INTER-COMMUNICATION
INLAND STEEL COMPANY
INDIANA HARBOR WORKS

DATE MARCH 27, 1985

TO R.J.GLATTHORN
TITLE SUPERINTENDENT
DEPT OPERATING TECHNOLOGY

FROM G.W.Henger
G.W.HENGER
TITLE ASST. SUPERINTENDENT
DEPT. OPERATING TECHNOLOGY
FILE REF. OMD FILE NO. 19875

COPIES TO J.HEISE, P.P.NOE, H.HENDRICKSON-6, H.PRESSWALLA, M.MONACO

SUBJECT

INRYCO POST TENSIONING DIVISION
JOSEPH M. FARLEY NUCLEAR PLANT, UNIT NO.2
ANCHOR HEAD INVESTIGATION
OMD INVESTIGATION NO. 19875 - FINAL REPORT

IN JANUARY OF 1985, SERVICE FAILURES WERE DISCOVERED ON TWO FIELD ANCHOR HEADS INSTALLED ON THE CONTAINMENT BUILDING OF THE JOSEPH M. FARLEY NUCLEAR PLANT, UNIT NO. 2 LOCATED AT DOLTON, ALABAMA. THE PLANT, WHICH HAS BEEN IN SERVICE FOR APPROXIMATELY SEVEN YEARS, IS OPERATED BY THE ALABAMA POWER COMPANY. THE ATTACHED REPORT BY MR. D.E.BUDINGER COVERS THE FAILURE ANALYSES AND METALLURGICAL EVALUATION OF THESE TWO ANCHOR HEADS, HV 016 AND HV 038. IN ADDITION, THE REPORT COVERS THE METALLURGICAL EVALUATION OF FOUR OTHER ANCHOR HEADS, WHICH WERE REMOVED FROM THE CONTAINMENT BUILDING BUT HAD NOT FAILED, THE METALLURGICAL EVALUATION OF ONE GREASE COVER AND THE CHEMICAL ANALYSES OF SEVERAL GREASE SAMPLES. MR. BUDINGER'S CONCLUSIONS ARE

1. THE FAILURE OF THE ANCHORAGES WAS DUE TO THE IN-SERVICE EMBRITTLEMENT AS INDICATED BY SIGNIFICANT AMOUNTS OF INTERGRANULAR SEPARATION (IGS) BEING EVIDENT ON THE FRACTURE FACES OF THE ANCHORAGES. THE CONCLUDED EMBRITTLING AGENT IS HYDROGEN, WHICH RESULTS IN HYDROGEN STRESS CRACKING (HSC).

2. THE MAJOR SOURCE OF THE HYDROGEN WAS THE PRESENCE OF WATER IN CONTACT WITH OR ADJACENT TO THE ANCHOR HEADS WITHIN THE GREASE COVERS. ATOMIC OR NACENT HYDROGEN WAS GENERATED BY THE CORROSION REACTIONS OF IRON AND ZINC IN THE PRESENCE OF WATER. THE FAILURES WOULD NOT HAVE OCCURRED WITHOUT THE PRESENCE OF WATER.

3. THE SOURCE OF THE WATER, WHICH WAS HEAVILY CONTAMINATED WITH CATIONS AND ANIONS, IS THE ON-SITE ENVIRONMENTAL CONDITIONS.

4. BOTH THE ANCHORAGE TENDON HOLES AND THE GREASE COVER INTERIOR SHOWED EVIDENCE THAT ACTIVE CORROSION HAD TAKEN PLACE.

5. NEITHER CRACKING INDUCED ON STRUCTURAL TESTING AT THE UNIVERSITY OF ILLINOIS NOR THE INLAND LABORATORY-CREATED FRACTURES ON TENSILE OR IMPACT SPECIMENS SHOWED IGS. THIS INDICATES THAT THE EMBRITTLING SPECIES IS NO LONGER PRESENT AND ELIMINATES TEMPER EMBRITTLEMENT AS THE SOURCE OF THE FAILURES. OTHER POSSIBLE SOURCES OF THE IGS WERE ELIMINATED BY THE COMBINATION OF SCANNING ELECTRON MICROSCOPY AND MECHANICAL TESTING.

THE METALLURGICAL EVALUATION INDICATED THAT THE ANCHORAGES HAD HIGHER STRENGTHS BUT DUCTILITIES WITHIN THE RANGE OF PREVIOUSLY TESTED ALUMINUM GRAIN REFINED FIELD ANCHOR HEADS. THE HIGHER STRENGTHS WOULD NOT HAVE RESULTED IN THE SUBJECT FAILURES, HOWEVER, WOULD INCREASE THE SUSCEPTIBILITY TO HSC AND IGS. THE ANCHORAGES MET THE HARDNESS REQUIREMENTS OF THE INRYCO SPECIFICATION AND THE CHEMICAL REQUIREMENTS OF THE ASTM AND INRYCO SPECIFICATIONS. THE MICROSTRUCTURES AND MICROCLEANLINESSES WERE AS EXPECTED FOR THE STEEL GRADE AND CONDITION. RETEMPERED ANCHORAGES INDICATED THAT THE HEADS WERE HEAT TREATED AS SPECIFIED.

FINALLY, THE FOLLOWING RECOMMENDATIONS WERE MADE:

1. ELIMINATION OF WATER IN THE POST TENSIONING SYSTEM IS ESSENTIAL FOR THE ELIMINATION OF THE RECURRENCE OF SIMILAR SERVICE FAILURES. THE AMOUNT OF WATER THAT CAN BE TOLERATED CAN NOT BE DETERMINED WITH ANY CERTAINTY.

2. IF THE WATER CAN NOT BE ELIMINATED, THEN THE ANCHORAGES SHOULD BE INSPECTED AT SOME INCREASED FREQUENCY TO INSURE AGAINST FAILURES AND THE COLLECTION OF EXCESSIVE AMOUNTS OF WATER. VERTICAL TENDONS, DUE TO THEIR ORIENTATION, SHOULD BE THOROUGHLY EXAMINED FOR WATER.

3. CURRENT VISUAL INSPECTION PROCEDURES WILL NOT DETERMINE IF THE ANCHORAGE IS CRACKED IN THE CENTER OF THE HONEYCOMB AT THE SHIM FACE. DETENSIONING AND MAGNETIC PARTICLE INSPECTION ARE NECESSARY TO DETERMINE IF SUCH CRACKING IS PRESENT.

4. THE STRENGTH LEVELS OF THE ANCHORAGES SHOULD BE LOWERED IF POSSIBLE WITHIN THE SCOPE OF THE ORIGINAL DESIGN. WHILE THIS WILL REDUCE THE SUSCEPTIBILITY TOWARD HYDROGEN STRESS CRACKING (HSC), IT DOES NOT PRECLUDE THE OCCURRENCE OF HSC. DETERMINATION OF THE OPTIMUM STRENGTH LEVELS IS OUTSIDE THE SCOPE OF THIS INVESTIGATION.

PPN/R-SCRIPT

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TABLE 1. INLAND STEEL METALLURGICAL LABORATORY
METALLURGICAL TEST DATA ON FARLEY UNIT NO. 2
ANCHOR HEAD HV 016

CHEMICAL ANALYSIS:

C	MN	P	S	SI	CU	NI	MO	CR	AS	CB	V	TI	AL	N	O2	SN	SB
.43	.97	.014	.028	.24	.16	.13	.22	[illegible]	.016	-.008	.01	.004	.018	.008	58 PPM	.01	.008

MICROANALYSIS:

CLEANLINESS (J-K RATING ON APPEARANCE) A[illegible]-4H, B2H
CARBIDE MORPHOLOGY TEMPERED MARTENSITE

MACROANALYSIS: SOUND KILLED STEEL

HARDNESS (SURFACE): BHN 429-444 (HRC CONVERTED 45-47)
HRC ACTUAL 40-41

TENSILE PROPERTIES:

SAMPLE TEST DIRECTION	GAUGE	YIELD* STRENGTH (KSI)	TENSILE STRENGTH (KSI)	TOTAL ELONGATION (% IN 2")	REDUCTION IN AREA (%)	ELASTIC RATIO YS/TS
TRANSVERSE	.503"	163.6	201.3	11.0	18.6	0.81
TRANSVERSE	.498	168.2	198.5	8.0	13.9	0.85
LONGITUDINAL	.498	174.6	206.2	13.0	35.9	0.85
LONGITUDINAL	.499	169.2	200.2	13.0	35.5	0.85

* 0.2% OFF-SET YIELD STRENGTH.

IMPACT PROPERTIES:

TEST	IMPACT PROPERTY	ROOM TEMPERATURE		212 DEGREES F	
		LONGITUDINAL	TRANSVERSE	LONGITUDINAL	TRANSVERSE
1	ENERGY ABSORPTION, FT.-LBS.	12	6	20	8
	BRITTLE FRACTURE, %	95	95	90-95	95
2	ENERGY ABSORPTION, FT.-LBS.	13	8	20	10
	BRITTLE FRACTURE, %	95	95	90-95	95

REFER TO FIGURES 2A-2C FOR THE TEST POSITIONS AND ORIENTATIONS.

TABLE 2. INLAND STEEL METALLURGICAL LABORATORY
METALLURGICAL TEST DATA ON FARLEY UNIT NO. 2
ANCHOR HEAD HV 038

CHEMICAL ANALYSIS:

C	MN	P	S	SI	CU	NI	MO	CR	AS	CB	V	TI	AL	N	O2	SN	SB
.45	.98	.011	.029	.22	.11	.14	.22	1.12	.014	-.008	.01	.008	.021	.009	97 PPM	.01	.010

MICROANALYSIS:

CLEANLINESS (J-K RATING ON APPEARANCE)	A3-4H
CARBIDE MORPHOLOGY	TEMPERED MARTENSITE

HARDNESS (SURFACE): BHN 429-444 (HRC CONVERTED 45-47)
HRC ACTUAL 44.0-44.5

TENSILE PROPERTIES:

SAMPLE TEST DIRECTION	GAUGE	YIELD* STRENGTH (KSI)	TENSILE STRENGTH (KSI)	TOTAL ELONGATION (% IN 2")	REDUCTION IN AREA (%)	ELASTIC RATIO YS/TS
TRANSVERSE	.505*	**	202.4	8.0	11.1	**
TRANSVERSE	.505	161.3	192.7	8.0	13.4	0.84
LONGITUDINAL	.504	170.4	196.7	15.0	44.9	0.87
LONGITUDINAL	.503	176.6	199.8	13.0	45.6	0.88

* 0.2% OFF-SET YIELD STRENGTH. ** CHART PAPER JAMMED.

IMPACT PROPERTIES:

TEST	IMPACT PROPERTY	ROOM TEMPERATURE		212 DEGREES F	
		LONGITUDINAL	TRANSVERSE	LONGITUDINAL	TRANSVERSE
1	ENERGY ABSORPTION, FT.-LBS.	13	8	23	10
	BRITTLE FRACTURE, %	95	95	95	95
2	ENERGY ABSORPTION, FT.-LBS.	13		23	
	BRITTLE FRACTURE, %	95		90	

REFER TO FIGURES 2A-2C FOR THE TEST POSITIONS AND ORIENTATIONS.

TABLE 3. INLAND STEEL METALLURGICAL LABORATORY
METALLURGICAL TEST DATA ON FARLEY UNIT NO. 2
ANCHOR HEAD HV 027 AFTER RETEMPERING

CHEMICAL ANALYSIS:

C	MN	P	S	SI	CU	NI	MO	CR	AS	CB	V	TI	AL	N	O2	SN	SB
.43	1.01	.012	.027	.24	.11	.12	.23	1.10	.012	-.008	.01	.002	.022	.006	83 PPM	.01	-.002

MICROANALYSIS:

CLEANLINESS (J-K RATING ON APPEARANCE)	A3-4H, B2H
CARBIDE MORPHOLOGY	TEMPERED MARTENSITE

HARDNESS (PROFILE):

	HRC CONVERTED FROM BHN			HRC ACTUAL		
	OUTER	MIDDLE	INNER	OUTER	MIDDLE	INNER
TOP	47	45	47	43	43	44
MIDDLE	45	44	45	43	40	42
BOTTOM	45	45	47	43	43	44

TENSILE PROPERTIES:

SAMPLE TEST DIRECTION	GAUGE	YIELD* STRENGTH (KSI)	TENSILE STRENGTH (KSI)	TOTAL ELONGATION (% IN 2")	REDUCTION IN AREA (%)	ELASTIC RATIO YS/TS
TRANSVERSE 1	.504"	168.0	190.5	8.0	5.5	0.88
TRANSVERSE 2	.503	156.5	183.2	9.0	14.1	0.85

* 0.2% OFF-SET YIELD STRENGTH.

IMPACT PROPERTIES:

IMPACT PROPERTY	ROOM TEMPERATURE		
	TRANSVERSE 1	TRANSVERSE 2	TRANSVERSE 3
ENERGY ABSORPTION, FT.-LBS.	8	8	8
BRITTLE FRACTURE, %	95-100	95-100	95-100
LATERAL EXPANSION, IN.	.005	.008	.005

REFER TO FIGURES 2A-2C FOR THE TEST POSITIONS AND ORIENTATIONS.

TABLE 4. INLAND STEEL METALLURGICAL LABORATORY
METALLURGICAL TEST DATA ON FARLEY UNIT NO. 2
ANCHOR HEAD HV 028 (NOT RETEMPERED)

CHEMICAL ANALYSIS:

C	MN	P	S	SI	CU	NI	MO	CR	AS	CB	V	TI	AL	N	O2	SN	SB
.44	1.04	.013	.027	.25	.11	.13	.24	1.13	.013	-.008	.01	.002	.023	.009	159 PPM	.01	-.002

MICROANALYSIS:

CLEANLINESS (J-K RATING ON APPEARANCE)	A3-4H, B3H
CARBIDE MORPHOLOGY	TEMPERED MARTENSITE

HARDNESS (PROFILE):

	HRC CONVERTED FROM BHN			HRC ACTUAL		
	OUTER	MIDDLE	INNER	OUTER	MIDDLE	INNER
TOP	48	48	48	46	45	46
MIDDLE	48	47	47	44	44	44
BOTTOM	48	48	48	46	46	46

TENSILE PROPERTIES:

SAMPLE TEST DIRECTION	GAUGE	YIELD* STRENGTH (KSI)	TENSILE STRENGTH (KSI)	TOTAL ELONGATION (% IN 2")	REDUCTION IN AREA (%)	ELASTIC RATIO YS/TS
TRANSVERSE 1	.504"	172.9	202.5	9.0	14.5	0.85
TRANSVERSE 2	.505	158.5	192.3	9.0	10.7	0.82

* 0.2% OFF-SET YIELD STRENGTH.

IMPACT PROPERTIES:

IMPACT PROPERTY	ROOM TEMPERATURE		
	TRANSVERSE 1	TRANSVERSE 2	TRANSVERSE 3
ENERGY ABSORPTION, FT.-LBS.	5	6	7
BRITTLE FRACTURE, %	95-100	95-100	95-100
LATERAL EXPANSION, IN.	.001	.004	.005

REFER TO FIGURES 2A-2C FOR THE TEST POSITIONS AND ORIENTATIONS.

TABLE 5. INLAND STEEL METALLURGICAL LABORATORY
METALLURGICAL TEST DATA ON FARLEY UNIT NO. 2
ANCHOR HEAD HV 039 (NOT RETEMPERED)

CHEMICAL ANALYSIS:

C	MN	P	S	SI	CU	NI	MO	CR	AS	CB	V	TI	AL	N	O2	SN	SB
.44	.99	.013	.027	.24	.11	.12	.23	1.11	.013	-.008	.01	.002	.023	.004	261 PPM	.01	-.002

MICROANALYSIS:

CLEANLINESS (J-K RATING ON APPEARANCE)	A3-4H, B2H
CARBIDE MORPHOLOGY	TEMPERED MARTENSITE

HARDNESS (PROFILE):

	HRC CONVERTED FROM BHN			HRC ACTUAL		
	OUTER	MIDDLE	INNER	OUTER	MIDDLE	INNER
TOP	48	48	48	46	46	47
MIDDLE	48	47	47	46	44	44
BOTTOM	48	48	48	47	46	44

TENSILE PROPERTIES:

SAMPLE TEST DIRECTION	GAUGE	YIELD* STRENGTH (KSI)	TENSILE STRENGTH (KSI)	TOTAL ELONGATION (% IN 2")	REDUCTION IN AREA (%)	ELASTIC RATIO YS/TS
TRANSVERSE 1	.505*	183.8	207.3	9.0	15.9	0.89
TRANSVERSE 2	.503	169.8	199.8	8.0	15.9	0.85

* 0.2% OFF-SET YIELD STRENGTH.

IMPACT PROPERTIES:

IMPACT PROPERTY	ROOM TEMPERATURE		
	TRANSVERSE 1	TRANSVERSE 2	TRANSVERSE 3
ENERGY ABSORPTION, FT.-LBS.	6	7	7
BRITTLE FRACTURE, %	95-100	95-100	95-100
LATERAL EXPANSION, IN.	.006	.006	.004

REFER TO FIGURES 2A-2C FOR THE TEST POSITIONS AND ORIENTATIONS.

