February 12, 1985

Docket Nos. 50-348
and 50-364

LICENSEE: Alabama Power Company (APCo)

FACILITY: Joseph M. Farley Nuclear Plant, Units 1 and 2

SUBJECT: SUMMARY OF MEETING HELD ON FEBRUARY 7, 1985, BETWEEN NRC AND APCo REPRESENTATIVES TO DISCUSS APCo's ACTION PLAN RELATING TO FAILURE OF A CONTAINMENT TENDON FIELD ANCHOR AT FARLEY UNIT 2

INTRODUCTION

The NRC Project Manager (E. Reeves) reviewed the purpose of the meeting as a presentation by APCo representatives to the NRC staff of background information, laboratory analyses to date, and the action plant underway following failure of one containment tendon field anchor at Farley Unit 2. On January 25, 1985, a containment vertical tendon (V17) was found to have abnormalities as evidenced during visual inspection in preparation for conducting the containment 5-year integrated leak rate test (ILRT) required by Technical Specifications and 10 CFR 50 Appendix J. Further examinations determined the following: (1) The bottom tendon field anchor head had broken into pieces, (2) Many of the 170 tendon wires were severed at the head, (3) A small portion of the honey-comb section of the field anchor head was still intact and in the funnel area, and (4) The upper end shop anchor head had left an impression on the upper plate of the grease cap which was leaking grease.

Pieces of the broken field anchor were sent to Inland Steel and to Battelle Laboratory for analysis. Analyses are also being preformed on the shim and on the grease used in the specific installation.

APCo presented a briefing of the event as well as actions taken and being taken at the time. Personnel from Bechtel, the containment designer, and INRYCO (an Inland Steel Company) also provided portions of the discussions. The briefing index, list of attendees present, and copy of viewgraphs presented are enclosed.

DISCUSSION AND CONCLUSION

APCo (R. McDonald) initiated the briefing and advised that the APCo team has taken extreme care after the event was noted to assure continued containment integrity and personnel safety. Farley Unit 2 is in the latter stages of the third refueling outage (RO) which started January 5, 1984. Teams of personnel are at Farley site now, procedures have been prepared, reviewed, and approved for detensioning of all tendons with anchor heads of the heat number (HV) 6061524 that failed. A second field anchor (V21) with the same heat number contains a crack. Partial detensioning of V21 has been accomplished at this time in an attempt to remove the field anchor for tests.

Bechtel (G. Thomas) described the containment design using viewgraphs, Enclosure 3 pages 1-8. The containment post tensioning system consists of a total of 357 tendons (134 hoop, 130 vertical, 93 dome) designed to prestress the conreter to create an effective negative pressure on the containment equal to at least 1.2 times accident pressure at the end of 40 years. The loss of a vertical tendon such as occurred would impose less than ± 22 psi stress change in the concrete out of approximately 1500 psi design stress.

APCo (D. Mansfield) described the post tensioning system, installation history, the surveillance history to date, and the problem identification and status, using viewgraphs, Enclosure 4 pages 1-2 and Enclosure 5. Tendon installation began in September 1976 and was complete in June 1977. Structural integrity test (SIT) was completed May 30, 1980. The first ILRT was completed on June 8, 1980. Subsequent visual surveillances were conducted during April and May 1981, and during June and July 1983 as required by Technical Specifications. Photographs were shown describing the "as-found" condition of field anchor, V17, which had failed (see Enclosure 5).

INRYCO (H. Presswalla) presented the original field anchor design and manufacturing specifications, original testing, history of the Byron Unit 1 and Bellefonte nuclear plant problems as reviewed by INRYCO, and the current design and manufacturing specifications. Viewgraphs, Enclosure 6 pages 1-26 were used. INRYCO's evaluation shows that the Byron and Bellefonte failure causes were unique to each plant. The material chemistry of the vanadium bearing material of the Byron 1 anchor (see Enclosure 6 page 16 and 17) and possible inadequate installation of the support mortar under the bearing plates (see Enclosure 6 page 24) at Bellefonte were causal factors. INRYCO's preliminary analysis indicates that neither the Byron nor Bellefonte failures are directly applicable at Farley 2. Further investigation and evaluation is underway at this time.

INRYCO (G. Henger) presented photos of the preliminary laboratory analysis underway at Inland Steel laboratories. These photographs will be part of the final analysis report. In addition, viewgraph Enclosure 7 page 1 was used to show a comparison of the HV anchor ladle analysis with current ASTM A-322 chemical requirements. Metallurgical properties of field anchor HV16 is shown in Enclosure 7 page 2.

APCo (G. Hairston) presented viewgraphs of Enclosure 8 pages 1-4 describing the program which includes detensioning all tendons (49) with HV heat code material for inspection and replacement with new anchors. Also 55 other tendons with non-HV type material will be inspected to establish a 95 percent probability with a 95 percent confidence level that no problems exist in these tendons. INRYCO will accomplish these activities using seven hydraulic rams and six work platforms. Dedicated APCo managers are to oversee this program.

SUMMARY

The NRC staff thanked APCo management for the detailed discussion and program as planned. Inspection and Enforcement Notice (IEN 85-10 dated February 6, 1985) which relates to the Farley 2, Byron 1 and Bellefonte plant problems was made available to APCo. APCo was advised that Region 2 has transferred technical responsibility to NRR because of the potential generic effects. The NRR Project Manager is the designated contact.

Edward A. Reeves, Project Manager
Operating Reactors Branch #1
Division of Licensing

ORB#1:DL
EReeves;ps
2/12/85

ENCLOSURE 1

NRC MEETING ATTENDANCE

DATE: FEBRUARY 7, 1985 PLACE: MNBB 6110

SUBJECT: FARLEY 2 - CONTAINMENT TENDON ANCHOR HEAD FAILURE

APCO PERSONNEL

W. G. Hairston - Mgr. NETS
R. P. McDonald - VP. Sr.
D. E. Mansfield - Super't - NETS

BECHTEL

Kenneth Y. Lee
Kanti Gandhi
Eugene Thomas
Gary Schmidt

NRC PERSONNEL

Ed Reeves, Project Manager ORB#1
F. S. Cantrell, Reg II
B. R. Crowley, Reg II
C. D. Sellers, MTEB
R. E. Shewmaker, IE
Gunter Arndt, RES
Alex Dromerick, IE
Jerry Carter, ORAB
S. Varga, BC-ORB#1
G. Lainas, AD-OR:DL
G. Lear, BC-SGEB:DE
E. Merschoff
S. Schwartz, IE
P. T. Kuo, SGEB:DE
C. P. Tan, SGEB:DE

OTHERS

G. W. Henger, Inland Steel
R. W. Lawler, INRYCO
H. H. Presswalla, INRYCO
R. Hough, INRYCO

ENCLOSURE 2

NRC BRIEFING FARLEY UNIT 2
CONTAINMENT TENDON PROBLEM

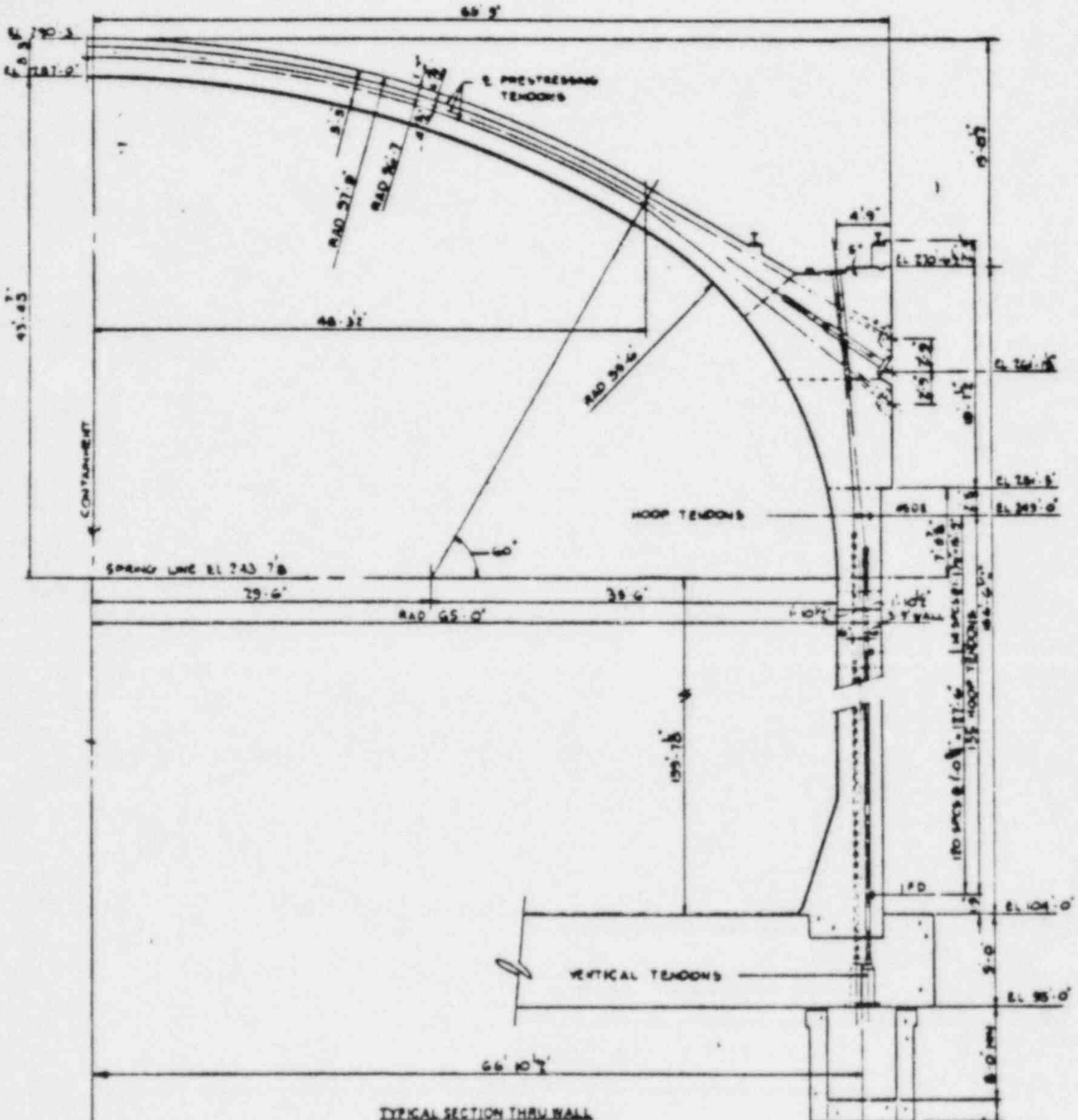
Maryland National Bank
7735 Old Georgetown Road
Bethesda, MD
Room 6110

