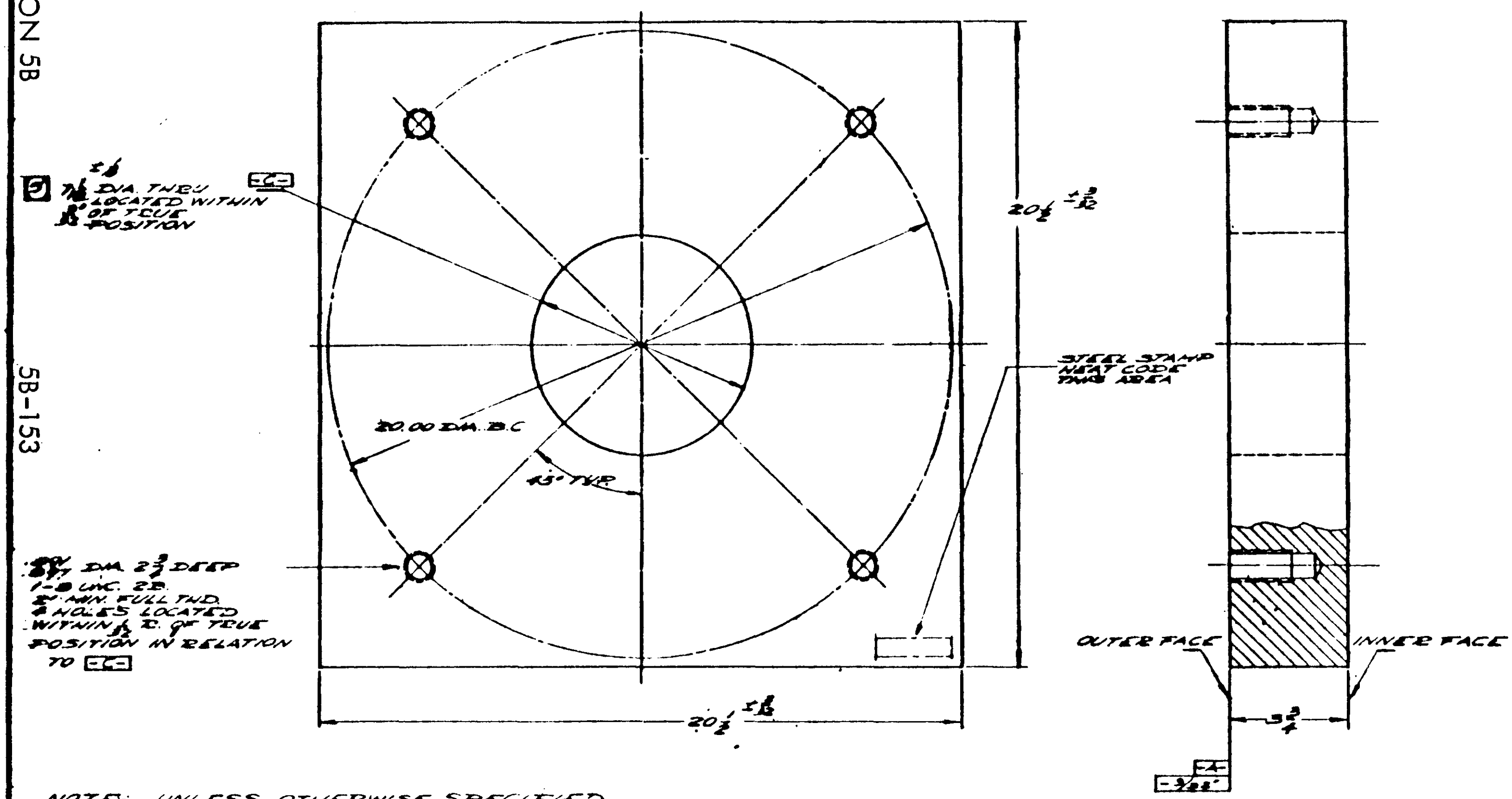
HARDENED & TEMPERED TO R/C 42-2 PER MIL H 6875B

SERIAL NOS. 593-584-599-562-597-600-563-572-596-566-576-595-
564-575-565-598-574-585-594-573-591-560-571-582-
592-583-561-570

ACCURATE STEEL TREATING

BY Paul Lunghofer

All processes involved requiring Government Process approval have been so approved and certifications are on file subject to examination



NOTE: UNLESS OTHERWISE SPECIFIED

1. REMOVE SLAG & BURRS FROM ALL EDGES
2. MATERIAL PER ASTM A36, SILICON KILLED FINE GRAIN PRACTICE
3. USE WITH 10' SQ. SPLIT SHIMS, 2" MIN. THICKNESS
4. DIM. SHOWN ARE FOR SURFACE -A- 1 1/2 DEG. BEVEL ALLOWABLE FOR FLAME CUTTING
5. DIA. OF HOLE TO BE 7.00 MIN. FOR FULL DEPTH.
6. FLATS TO BE AS ROLLED FINISH, EDGES FLAME CUT