TABLE 6. INLAND STEEL METALLURGICAL LABORATORY
METALLURGICAL TEST DATA ON FARLEY UNIT NO. 2
ANCHOR HEAD HV 049 AFTER RETEMPERING

CHEMICAL ANALYSIS:

C	MN	P	S	SI	CU	NI	MO	CR	AS	CB	V	TI	AL	N	O2	SN	SB
.44	1.03	.012	.027	.24	.11	.13	.24	1.13	.010	-.008	.01	.002	.023	.004	86 PPM	.01	-.002

MICROANALYSIS:

CLEANLINESS (J-K RATING ON APPEARANCE) A3-4H, B2H
CARBIDE MORPHOLOGY TEMPERED MARTENSITE

HARDNESS (PROFILE):

	HRC CONVERTED FROM BHN			HRC ACTUAL		
	OUTER	MIDDLE	INNER	OUTER	MIDDLE	INNER
TOP	47	47	47	46	44	45
MIDDLE	47	45	44	45	43	43
BOTTOM	48	48	47	44	44	45

TENSILE PROPERTIES:

SAMPLE TEST DIRECTION	GAUGE	YIELD* STRENGTH (KSI)	TENSILE STRENGTH (KSI)	TOTAL ELONGATION (% IN 2")	REDUCTION IN AREA (%)	ELASTIC RATIO YS/TS
TRANSVERSE 1	.504"	174.9	195.5	7.0	9.3	0.89
TRANSVERSE 2	.504	155.9	188.0	9.0	17.4	0.83

* 0.2% OFF-SET YIELD STRENGTH.

IMPACT PROPERTIES:

IMPACT PROPERTY	ROOM TEMPERATURE		
	TRANSVERSE 1	TRANSVERSE 2	TRANSVERSE 3
ENERGY ABSORPTION, FT.-LBS.	7	6	7
BRITTLE FRACTURE, %	95-100	95-100	95-100
LATERAL EXPANSION, IN.	.007	.004	.004

REFER TO FIGURES 2A-2C FOR THE TEST POSITIONS AND ORIENTATIONS.

Appendix A. Inland Steel Company Chemical Department Grease Analyses of February 12, 1985. Reduced copy.

REPORT OF CHEMICAL ANALYSIS

INLAND STEEL COMPANY

CHEMICAL DEPARTMENT - QUALITY CONTROL

DATE REPORTED: February 12, 1985

SAMPLE IDENTIFICATION: Grease from Tendon Anchorhead, Inryco

DATE RECEIVED: February 2, 1985

RECEIVED FROM: Operating Metallurgy, P. Noe

ANALYSIS: G-5395

SAMPLE	H_2O % ASTM D95	TAN ASTM D974 (a)	H_2O Extractable Ions (b) Cl^- ppm	NO_3^- ppm	NO_2^- ppm	$SO_4^=$ ppm	A_1 (c)	A_2 (d)	Na ppm	K ppm	Ca ppm	Mg ppm
#1, V17, Top, Sample 1, 1/27/85, 840069	0.22	0.77	3.9	<0.5	<2	160	2.8	0.24	11	4	370	0.7
#2, V17, Top, Sample 2, 1/27/85 840070	0.13	0.79	3.4	<0.5	<2	150	2.5	0.21	11	3	410	0.7
#3, V17, Bottom, Lowest point of can, 840071	1.2	0.61	13	<0.5	<2	29	7.3	0.21	54	7	240	1.5
#4, V17, Bottom, First grease from can, 840072	(e)	(e)	12	<0.5	<2	28	6.5	0.44	27	5	230	0.9
#5, V17, Bottom, Upper portion of can, 840073	1.4	0.62	14	<0.5	<2	35	7.6	0.23	60	14	190	2.6
Grease from interior of anchorhead	(f)	1.7	35	<0.5	<2	120	48	<.01	380	21	430	21
New Grease, Visconorust 2090-P4	0.12	1.1	8	<0.5	<2	110	13	0.50	14	12	540	6.5

Continued.....

ASSISTANT SUPERINTENDENT: D.E. Smith

RC 2/14

Appendix A continued.

REPORT OF CHEMICAL ANALYSIS

INLAND STEEL COMPANY

CHEMICAL DEPARTMENT - QUALITY CONTROL

DATE REPORTED: February 12, 1985

SAMPLE IDENTIFICATION: Grease from Tendon Anchorhead, Inryco

DATE RECEIVED: February 1, 1985

FILE OR FROM: Operating Metallurgy, P. Moe

ANALYSIS

G-5395 Continued page two.....

(a) Neutralization number by color-indicator titration. These numbers will not be the same as those obtained using Inryco's method (ASTM D664. Neutralization Number by Potentiometric Titration) but should suffice for comparison purposes. We are not presently set up to run TAN by ASTM D664.

(b) The extraction procedure is a single-extraction version of the procedure in ASTM D974. (Since it is a bulk extraction method, it would be expected to give higher results than Inryco's surface extraction procedure, but it was thought to be more appropriate for highly contaminated samples.) A weighed amount (approx. 10g) of grease was shaken in a separatory funnel with 100 ml of near-boiling water. The phases were allowed to separate and the bottom layer drawn off for analysis. For anion analysis, an aliquot was injected through a syringe filter (Acrodisc 4192, 0.2 micron) into an ion chromatograph (Dionex 2000i with AS-3 separator column). Quantitation was done by comparison of peak heights with those of aqueous standards. Cation analysis was done by flame AA.

(c) Units are relative peak heights. The species responsible could not be identified. The retention time indicated that it (they) interacted only very weakly with the resin. Carbonate, organic acids, tetraborate, and fluoride behave similarly.

(d) Units are relative peak heights. The species responsible could not be identified. The retention time indicated that it (they) interacted strongly with the resin. Sulfate interacts less strongly and phthalate more so.

(e) Insufficient sample. It appeared that most of the contents of the container had been removed prior to our receiving it.

Continued.....

ASSISTANT SUPERINTENDENT

D.E. Smith

Appendix A continued.

REPORT OF CHEMICAL ANALYSIS

INLAND STEEL COMPANY

CHEMICAL DEPARTMENT - QUALITY CONTROL

DATE REPORTED: February 12, 1975

SAMPLE IDENTIFICATION: Grease from Tendon Anchorhead, Inryco

DATE RECEIVED: February 1, 1975

RECEIVED FROM: Operating Metallurgy, P. Noe

ANALYSIS:

G-8205 Continued page three

(f) Insufficient sample. Water analysis on this sample may be moot anyway since liquid water was encountered in the interior of the anchorhead during grease sampling.

All the used grease samples were laden with particulate debris. Samples 1,2,3, and 5 had flakes of zinc, some of them fingernail size, all friable. The presence of particulate debris of unknown composition may make the data for extractable ions difficult to interpret since the distribution of contaminants will affect the representativeness of a sample and their corrosive influence.

Conclusions:

The following conclusions can be drawn from the above data.

1. Water is getting into the anchorhead container probably in liquid form since the design would seem to eliminate the possibility of condensation. Liquid water may carry large quantities of dissolved materials.

2. The samples are highly contaminated with particulate debris. The distribution and sources of the debris need to be investigated. Any kind of particulate debris would seem to be undesirable.

3. There are large differences in the grease analyses, yet the samples form three neat groups - top, bottom, and anchorhead interior - giving the data increased credibility. Some reasons for these differences may be:

   a) The samples may be mixtures of greases from different lots. Grease is removed during routine inspection and replaced with new grease.

   b) Contaminants already present may be redistributed by water.

Continued.....

VISIBILITY SUPPLY & ENGRG

D.E. Smith

Appendix A continued.

REPORT OF CHEMICAL ANALYSIS

INLAND STEEL COMPANY

CHEMICAL DEPARTMENT - QUALITY CONTROL

DATE REPORTED: February 12, 1988

SAMPLE IDENTIFICATION: Grease from Tendon Anchorhead, Inryco

DATE RECEIVED: February 1, 1988

RECEIVED FROM: Operating Metallurgy, P. Noe

ANALYSIS: G-5395 Continued page four.....

c) Different levels of contamination by solids, water, and water-borne materials may exist.

d) The grease may be deteriorating. Higher total acid numbers and the large A_1 and nonexistent A_2 for the anchorhead interior sample suggest this but are far from conclusive.

4. The most highly contaminated grease is that from the anchorhead interior, the most critical location. This suggests that the anchorhead itself may be the point of entry of the contaminants possibly with the tendon acting as a conduit.

cc: P. Noe 2-104
D. Budinger 2-104
G. Henger 2-104
R. Carr 2-101
P. Hawkins 2-111
D. Smith 2-101

R. Rheaume /lab — ASSISTANT SUPERINTENDENT: D.E. Smith

Appendix B. Inland Steel Company Chemical Department Grease Analyses of February 26, 1985. Reduced copy.

REPORT OF CHEMICAL ANALYSIS

INLAND STEEL COMPANY

CHEMICAL DEPARTMENT - QUALITY CONTROL

DATE REPORTED: February 26, 1985

SAMPLE IDENTIFICATION: Grease from Tendon System

DATE RECEIVED: February 15, 1985

RECEIVED FROM: Operating Technology, P. Noe

ANALYSIS

Lab No.: G-5439

	Water Extract Analysis (d)										
	Cl^- ppm	NO_2^- ppm	NO_3^- ppm	$SO_4^=$ ppm	A_1 (b)	A_2 (b)	Na ppm	K ppm	Ca ppm	Mg ppm	pH
V21, layer 2, perimeter	9	<0.5	<2	27	4.7	1.7	24	4	200	1	7.4
V21, layer 2, center	6	<0.5	<2	20	3.8	1.8	21	4	200	1	7.7
V21, layer 5, perimeter (a)	5	<0.5	<2	16	2.5	1.2	19	3	180	1	7.8
V21, layer 5, center (a)	6	<0.5	<2	19	3.5	1.8	110	4	190	1	7.7
HVCIS, conduit side (a)	17	<0.5	(c)	35	14	0.2	170	11	190	6	7.3
HVCIS, cap side (a)	30	<0.5	(c)	48	30	<.03	313	22	250	9	7.3
Visconorust 2090-P2 Grease, new	4	<0.5	2	70	1.0	<.03	670	2	160	3	9.3
Visconorust 1601 Amber, new	(c)	<0.5	(c)	5	38	1.7	1100	4	610	8	8.3
Water from fill end of V21	150	<0.5	<5	250	35	<0.1	280	15	480	4	8.3

(a) Liquid water encountered during sampling.
(b) Units are relative peak heights. The species responsible could not be identified.
(c) Not determinable due to interference.
(d) Modified version of that in ASTM D974. See footnote (b), G-5395.
(e) pH of extract of manufacturer's sample of 2090-P4 is 9.4.

Grease from V21 was sampled in 6 approximately 3" layers until the bottom (fill end) was reached.

Infrared spectra of cap and anchorhead grease samples associated with V21 and V17 were a good match for the spectrum of a manufacturer's sample of 2090-P4 and substantially different from those of manufacturer's samples of 2090-P2 (old formulation) and 1601 Amber (tendon anticorrosion coating). Comparison of spectra also indicated that there is little or none of formulations 2090-P2 and 1601 Amber in the used grease samples so far analyzed.

cc: P. Noe 2-104
D. Budinger 2-104
G. Henger 2-104
R. Carr 2-101
D. Smith 2-101

Analyst: R. Riesenman

ALLEGHENY LUDLUM STEEL

D. E. Smith

Appendix C. Suburban Laboratories, Inc., Grease Analyses of February 21, 1985. Reduced copy.

Telephone (312) 544-3260

SUBURBAN LABORATORIES, Inc.

4140 LITT DRIVE HILLSIDE, ILLINOIS 60162 - 1183

EARL HOSENFELD
President

H.R. THOMAS JR
Director

February 21, 1985

Inryco, Inc.
Concrete Systems Division
7200 South Narragansett Avenue
Bedford Park
Chicago, Illinois 60638

Re: P. O. #81T2900-S

Attention: Mr. Harry Hendrickson

Samples Received: 2/19/85	Chlorides (ppm)	Nitrates (ppm)	Sulfides (ppm)	Water Content %	Neutralization No. Total Base No. (mg KOH/g)
S/L #1537 - Sample A, Uncontrolled Button Head Surface Field End, HV038V21 w/tape	4.30	0.113	0.002	3.21*	46.97
S/L #1538 - Sample B, Uncontrolled around Threads Field End HV038 V21	0.70	0.113	0.007	1.02	47.86
S/L #1539 - Sample #1, V64 Uncontrolled	1.40	0.113	0.007	0.18	51.35
S/L #1540 - Grease Can, V102 Top	0.80	0.075	0.012	0.19	49.48
S/L #1541 - Heated Pumped Out V21, Top	0.70	0.075	0.007	0.17	50.57
S/L #1542 - #890069 Tendon V-17 Top #1	1.40	0.325	0.007	0.27	50.88
S/L #1543 - #890070 Tendon V-17 Top #2	2.90	0.150	0.002	0.18	48.50
S/L #1544 - #890071 V-17, Bottom Grease from Lowest Point #3	2.00	0.180	0.012	1.52	48.18
S/L #1545 - #890072 Tendon V-17, Bottom Cap Grease Cup #4	1.80	0.300	0.012	**	50.02
S/L #1546 - #890073 V-17, Bottom Dome Section #5	1.80	0.230	0.012	1.34	45.84

(Continued)

Appendix C continued.

Inryco, Inc.
February 21, 1985
Page #2

Samples Received: 2/14/85	Chlorides (ppm)	Nitrates (ppm)	Sulfides (ppm)	Water Content %	Neutralization Total Base N. (mg KOH/g)
Field Anchor Cap / V-21					
S/L #1547 - Grease wrapped in Plastic	1.40	0.250	0.012	1.11	48.36
S/L #1548 - Layer #1, Top Edge	0.40	0.280	0.016	0.54	46.33
S/L #1549 - Layer #1, Top Center	0.70	0.280	0.002	0.77	44.37
S/L #1550 - Layer #3, Edge	0.70	0.280	0.016	0.27	46.95
S/L #1551 - Layer #3, Center	0.70	0.300	0.020	0.44	45.46
S/L #1552 - Layer #4, Edge	2.00	0.300	0.012	0.38	45.74
S/L #1553 - Layer #4, Center	0.70	0.300	0.012	0.54	47.67
S/L #1554 - Layer #6, Bottom Edge	0.70	0.325	0.016	0.70	45.37
S/L #1555 - Layer #6, Bottom Center	2.00	0.325	0.012	1.42	46.55
Interior Anchor Head					
S/L #1556 - Field End / V-17	0.70	0.280	0.012	**	**
Dates Tested:	2/19/85 & 2/20/85		2/20/85	2/20/85	2/19/85

ANALYSIS CERTIFIED BY: _____, Director (IFT:ih)

Chlorides	(Sect. 5.1)	Method: ASTM D-512
Nitrates	*	Method: ASTM D-992
Sulfides	*	Method: APHA 427-C
Water Content	(Sect. 5.2)	Method: ASTM 4-95
Neutralization Number	(Sect. 5.3)	Method: ASTM D-974 (Modified)

* Black color appears in the water layer

** Insufficient sample

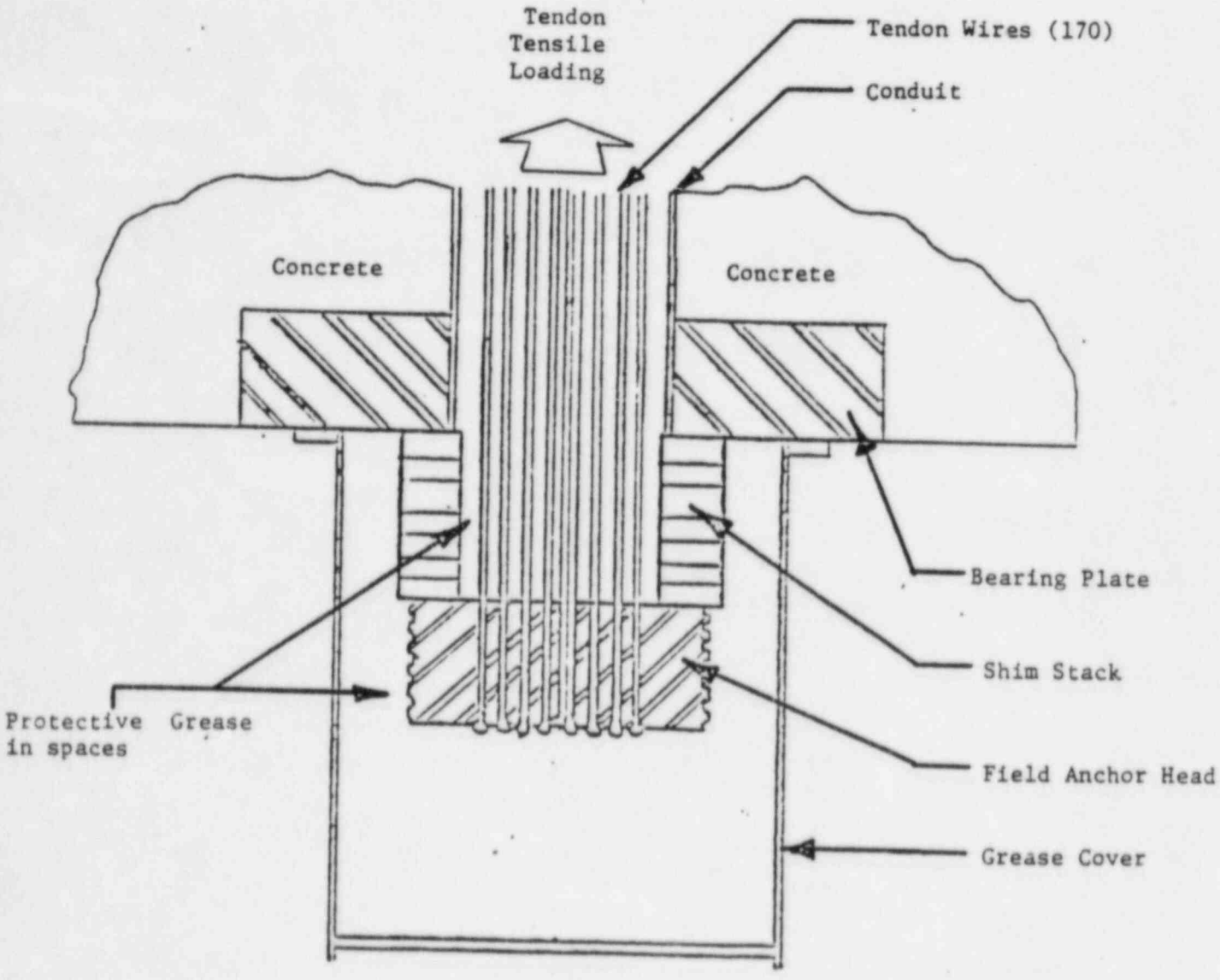


Figure 1. Sketch showing the approximate orientation and layout of the components at the lower end of the vertical tendons. The sketch is not to scale.