Opening Remarks	R. P. McDonald	5 minutes
General Containment Design	Bechtel (G. THOMAS)	5 minutes
Post Tensioning System Installation History and Surveillance History	D. E. Mansfield	5 minutes
Identification of Problem and Current Problem Status	D. E. Mansfield	5 minutes
Original Field Anchor Design and Manufacturing Specifications including Original Design Testing	INRYCO (H. PRESSWALLA)	5 minutes
Field Anchor Head History (Byron and Bellefonte Problem Review)	INRYCO (H. PRESSWALLA)	5 minutes
Current Design and Manufacturing Specifications	INRYCO (H. PRESSWALLA)	5 minutes
Lab Analysis of FNP Field Anchors to Date	INRYCO (G. HENGER)	10 minutes
FNP Inspection and Repair Program	W.G. Hairston	10 minutes
Open Discussion	ALL	----

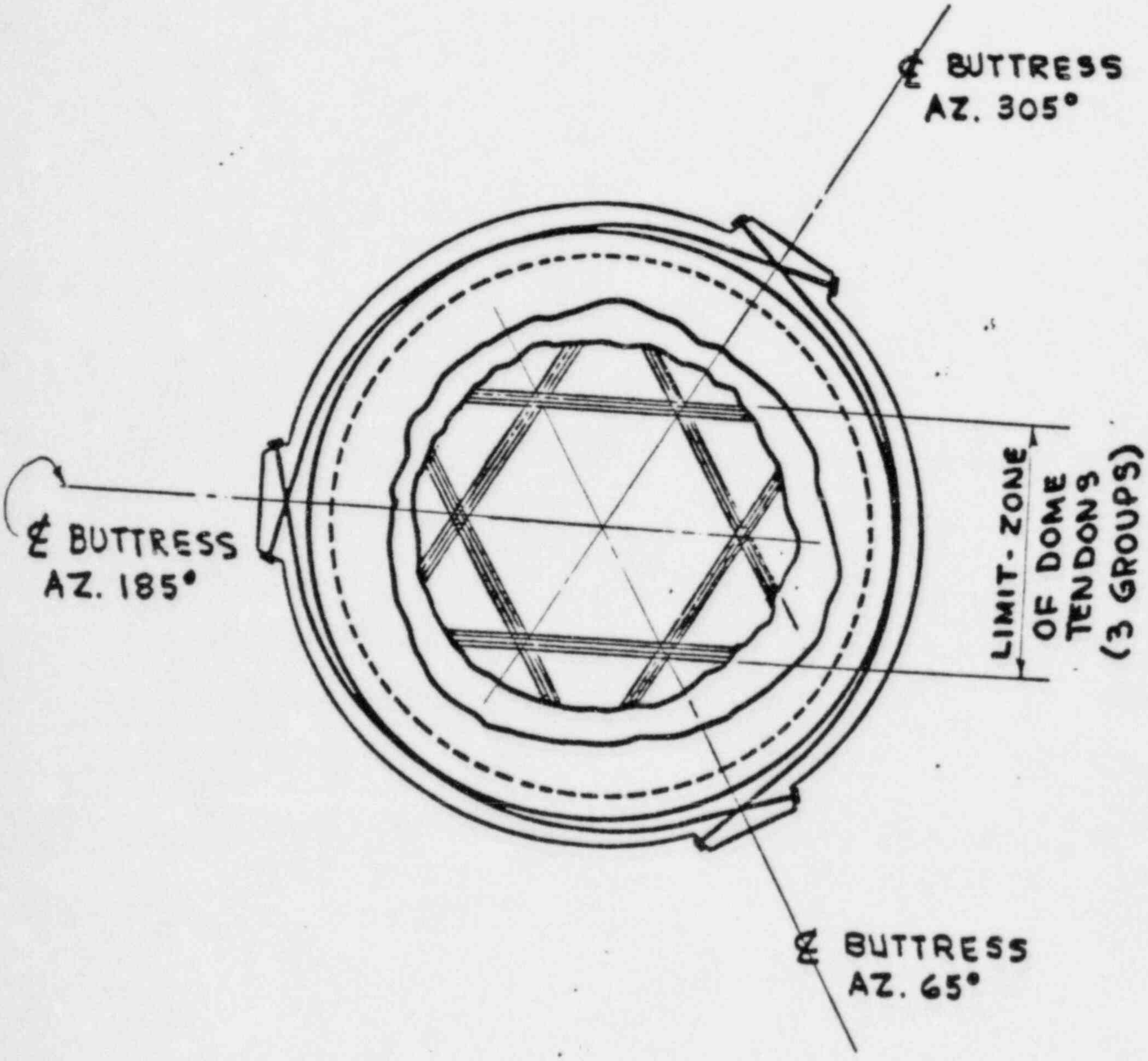
ENCLOSURE 3

GENERAL CONTAINMENT DESIGN

BECHTEL PRESENTATION



TYPICAL SECTION THRU WALL AND DOME



DOME & HOOP TENDONS

JOSEPH M. FARLEY
NUCLEAR PLANT
UNIT 1 AND UNIT 2

POST TENSIONING SYSTEM

o THREE MAIN GROUPS

134 HOOP } SHELL
130 VERTICAL }
93 DOME
357 TOTAL

o PURPOSE IS TO PRELOAD CONTAINMENT TO COUNTERACT THE EFFECT OF DESIGN ACCIDENT PRESSURE (Pa=54 PSIG)

- PRESTRESS CREATES AN EFFECTIVE NEGATIVE PRESSURE ON THE CONTAINMENT EQUAL TO (AT LEAST) 1.2 x Pa

  - CREATES COMPRESSION STRESS OF APPROXIMATELY 1500 PSI

- PRESSURIZATION DUE TO LOCA UNLOADS THE CONCRETE

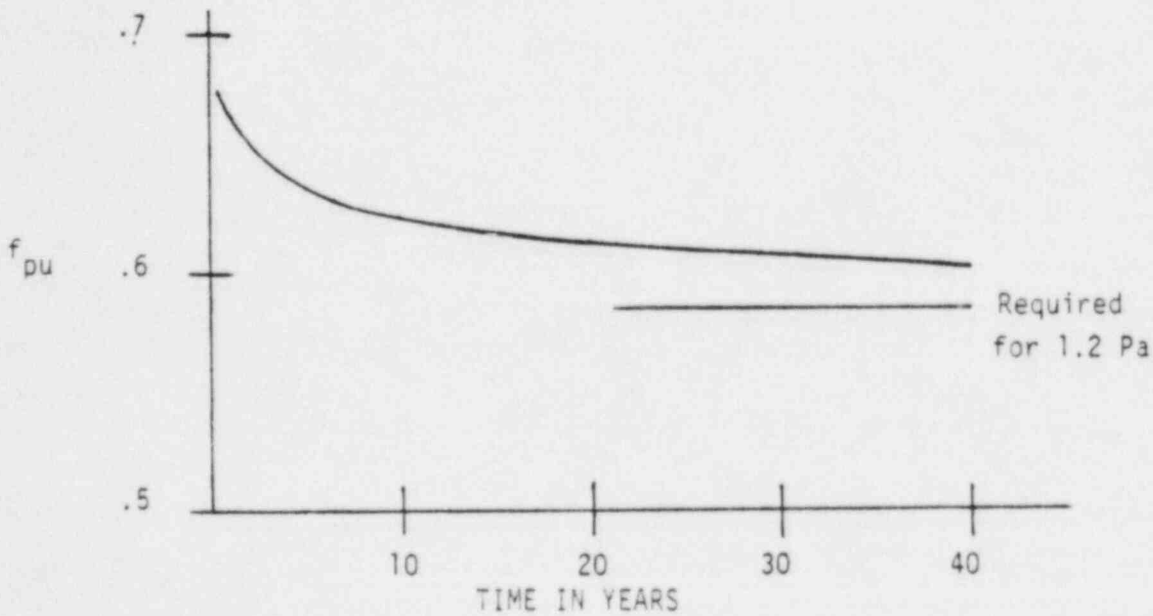
- CONTAINMENT IS DESIGNED TO WITHSTAND 1.5 x Pa AND REMAIN ELASTIC