NOTE: THIS DWG. IS A REDUCTION

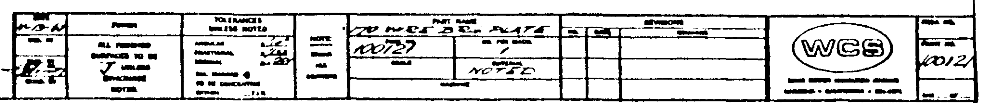


FIG. A1-4

UPDATE - 1
7/82

RYERSON CERTIFIED TEST REPORT

Los Angeles - Attn: Scheibel

DATE	RYERSON ORDER NUMBER	CUSTOMER'S ORDER NUMBER
10/30/69	14-406820	12W01631A

DESCRIPTION OF MATERIAL AND SPECIFICATIONS

1 Plt. HR A36 4 x 24 x 4'0"

CHEMICAL ANALYSIS

HEAT NO.	CARBON	MANG.	PHOS.	SULPHUR	SILICON	NICKEL	CHROME	MOLY.	COPPER	TI.	ALUM.	LEAD	OTHER
48271	.18	.97	.014	.029	.24								

MECHANICAL PROPERTIES AND TESTS

TENSILE PSI	YIELD PSI	% ELONGATION	REDUCTION OF AREA %	HARDNESS	BEND	GRAIN	EMB.	COR.	HARDENABILITY	
66,050/ 66,140	36,420/ 41,760	30.0/ 8" 24.0			OK OK				/16–	/16–

MANUFACTURER	OTHER MECHANICAL PROPERTIES AND TESTS
Kaiser Steel	

DESCRIPTION OF MATERIAL AND SPECIFICATIONS

CHEMICAL ANALYSIS

HEAT NO.	CARBON	MANG.	PHOS.	SULPHUR	SILICON	NICKEL	CHROME	MOLY.	COPPER	TI.	ALUM.	LEAD	OTHER

MECHANICAL PROPERTIES AND TESTS

TENSILE PSI	YIELD PSI	% ELONGATION	REDUCTION OF AREA %	HARDNESS	BEND	GRAIN	EMB.	COR.	HARDENABILITY	
									/16–	/16–

MANUFACTURER	OTHER MECHANICAL PROPERTIES AND TESTS

DESCRIPTION OF MATERIAL AND SPECIFICATIONS

CHEMICAL ANALYSIS

HEAT NO.	CARBON	MANG.	PHOS.	SULPHUR	SILICON	NICKEL	CHROME	MOLY.	COPPER	TI.	ALUM.	LEAD	OTHER

MECHANICAL PROPERTIES AND TESTS

TENSILE PSI	YIELD PSI	% ELONGATION	REDUCTION OF AREA %	HARDNESS	BEND	GRAIN	EMB.	COR.	HARDENABILITY	
									/16–	/16–

MANUFACTURER	OTHER MECHANICAL PROPERTIES AND TESTS

THE ABOVE TESTS CONFORM TO THE REQUIREMENTS OF THE SPECIFICATIONS LISTED

THIS CERTIFICATE NOTARIZED ONLY WHEN REQUIRED

I, ____________, a Notary Public do hereby certify that this affidavit was subscribed and sworn to before me by a duly authorized agent of Joseph T. Ryerson & Son, Inc., this ______ day of __________

We hereby certify that the foregoing data is a true copy of the data furnished us by the producing mill or the data resulting from tests performed in the Ryerson Laboratory.

JOSEPH T. RYERSON & SON, INC.

BY ____________ Authorized Agent

MY COMMISSION EXPIRES ____________ NOTARY PUBLIC

JOSEPH T. RYERSON & SON, INC.

FORM 230.29-3 JUL 62 COPYRIGHT 1959

PLANTS AT: NEW YORK • WALLINGFORD, CONN. • BOSTON • BUFFALO • PHILADELPHIA • CHARLOTTE, N. C. PITTSBURGH • CLEVELAND • CINCINNATI • DETROIT • MILWAUKEE • CHICAGO • ST. LOUIS DALLAS • HOUSTON • INDIANAPOLIS • LOS ANGELES • SAN FRANCISCO • SEATTLE • SPOKANE

APPENDIX A2.0

METERIAL TESTS AND EXAMINATIONS

ARMCO **Armco Steel Corporation**
Kansas City, Mo. 64125

CERTIFICATION OF TEST
TUFWIRE

DATE October 7, 1969

CUSTOMER: Western Concrete Structures

NOMINAL WIRE DIA. .250"

MIN. SPECIFICATIONS

REQ'D. BREAKING STRENGTH 11,78[illegible] LBS. 240,000 P.S.I.