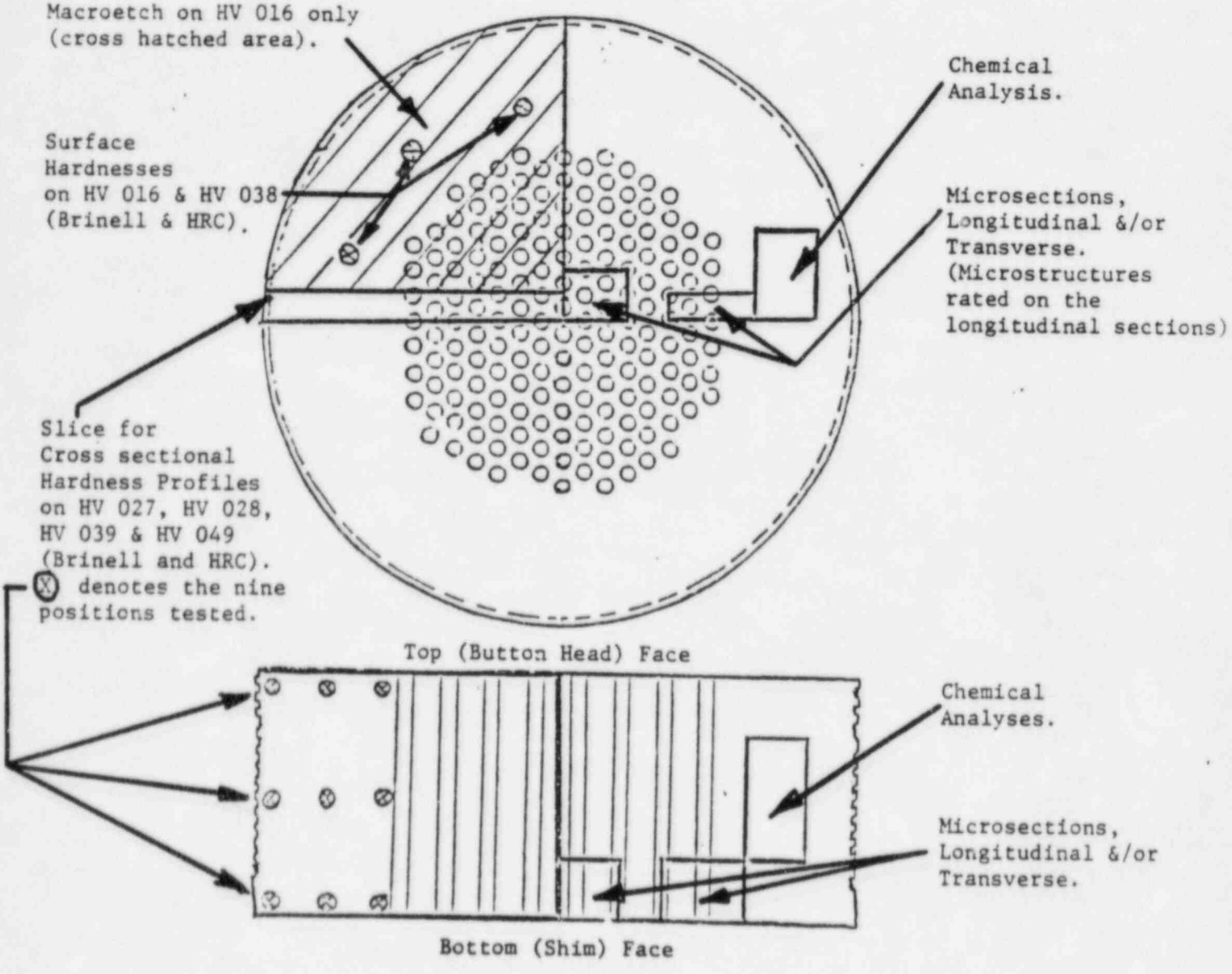


Figure 2A. Test locations for the macroetch, hardnesses and microsections. Figure is not drawn to scale.

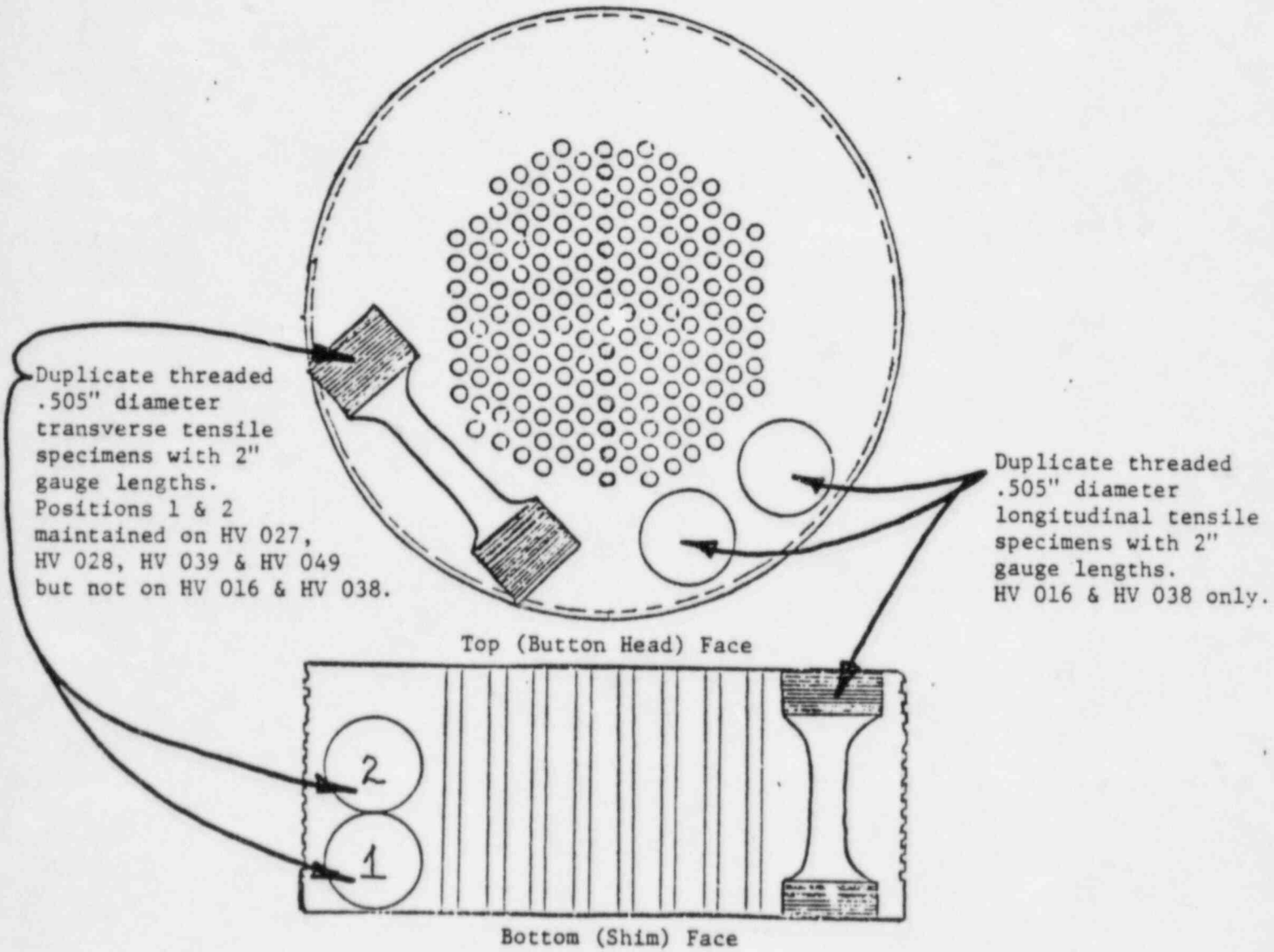


Figure 2B. Test locations for the Tensile Specimens. Figure is not drawn to scale.

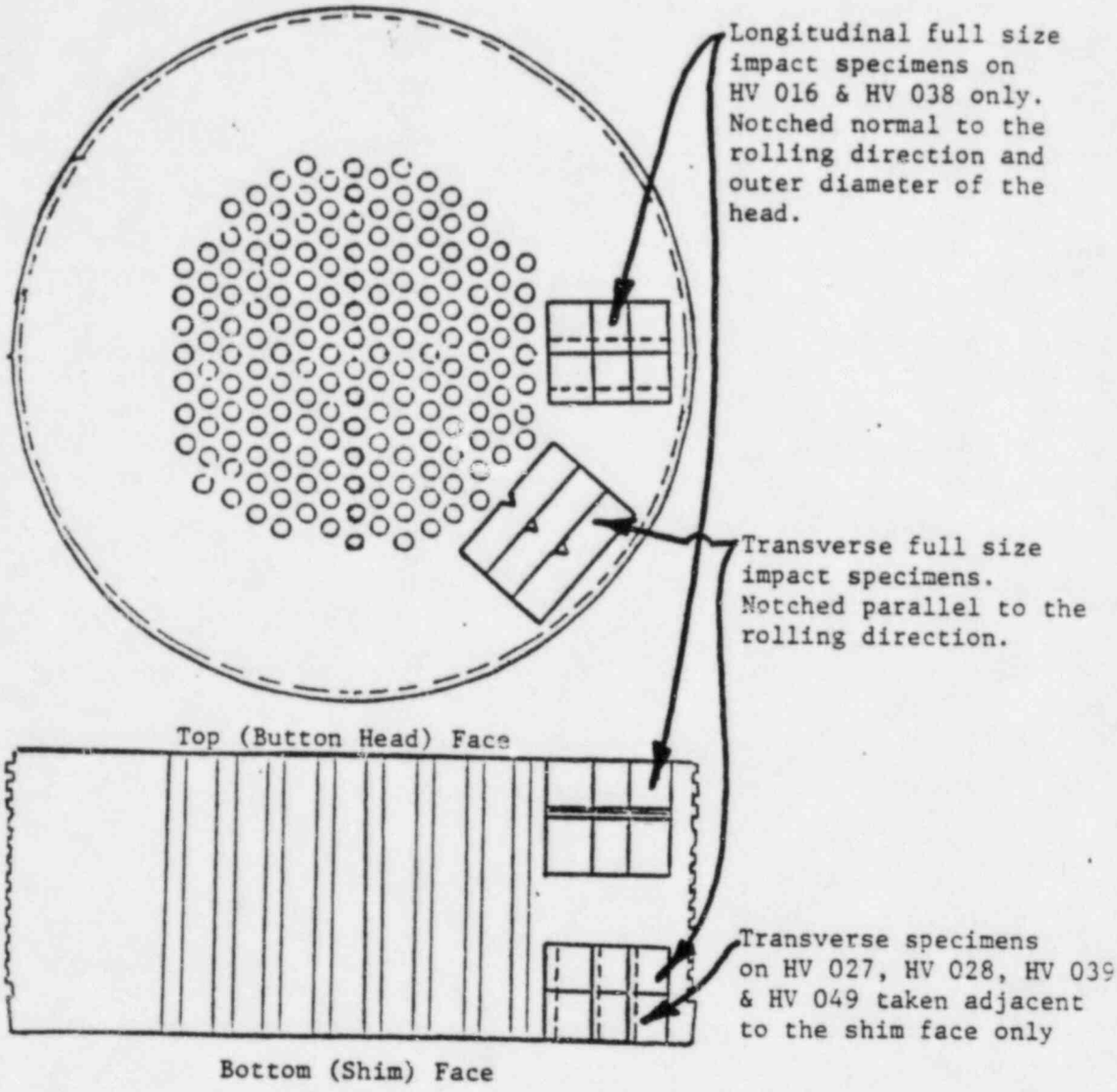


Figure 2C. Test locations for the Charpy V Notch impact specimens. Figure is not drawn to scale.

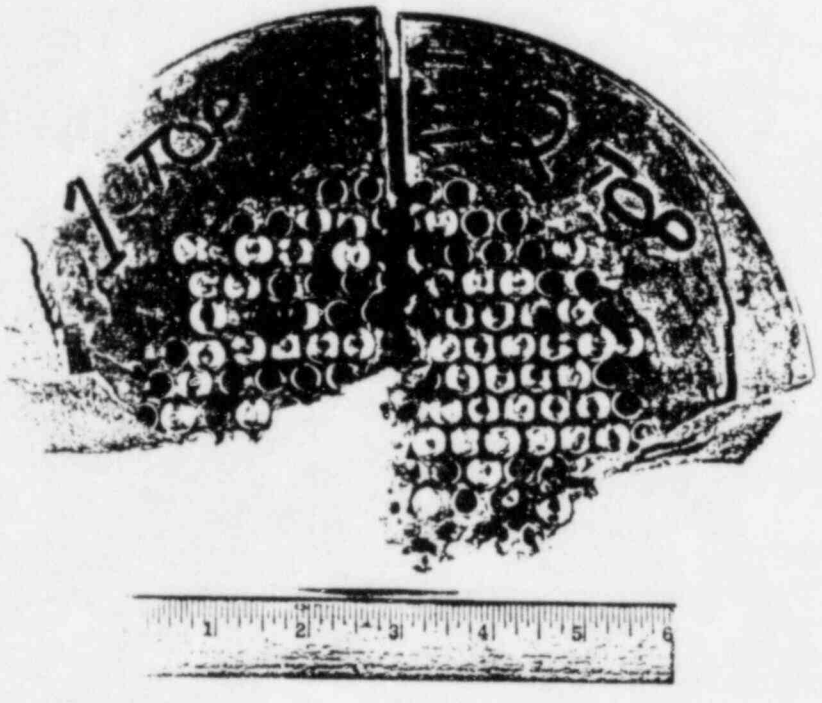
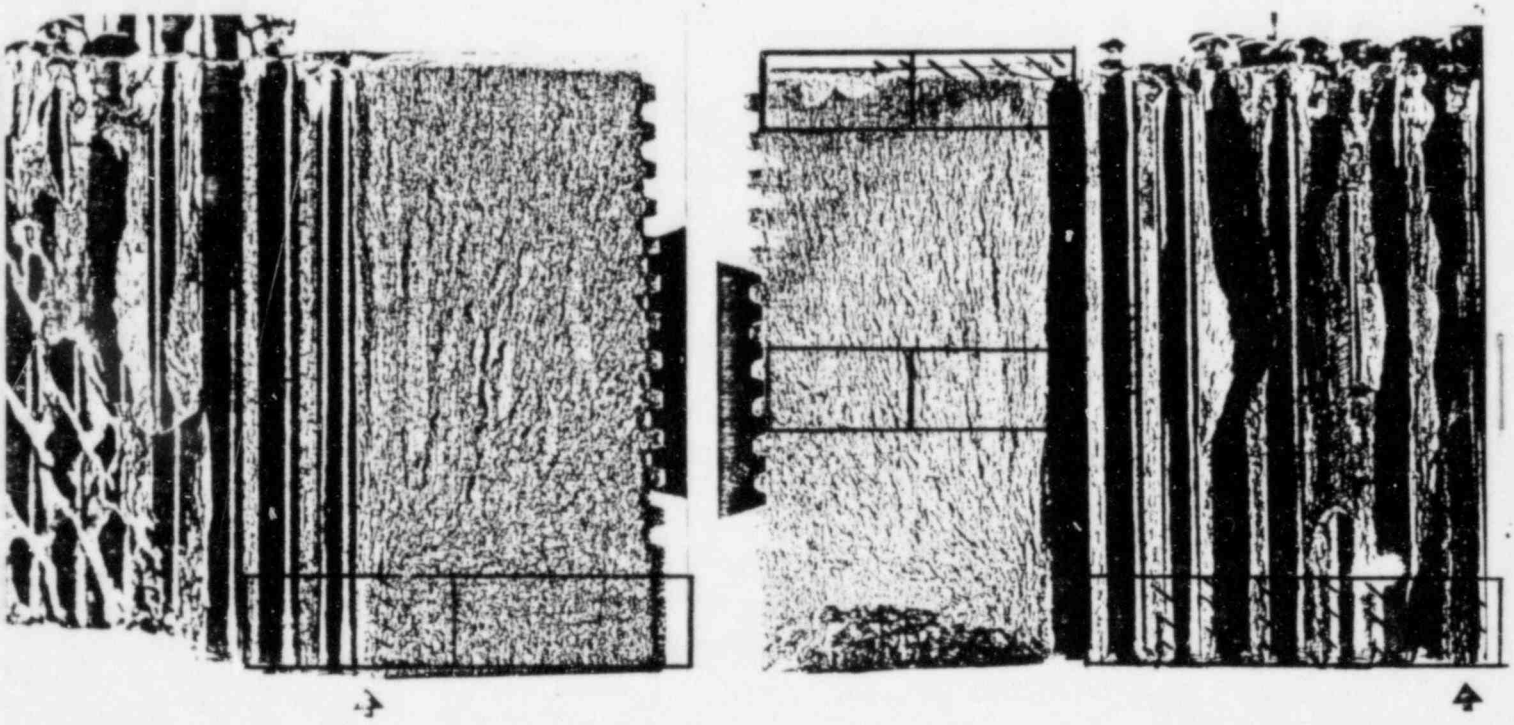


Figure 3. Buttonhead face of the two sections of Anchor Head HV 016 submitted for metallurgical analysis. Arrows indicate mating fracture faces. Note the angled nature of the non-mating faces and the spalling on the button head faces.