OTHER FEATURES

- TENDONS INITIALLY "LOCKED OFF" AT APPROXIMATELY 0.7 x GUARANTEED ULTIMATE STRENGTH OF WIRE (f_{pu})

- CONCRETE CREEP AND WIRE RELAXATION CAUSES TENDON TO LOSE FORCE WITH TIME

- ACCOUNTING FOR THESE LOSSES, TENDON FORCE AT END OF 40 YEARS EXCEEDS DESIGN REQUIREMENT OF 1.2 x Pa



- THREE ADDITIONAL TENDONS ARE PROVIDED IN EACH GROUP (BUT NOT INCLUDED AS DESIGN REQUIREMENT) FOR SURVEILLANCE PURPOSES

LOSS OF TENSION - EFFECT ON CONTAINMENT

- LOSS OF TENDON UNLOADS CONCRETE

- PRELIMINARY ESTIMATE INDICATES SUDDEN LOSS OF VERTICAL TENDON IMPOSES LESS THAN ± 22 PSI STRESS CHANGE IN CONCRETE

DESTRESSING SEQUENCE

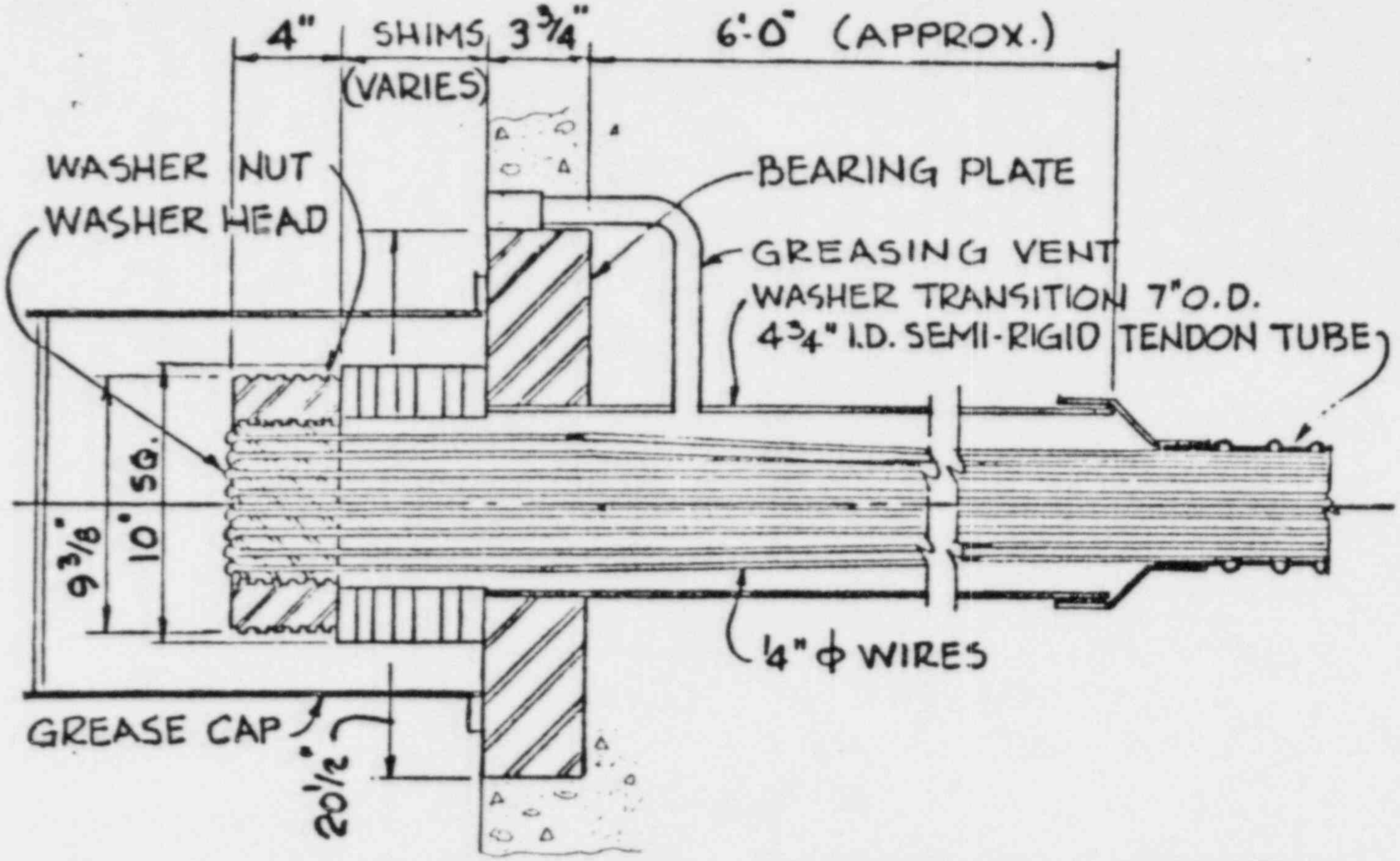
- CRITERIA WAS ESTABLISHED TO ASSURE CONTAINMENT WOULD NOT EXPERIENCE SEVERE LOAD CHANGES.

  - NO MORE THAN SEVEN TENDONS TO BE DETENSIONED AT ONE TIME (APPROXIMATELY 2% OF TOTAL)

  - NO MORE THAN THREE TENDONS (FOUR VERTICAL TENDONS) TO BE DETENSIONED AT ONE TIME IN ANY ONE GROUP (APPROXIMATELY 3% OF TOTAL IN ANY ONE GROUP)

  - EMPHASIS PLACED ON MAINTAINING REASONABLE LOADING SYMMETRY WITHIN ANY GROUP

  - NO MORE THAN TWO TENDONS BETWEEN THE SAME TWO BUTTRESSES (HOOP) OR IN SAME DOME SUBGROUP ARE DETENSIONED AT ONE TIME, AND THEN ONLY IF THEY ARE SEPARATED BY AT LEAST THREE TENSIONED TENDONS.



FARLEY 170 WIRE PRESTRESS SYSTEM

NOTE: SHOP END SHOWN.
ON FIELD END WASHER HEAD AND NUT ARE AN INTEGRAL PART.

ENCLOSURE 4

UNIT II POST TENSIONING SYSTEM
INSTALLATION AND SURVEILLANCE
HISTORY

INSTALLATION HISTORY:

1.	TENDON PLACEMENT	09/09/76 THRU 04/25/77
2.	BUTTON HEADING	10/04/76 THRU 04/28/77
3.	STRESSING	11/15/76 THRU 06/20/77
4.	GREASING	01/08/77 THRU 06/25/77

SURVEILLANCE HISTORY:

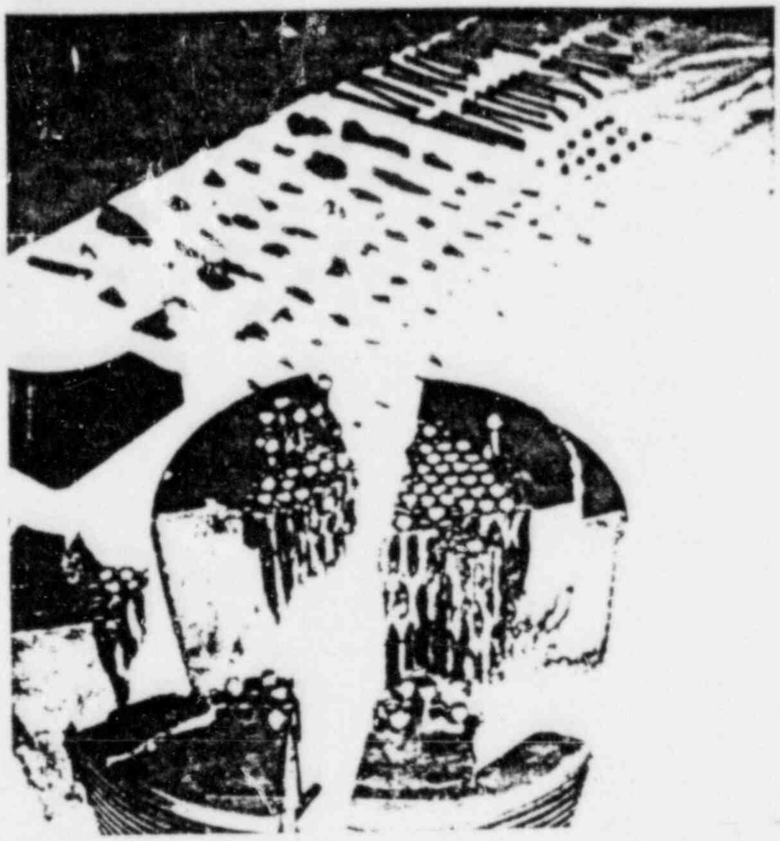
1.	S.I.T.	05/27/80 THRU 05/30/80
2.	PRE-OP ILRT	06/03/80 THRU 06/08/80
3.	ONE YEAR SURVEILLANCE (VISUAL INSPECTION OF 25 TENDONS)	04/22/81 THRU 05/21/81
4.	THREE YEAR SURVEILLANCE (VISUAL INSPECTION OF 21 TENDONS)	06/01/83 THRU 07/14/83