MINIMUM ELONGATION IN 10" 4.00 PERCENT

Customer Order No. 4958

COIL NO.	DIAMETER FRONT	DIAMETER BACK	BREAKING STRENGTH LBS. FRONT	BREAKING STRENGTH LBS. BACK	ULT. TENSILE STR. PSI FRONT	ULT. TENSILE STR. PSI BACK	% ELONG 10"	BENDS	STRAIGHT-NESS	BUTTON HEAD
349	.250	.250	12,600	12,6[illegible]	[illegible]	[illegible]				
353	.251	.251	12,400	12,5[illegible]	[illegible]	[illegible]				
355	.252	.251	12,600	12,9[illegible]	[illegible]	[illegible]	5.20			
358	.250	.250	12,500	12,7[illegible]	[illegible]	[illegible]				
362	.251	.251	12,900	12,6[illegible]	[illegible]	[illegible]				
370	.250	.250	12,1[illegible]	12,6[illegible]	[illegible]	[illegible]				
373	.251	.251	12,600	12,7[illegible]	[illegible]	[illegible]				
375	.250	.250	12,300	12,5[illegible]	[illegible]	[illegible]	5.70			
					8 Coils,					

A S T M Specification A 421-65

HEAT NO. 25590

ANALYSIS: .79 C .82 MN .010 P .021 S .26 SI

THE PHYSICAL OR MECHANICAL TEST REPORTED ABOVE ARE CORRECT AS CONTAINED IN THE RECORDS OF THE CORPORATION.

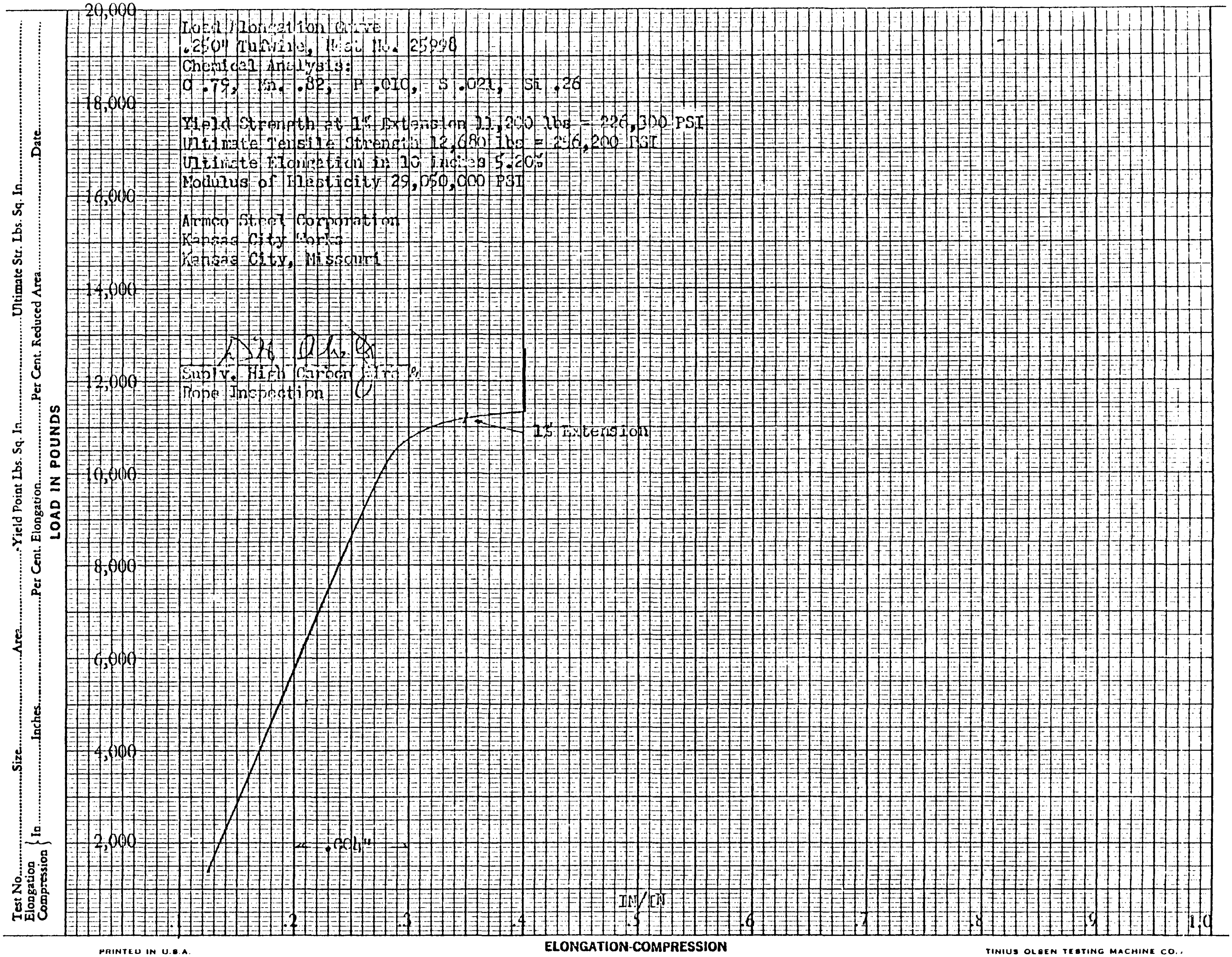
Subscribed and sworn to before me, A Notary Public,
in and for Jackson County the State of Missouri,
This the 22 day of Oct. 1969
My Commission Expires Apr. 3 1970
Gordon K. Allen