Approx. 0.48X



A B

ıres 4A and 4B. Light fractographs of the mating fractured faces from Anchor Head HV 016. Note the woody appearance of the fractures. Arrows point to region shown in Figures 14A and 14B. The light chevron pattern on the outer ring indicates the ring fractures originated at or adjacent to the honeycomb and near the shim face (bottom surface as shown).

Approx. 0.77X

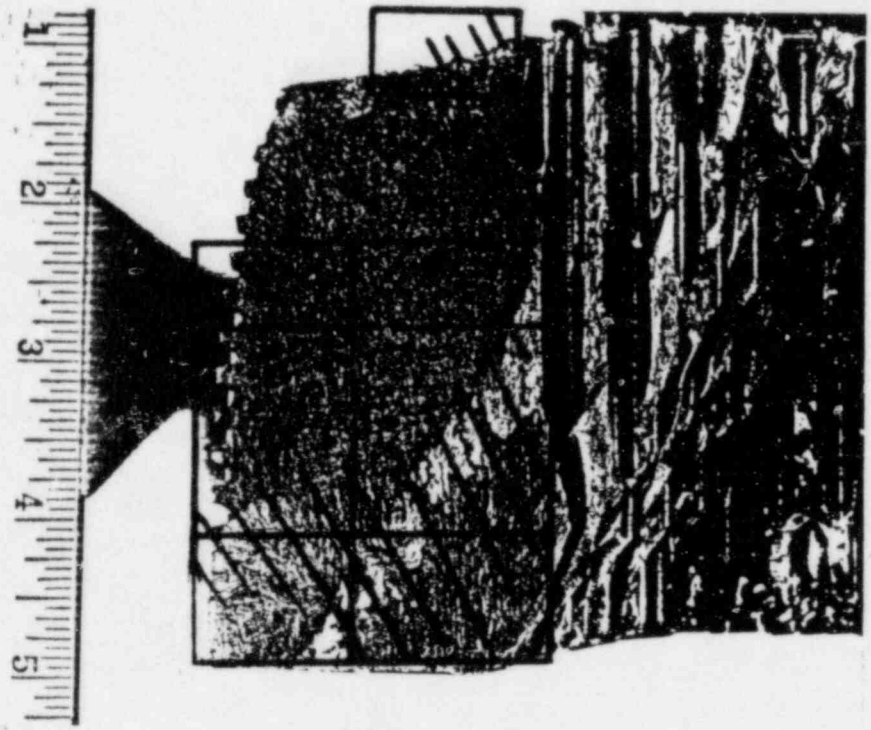


Figure 5. Second fracture face of Section #1, Anchor Head HV 016. Note the striations on the upper two-thirds of the ring fractured face. Origin at lower inner corner of ring. Also note the angled honeycomb fractures.

Approx. 0.82X

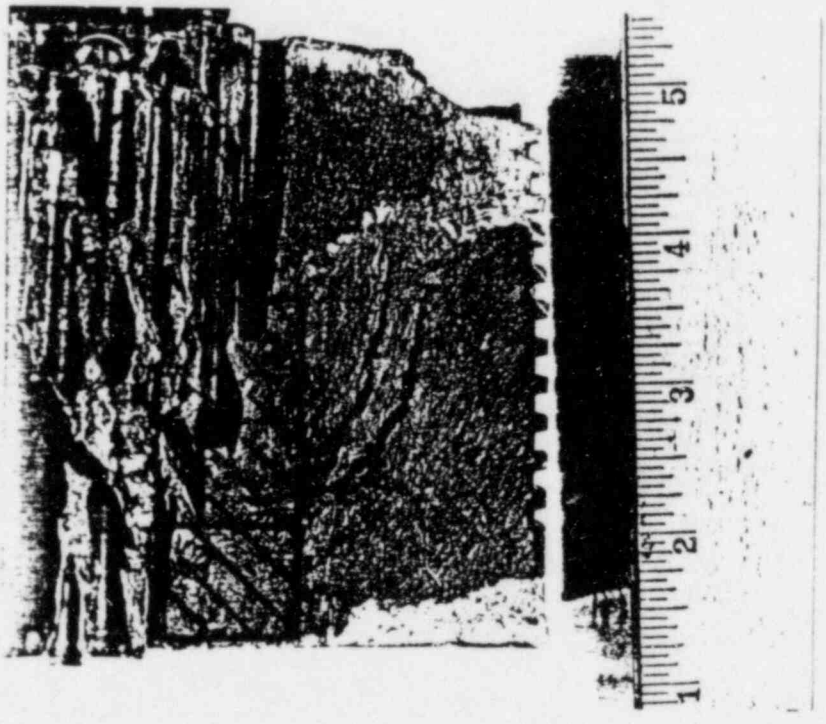


Figure 6. Second fracture face of Section #2, Anchor Head HV 016. Note the fracture appeared to originate at multiple origins in the lower half of the honeycomb. Note the light striations and angled honeycomb fractures.

Approx. 0.78X

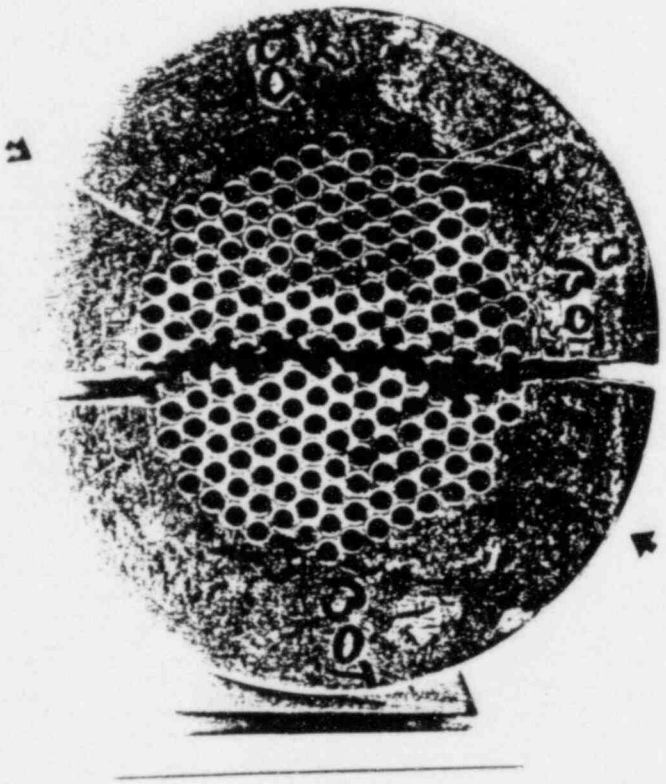


Figure 7. Photograph of the inboard end (shim face) of HV 038. Note the crack between Sections #2 and #3. The split shim spacing is denoted by the arrows. Section #1 (lower half) was retained by Battelle along with a small fragment from the honeycomb area. Sections #2 and #3 (upper half) were retained by Inland.

Approx. 0.36X

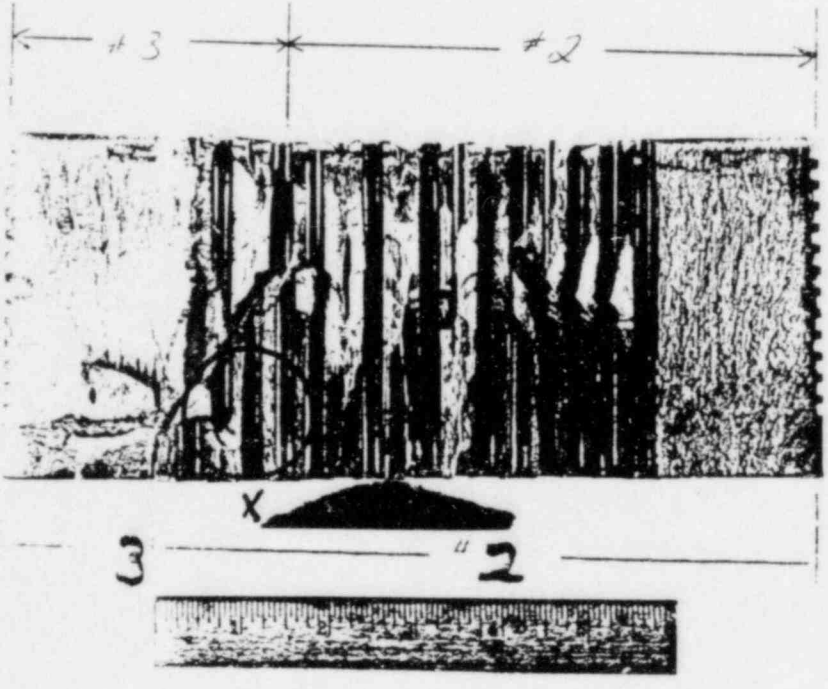


Figure 8. Light fractograph of Sections #2 and #3 of HV 038 retained by Inland. The inboard (shim face) end of the head is the bottom surface, as shown. The small honeycomb fragment retained by Battelle came from the circled area denoted by the "X". Refer to Figures 3 and 4 for detailed fractographs of Sections #3 and #2, respectively.

Approx. 0.46X

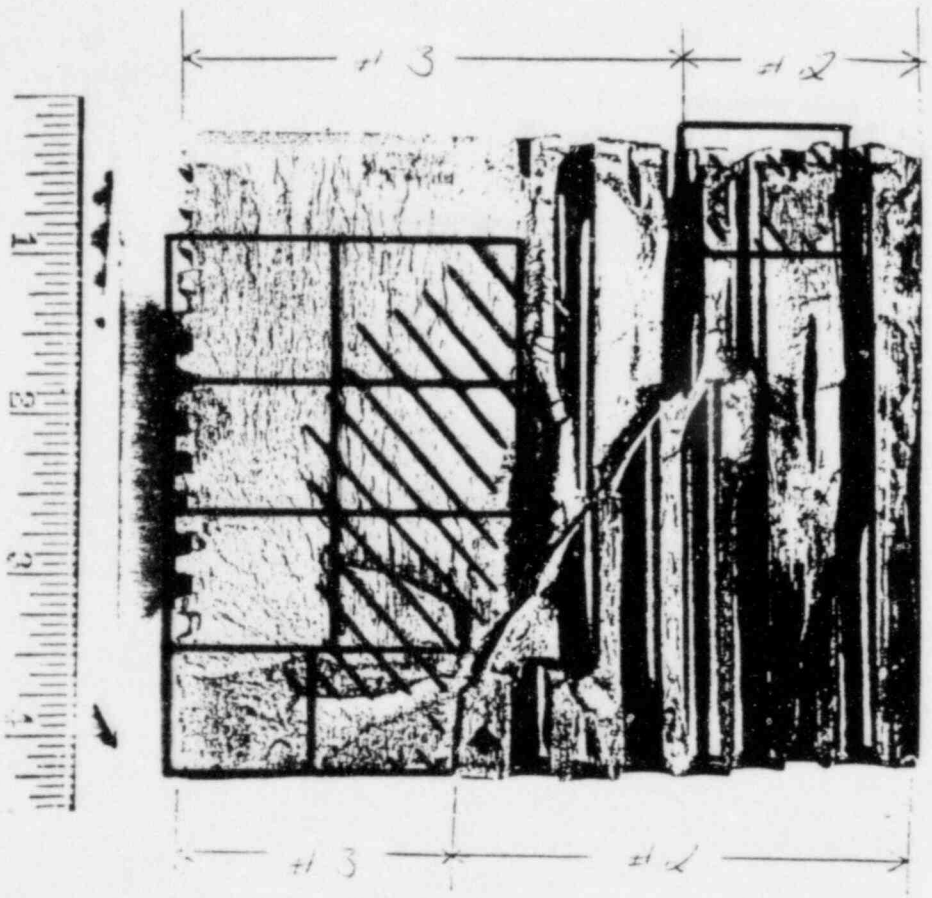


Figure 9. Light fractograph of Section #3 and a portion of Section #2, Anchor Head HV 038. Note the woody appearance of the fracture. The fracture of the outer ring appears to have propagated from the location denoted by the arrow. However, it is suspect that the head fracture origin was located within the honeycomb area, which exhibited multi-directional and possibly multi-origin fracture faces. The small fragment retained by Battelle was above and to the right of the arrow.

Approx. 0.82X

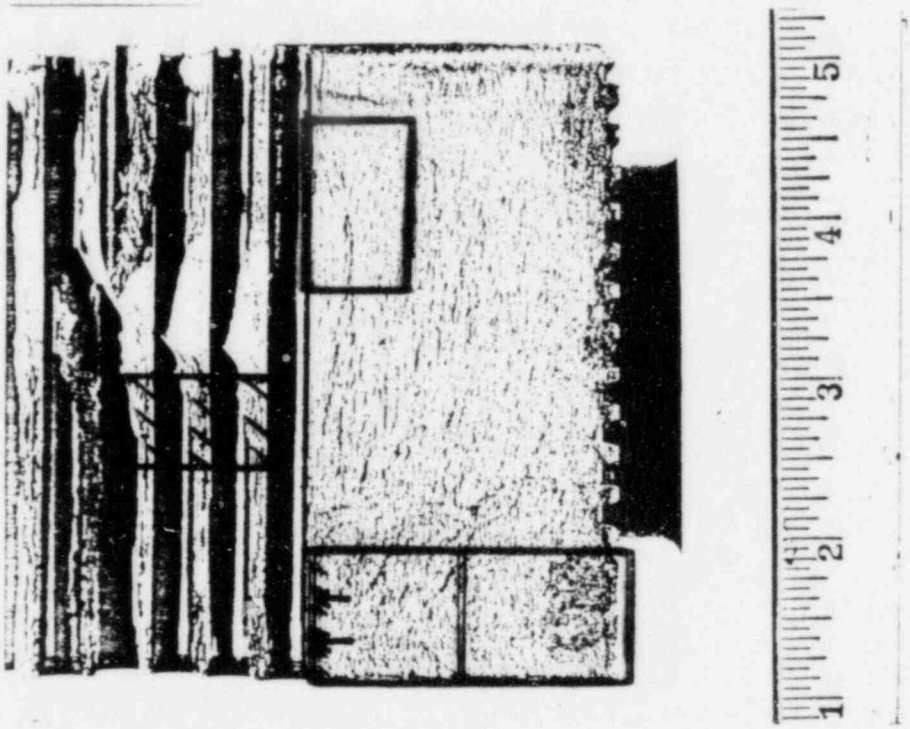


Figure 10. Light fractograph of the remainder of Section #2, Anchor Head HV 038. Note the woody appearance of the fracture. The fracture of the outer ring appears to have propagated from the location denoted by the arrows. However, it is suspect that the head fracture originated within the honeycomb.

Approx. 0.82X

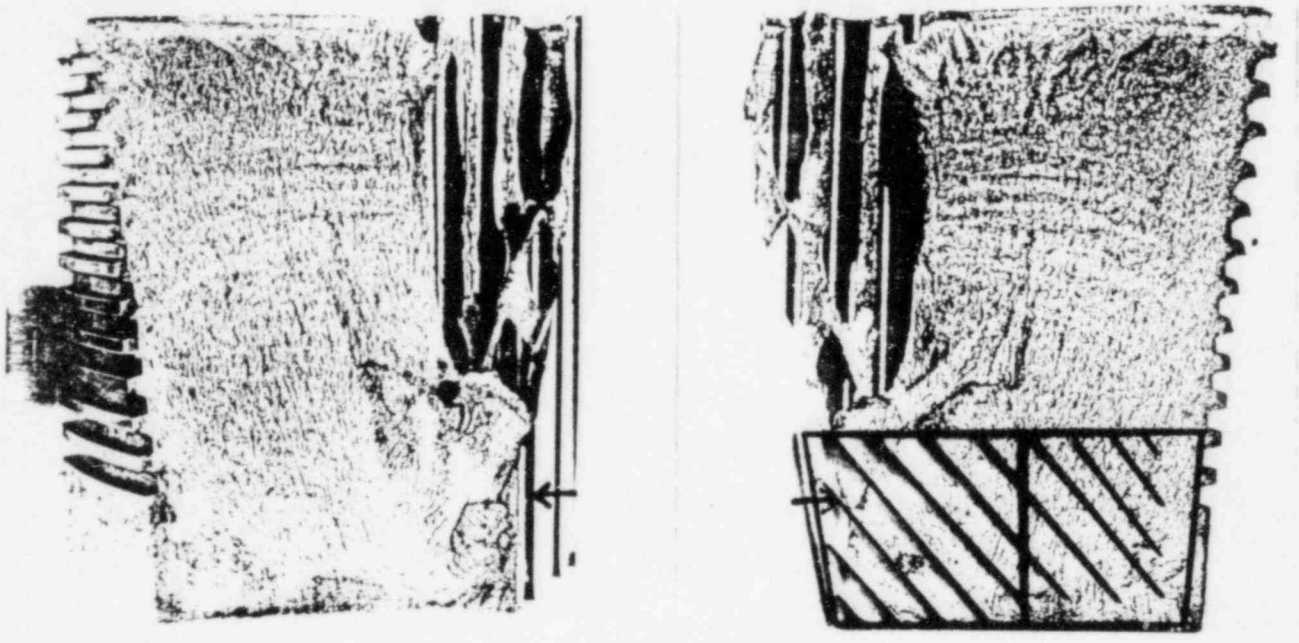


Figure 11. Light fractograph of the mating fracture faces of Anchor Head HV 038 between Sections #2 and #3. Note the woody appearance of the fracture and the striations on the upper half of the ring face. The fracture appears to have propagated from the location denoted by the arrows.