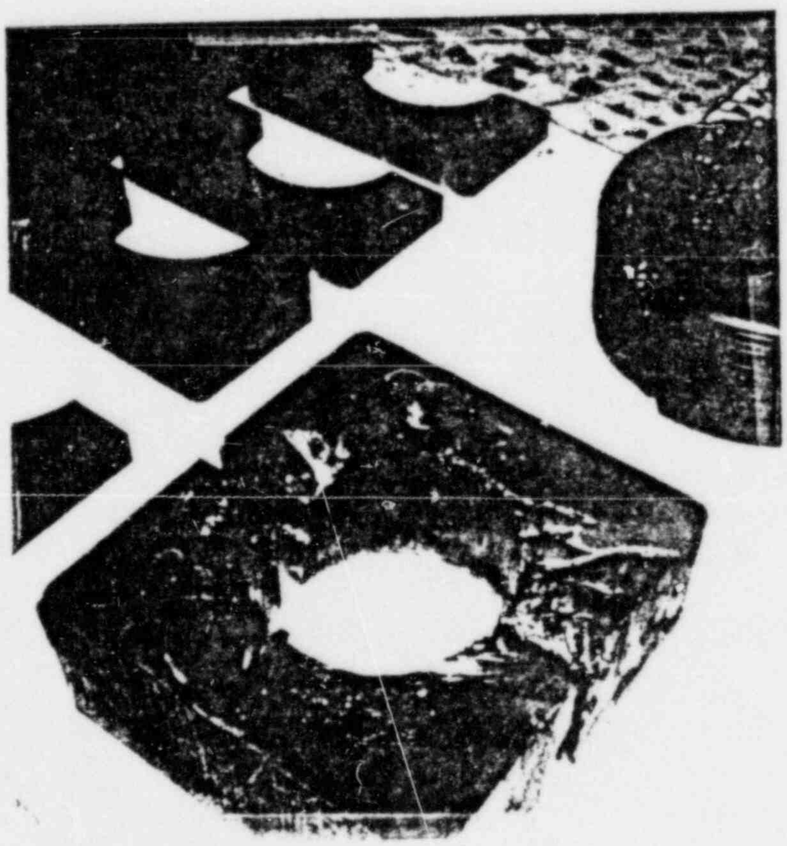
Indication of Problem and Current Problem Status

On Friday, January 25 of this year, while doing routine visual inspections of the containment as a part of the preparations for the ILRT, the grease can for the upper end of vertical tendon V17 was found to have a buldge in the end-cap and grease around the mounting base of the end-cap. Further examination determined the following. 1) The bottom tendon field anchor head had broken. 2) Many of the wires of the tendon were severed at the head. 3) A small portion of the honey-comb section of the head was still intact at the tendon and was located in the funnel area. 4) The upper head had left an impression on the upper plate of the grease end-cap.

Appropriate personnel were assembled for an on-site meeting to discuss this problem and determine an action plan. This plan consisted of sending the broken anchor pieces to Inland and Battelle for chemical and physical analysis as well as sending the 4 inch shim to a lab in Birmingham for physical analysis. The grease from around the lower head was sent to Law and Company for chemical analysis. Parallel with these activities, a program was initiated to examine other field anchor heads and their associate shim stacks. Shortly after initiating the field portion of this plan, V21 a vertical tendon of the same heat number as V17, was found to contain a crack.

To date, after modifying the action plan, V21 has been partially detentioned from the shop anchor end. The anchor is now cracked through but still held in position. Once this tendon is completely detentioned, the head will be sent to Inland lab and similarly analyzed to that of V17.





ENCLOSURE 6

INRYCO PRESENTATION

CONDITION	AUTHORITY	FACTOR × P'_{im}	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}).

PERFORMANCE CRITERIA

ASME : atleast 100 % GUTS
atleast 2 % ELONGATION

INRYCO : Anchorage Strength Tendon Strength = 2002.8 Kips
P = (x - 3)(Fy/Fu) 2002.8 Kips
Try for prelim:
P = 1.5 x 2002.8 = 3004.2 Kips

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	172	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	[illegible]	[illegible]

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.

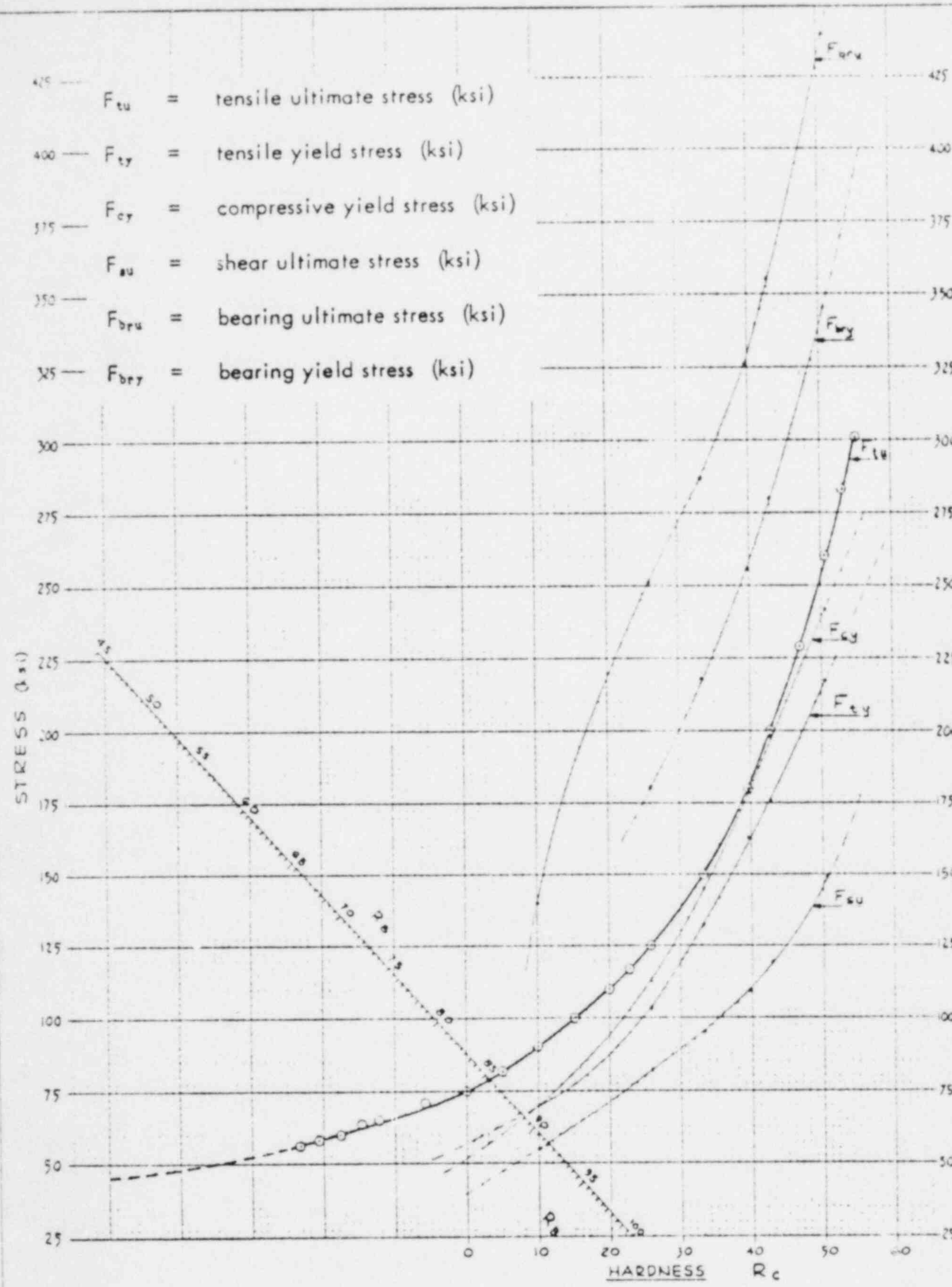


FIG. 3.2-6 Mechanical properties vs. hardness. The curve for tensile ultimate (F_{tu}), showing UTS plotted against Rockwell Hardness (R_B or R_C) is derived from information contained in the 1965 SEA Handbook, pages 107 and 109. Curves designated F_{bru}, F_{bry}, F_{cy}, F_{ty} and F_{su} show other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