BY D.A. Scholz
TITLE Sup't. High Carbon [illegible] & Rope Inspection

MU-2586 7/68

SECTION 5B
5B-156

UPDATE - 1
7/82


Load Elongation Curve
.250" Tufwire, Heat No. 25998
Chemical Analysis:
C .79, Mn. .82, P .010, S .021, Si .26
Yield Strength at 1% Extension 11,200 lbs = 226,300 PSI
Ultimate Tensile Strength 12,680 lbs = 256,200 PSI
Ultimate Elongation in 10 Inches 5.20%
Modulus of Elasticity 29,050,000 PSI
Armco Steel Corporation
Kansas City Works
Kansas City, Missouri
Suply. High Carbon Wire &
Rope Inspection
1% Extension
.004"
IN/IN
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
LOAD IN POUNDS
ELONGATION-COMPRESSION
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
PRINTED IN U.S.A.
TINIUS OLSEN TESTING MACHINE CO.

UPDATE - 1
7/82

CERTIFIED REPORT OF PHYSICAL TEST

METAL SPECIALISTS • CHEMISTS • METALLURGISTS

RECEIVED NOV 10 1969 WESTERN CONCRETE STRUCTURES INC.

ATLAS TESTING LABORATORIES, INC.

6929 EAST SLAUSON AVE., LOS ANGELES, CALIFORNIA 90022

TOM H. EVANS JOHN A. STEVENS TEL.: (213) 685-4242 — 722-8810

IN ACCOUNT WITH

WESTERN CONCRETE STRUCTURES
19113 SOUTH HAMILTON
GARDENA, CALIF.

DATE 11/7/69 CUSTOMER ORDER NO. 6999 CUSTOMER SHIPPER NO.

LABORATORY NO. 16228-1 IDENTIFIED See Below PART NO.

MATERIAL Steel SPECIFICATION

HEAT TREATING CO. WITNESSED BY

PHYSICAL PROPERTIES

			Yield Point		Tensile						
	Actual Size	Actual Area	Actual Load in Lbs.	Pounds per Sq. Inch	Actual Load in Lbs.	Pounds per Sq. Inch	Elongation 1.4"	Elongation Per Cent	Reduced Dimension	Reduction of Area Per Cent	Hardness
T1 LT	.352	.0973	3,300	33,900	6,300	64,750	.50	35.7	.204	66.4	
T2	.337	.0892	3,240	36,300	5,920	66,350	.46	32.9	.202	64.1	
T3	.342	.0919	3,200	34,800	6,090	66,250	.47	33.6	.210	62.4	
S1 ST	.355	.0990	3,650	36,850	6,280	63,450	.15	10.7	.330	13.5	
S2	.355	.0990	3,670	37,050	6,030	60,900	.12	8.6	.320	18.8	
S3	.352	.0973	4,260	43,800	6,340	65,150	.14	10.0	.306	24.5	
							In 2"				
L1 L	.506	.201	6,500	32,350	13,250	65,900	.60	30.0	.328	58.0	
L2	.504	.200	6,650	33,250	13,150	65,750	.65	32.5	.386	41.4	
L3	.505	.200	6,500	32,500	13,150	65,750	.58	29.0	.396	38.5	
REMARKS:											
MAXIMUM REQUIREMENTS											
MINIMUM REQUIREMENTS											

YIELD STRENGTH BY EXTENSOMETER AT .2% Offset

Code:
( ) (F) Indicates flow
( ) (G) " broke outside gauge mark
( ) (g) " broke at gauge mark

Subscribed and sworn to before me this

________ day of ______________ , 19____

______________________ Notary Public

In and for the County of Los Angeles, State of California

ATLAS TESTING LABORATORIES INCORPORATED JULY 7, 1955 CALIFORNIA

Respectfully submitted

ATLAS TESTING LABORATORIES, INC.
CHEMISTS AND METALLURGISTS

UPDATE - 1
7/82

CERTIFIED REPORT OF TEST

METAL SPECIALISTS • CHEMISTS • METALLURGISTS

ATLAS TESTING LABORATORIES, INC.

6929 EAST SLAUSON AVE., LOS ANGELES, CALIFORNIA 90022

TOM H. EVANS JOHN A. STEVENS TEL.: (213) 685-4242 – 722-8810

IN ACCOUNT WITH
WESTERN CONCRETE STRUCTURES
19113 SOUTH HAMILTON
GARDENA, CALIF.

DATE	11/7/69	CUSTOMER ORDER NO.	6999	CUSTOMER SHIPPER NO.	
LABORATORY NO.	16228-2	IDENTIFIED		PART NO.	
MATERIAL	Steel			SPECIFICATION	

CARBON	MANGANESE	PHOSPHORUS	SULFUR	SILICON
0.21%	1.22	0.016	0.019	0.28

CHROMIUM	NICKEL	COPPER	MOLYBDENUM	TITANIUM

COLUMBIUM	TANTALUM	SELENIUM	IRON	ALUMINUM

COBALT	VANADIUM	BORON	ZIRCONIUM	

Subscribed and sworn to before me this
________ day of ________________, 19___

________________________ Notary Public
In and for the County of Los Angeles, State of California

ATLAS TESTING LABORATORIES INCORPORATED JULY 7, 1955 CALIFORNIA

Respectfully submitted,

ATLAS TESTING LABORATORIES, INC.