Approx. 0.78X

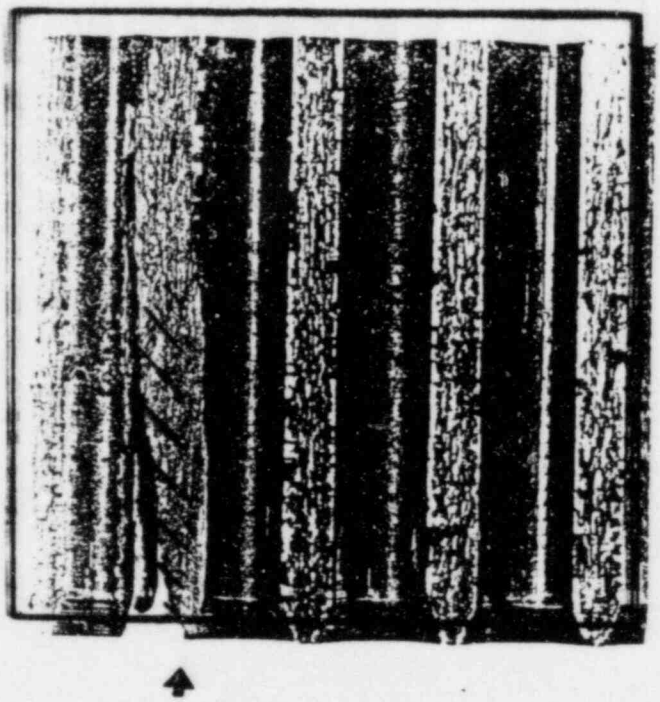


Figure 12. Light fractograph of the fracture face of Anchor Head HV 039, which was separated mechanically. The arrow indicates the precracked web where it appears a fracture originated. Note the smoother, more crystalline appearance of the pre-cracked area versus the balance of the fracture surfaces.

Approx. 1.8X

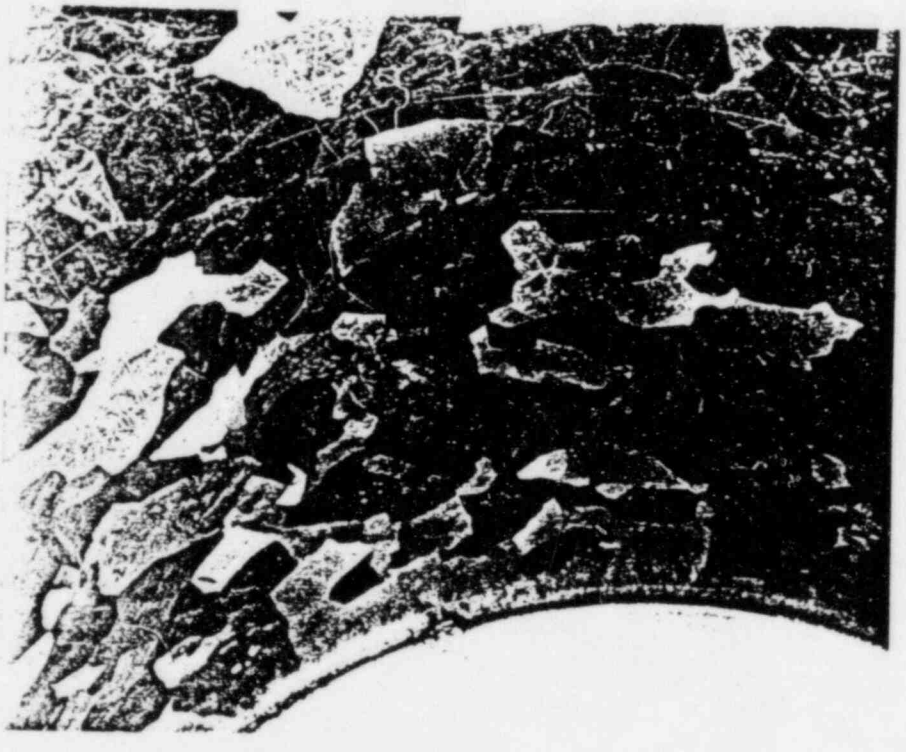


Figure 13A. Photograph of the interior surface of the galvanized grease cover from V-21 (HV 038) after removal of the grease. Note the "etched" condition of the galvanized coating.

Approx. 0.20X

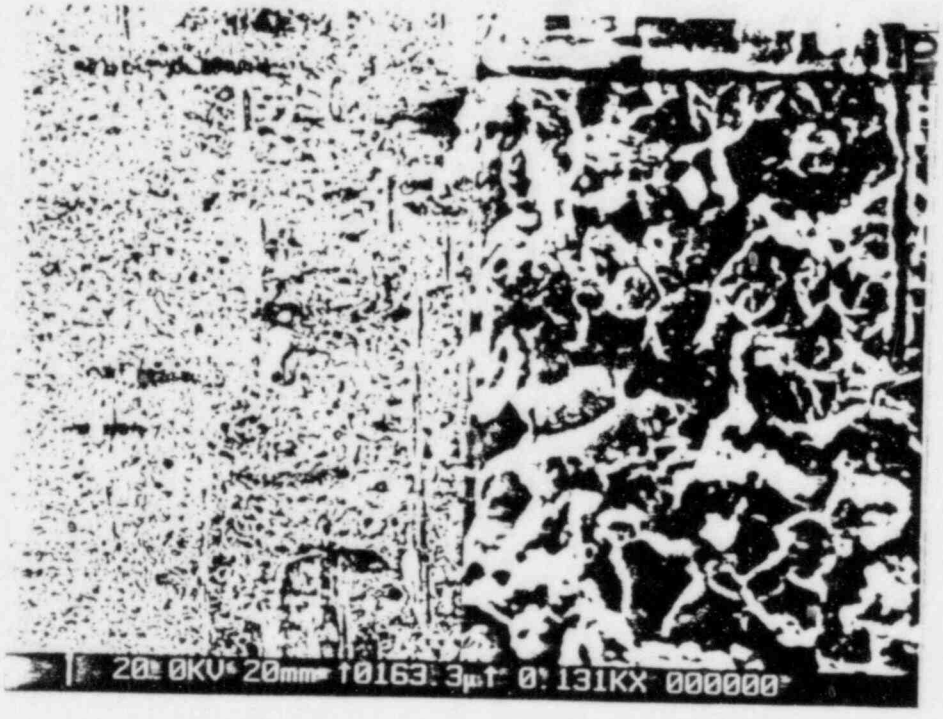
Figure 13B. Photograph of the interior surface of the galvanized grease cover from V-21 (HV 038) after removal of the grease. Note the surface irregularities (dross) of the galvanized coating.

Approx. 0.50X

300X

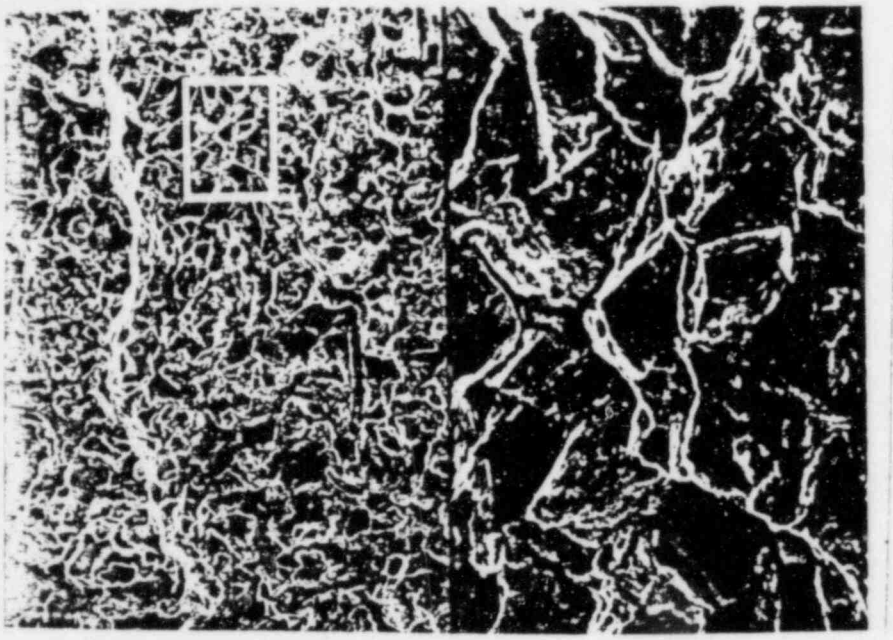
3,010X

Figure 14A. SEM fractograph of HV 016 of region denoted by arrow in Figure 4A. The low magnification shows the inclusion troughs. The high magnification shows the intergranular separation.



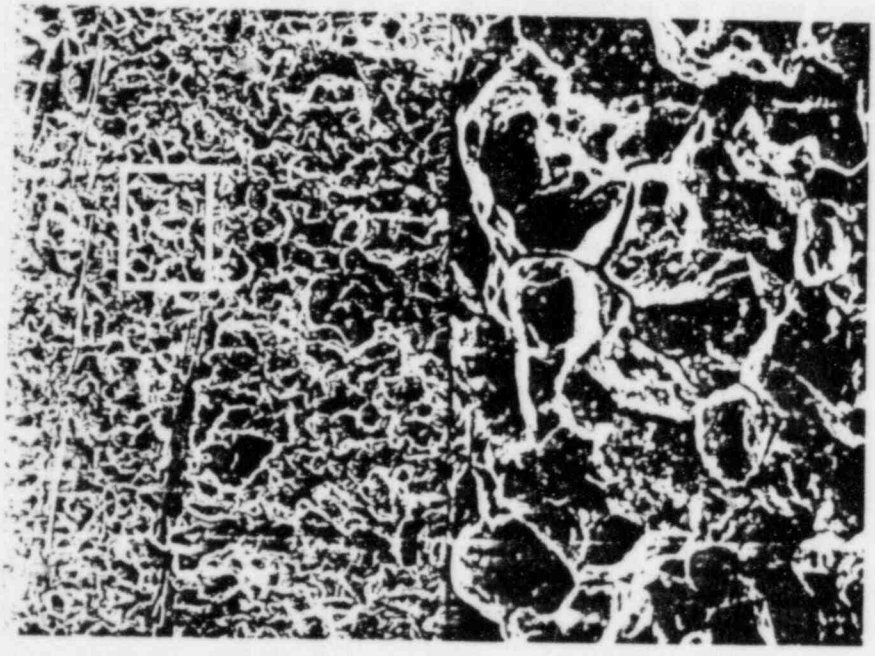
131X 951X

Figure 14B. SEM fractograph of HV 016 of region denoted by arrow in Figure 4B. The low magnification shows the inclusion troughs. The high magnification shows the intergranular separation.



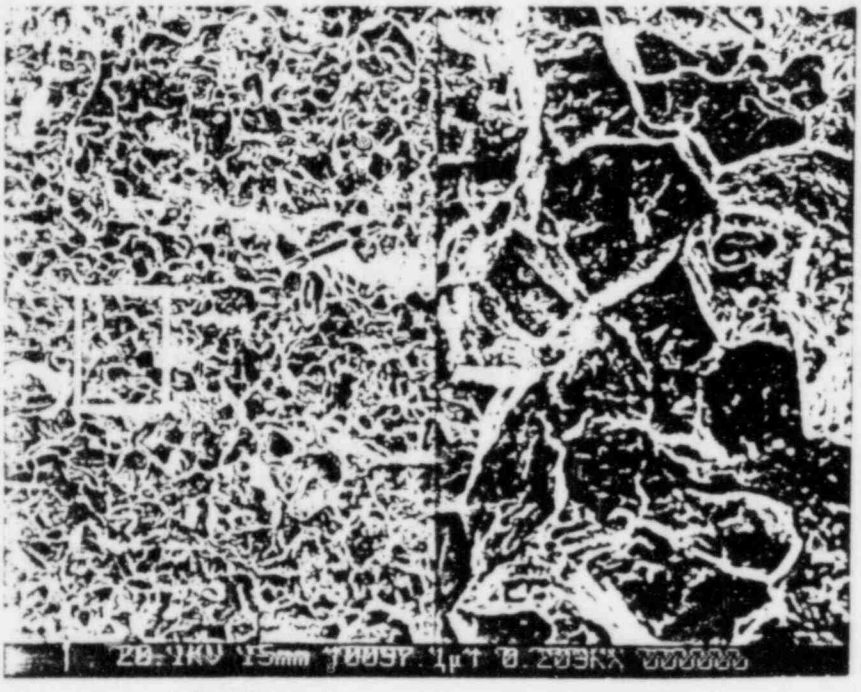
200X 1,000X

Figure 15A. SEM fractograph of HV 038 of the selected region denoted by the arrow in Figures 8 and 9 (outer ring near the junction of Sections #2 and #3 and approximately 1" above the shim face). The lower magnification (left side) shows scattered inclusion troughs. The higher magnification (right side showing the area in the box on the left side) clearly shows heavy IGS. Note the relative cleanliness (lack of corrosion products) of the fracture face.



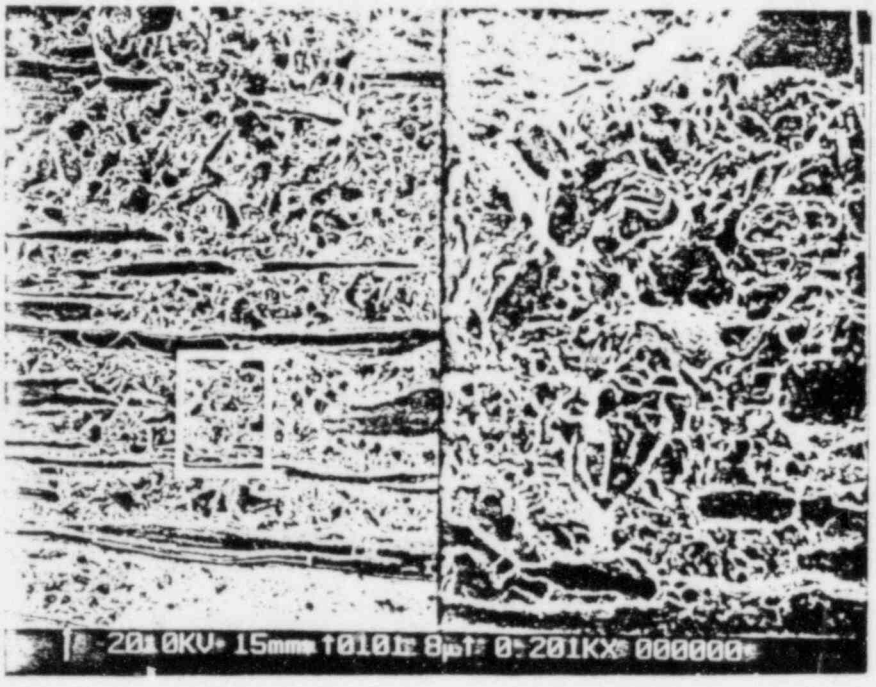
200X 1,000X

Figure 15B. SEM fractograph of HV 038 of the selected region denoted by the arrows in Figure 10. The lower magnification (left side) shows scattered inclusion troughs. The higher magnification (right side showing the area in the box on the left side) clearly shows heavy IGS. Note the relative cleanliness of the fracture face.



200X 1,000X

Figure 16A. SEM fractograph of the precracked web of Anchor Head HV 039, Figure 12, approximately 3/4" from the bottom surface. The lower magnification (left side) shows the general IGS condition. The higher magnification (right side showing the area in the box on the left side) clearly shows heavy IGS. Note the relative cleanliness of the fracture face.



200X 1,000X

Figure 16B. SEM fractograph of the cracked web of Anchor Head HV 039, Figure 12, approximately 1-1/4" from the bottom surface. The lower magnification (left side) shows scattered inclusion troughs. The higher magnification (right side showing the area in the box on the left side) clearly shows the cleavage and ductile fracture modes.

INLAND STEEL COMPANY
OPERATING TECHNOLOGY DEPARTMENT

INRYCO POST TENSIONING DIVISION
JOSEPH M. FARLEY NUCLEAR PLANT, UNIT NO. 2
ANCHOR HEAD INVESTIGATION

METALLURGICAL LABORATORY INVESTIGATION NO. 19975 - FINAL REPORT

BY

D.E.BUDINGER
ASSOCIATE METALLURGIST
OPERATING METALLURGY DIVISION
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INTRODUCTION

THE JOSEPH M. FARLEY NUCLEAR PLANT, UNIT NO. 2 - DOLTON, ALABAMA, OPERATED BY ALABAMA POWER COMPANY (APCO), ENCOUNTERED THE FIELD FAILURE OF TWO FIELD ANCHOR HEADS, HV 016 AND HV 038. THE ANCHOR HEADS ARE PART OF THE POST TENSIONING SYSTEM USED IN THE REACTOR CONTAINMENT BUILDING. ANCHOR HEADS HV 016 AND HV 038 WERE LOCATED AT THE LOWER POSITION OF VERTICAL TENDONS V-17 AND V-21, RESPECTIVELY. BOTH HEADS HAD BEEN STRESSED FOR APPROXIMATELY SEVEN TO EIGHT YEARS (STRESSED ON NOVEMBER, 1976, THROUGH JUNE, 1977). THE ANCHORAGES WERE LAST INSPECTED IN JUNE-JULY, 1983, AT WHICH TIME THE INSPECTED ANCHORAGES (21) APPEARED TO BE INTACT BASED ON THE VISUAL INSPECTION PROCEDURES IN USE AT THAT TIME. THREE ANCHORAGES FROM THE HV HEAT GROUP, BUT NEITHER OF THE FAILED HEADS, WERE INSPECTED IN 1983.