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

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

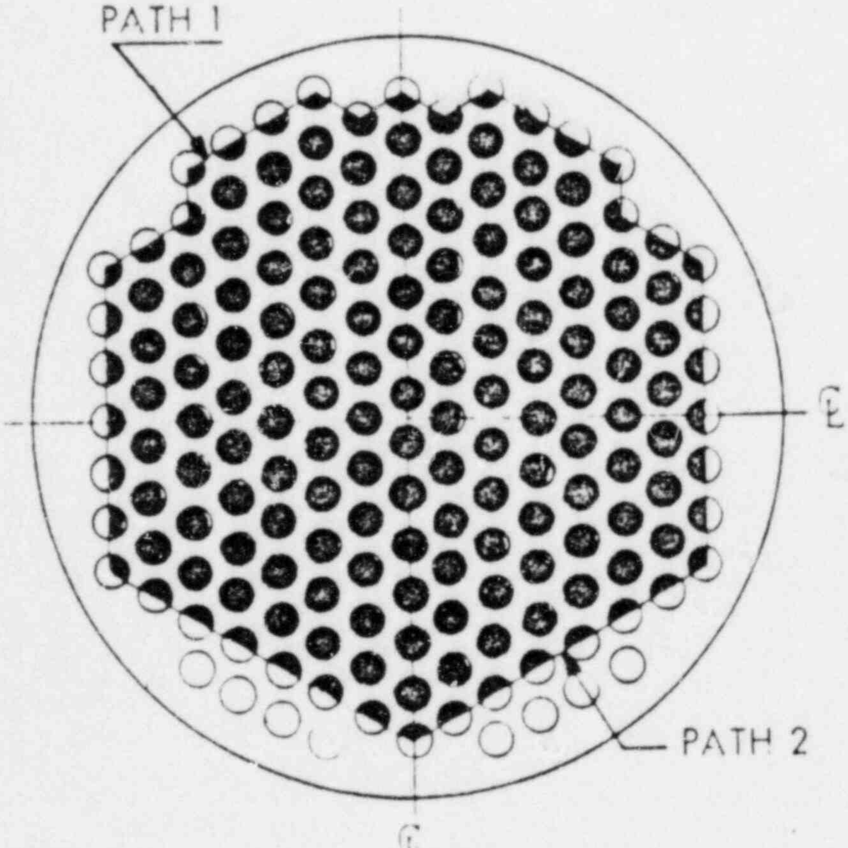


FIG. 3.2.8: Alternate shear paths for wire hole web shear failure with Path 1 shown above horizontal ℄ and Path 2 below. Path 2 is slightly more critical than Path 1.

3.3.11 SUMMARY CONCLUSIONS (TESTING)

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).

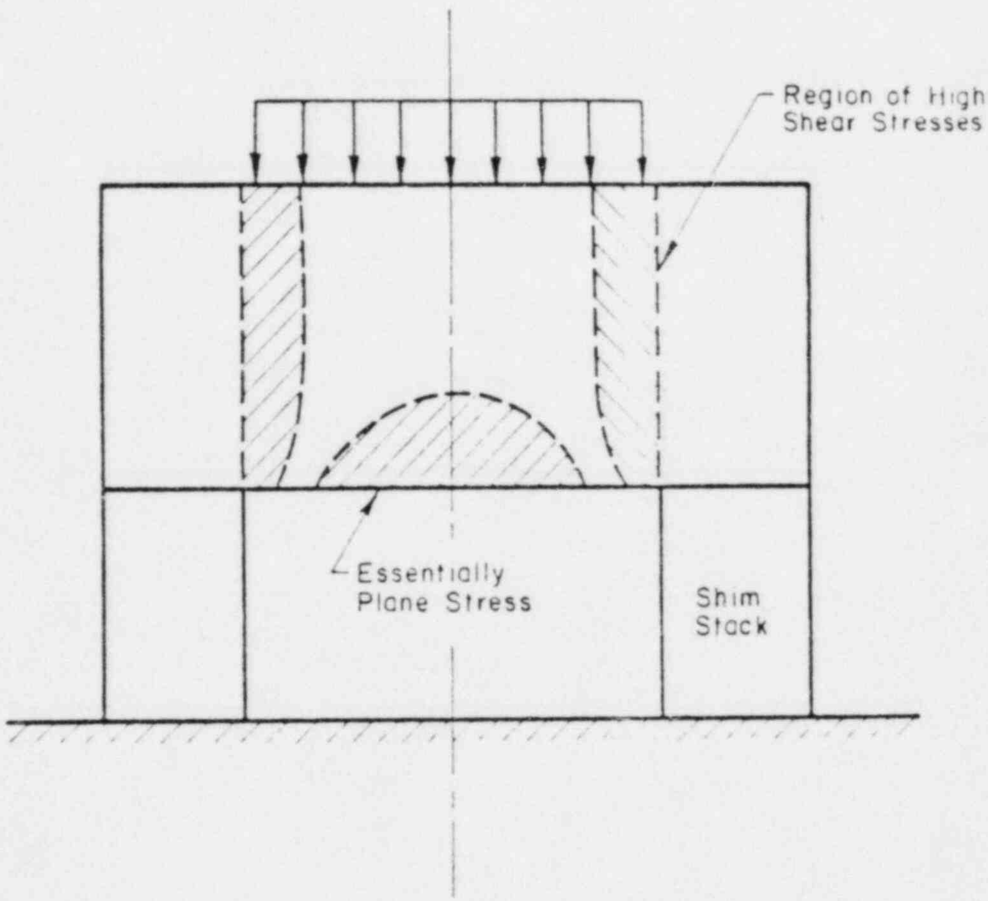


Fig. 6 Load Carrying Mechanisms of Anchor Head (Schematic)

ANALYSIS PROCEDURE

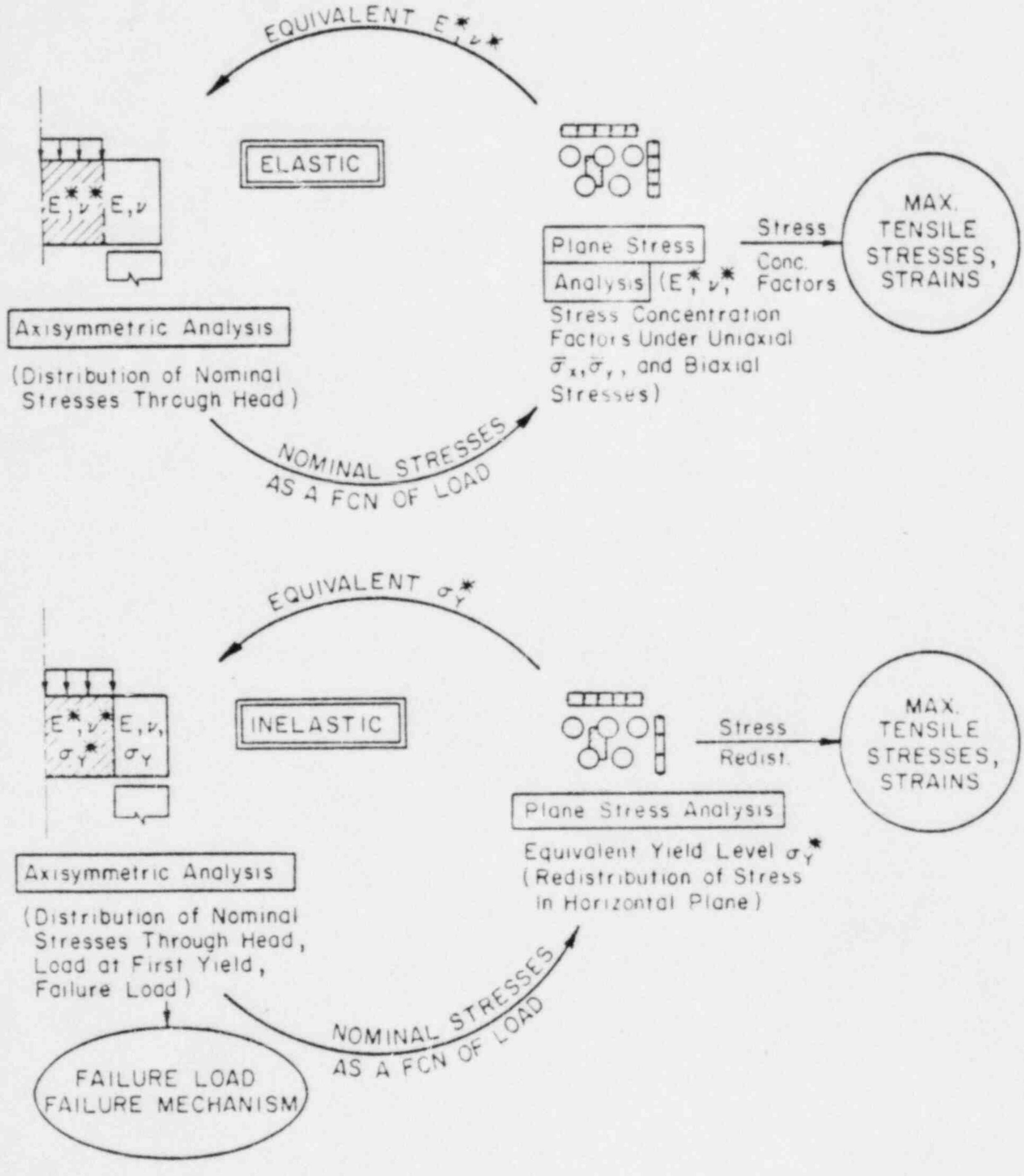


Fig. 7 Analysis Procedure Showing Interactive Use of Ligament and Axisymmetric Models