5M 6.69 Y777

SECTION 5B

5B-159

UPDATE – 1
7/82

ALLISON STEEL MANUFACTURING CO.
P. O. BOX 6598 • PHOENIX, ARIZONA • 252-5071

MILL

DATE	10/13/69
CUSTOMER NO. OR CONTRACT NO.	3066
DATE REQUIRED	SEE BELOW
JOB NO.	29548
Credit Approval	DM

F.O.B. POINT	FREIGHT	FOR RESALE	SHIP VIA	SALESMAN	TERMS OF PAYMENT
☒ DESTINATION ☐ TEMPE MILL	☒ INCLUDED IN PRICE ☐ CHARGE CUSTOMER ☐ WILL CALL ☐ SHIP COLLECT	☒ YES ☐ NO	☒ TRUCK ☐ RAIL	TATUM	NET 10th E.O.M.

CUSTOMER NO.	SALES LOC.	SOURCE CARD	CARD TYPE	BATCH NO.	SALES CODE	REBAR POUNDS	TAX CODE	JOB AMOUNT
			1- -3					

SOLD TO:
LIVERMORE STEEL INC
RELIANCE REINFORCING
2670 MARKET STREET
RIVERSIDE CALIF 92507

SHIP TO:
RELIANCE REINFORCING
2670 MARKET ST
RIVERSIDE CALIF

	ORDERED APPROX. QTY.	UNIT	BAR SIZE	LENGTH	GRADE	SHIPPED QUANTITY	UNIT	POUNDS
1	22 1/2	TON	5	60	40			
2	15	TON	7	60	40	6	Bdls	30168
3	7 1/2	TON	10	60	40			
4	10	TON	11	63	60			
5	7 1/2	TON	10	60	60	3	Bdls	15492
6	5	TON	9	60	60			45660
7	FREIGHT							
8								
9								
10								

HEAT NO.'S

SHIPPING CODE	JOB NO.	SHIP. LOC.	DATE SHIPPED	SHIPPING No.	REL. NO.	B/L NO.
	29548	2	10-13-69	C7006		5081

REPORT OF ANALYSIS AND/OR PHYSICAL PROPERTIES

CARRIER Rel   CAR OR TRL. NO. 190-322

SIZE	HEAT NO.	YIELD POINT P.S.I.	TENSILE STRENGTH P.S.I.	% ELONG. IN—IN	BEND TEST	LBS. PER FT.	AREA	C	MN	S	P
7	~~[illegible]~~	~~[illegible]~~	~~[illegible]~~	~~17.2~~	~~[illegible]~~	~~204~~	~~[illegible]~~	~~32~~	~~[illegible]~~	~~[illegible]~~	~~021~~
	~~[illegible]~~	~~[illegible]~~	~~[illegible]~~	~~[illegible]~~	~~[illegible]~~	~~204~~	~~[illegible]~~	32	65	~~[illegible]~~	~~[illegible]~~
10	54372	62756	99931	18.8	H	415	1221	32	68	050	027
	~~[illegible]~~	~~[illegible]~~	~~[illegible]~~	~~21.9~~	~~[illegible]~~	~~[illegible]~~	~~1226~~	~~34~~	~~68~~	~~032~~	~~020~~
	~~23109~~	~~62562~~	~~99523~~	~~[illegible]~~	~~[illegible]~~	~~415~~	~~[illegible]~~	~~34~~	~~[illegible]~~	~~[illegible]~~	~~017~~

I certify the above test information to be correct as contained in the records of the Company.

By S. Williams   5B-160

PACKING LIST AND TEST REPORT SECTION 5B

UPDATE - 1
7/82

(b) (5)

[redacted]

(b) (5)

[redacted]

(b) (5)

[redacted]

(b) (5)

[redacted]

(b) (5)

[redacted]

(b) (5)

[redacted]

(b) (5)

[redacted]

APPENDIX A3.0

TEST DATA SHEETS

CKD. BY | DWN. BY | DES. BY | DATE

SECTION 5B

5B-169

WCS

1913 SOUTH HAMILTON AVENUE
GARDENA · CALIFORNIA · 321-1971

SHT 1 OF 4

PROJ. NO

UPDATE - 1
7/82

DS-1

COOL-DOWN DATA — THREE MILE ISLAND NDT TEST

DATE 11/25/69

RECORDER: MLC

WITNESS:

Ref. Junction: 32° F

TIME	TEMPERATURES T1	T2	T3	T4		STRAIN GAGES G1 X	G1 Y	G1 Z	G2 X	G2 Y	G2 Z	COMMENTS
	7	8	9	10		1	2	3	4	5	6	CHANNEL
	mv	mv	mv	mv		~~mv~~	~~mv~~	~~mv~~	~~mv~~	~~mv~~	~~mv~~	
	°F	°F	°F	°F		μin/in	μin/in	μin/in	μin/in	μin/in	μin/in	
10.00	.740	.785	.750	.750								
AM	66	68	66	66		11680	11750	115[illegible]	12680	13730	13450	NO LOAD
11 00	.850	.915	.880	1.00								
AM	71	74	66	66		11920	12580	12755	12345	14355	14220	
330	.305	.335	.625	.500								
PM	46	48	61	55		11935	12[illegible]10	12755	12450	14410	14240	6725 PSIG RAM PRESSURE
4.00	.220	.765	.355	.445		11920	12600	12750	12430	14410	14240	↓
	43	60	48	52								
445	00	.835	.748	.668		11922	12635	12805	12370	14440	14270	
	32	70	66	64								
5.10	.065	.7000	.614									
	29	64	60			11920	12[illegible]2	12910	12318	14437	14232	
630	.760	.342	.210	.335		11922	12610	12717	12260	14441	14313	
	-5	48	43	43								
PM 700	.805	.372	.130	.018		11923	12600	12715	12[illegible]	14441	[illegible]	
	-7	45	28	33								
PM [illegible]30	.693	.170	.092	.090		[illegible]200	[illegible]	12712	12175	144[illegible]	14330	
	-3	40	36	32								↓

SECTION 5B

5B-170

DS-1

COOL-DOWN DATA — THREE MILE ISLAND NDT TEST

DATE 11/25/69

RECORDER: W DeVolse

WITNESS:

Ref. Junction: 32°F

TIME	TEMPERATURES T1 (7) mv / °F	T2 (8) mv / °F	T3 (9) mv / °F	T4 (10) mv / °F		STRAIN GAGES G1 X (1) µin/in	G1 Y (2) µin/in	G1 Z (3) µin/in	G2 X (4) µin/in	G2 Y (5) µin/in	G2 Z (6) µin/in	COMMENTS (CHANNEL)
PM	-1.860	-.178	-.568	-.827								
9:00	-61	24	5	-7		11913	12711	12882	12073	14412	14283	6225 PSIG RAM PRESSURE
PM	-1.775	-.490	-.655	-.888		11800	12582	12800	11970	[illegible]	14260	
9:30	-57	9	1	-11								
PM	-1.819	-.550	-.778	-1.0[illegible]		11860	12575	[illegible]	12020	14432	14292	
10:00	-59	6	-6	-16								
PM	-1.935	-.696	-.910	-1.056		11873	[illegible]	[illegible]	[illegible]	[illegible]	14408	
10:30	-65	-1	-12	-19								
PM	-2.080	-.852	-.978	-1.230								
11:00	-73	-9	-15	-28		11885	12712	12892	12032	14413	14362	
PM	-2.290	-1.038	-1.145	-1.542								
11:30	-85	-18	-24	-44		11878	12705	12885	12025	14432	14362	
MIDN	-2.440	-1.118	-1.310	-1.590								
12:00	-93	-22	-32	-47		11880	12710	12900	12040	14450	14370	
12:30	2.879	1.373	1.4[illegible]	1.83[illegible]								
	-118	-35	-48	-60		11900	12730	12930	12090	14495	14425	
AM 1:00	2.705	1.485	1.554	1.832		11910	12745	12940	12085	14515	14445	
	-109	-26	-50	-60								

Loosened Pressure 9:45 T_H

WCS

19113 SOUTH HAMILTON AVENUE
GARDENA · CALIFORNIA · 321-1571

SHT 2 OF 4

UPDATE - 1
7/82

DS-1

COOL-DOWN DATA — THREE MILE ISLAND NDT TEST

DATE 11/26/69

RECORDER: [illegible signature]

WITNESS:

Ref. Junction: 32° F

TIME	TEMPERATURES T1 (7) mv / °F	T2 (8) mv / °F	T3 (9) mv / °F	T4 (10) mv / °F	STRAIN GAGES G1 X (1) µin/in	G1 Y (2) µin/in	G1 Z (3) µin/in	G2 X (4) µin/in	G2 Y (5) µin/in	G2 Z (6) µin/in	COMMENTS
1:30 AM	2.915 / -121	1.566 / -45	1.760 / -56	1.945 / -66	11905	12744	12943	13000	14535	14460	CHANNEL
2.00 AM	2.765 / -112	1.639 / -49	1.779 / -57	1.920 / -67	11950	12781	12980	12125	14570	14451	
2:30 AM	2.740 / -111	1.631 / -49	1.765 / -56	1.925 / -63	11910	12745	12945	12025	14545	14452	
3.00 am	2.810 / -115	1.752 / -55	1.535 / -62	1.925 / -68	11880	12715	12910	12070	14525	14425	
3:30 am	2.315 / -115	1.797 / -58	1.817 / -63	1.990 / 68	11875	12705	12904	12069	14521	14420	
4.00 AM	2.841 / -117	1.819 / -59	1.911 / -64	2,000 / -69	11885	12720	12915	12081	14541	14431	
4:30 AM	[illegible] / 117	[illegible] / 59	1920 / 64	2,1[illegible] / 76	11890	1272[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
5:00 AM	2.765 / -112	1.7[illegible] / -53	1.725 / -54	1.821 / -59	11890	12720	12913	12092	14551	1444[illegible]	
5.30 AM	2.7[illegible]0 / -114	1.790 / -57	1.925 / -58	1.911 / 64	11950	12810	130[illegible]	[illegible]	[illegible]35	14515	