ANCHOR HEAD HV 016 WAS DISCOVERED JANUARY 25, 1985, DURING A 30-DAY REFUELING SHUTDOWN OF UNIT NO. 2. THE RING PORTION OF THE HEAD HAD FRACTURED INTO FIVE SECTIONS AND THE HONEYCOMB PORTION HAD SHATTERED INTO APPROXIMATELY 80 PIECES. TWO MAJOR FRACTURE SECTIONS OF THE ANCHOR HEAD HV 016, LABELED #1 AND #2, WERE RECEIVED AT THE INLAND METALLURGICAL LABORATORY ON JANUARY 29, 1985, FOR FAILURE ANALYSES. THE OTHER MAJOR FRACTURE SECTIONS OF ANCHOR HEAD HV 016 WERE SENT TO BATTELLE FOR SIMILAR FAILURE ANALYSES. INSPECTION OF THE OTHER ANCHOR HEADS IN THE CONTAINMENT WAS CONCURRENTLY BEING PERFORMED. IN ADDITION, FIVE GREASE SAMPLES FROM THE LOWER END OF TENDON V-17 WERE SUBMITTED TO THE INLAND METALLURGICAL LABORATORY FOR CHEMICAL ANALYSES.

ON JANUARY 30, 1985, DURING THE INSPECTION OF UNIT NO. 2, FRACTURED ANCHOR HEAD HV 038 WAS DISCOVERED. THE HEAD HAD FRACTURED INTO THREE SECTIONS PLUS ONE SMALL FRAGMENT FROM THE HONEYCOMB AREA. THE ENTIRE ANCHOR HEAD WAS RECEIVED AT THE INLAND METALLURGICAL LABORATORY ON FEBRUARY 16, 1985, AND WAS JOINTLY INSPECTED (VISUALLY, USING A LOW POWER MICROSCOPE AND SCANNING ELECTRON MICROSCOPE, SEM, ON THE SMALL FRAGMENT) BY INLAND METALLURGICAL LABORATORY PERSONNEL, G. SCHMIDT OF BECHTEL REPRESENTING THE APCO, T. GROENEVELD OF BATTELLE AND H. PRESSWALLA OF INRYCO ON FEBRUARY 18, 1985. AFTER THE EXAMINATION AND A

JOINT AGREEMENT, SECTION #1, REPRESENTING APPROXIMATELY 50% OF THE ANCHOR HEAD, AND THE SMALL HONEYCOMB FRAGMENT WERE RETAINED BY BATTELLE FOR THEIR ANALYSES OF THE FAILURE. SECTIONS #2 AND #3 WERE RETAINED BY INLAND FOR FAILURE ANALYSES. AT THIS TIME, ALL 49 ANCHOR HEADS OF THE HV HEAT IDENTIFICATION WERE BEING REMOVED FROM THE CONTAINMENT BUILDING.

PRIOR TO RECEIVING ANCHOR HEAD HV 038, THE GREASE COVER FROM THE LOWER END OF VERTICAL TENDON V-21 WAS SUBMITTED TO THE INLAND METALLURGICAL LABORATORY ON FEBRUARY 8, 1985. THE GREASE COVER CONTAINED THE GREASE RETAINED UPON REMOVAL FROM THE TENDON. ALSO SUBMITTED WERE TWO UNCONTROLLED GREASE SAMPLES TAKEN FROM ANCHOR HEAD HV 038 AFTER UNCOVERING AND PRIOR TO DETENSIONING THE HEAD. SAMPLING AND ANALYSES OF THE GREASE AND A METALLURGICAL EVALUATION OF THE GALVANIZED GREASE COVER WERE REQUESTED.

FOUR ANCHOR HEADS, HV 027, HV 028, HV 039 AND HV 049, WHICH WERE DETENSIONED AND REMOVED FROM THE CONTAINMENT BUILDING, WERE RECEIVED BY THE INLAND METALLURGICAL LABORATORY ON FEBRUARY 20, 1985, FOR MODIFIED (ABBREVIATED) TESTING. THESE ANCHOR HEADS WERE MAGNETIC PARTICLE INSPECTED AFTER DETENSIONING AND ANCHOR HEAD HV 039 WAS FOUND TO BE CRACKED (REFERRED TO AS PRECRACKED) ON THE SHIM FACE IN THE CENTER OF THE HONEYCOMB WEBS. THE REMAINING THREE HEADS WERE NOT PRECRACKED. ANCHOR HEADS HV 027 AND HV 049 WERE THEN SENT TO FPM HEAT TREATING - ELK GROVE VILLAGE, ILLINOIS, AND WERE RETEMPERED AT 850 DEGREES F FOR FOUR HOURS. THE FOUR ANCHOR HEADS WERE THEN LOAD TESTED AT THE UNIVERSITY OF ILLINOIS, CHAMPAIGN-URBANA, ILLINOIS, BY INRYCO. AFTER LOAD TESTING, THE ANCHOR HEADS WERE AGAIN MAGNETIC PARTICLE TESTED WITH CRACKS BEING NOTED ON ANCHOR HEADS HV 027 AND HV 049 (REFERRED TO AS POST-CRACKS) AND ANCHOR HEAD HV 039 FURTHER CRACKED (PRECRACKED AND POST-CRACKED) IN THE CENTER OF THE HONEYCOMB WEBS ON THE SHIM FACE. THE LOAD TEST CONSISTS OF SIMULATING THE ACTUAL LOADING CONDITIONS OF THE ANCHOR HEADS (LOADED TO 120-150% GUTS, I.E., THE MINIMUM GUARANTEED ULTIMATE TENSILE STRENGTH OF THE TENDON) AS CLOSELY AS POSSIBLE USING A 3,000,000 LB. UNIVERSAL TESTING MACHINE. ALL FOUR HEADS WERE LOAD TESTED SATISFACTORILY; THAT IS, NO RADIAL (FLEXURAL) FRACTURES OR PREMATURE PUNCHOUT (SHEAR) FAILURES OF THE HONEYCOMB OCCURRED.

THE FIELD ANCHOR HEADS ARE 4" THICK BY 9.375" DIAMETER CYLINDRICAL PARTS AND ARE SUBJECTED TO A COMBINATION OF SHEAR, COMPRESSIVE AND TENSILE LOADS IN SERVICE. FIGURE 1 IS A SKETCH OF THE APPROXIMATE LAYOUT OF THE SYSTEM COMPONENTS AT THE LOWER END OF THE VERTICAL TENDONS. ONE HUNDRED SEVENTY (170) 0.257" DIAMETER HOLES ARE DRILLED LONGITUDINALLY THROUGH THE CENTRAL HONEYCOMB AREA OF THE ANCHOR HEAD. THE STEEL WIRES OF THE TENDONS FIT THROUGH THE HOLES AND ARE COLD HEADED. AFTER INSTALLATION IN THE STRUCTURE, THE ANCHOR HEADS ARE THEN JACKED AWAY FROM THE BEARING PLATE TO STRESS (TENSION) THE TENDONS. SPLIT SHIM PLATES ARE THEN INSERTED BETWEEN THE ANCHOR HEAD AND THE BEARING PLATE TO MAINTAIN THE TENSILE STRESS. AFTER TENSIONING, GALVANIZED GREASE COVERS ARE PLACED OVER THE HEADS AND A HEATED CORROSION PROTECTION GREASE (VISCO 0 2090P WAX-BASED PETROLEUM NUCLEAR CASING FILLER PACKING GREASE) IS THEN PUMPED INTO THE SYSTEM FROM THE LOWER END OF THE TENDON AND CIRCULATED UNTIL A CONSTANT TEMPERATURE IS ACHIEVED. THE GREASE COMPLETELY ENCASES THE ANCHORAGES AND TENDONS. PERIODICALLY, THE GREASE IS "TOPPED-OFF" FROM THE UPPER END OF THE TENDON. THERE ARE 357 TENDONS IN THE CONTAINMENT STRUCTURE OF WHICH 130 ARE VERTICAL, 134 ARE HOOP AND 93 ARE DOME.

THE ANCHOR HEADS ARE MACHINED FROM 10" DIAMETER HOT WORKED AND ANNEALED ASTM A-322 GRADE 4140 OR 4142 ALLOY STEEL ROUNDS. THE HV ANCHOR HEADS WERE PRODUCED FROM STEEL PURCHASED BY WESTERN CONCRETE FROM E. M. JORGENSON, WHO PURCHASED IT FROM REPUBLIC STEEL COMPANY, HEAT #8061524. THE HEAT WAS MADE IN 1973. THE ANCHOR HEADS WERE HEAT TREATED BY DOWNEY STEEL TREATING - DOWNEY, CALIFORNIA, TO MILITARY SPEC. MIL-H6875 TO A HARDNESS OF HRC 40-44. HEAT TREATING CHARTS OR TEMPERATURE RECORDS WERE NOT REQUIRED AT THE TIME THE HEADS WERE MANUFACTURED.

THIS REPORT COVERS THE FAILURE ANALYSES OF ANCHOR HEADS HV 016 AND HV 038 AND THE METALLURGICAL EVALUATION OF THESE ANCHORAGES ALONG WITH ANCHORAGES HV 027, HV 028, HV 039 AND HV 049. ALSO INCLUDED ARE THE CHEMICAL EVALUATIONS OF GREASE SAMPLES OBTAINED FROM THE LOWER ENDS OF THE VERTICAL TENDONS V-17 AND V-21 (ANCHORAGES HV 016 AND HV 038, RESPECTIVELY). THE GALVANIZED GREASE COVER FROM V-21 (HV 038) WAS ALSO EXAMINED. IN ADDITION, INFORMATION ON THE ON-SITE CONDITIONS AND PHOTOGRAPHS OF THE ON-SITE CONDITIONS WERE CONSIDERED.

TESTING PROCEDURES

THE BASIC METALLURGICAL TESTING PROCEDURES FOR THE TESTING OF THE SUBMITTED FIELD ANCHOR HEAD SAMPLES WERE AS FOLLOWS:

1. VISUAL EXAMINATION WAS DONE IN THE AS-RECEIVED CONDITION OF BOTH ANCHOR HEADS AND GREASE SAMPLES. SAMPLES OF THE GREASE RETAINED ON ANCHOR HEADS HV 016 AND HV 038 WERE OBTAINED. THE GREASE SAMPLING FROM THE GREASE COVER FROM TENDON V-21 AND VISUAL EXAMINATION OF THE GREASE SAMPLES WILL BE COVERED IN THE GREASE ANALYSES SECTION OF THIS REPORT.

2. SAMPLES WHICH REQUIRED DEGREASING WERE THEN CLEANED WITH STODDART'S SOLVENT OR ALCHOHOL AND FURTHER EXAMININED WITH BOTH THE UNAIDED EYE AND LOW POWER MICROSCOPE. PHOTOGRAPHS WERE OBTAINED OF ANCHOR HEADS HV 016 AND HV 038 AND THE FRACTURE FACES OF THE CRACKS ON HV 039. THE GREASE COVER FROM TENDON V-21 WAS ALSO PHOTOGRAPHED.

3. SCANNING ELECTRON MICROSCOPE (SEM) FRACTOGRAPHY WAS PERFORMED ON ALL OF THE FRACTURE FACES LOCATED ON THE ANCHOR HEADS AFTER THE HEADS WERE SECTIONED TO A SUITABLE SIZE. IN ADDITION, ALL OF THE TRANSVERSE TENSILE TEST FRACTURE FACES AND SELECTED CHARPY V NOTCH IMPACT SPECIMEN FRACTURE FACES WERE EXAMINED. ALL OF THE ABOVE FRACTURES WERE EXAMINED FOR FRACTURE MODES, I.E., DUCTILE, BRITTLE (CLEAVAGE), SHEAR OR INTERGRANULAR SEPARATION (IGS). ANY OTHER FEATURES OF INTEREST WERE NOTED.

4. COMPLETE CHEMICAL ANALYSES INCLUDING RESIDUAL ELEMENTS WERE OBTAINED FROM THE ANCHOR HEADS.

5. MECHANICAL PROPERTIES INCLUDED THE FOLLOWING:

   A.) BRINELL AND ROCKWELL (HRC) HARDNESS WERE OBTAINED ON THE RING SURFACE OF ANCHOR HEADS HV 016 AND HV 038 AND ON THE RING CROSS-SECTION OF ANCHOR HEADS HV 027, HV 028, HV 039 AND HV 049.

   B.) TENSILE PROPERTIES WERE OBTAINED FROM THE RING AREA OF EACH ANCHOR HEAD USING STANDARD .505" DIAMETER ROUND TENSILE SPECIMENS WITH 2" GAUGE LENGTHS. ANCHOR HEADS HV 016 AND HV 038 WERE TESTED IN THE LONGITUDINAL AND TRANSVERSE DIRECTIONS AND THE BALANCE OF THE ANCHOR HEADS WERE TESTED IN THE TRANSVERSE DIRECTION ONLY.

THE FOLLOWING PROPERTIES WERE OBTAINED:

1.) YIELD STRENGTH, KSI (0.2% OFF SET)
2.) ULTIMATE TENSILE STRENGTH, KSI
3.) TOTAL ELONGATION, % IN 2" GAUGE LENGTH
4.) REDUCTION OF AREA, %

IN ALL CASES, INDIVIDUAL TEST RESULTS WERE REPORTED WITH NO AVERAGING BEING DONE.

C.) CHARPY V NOTCH IMPACT PROPERTIES USING FULL SIZE IMPACT SPECIMENS WERE OBTAINED FROM THE RING AREA. ANCHOR HEADS HV 016 AND HV 038 WERE TESTED IN THE LONGITUDINAL AND TRANSVERSE DIRECTIONS AT ROOM TEMPERATURE AND 212 DEGREES F. THE BALANCE OF THE ANCHOR HEADS WERE TESTED AT ROOM TEMPERATURE IN THE TRANSVERSE DIRECTION ONLY. THE FOLLOWING PROPERTIES WERE OBTAINED:

1.) ENERGY ABSORPTION, FT.-LBS.
2.) BRITTLE FRACTURE, %
3.) LATERAL EXPANSION, INCHES (HV 027,HV 028,HV 039,HV 049)

IN ALL CASES, INDIVIDUAL TEST RESULTS WERE REPORTED WITH NO AVERAGING BEING DONE. IN MOST CASES, DUPLICATE OR TRIPLICATE TESTS WERE OBTAINED.

6. METALLOGRAPHIC EXAMINATION TO EVALUATE THE MICROSTRUCTURE (AN EVALUATION OF THE HEAT TREATMENT) AND MICROCLEANLINESS AS RATED ON LONGITUDINAL MICROSPECIMENS WERE OBTAINED FROM THE RING AREAS USING THE J-K RATING SYSTEM BY APPEARANCE ONLY. IN ADDITION, SELECTIVE MICROSECTIONS FROM THE HONEYCOMB AREAS WERE ALSO EXAMINED.

THE LOCATIONS OF THE BASIC TESTING OF THE ANCHOR HEADS ARE SHOWN IN FIGURES 2A-C, AS WELL AS COULD BE MAINTAINED ON THE SUBMITTED SAMPLES. IT SHOULD BE NOTED THAT, IN SOME INSTANCES, THE TESTING WAS LIMITED DUE TO THE SAMPLE SUBMITTED.

THE GREASE COVER FROM THE LOWER END OF VERTICAL TENDON V-21 WAS EXAMINED VISUALLY AS RECEIVED AND AFTER GREASE SAMPLING. THE COVER WAS THEN SECTIONED IN ORDER TO OBTAIN ZINC COATING WEIGHTS AND MICROSECTIONS FOR EVALUATION OF THE GALVANIZED COATING INTEGRITY.

TEST RESULTS

VISUAL EXAMINATION

ANCHOR HEAD HV 016 (FIELD FAILURE)

THE TWO SUBMITTED SECTIONS OF ANCHOR HEAD HV 016 ARE SHOWN IN FIGURE 3. THE MATING FRACTURED FACES OF THE HEAD EXHIBITED A WOODY, FIBROUS-TYPE FRACTURE APPEARANCE. THE FRACTURE FACES WERE NORMAL TO THE INBOARD (SHIM FACE) AND WERE STRAIGHT AND ALIGNED PARALLEL TO THE ROLLING DIRECTION. IT IS NOT KNOWN IF THE FRACTURE COINCIDED WITH THE SPLIT SHIM SPACE. IT APPEARS THAT THE FRACTURE OF THE RING PORTIONS OF THE HEAD ORIGINATED AT OR NEAR THE SHIM FACE OF THE HEAD NEAR OR AT THE HONEYCOMB; SEE FIGURE 4. NOTE THE INDICATIONS OF A LIGHT CHEVRON PATTERN POINTING TOWARD THESE LOCATIONS. A DEFINITE ORIGIN OF THE HONEYCOMB FRACTURE WAS NOT APPARENT, ALTHOUGH THE FAILURE OF THE HEAD PROBABLY ORIGINATED WITHIN THE HONEYCOMB AND PROPAGATED TO THE OUTER RING. NOTE THAT THE HONEYCOMB HAD REPORTEDLY SHATTERED INTO APPROXIMATELY 80 PIECES; HOWEVER, THE HONEYCOMB FRACTURES IN THE AREA OF THE MATING FACES REMAINED PARALLEL TO THE ROLLING DIRECTION AND NORMAL TO THE SHIM FACE INDICATING A BIAXIAL TENSILE LOADING.