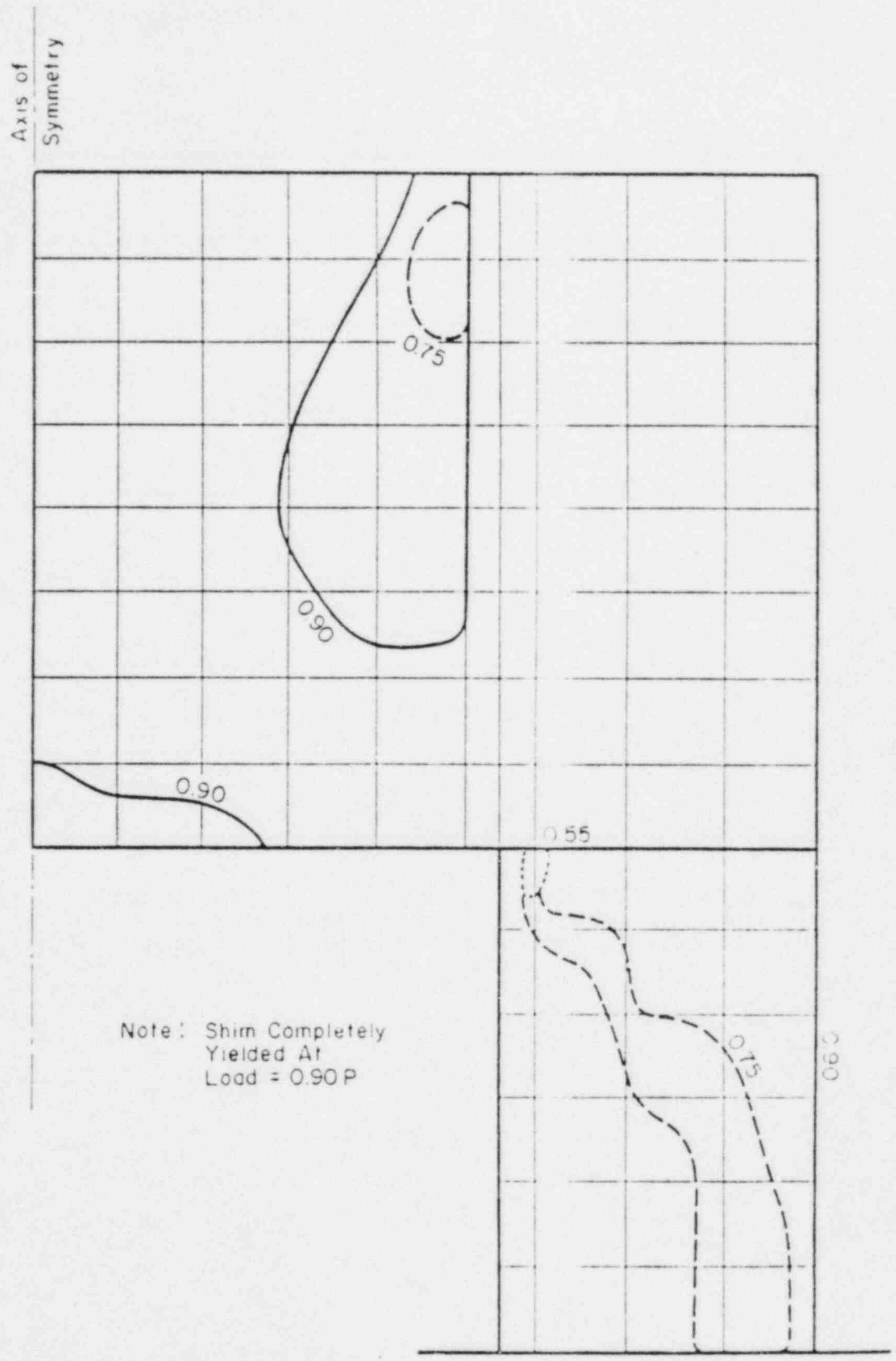


Fig. 48 Development of Yield Zones in Field Head ("Inelastic Shims/No Friction" Boundary Conditions and Effective Yield Stress 51 ksi in Flexural Region, 52.5 ksi in Shear Region of Honeycomb, 36 ksi in Shims)

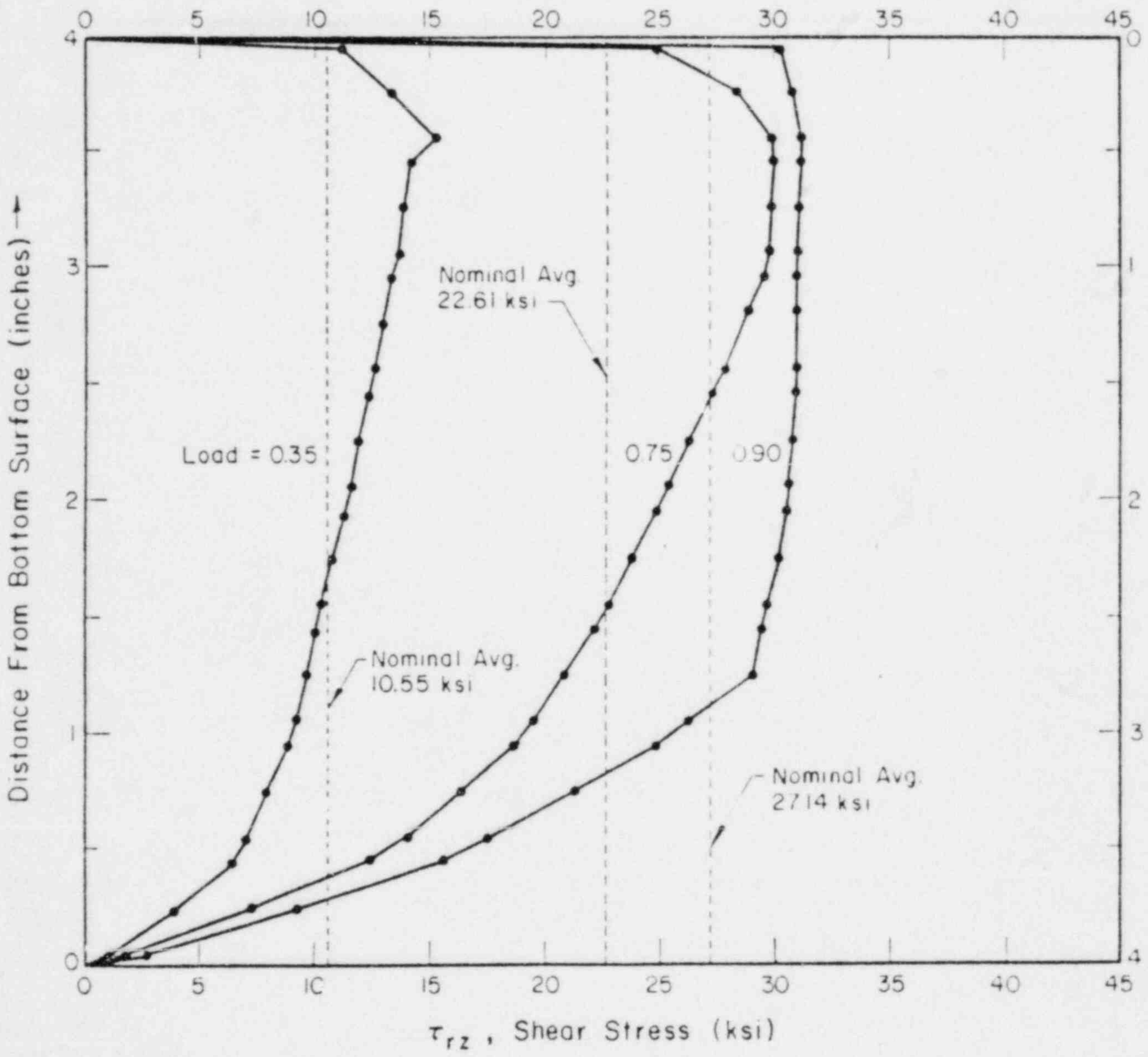


Fig. 45 Inelastic Distribution of Transverse Shear Stress at Edge of Honeycomb vs Applied Load (Field Head with "Inelastic Shims/No Friction" Boundary Conditions and Effective Yield Stress 51 ksi in Flexural Region, 52.5 ksi in Shear Region of Honeycomb, 36 ksi in Shim)