DATE	
CHK. BY	
DWN. BY	
CAD. BY	

+4 1.130

SECTION 5B

WCS

19113 SOUTH HAMILTON AVENUE
GARDENA · CALIFORNIA · 321-1571

PROJ. NO

SHT 3 OF 4

UPDATE - 1
7/82

DS-1

COOL-DOWN DATA — THREE MILE ISLAND NDT TEST

DATE 11/26/69
RECORDER: Cleland
WITNESS:

Ref. Junction: 32° F

TIME	TEMPERATURES T₁ 7	T₂ 8	T₃ 9	T₄ 10	STRAIN GAGES G₁ X 1	G₁ Y 2	G₁ Z 3	G₂ X 4	G₂ Y 5	G₂ Z 6	COMMENTS
	mv / °F	mv / °F	mv / °F	mv / °F	µin/in	µin/in	µin/in	µin/in	µin/in	µin/in	CHANNEL
6.00 AM	2.875	1.930	1.980	2.032							
	-119	-65	-68	-73	11940	12775	12970	12135	14605	14495	6725 PSIG RAM PRESSURE
6:30 AM	2.835	1.860	1.965	2.128							
	-116	-61	-68	-76	11912	12739	12950	12110	14590	14475	↓
7:00 AM	2.575	1.895	1.925	2.12[illegible]							
	-119	-63	-65	-76	11975	12712	12915	12080	14565	14445	↓
7:30 AM	2.794	1.870	1.910	2.085							
	-114	-62	-64	-73	11860	12700	12909	12050	14570	14439	↓
8:00 AM	2.805	1.869	1.975	2.145							
	-115	61	67	77	11875	12715	12921	12102	14579	14451	↓
8:30 AM	2.665	1.873	1.942	2.132							
	-106	-62	-66	-76	11871	12711	12920	12105	14605	14450	↓
9:00 AM	3.040	2.135	2.177	2.361							
	-129	-76	-79	-89	11880	12731	12931	12119	14619	14455	↓
9.30 AM	2.942	2.100	2.213	2.353							
	-123	-74	-81	-88	11906	12765	12960	12145	14705	14489	↓
10 00 AM	3.039	2.085	2.225	2.254							
	-128	-73	-81	-83	11979	12855	1335	12330	14785	14565	

DATE / DES. BY / DWN. BY / CHK. BY / PROJ. NO

WCS
19113 SOUTH HAMILTON AVENUE
GARDENA · CALIFORNIA · 321-1571

SECTION 5B

5B-173

WCS
19113 SOUTH HAMILTON AVENUE
GARDENA · CALIFORNIA · 321-1571

DS-2

CYCLIC LOADING DATA – THREE MILE ISLAND NDT TEST

DATE 11/27/69

RECORDER: MLC

Ref. Junction: 32 °F

WITNESS:

TIME	NO. OF Cycles	LOAD PSI / LBS.	TEMPERATURES T4 (10) mV / °F	T2 (8) mV / °F	T3 (9) mV / °F	EXCIT. VOLT	STRAIN GAUGES G1 X (1) mV / µin/in	G1 Y (2) mV / µin/in	G1 Z (3) mV / µin/in	G2 X (4) mV / µin/in	G2 Y (5) mV / µin/in	G2 Z (6) mV / µin/in	CHANNEL
		5796											
10.15	0	7728	2.191 / -79	2.073 / -73	2.175 / -78		12110	12,990	13,005	12,351	14,940	14,730	HELD 7728 FOR 15 MIN
10.30	0	5796					12040	12885	13065	12280	[illegible]	14570	
		7728	2.265 / -83	2.095 / -74	2.165 / -78		12125	13010	13215	12359	14950	14729	
11 30	92	7728	2.260 / -83	2.098 / -74	[illegible] / -80		11930	12810	13030	12180	14805	14575	
		5796					11,915	12,770	12,950	12,170	14,718	14,485	
1250	200	7728	2.235 / -82	2.110 / -75	2.194 / -79		11875	12755	12978	12140	14735	14537	
		5796					11860	12710	12895	12140	14715	14,461	
1:45	300	7728	2.315 / -86	2.161 / -77	2.261 / -83		11,960	12,845	13,065	12,230	14,885	14,630	
		5796					11,889	12735	12925	12160	14719	14,460	

SECTION 5B

5B-174

DS-2

CYCLIC LOADING DATA – THREE MILE ISLAND NDT TEST

DATE 11/27/69

RECORDER: MLC

WITNESS:

Ref. Junction: 32°F

TIME	NO. OF Cycles	LOAD PSI / LBS.	TEMPERATURES T_4 10 mV / °F	T_2 8 mV / °F	T_3 9 mV / °F	EXCIT. VOLT	STRAIN GAUGES G_1 X 1 mV / µin/in	G_1 Y 2 mV / µin/in	G_1 Z 3 mV / µin/in	G_2 X 4 mV / µin/in	G_2 Y 5 mV / µin/in	G_2 Z 6 mV / µin/in	CHANNEL
2.45	400	7728	2.273 / -84	2.105 / -74	2.190 / -79		12135	12990	13200	12360	14991	14750	
		5796					12045	12895	13065	12305	14850	14600	
4.00	500	7728	2.340 / -87	2.131 / -76	2.335 / -87		12095	12970	13170	12330	14660	14710	
		5800					12000	12850	13055	12260	14815	14550	

WCS

15113 SOUTH HAMILTON AVENUE
GARDENA · CALIFORNIA · 321-1571

2 of 2

DS-3

TENDON GUARANTEED ULTIMATE LOAD

THREE MILE ISLAND NDT TEST

DATE: 11/26/69

RECORDER: MLC

WITNESS: ______

TIME: 400 PM

T_1 – 87 (CHAMBER)

T_2 – 76 (INSIDE FACE)

T_3 – 87 (OUTSIDE FACE)

EXCIT. VOLT 2.05

REF. JUNCTION 32°F

LOAD		GAUGE READING		~~ELONG.~~	STRAIN GAUGES					
					G1			G2		
% GUTS	FORCE NOM. / ACT. LBS.	NOM. PSI	ACT. PSI	~~INCHES~~	X 1 ~~mv~~ μin/in	Y 2 ~~mv~~ μin/in	Z 3 ~~mv~~ μin/in	X 4 ~~mv~~ μin/in	Y 5 ~~mv~~ μin/in	Z 6 ~~mv~~ μin/in
0	0				11810	12072	11833	12085	13910	[illegible]
20	39.8	1930								
40	79.6	3860								
60	119.4	5796	5796		12000	12850	13025	12260	14815	14550
70	139.3	6762	6770		12050	12910	13100	12360	14960	14140
80	159.2	7728	7725		12085	12965	13180	12340	14975	1472[illegible]
90	179.1	8690	8600	HELD 20 MIN	12125	13025	13260	12370	15050	149[illegible]
95	189.1	9179	9200		12145	13055	13315	12370	15095	1435[illegible]
100	199.0	9660	9500 / 9625		12155	13090	13375	12380	15140	1498[illegible]

DATE

DES. BY

DWN. BY

CKD. BY

SECTION 5B

5B-175

WCS

19113 SOUTH HAMILTON AVENUE
GARDENA · CALIFORNIA · 321-1571

PROJ. NO.

SHT 1 OF 1

UPDATE - 1
7/82

STRESSING RAM CALIBRATION DATA

FILE NO. 001

Date: 11/24/69

Ram No: 4

Model No: 1000T

Ram Capacity: 1000T tons @ 9405 psi

Effective Area: 212.65 sq. inches

Maximum Pressure Not To Exceed 10,000 psi

Ram Gauge No: 1004

Test Gauge No: 1

Load Cell Calibration:

Indicator No. 148

Load Cell Serial No. 2994

Date Last Calibrated: 2/12/69

% Error Reported: ______ Full Scale

Calibrated By: TRANSDUCERS INC

Lab Report No. 4855

Test Gauge Run #1	Test Gauge Run #2	Test Gauge Run #3	Test Gauge Ave.	Ram Gauge Run #1	Ram Gauge Run #2	Ram Gauge Run #3	Ram Gauge Ave.	Load Cell Reading	Ram Gauge Deviation Percent	Std. Curve Gauge Reading	Load Cell Force Kips
500	500	500	500	475	500	475	483	90.5	2.34	472	100
1000	975	975	983	975	975	975	975	180	3.99	973	200
1475	1475	1475	1475	1475	1475	1475	1475	270.5	4.24	1415	300
1975	1950	1950	1958	1975	1950	1950	1958	361	3.82	[illegible]	400
2450	2450	2450	2450	2450	2450	2450	2450	452	3.92	2359	500
2925	2925	2900	2916	2925	2925	2925	2925	541	3.39	[illegible]	600
3400	3400	3400	3400	3400	3400	3400	3400	632	3.00	[illegible]	700
3900	3875	3900	3892	3900	3900	3900	3900	723	3.37	3773	800
4375	4400	4375	4383	4375	4400	4375	4383	815.5	3.25	[illegible]	900
4875	4875	4875	4875	4875	4875	4875	4875	906	3.37	[illegible]	1,000
5350	5350	5350	5350	5350	5375	5350	5358	998	3.27	[illegible]	1,100
											1,200

Comments:

Certified By: Merrill R. Walstad
Merrill R. Walstad. Civil Engineer 13435

WESTERN CONCRETE STRUCTURES CO. INC.

1911? S... GARDENA, CALIFORNIA