THE ADDITIONAL TWO FRACTURE FACES APPEAR TO BE SECONDARY FAILURES. THEY ALSO HAVE THE WOODY FRACTURE APPEARANCE, BUT THE FRACTURE FACES ARE ANGLED AT APPROXIMATELY 10 DEGREES FROM THE ROLLING DIRECTION. THE FRACTURE FACE FROM SECTION #1 ALSO HAS A STRIATED APPEARANCE ON THE UPPER TWO-THIRDS OF THE FRACTURE INDICATING A PROGRESSIVE FRACTURE WHICH PROBABLY OCCURRED LAST AND ORIGINATED NEAR THE BOTTOM (SHIM FACE) OF THE HEAD. THE FRACTURE FACE OF SECTION #2 APPEARS TO HAVE ORIGINATED AT MULTIPLE ORIGINS (AS INDICATED BY THE RATCHET MARKS) AT, NEAR OR WITHIN THE HONEYCOMB; SEE FIGURES 5 AND 6. THE FRACTURES IN THE HONEYCOMB AREAS ADJACENT TO THE SECONDARY FRACTURES WERE ANGLED TO THE ROLLED DIRECTION INDICATING A MORE COMPLEX, POSSIBLY TENSILE-SHEAR LOADING. IT WAS ALSO NOTED THAT SPALLING OF THE BUTTONHEAD SURFACES OF THE HEAD HAD OCCURRED ADJACENT TO THE SECONDARY FRACTURES INDICATING SIGNIFICANT COMPRESSIVE LOADING ALONG THAT SURFACE; SEE FIGURE 3.

ANCHOR HEAD HV 038 (FIELD FAILURE)

THE SHIM FACE OF ANCHOR HEAD HV 038 IS SHOWN IN FIGURE 7. WHEN THE ANCHOR HEAD WAS RECEIVED, SECTION #3 WAS NOT COMPLETELY SEPARATED FROM SECTION #2. THERE WAS ALSO A SMALL FRAGMENT OF THE HONEYCOMB FROM THE AREA CIRCLED IN FIGURE 8. THE FRAGMENT WAS JOINTLY EXAMINED AND RETAINED BY BATTELLE. A LIGHT FRACTOGRAPH OF THE RADIAL FRACTURE OF SECTIONS #2 AND #3 IS SHOWN IN FIGURE 8. THE FRACTURE FACES AS SHOWN IN FIGURE 8 ALSO HAD A WOODY, FIBROUS APPEARANCE, WERE NORMAL TO THE SHIM FACE AND WERE STRAIGHT AND ALIGNED PARALLEL TO THE ROLLING DIRECTIONS EXCEPT IN THE AREA WHERE THE FRACTURE FACES OF SECTIONS #1, #2 AND #3 INTERSECTED. THE FRACTURES WERE NOT ALIGNED WITH THE SPLIT SHIM SPACE, WHICH IS DENOTED BY THE ARROWS IN FIGURE 7. A DEFINITE FAILURE POINT ORIGIN IS NOT READILY APPARENT IN FIGURE 8 OR THE DETAIL FIGURES 9 AND 10. HOWEVER, THE FRACTURES OF THE OUTER RING AREAS APPEAR TO HAVE ORIGINATED AT OR ADJACENT TO THE HONEYCOMB AND IN THE LOWER QUARTER OF THE RING. INDEED, THE FAILURE OF THE HEAD MAY HAVE ORIGINATED WITHIN THE HONEYCOMB AREA AND PROPAGATED TO THE OUTER RING.

SECTION #3 WAS SEPARATED FROM SECTION #2 AND APPEARS TO BE A SECONDARY FAILURE. AGAIN, THE FRACTURED FACES EXHIBITED THE WOODY FRACTURE APPEARANCE, BUT THE FACES ARE ANGLED AT APPROXIMATELY 10 DEGREES FROM THE ROLLING DIRECTION. THE FRACTURED FACES ALSO HAVE A STRIATED APPEARANCE ON THE UPPER HALF OF THE FRACTURE, SIMILAR TO THE SECONDARY FRACTURES OF ANCHOR HEAD HV 016. IT APPEARS THAT THIS FRACTURE ALSO ORIGINATED AT OR ADJACENT TO THE HONEYCOMB AND SHIM FACE; SEE FIGURE 11.

ANCHOR HEADS HV 027, HV 028, HV 039, HV 049
(DETENSIONED ANCHOR HEADS WHICH HAD NOT FAILED)

ANCHOR HEAD HV 028 HAD NO CRACKS. THE OTHER THREE ANCHORAGES REVEALED CRACKS ALONG THE CENTRAL HONEYCOMB WEBS ON THE INBOARD (SHIM) FACE. HONEYCOMB SECTIONS WERE CUT OUT OF THE THREE ANCHORAGES CONTAINING THE CRACKS AND THEN SEPARATED TO REVEAL THE

FRACTURE FACES. CARE WAS TAKEN IN SECTIONING HV 039 TO INCLUDE BOTH PRECRACKS AND POST-CRACKS. THE FRACTURED FACES OF THE THREE ANCHORAGES ALSO SHOWED THE WOODY, FIBEROUS APPEARANCE. FIGURE 12 SHOWS THE FRACTURE FACE OF HV 039; THE ARROW INDICATES THE PRE-CRACKED WEB AREA WHICH HAD A SMOOTHER, MORE CRYSTALLINE APPEARANCE AS COMPARED TO THE ADJACENT POST-CRACKED WEB AREAS.

GENERAL COMMENTS ON VISUAL EXAMINATION

THE ANCHORAGES SHOWED VARYING DEGREES OF CORROSION PITTING OF THE TENDON HOLES. HV 016 AND HV 038 APPEARED TO SHOW A HIGHER DEGREE OF PITTING THAN THE OTHER FOUR ANCHORAGES. THE CORROSION PITTING INDICATES THE ACTIVE CORROSION HAD OR WAS OCCURRING WITHIN THE TENDON HOLES.

THE GALVANIZED GREASE COVER FROM THE LOWER END OF VERTICAL TENDON V-21 (HV 038) EXHIBITED AN "ETCHED" CONDITION ON THE INNER SURFACES AS SHOWN IN FIGURE 13A. THE "ETCHED" CONDITION IS AN INDICATION THAT ACTIVE CORROSION HAD OCCURRED OR WAS OCCURRING WITHIN THE GREASE COVER. THE GREASE COVER FROM THE LOWER END OF TENDON V-17 (HV 016) HAD A SIMILAR "ETCHED" APPEARANCE BASED ON ON-SITE PHOTOGRAPHS. SURFACE IRREGULARITIES, WHICH APPEARED TO BE DROSS, WERE ALSO EVIDENT ON THE INNER SURFACES OF THE GALVANIZED COVER; SEE FIGURE 13B. WHEN OBTAINING GREASE SAMPLES FROM THE TENDON V-21 GREASE COVER, POCKETS OF LIQUID WATER WERE ENCOUNTERED WITH APPROXIMATELY 200 ML OF WATER BEING FOUND NEAR THE LOWER END OF THE COVER. THIS AMOUNT OF WATER IS EXCESSIVE.

PHOTOGRAPHS OF ANCHOR HEAD HV 038 BEFORE DETENSIONING SHOWED WATER BEADS BEING VISIBLE ON BOTH THE SHIM PLATES AND THE ANCHOR HEAD ITSELF.

SCANNING ELECTRON MICROSCOPY (SEM)

FIGURES 4-6 AND 9-12 HAVE ACCOMPANYING OVERLAYS. THE OVERLAYS SHOW BOTH THE POSITIONS AT WHICH SEM ANALYSES WERE OBTAINED, I.E., THE CROSS-HATCHED AREAS, AND THE POSITIONS AT WHICH INTERGRANULAR SEPARATION (IGS) WAS NOTED, I.E., THE RED HIGHLIGHTED AREAS. THE OVERLAY METHOD WAS USED IN ORDER TO CLEARLY PRESENT THE SEM ANALYSES OF THE HEAD FRACTURES AND ALSO ALLOW AN UNOBSTRUCTED VIEW OF THE FRACTOGRAPHS. IN ALL OF THE SECTIONS PERTAINING TO THE SEM FRACTOGRAPHY, THE TOP SURFACE OF THE ANCHOR HEAD REFERS TO THE BUTTONHEAD SURFACE AND THE BOTTOM SURFACE OF THE ANCHOR HEAD REFERS TO THE SHIM SURFACE.

ANCHOR HEAD HV 016 (FIELD FAILURE)

SCANNING ELECTRON MICROSCOPIC (SEM) ANALYSES WERE PERFORMED ON ALL THE RING FRACTURE FACES AND SELECTED AREAS OF THE HONEYCOMB; REFER TO FIGURES 4-6. THE RING OF THE HEAD AND HONEYCOMB REVEALED INTERGRANULAR SEPARATION (IGS) TO VARYING DEGREES; SEE FIGURES 14A AND 14B. IGS INDICATES THAT THE FRACTURE OCCURRED WHILE THE HEAD WAS IN A PARTIALLY EMBRITTLED CONDITION. THE MATING FRACTURE FACE, SHOWN IN FIGURES 4A AND 4B, REVEALED IGS AT THE TOP AND BOTTOM, INNER SIDE (ADJACENT TO THE HONEYCOMB) OF THE RING. THE BALANCE OF THE SECTIONS EXAMINED FROM THESE FRACTURES PREDOMINANTLY SHOWED COMBINATIONS OF CLEAVAGE AND DUCTILE FRACTURE MODES.

EXAMINATION OF THE SECONDARY FRACTURE FACES REVEALED THE FOLLOWING: SECTION #1, SHOWN IN FIGURE 5, EXHIBITED HEAVY IGS ACROSS THE BOTTOM THIRD OF THE RING; SECTION #2, SHOWN IN FIGURE 6, SHOWED HEAVY IGS AT THE BOTTOM HALF INNER SIDE OF THE RING.

THE HONEYCOMB AREA REVEALED IGS ON BOTH THE VERTICAL AND ANGLED WEB FRACTURES. ALSO, THE SPALLED AREAS OF THE TOP (BUTTONHEAD) END OF THE RING, SHOWN IN FIGURE 3, EXHIBITED HEAVY IGS.

ANCHOR HEAD HV 038 (FIELD FAILURE)

SEM ANALYSES WERE PERFORMED ON THE FRACTURED FACES OF ANCHOR HEAD HV 038; SEE FIGURES 9-11. AGAIN, THE RING AND HONEYCOMB SHOWED IGS; SEE FIGURES 15A AND 15B. THE RING PORTION OF SECTION #2 (RIGHT SIDE OF FIGURE 8 AND FIGURE 10) SHOWED A NARROW BAND OF IGS ADJACENT TO THE HONEYCOMB AT THE BOTTOM THIRD OF THE RING.

APPROXIMATELY 50% OF THE RING PORTION OF SECTION #3 (LEFT SIDE OF FIGURE 8 AND FIGURE 9) SHOWED INTERGRANULAR SEPARATION. THE MAIN LOCATION OF THE INTERGRANULAR SEPARATION WAS ON THE INNER SIDE (ADJACENT TO THE HONEYCOMB) OF THE RING. ONLY A SMALL AMOUNT OF INTERGRANULAR SEPARATION WAS SEEN AT THE BOTTOM OF THE RING.

THE NON-RADIAL FRACTURE FACE BETWEEN SECTIONS #2 AND #3; SEE FIGURE 11, SHOWED IGS ACROSS THE LOWER THIRD OF THE RING.

THE FRAGMENT OF THE HONEYCOMB, WHICH WAS RETAINED BY BATTELLE, WAS EXAMINED AND SHOWED HEAVY IGS ON BOTH SIDES OF THE FRAGMENT.

ANCHOR HEAD HV 039
(DETENSIONED ANCHOR HEAD WHICH HAD NOT FAILED)

THE ANALYSIS WAS PERFORMED ON THE HONEYCOMB FRACTURED FACES OF ANCHOR HEAD HV 039. THE PRECRACKED WEB, SHOWN IN FIGURE 12, EXHIBITED HEAVY IGS ALONG THE BOTTOM INCH OF THE WEB; SEE FIGURE 16A. ABOVE THE BOTTOM INCH THE FRACTURE MODE WAS A COMBINATION OF CLEAVAGE AND DUCTILE; SEE FIGURE 16B. THE OTHER WEBS WHICH WERE CRACKED DURING LOAD TESTING SHOWED A COMBINATION OF CLEAVAGE AND DUCTILE FRACTURE MODES. NO IGS WAS NOTED ON THESE POST-CRACKS.

ANCHOR HEAD HV 027, HV 049
(DETENSIONED ANCHOR HEADS WHICH HAD NOT FAILED)

THE FRACTURED WEBS WHICH WERE POST-CRACKED DURING LOAD TESTING EXHIBITED A COMBINATION OF CLEAVAGE AND DUCTILE FRACTURE MODES; NO IGS WAS PRESENT. BOTH OF THESE HEADS HAD BEEN RETEMPERED AT 850 DEGREES F FOR FOUR HOURS AND THE POST-CRACKING REPORTEDLY OCCURRED AT 115% GUTS.

GENERAL COMMENTS ON THE SEM FRACTOGRAPHY

THE PREDOMINANCE OF THE IGS WITHIN AND TOWARDS THE HONEYCOMB AREA AND THE TOP AND BOTTOM RING SURFACES IS AN INDICATION OF AN EXTERNAL EMBRITTLING AGENT RATHER THAN A TEMPER EMBRITTLEMENT PHENOMENON. TEMPER EMBRITTLEMENT SHOULD RESULT IN A MORE UNIFORMLY DISPERSED IGS WHICH SHOULD BE MORE EVIDENT IN THE MORE SLOWLY COOLED AREAS OF THE HEAD, I.E., THE CENTER PORTION OF THE OUTER RING.

IN ADDITION, SEM ANALYSES WERE PERFORMED ON THE TRANSVERSE TENSILE TESTS OF ALL THE ANCHOR HEADS AND SELECTED TRANSVERSE IMPACT TESTS. NO IGS WAS NOTED ON ANY OF THESE TEST SPECIMENS. THE LACK OF IGS ON THE TEST SPECIMENS IS ALSO AN INDICATION THAT THE EMBRITTLEMENT IS NOT TEMPER EMBRITTLEMENT AND THE EMBRITTLING AGENT IS NO LONGER PRESENT.

BASED ON THE "FRESH" APPEARANCE OF THE FRACTURE FACES, NO EVIDENCE OF QUENCH CRACKING WAS OBSERVED. QUENCH CRACKS WOULD HAVE AN OXIDIZED SURFACE DUE TO THE PRESENCE OF TEMPER SCALE.

THE FRACTURE FACES ALSO APPEARED TO BE FREE OF CORROSION PRODUCTS. THE LACK OF CORROSION PRODUCTS IS AN INDICATION THAT THE FRACTURES ARE PROBABLY NOT STRESS CORROSION CRACKING. ENERGY DISPERSIVE QUALITATIVE SEM X-RAY ANALYSES OF THE FRACTURE FACES SHOWED NO IDENTIFIABLE CORROSION PRODUCTS OR EMBRITTLING SPECIES. HOWEVER, IT SHOULD BE NOTED THAT THE X-RAY UNIT IS NOT CAPABLE OF DETECTING EITHER HYDROGEN OR CARBON.

THE WOODY FIBROUS NATURE OF THE FRACTURES WAS CAUSED BY THE PREFERENTIAL ALIGNMENT OF THE NONMETALLIC INCLUSIONS IN THE ROLLING DIRECTION. THE INCLUSIONS CREATE FLOW LINES WHICH ACT AS PLANES OF WEAKNESS. THIS CONDITION WOULD RESULT IN LOWER TRANSVERSE FRACTURE RESISTANCE OF THE HEADS.

MECHANICAL PROPERTIES

THE MECHANICAL PROPERTIES OF THE ANCHOR HEADS ARE PRESENTED IN THE ATTACHED TABLES 1-6. BOTH BRINELL AND ROCKWELL HARDNESS TESTS WERE CONDUCTED ON THE ANCHOR HEADS. HARDNESS TESTS WERE PERFORMED ON THE TRANSVERSE RING SURFACE OF ANCHORAGES HV 016 AND HV 038, AND CROSS-SECTIONAL HARDNESS PROFILES WERE OBTAINED ON ANCHORAGES HV 027, HV 028, HV 039 AND HV 049. THE ROCKWELL VALUES WERE ON THE AVERAGE 2 TO 3 POINTS LOWER THAN THE CONVERTED BRINELL VALUES. THE SPECIFIED HARDNESS RANGE WAS HRC 40-44.

THE TENSILE PROPERTIES WERE OBTAINED WITH MACHINED .505" DIAMETER SPECIMENS WITH 2" GAUGE LENGTHS FROM THE RING AREA OF THE HEADS. THE STRENGTH LEVELS ARE HIGHER AND THE DUCTILITIES ARE WITHIN THE RANGE OF DATA THAT WAS FOUND ON PREVIOUSLY TESTED FIELD ANCHOR HEADS PRODUCED FROM ALUMINUM GRAIN REFINED AISI 4140 OR 4142 ALLOY STEELS. THE HIGHER STRENGTH WOULD MAKE THE MATERIAL MORE SUSCEPTIBLE TO STRESS CORROSION CRACKING OR HYDROGEN STRESS CRACKING.

THE EFFECT OF THE HARDENABILITY OF AISI 4140 OR 4142 ALLOY STEEL ON THE TENSILE PROPERTIES IS SHOWN IN TABLES 3-6. TEST 1 FROM HEADS HV 027, HV 028, HV 039 AND HV 049 WAS OBTAINED IMMEDIATELY ADJACENT TO THE SHIM FACE. TEST 2 WAS APPROXIMATELY 1-1/2" ABOVE THE SHIM FACE. IN ALL CASES, TEST 2 SHOWED LOWER STRENGTH LEVELS. HOWEVER, ONLY THE RETEMPERED HEADS HV 027 AND HV 049 SHOWED GREATER DUCTILITY ON TEST 2 AS COMPARED TO TEST 1. HEADS HV 028 AND HV 039, WHICH WERE NOT RETEMPERED, SHOWED COMPARABLE OR LESS DUCTILITY ON TEST 2.