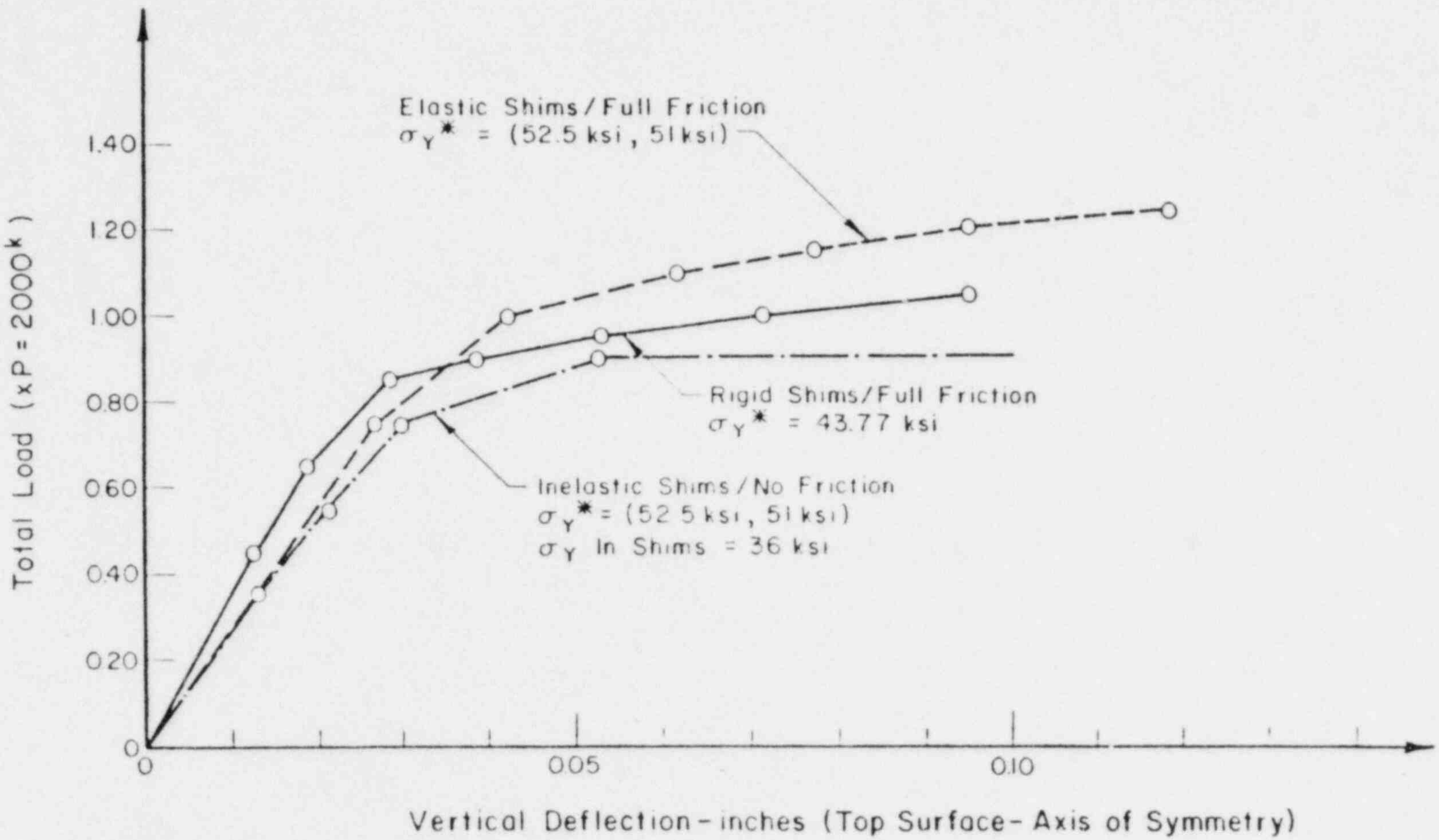


Fig. -9 Inelastic Load-Deflection Response of Anchor Head

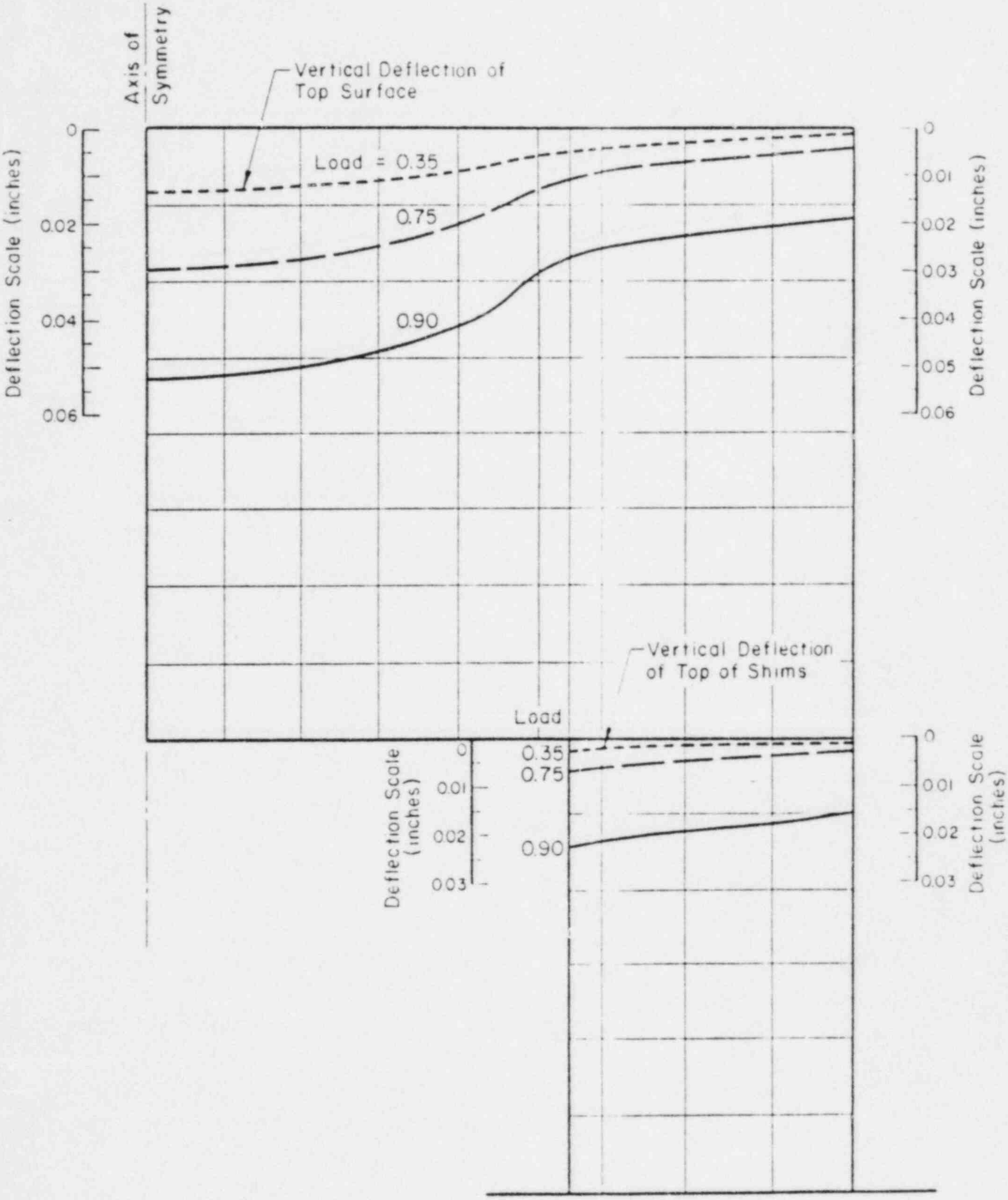


Fig. 51 Inelastic Deflection Profile Across Top Surface of Field Head vs Applied Load ("Inelastic Shims/No Friction" Boundary Conditions and Effective Yield Stress 51 ksi in Flexural Region, 52.5 ksi in Shear Region of Honeycomb, 36 ksi in Shim)