THE IMPACT PROPERTIES WERE OBTAINED WITH FULL SIZE CHARPY V NOTCH SPECIMENS, ALSO FROM THE RING AREA OF THE HEADS. THE IMPACT ENERGIES ARE NORMAL FOR THE ALLOY STEEL PRODUCT IN THE QUENCHED AND TEMPERED CONDITION.

THE ANCHORAGES WHICH WERE RETEMPERED AT 850 DEGREES F FOR FOUR HOURS DID NOT SHOW SIGNIFICANT DIFFERENCES AS COMPARED TO THE OTHER ANCHORAGES. THIS INDICATES THAT THE ANCHORAGES WERE PROBABLY HEAT TREATED AS SPECIFIED.

CHEMISTRY

THE CHEMICAL CHECK ANALYSES OF THE ANCHOR HEADS OBTAINED FROM THE OUTER RING ARE GIVEN IN THE ATTACHED TABLES 1-6. THE LADLE CHEMISTRY OF REPUBLIC HEAT #6061524 AND THE CHEMICAL REQUIREMENTS OF ASTM A-322 GRADE AISI 4140 OR 4142 HOT ROLLED ALLOY STEEL BARS ARE GIVEN BELOW:

DESCRIPTION	C	MN	P	S	SI	MO	CR
LADLE, HEAT 6061524	.44	.95	.015	.030	.23	.22	1.07
ASTM A-322* GRADE 4140 OR 4142	.38/ .45	.75/ 1.00	.035	.040	.20/ .35	.15/ .25	.80/ 1.00

*SINGLE NUMBERS ARE MAXIMUMS. THE ASTM SPECIFICATION IS IDENTICAL TO INRYCO SPECIFICATION 1649, DATED JULY 15, 1972, WITH THE EXCEPTION OF THE CARBON RANGE OF .40/.45% ON THE INRYCO SPECIFICATION.

THE CHEMICAL ANALYSES OF THE HEADS ARE IN LINE WITH THE ASTM SPECIFICATION AND IN GOOD AGREEMENT WITH REPUBLIC'S HEAT. IN ADDITION, CU, NI, AL, N, O2, AS, TI, CB, V, SN AND SB CHECKS WERE AT A SATISFACTORY RESIDUAL LEVEL. THE RESIDUAL ELEMENTS INDICATED A PROBABLE ELECTRIC FURNACE STEELMAKING ORIGIN.

COATING WEIGHTS OF THE GALVANIZED COATING OF THE GREASE COVER FROM THE LOWER END OF TENDON V-21 (HV 038) WERE 3.3 OZ./SQ.FT. ON THE INNER SURFACE AND 2.9 OZ./SQ.FT. ON THE OUTER SURFACE. WITHOUT KNOWLEDGE OF THE ORIGINAL COATING WEIGHTS, THE SIGNIFICANCE OF THESE COATING WEIGHTS CAN NOT BE DETERMINED. THE COATINGS ARE HEAVY, HOT DIPPED GALVANIZED COATINGS WHICH WOULD OFFER SATISFACTORY ATMOSPHERIC CORROSION RESISTANCE.

MICROANALYSES

LONGITUDINAL AND TRANSVERSE MICROSECTIONS WERE OBTAINED FROM BOTH THE RING AND HONEYCOMB AREAS OF ANCHORAGES HV 016 AND HV 038. IN ALL CASES, THE SECTIONS INTERSECTED FRACTURE FACES. THE FRACTURES APPEARED TO BE A COMBINATION OF BRITTLE, INTERGRANULAR OR DUCTILE FRACTURES. NO EVIDENCE OF PRIOR CRACKING WAS APPARENT.

LONGITUDINAL MICROSECTIONS FROM THE RING AND HONEYCOMB AREAS OF ANCHORAGES HV 027, HV 028, HV 039 AND HV 049 WERE SECURED. THE HONEYCOMB SECTIONS OF ANCHORAGES HV 027, HV 039 AND HV 049 INTERSECTED THE FRACTURE FACES CAUSED BY LOAD TESTING. THE FRACTURES APPEARED TO BE DUCTILE.

THE MICROCLEANLINESS OF THE HEADS WAS RATED A3-4H AND B2-3H ON THE AVERAGE, PER THE J-K RATING SYSTEM, AND RATED ON APPEARANCE ONLY. THE MICROSTRUCTURE OF THE HEADS WAS TEMPERED MARTENSITE, INDICATING A QUENCHED AND TEMPERED CONDITION. LIGHT REMNANTS OF BANDING WERE EVIDENT. THE TENDON HOLES SHOWED A LIGHT PARTIAL SURFACE DECARBURIZATION (<.001" DEEP). NO CLUSTERED SULFIDES WERE EVIDENT. PRIOR AUSTENITIC GRAIN SIZE WAS 8 OR FINER. THERE WERE NO CHROMIUM CARBIDES EVIDENT. THERE WAS NO EVIDENCE OF CARBON RESTORATION.

MICROSECTIONS WERE OBTAINED FROM THE GALVANIZED GREASE COVER OF V-21. NO DETECTABLE CORROSION ATTACK WAS EVIDENT ON THE GALVANIZED COATING. THE GENERAL COATING THICKNESS WAS BETWEEN .004" AND .007" THICK, BUT THICKNESS UP TO .042" WAS NOTED. ALL THE SURFACES OF THE COVER EXAMINED WERE COATED.

GREASE ANALYSES

ATTACHED IN APPENDICES A AND B ARE THE INLAND STEEL COMPANY CHEMICAL DEPARTMENT ANALYSES OF VARIOUS GREASE SAMPLES OBTAINED FROM THE GREASE SUPPLIER (UNUSED SAMPLES), FROM THE GREASE COVERS FROM THE LOWER END OF TENDONS V-17 AND V-21 AT VARIOUS LOCATIONS WITHIN THE COVERS, AND FROM THE SAMPLES OBTAINED FROM THE SUBMITTED ANCHORAGES HV 016 AND HV 038. THE SAMPLES FROM COVER V-17 WERE OBTAINED ON-SITE. THE SAMPLES FROM COVER V-21 AND ANCHORAGES HV 016 AND HV 038 WERE OBTAINED AFTER THE SAMPLES WERE SHIPPED TO THE INLAND METALLURGICAL LABORATORY.

LIQUID WATER WAS ENCOUNTERED DURING THE SAMPLING OF ANCHORAGES HV 016 AND HV 038 AND COVER V-21. PARTICULATE DEBRIS AND ZINC FLAKES WERE ALSO FOUND IN THE SAMPLES FROM COVER V-17 AND ANCHORAGE HV 016. THE WATER FROM COVER V-21 HAD A PH OF 8.3 AND CONTAINED 150 PPM CL, 250 PPM SO4, 290 PPM NA, 15 PPM K AND 460 PPM CA. THERE CAN BE NO DOUBT THAT THE POST TENSIONING SYSTEM OF THE FARLEY UNIT NO. 2 IS CONTAMINATED WITH WATER.

NOTE THAT INLAND USED A DIFFERENT EXTRACTION METHOD FOR THE WATER EXTRACTABLE ION ANALYSIS OF THE GREASE. INLAND USED A BULK EXTRACTION METHOD AND INYRCO'S PROCEDURE SPECIFIES A SURFACE EXTRACTION METHOD WHICH COULD NOT BE RUN ON A TIMELY BASIS AT INLAND. THE BULK METHOD, WHICH WOULD BE EXPECTED TO RESULT IN HIGHER LEVELS OF IONS, MAY BE MORE REPRESENTATIVE OF THE RESPECTIVE GREASE SAMPLE.

APPENDIX C, ATTACHED, IS A COPY OF THE GREASE ANALYSES OF VARIOUS GREASE SAMPLES AS OBTAINED BY SUBURBAN LABORATORIES, INC., OF HILLSIDE, ILLINOIS. SAMPLES WERE SENT TO SUBURBAN WHEN IT WAS DETERMINED THAT INLAND COULD NOT CONFORM TO INYRCO'S SPECIFIED TEST METHODS FOR THE GREASE ANALYSES ON A TIMELY BASIS.

INLAND RECEIVED AND FORWARDED TO SUBURBAN SAMPLES S/L 1537-1541 WITHOUT ANY ANALYSES BEING DONE AT INLAND. SAMPLES S/L 1542-1546 WERE ANALYZED BY INLAND AND ARE COVERED IN INLAND REPORT DATED 2/12/85. INLAND SAMPLED, BUT DID NOT ANALYZE, SAMPLES S/L 1547-1555 FROM COVER V-21. INLAND RETAINED AND ANALYZED LAYERS #2 AND #5 FROM COVER V-21, WHICH ARE COVERED IN INLAND REPORT DATED 02/26/85 ALONG WITH SAMPLE S/L 1556 (HV 038).

IN ADDITION, A WATER SAMPLE OBTAINED FROM COVER V-21 WAS SENT TO SUBURBAN FOR ANALYSES, HOWEVER, IS NOT INCLUDED IN THE ATTACHED REPORT.

COMMENTS ON THE ANALYSES COVERED IN THE ATTACHED SUBURBAN REPORT SHOULD BE SOLICITED FROM SUBURBAN LABORATORIES, INC.

CONCLUSIONS

FOLLOWING ARE THE CONCLUSIONS BASED ON THE FAILURE ANALYSES OF ANCHOR HEADS HV 016 AND HV 038 AND THE METALLURGICAL EVALUATION OF THESE ANCHORAGES ALONG WITH ANCHORAGES HV 027, HV 028, HV 039 AND HV 049. THE CONCLUSIONS ARE ALSO BASED ON OBSERVATIONS AND CHEMICAL EVALUATIONS OF GREASE SAMPLES OBTAINED FROM GREASE COVERS FROM THE BOTTOM END OF TENDONS V-17 AND V-21 WHICH COVERED ANCHORAGES HV 016 AND HV 038, RESPECTIVELY. ALSO EXAMINED WAS THE GALVANIZED GREASE COVER FROM V-21 (HV 038). IN ADDITION, INFORMATION ON THE ON-SITE CONDITIONS AND PHOTOGRAPHS OF THE ON-SITE CONDITIONS WERE CONSIDERED.

1. THE FAILURE OF ANCHORAGES HV 016 AND HV 038 WAS DUE TO THE IN-SERVICE PARTIAL EMBRITTLEMENT OF THE ANCHORAGES AS INDICATED BY THE PRESENCE OF SIGNIFICANT AMOUNTS OF INTERGRANULAR SEPARATION (IGS) ON THE FRACTURE FACES. WE HAVE CONCLUDED THAT THE EMBRITTLING SPECIES IS HYDROGEN, WHICH RESULTS IN HYDROGEN STRESS CRACKING (HSC). THE IGS WAS MOST PRONOUNCED IN THE ANCHORAGE CENTRAL HONEYCOMB AREA AND EXPOSED AREAS OF THE ANCHORAGE BEARING AND BUTTONHEAD FACES.

2. THE MAJOR SOURCE OF THE HYDROGEN WAS THE PRESENCE OF WATER IN CONTACT OR ADJACENT TO THE ANCHOR HEADS WITHIN THE GREASE COVERS. ATOMIC OR NACENT HYDROGEN WAS GENERATED BY THE CORROSION REACTIONS OF IRON AND ZINC IN THE PRESENCE OF WATER. SAMPLES OF GREASE FROM BOTH V-17 AND V-21 WERE CONTAMINATED WITH WATER. THE FAILURES WOULD NOT HAVE OCCURRED WITHOUT THE PRESENCE OF THE WATER.

3. THE WATER PRESENT IN THE GREASE COVERS IS HEAVILY CONTAMINATED WITH CATIONS AND ANIONS. WE CONCLUDE THIS WATER IS PRESENT BECAUSE OF ENVIRONMENTAL CONDITIONS.

4. THE TENDON HOLES OF THE ANCHORAGES SHOWED VARYING DEGREES OF CORROSION PITTING INDICATING THAT ACTIVE GENERAL CORROSION WAS OCCURRING WITHIN THE ANCHORAGES.

5. THE INNER SURFACES OF THE GREASE COVER, WHICH ARE ZINC COATED ALSO SHOWED AN "ETCHED" CONDITION INDICATING ACTIVE CORROSION AND ZINC-RICH PARTICLES WERE FOUND IN THE GREASE SAMPLES FROM V-17.

6. ANCHOR HEAD HV 039, WHICH WAS DETENSIONED, MAGNETIC PARTICLE INSPECTED, LOAD TESTED AT THE UNIVERSITY OF ILLINOIS AND RE-MAGNETIC PARTICLE INSPECTED WAS FOUND TO BE CRACKED ON DETENSIONING AND FURTHER CRACKED ON LOAD TESTING. THE CRACKS ON DETENSIONING WERE PREDOMINANTLY IGS, WHILE THE CRACKS ON LOAD TESTING WERE A COMBINATION OF CLEAVAGE AND DUCTILE FRACTURE MODES. THIS INDICATES THAT THE EMBRITTLING SPECIES WAS PRESENT DURING THE FORMATION OF THE IN-SERVICE CRACKS AND WAS NOT DURING THE FORMATION OF THE LOAD TESTING CRACKS. ANCHORAGE HV 039 HAD INITIATED AN IN-SERVICE FAILURE AND, IN TIME, WOULD HAVE FAILED.

7. OTHER POSSIBLE SOURCES OF THE IGS HAVE BEEN ELIMINATED BY THE COMBINATION OF SCANNING ELECTRON MICROSCOPY (SEM) AND MECHANICAL TESTING OF THE ANCHORAGES. NONE OF THE LABORATORY-CREATED FRACTURES (TENSILE SPECIMENS AND IMPACT SPECIMENS) SHOWED ANY IGS. THE IN-SERVICE FRACTURES WERE RELATIVELY CLEAN AND SHOWED NO EVIDENCE OF OXIDE OR IDENTIFIABLE CORROSION PRODUCTS.

ADDITIONAL CONCLUSIONS

THE SUBMITTED ANCHORAGES HAD HARDNESSES WHICH WERE WITHIN THE SPECIFICATION. THE SUBMITTED ANCHORAGES HAD STRENGTH LEVELS WHICH WERE HIGHER BUT DUCTILITIES WHICH WERE WITHIN THE RANGE OF DATA THAT WAS FOUND ON PREVIOUSLY TESTED ALUMINUM GRAIN REFINED FIELD ANCHOR HEADS. THE HIGHER STRENGTH LEVELS WOULD RESULT IN A GREATER SUSCEPTIBILITY TO HSC AND IGS. THESE HIGHER STRENGTH LEVELS ALONE WOULD NOT HAVE RESULTED IN THE SUBJECT FAILURES.

THE ANCHOR HEAD SAMPLES MET THE CHEMICAL REQUIREMENTS OF THE ASTM AND INRYCO SPECIFICATIONS AND ALL RESIDUAL ELEMENTS WERE AT ACCEPTABLE LEVELS.

THE MICROSTRUCTURES AND MICROCLEANLINESS OF THE SUBMITTED SAMPLES WERE AS EXPECTED FOR THE STEEL GRADE AND CONDITION.

THE RETEMPERED ANCHORAGES INDICATED THAT THE HEADS WERE HEAT TREATED AS SPECIFIED.

RECOMMENDATIONS

1. ELIMINATION OF WATER IN THE POST TENSIONING SYSTEM IS ESSENTIAL FOR THE ELIMINATION OF THE RECURRENCE OF SIMILAR FAILURES. THE AMOUNT OF WATER THAT CAN BE TOLERATED CAN NOT BE DETERMINED WITH ANY CERTAINTY.

2. IF THE WATER CAN NOT BE ELIMINATED, THEN THE ANCHORAGES SHOULD BE INSPECTED AT SOME INCREASED FREQUENCY TO INSURE AGAINST FAILURES AND THE COLLECTION OF EXCESSIVE AMOUNTS OF WATER WITHIN THE SYSTEM. THE VERTICAL TENDONS, DUE TO THEIR ORIENTATION, SHOULD BE SUSPECT AND THOROUGHLY EXAMINED FOR THE PRESENCE OF WATER. HOWEVER, THIS DOES NOT PRECLUDE INSPECTION OF THE HOOP OR DOME TENDONS.

3. BASED ON CURRENT VISUAL INSPECTION PROCEDURES, IT IS NOT POSSIBLE TO DETERMINE IF AN ANCHORAGE IS CRACKED IN THE CENTER AREA OF THE HONEYCOMB ON THE SHIM SIDE OF THE ANCHORAGE. DETENSIONING AND MAGNETIC PARTICLE INSPECTION ARE NECESSARY TO DETERMINE IF CRACKING SUCH AS THAT NOTED ON ANCHORAGE HV 039 IS PRESENT.

4. WE RECOMMEND LOWERING THE STRENGTH LEVELS OF THE ANCHORAGES IF POSSIBLE WITHIN THE SCOPE OF THE ORIGINAL DESIGN. WHILE THIS WILL REDUCE THE SUSCEPTIBILITY OF THE ANCHORAGE TO HYDROGEN STRESS CRACKING (HSC), IT DOES NOT PRECLUDE THE OCCURRENCE OF HSC. DETERMINATION OF THE OPTIMUM STRENGTH LEVELS IS OUTSIDE THE SCOPE OF THIS INVESTIGATION.

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* THE ABOVE REFERENCES ARE NOT FOOTNOTED IN THE REPORT.

DEB:RLB
ATTACHMENTS
PHOTOGRAPHS