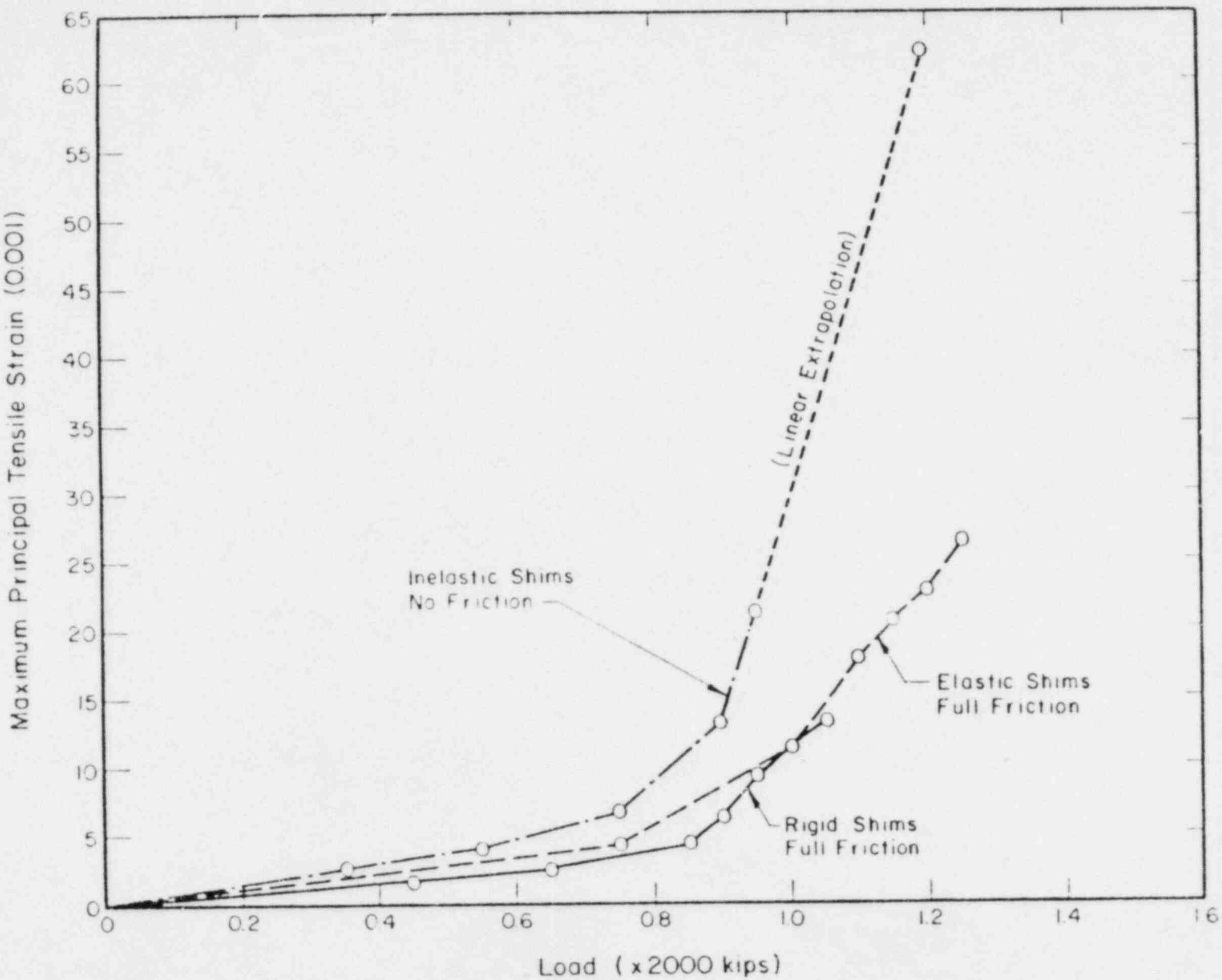


Fig. 63 Maximum Principal Tensile Strain in Ligament vs Applied Load

INRYCO, Inc.
Post Tensioning Division
1560 North 25th Avenue, Box 1056
Melrose Park, Illinois 60161

312 379 9600

Inryco

ATTENTION:

SUBJECT: SUMMARY REPORT OF ANCHORHEAD FAILURES AT BYRON UNIT I

Gentlemen:

I. Introduction

In late November, 1979, four field anchorheads failed in the subject containment structure between 1 and 64 days. All failures were from two heats, both from material supplied by one specific vendor. On May 30, 1980, Inryco completed its study to explain the cause of this unique failure, to evaluate the likelihood of a similar failure on other past and present projects and to make recommendations to preclude the likelihood of a repetition of such a failure on present and future projects using material ordered to new specifications.

II. Objective

The objective of this report is to summarize the findings of Inryco's study.

III. Discussion

The heads failed in a flexure mode, one that was not the predicted failure mode as identified by the designer of the system.[1] The predicted failure mode is web shear, wherein the honeycombed core

Punches out of the solid ring, the failure path following approximately centerline of the outer ring of holes.

The following is the outline of Inryco's action plan to determine the cause of the problem:

A) A Stress Analysis of the anchorhead using a finite element analysis with inelastic capabilities was performed. This would:

1) Verify the ultimate load capacity of the anchorhead as obtained by load tests.

2) Yield information of total strain required at rupture to result in a desired failure load.

3) Explain the flexural mode of failure.

4) Provide details of the stresses and state of stress within the anchorhead so design modifications could be made if necessary.

B) Load Tests were performed using a 3 million pound universal testing machine of randomly selected samples of heads from different mill heats and heat treat lots. Load and support conditions were duplicated from actual field conditions as closely as possible. The load tests would:

1) Give the actual strength of the heads from different heat treat lots.

2) Incorporate the effects of flaws such as non-metallic inclusions, etc. that are present in the actual head, and which cannot be considered by the stress analysis.

3) Verify the validity of the assumptions used in the stress analysis.

C) After load testing, the heads were metallurgically evaluated at the Inland Steel Co. The following analyses were performed:

1) Visual examinations of the head for obvious anamolies; dye penetrant or magnetic particle testing to observe hairline cracks.

2) Fractorgraphic Examination of the fracture surfaces using low and high power microscopes. Selected areas were also examined using the SEM to identify failure mode: ductile, brittle (cleavage or intergranular), etc.

3) Chemical Analysis of the alloying elements as well as trace elements to determine effects of residuals and to check compliance with AISI 4140/42 requirements.

4) Determination of mechanical properties such as hardness tensile and yield strength, total elongation, reduction of area, elastic ratio and Charpy V notch impact properties - both in longitudinal and transverse directions. Low transverse properties, especially RA and Charpy values, would indicate dirty steels and/or poor heat treatment. Low transverse to longitudinal ratios would indicate dirty steels.

5) Metallographic Examination to evaluate the microstructure and micro cleanliness.

6) Auger Analysis was performed to determine the chemical composition of the grain boundary elements and explain grain boundary embrittlement.

7) Fracture toughness values were determined of various heats to study the toughness of the heat treated steel and compare the failed heats with the ones that did not fail. RA was found to be as good an indicator, and no fracture toughness tests were conducted.

8) Time-delay in the field failures was investigated. Fatigue, stress corrosion cracking, hydrogen embrittlement and a decreasing stress field can all create time delays and they were investigated.

IV. Conclusions

A) The failures of the anchorheads at Byron Unit I are a result of insufficient tempering temperatures for the particular (unique) chemistry of the vanaduim bearing material. The material exhibits a comparable response to tempering temperatures as other materials but at a higher temperature. Thus, to achieve the same degree of strength and ductility as other materials, the material should be tempered to higher temperatures.

B) The upward shift of the temper response also could have resulted in an upward shift of the 500F embrittlement range. Normally this range occurs at 400-700F[2]. For the subject material, this could well have shifted up to the 800F or 900F value, resulting in Intergranular Separation in the steel.

C) It was verified that the heat-treatment records supplied to Inryco by the heat-treaters were accurately depicting the actual temperatures inside the mass of the steel. Records are based on furnace temperatures monitored by a certified thermostat.

D) It was verified that the steel (4140/42) is <u>not</u> susceptible to temper embrittlement.[2] This was done by extreme slow cooling through the critical range (700F - 1070F) without affecting the properties.

E) High levels of clustered inclusions found in the failed material, coupled with its low RA (ductility) contributed to the failures. High stress concentrations arise at the tips of these inclusions. If sufficient ductility is not present to blunt the tip of the crack by allowing the material to yield locally, a brittle failure can occur.

F) None of the other vendors' material will undergo this type of failure as the tempering temperature (900F) is appropriate for all other material.

G) The design of the anchorhead[1] was not at fault and should not be modified.

IV. <u>Recommendations</u>

Not all the material supplied by the failed material vendor is sensitive to the embrittlement. Thus a large number of samples from each of the vendor's heat were tested to isolate the bad heats. All such heats were removed from the affected projects.

Past projects were not supplied with this vendor's material and are not affected. Some heads were available for testing from past projects and were shown to have far superior properties.

Future material to be used on present as well as future projects will be ordered to strict cleanliness tolerances. The material will be aluminum killed. Phosphorous and sulfur will be controlled to .015 max. Tin will be limited to .020 max. Inclusion shape control will be provided by the addition of calcium or cerium. The material will otherwise conform to hot finished, AISI grade 4140, vacuum degassed round seamless bars or tubings, made by the electric furnace method.

Samples of the heat will be provided to Inryco for testing prior to heat treatment so that an intelligent determination of the tempering temperature could be made.

Hoshang H Presswalla

Hoshang H. Presswalla, P.E., S.E.
Manager, of Engineering & Development
Inryco, Inc.
Post Tensioning Division

References

1. WCS Technical Report Number 8, Western Concrete Structures Interim Report: Chapter 3, January, 1968.

2. ASM Metals Handbook, 9th Edition, Vol. 1.

Bellefonte (TVA) Rock anchor Failures
April 12, 1976

ABSTRACT

An examination has been conducted on three Type 4140 rock anchor heads that cracked shortly after installation at the TVA Bellefonte Nuclear Plant. The anchor heads were immersed in lime water at pH 11 to 11.5. Chemical analyses revealed the heat to be close to specifications. Tests revealed a hardness of R_c 43 to 47 (slightly above the specified R_c 42), and a low room-temperature Charpy impact value of 6 ft-lb in the plane of the fracture. SEM and metallographic examination revealed that the failures initiated as intergranular cracks on the ID surface of tendon holes and propagated semiductility. Inclusion counts were low and probably did not contribute to crack propagation although they may have played a role in crack initiation by providing trench-like pitting sites. The results suggest that stress-corrosion cracks (SCC) initiated in the lime-water environment and after attaining a critical size caused the remainder of the anchor head to crack under plane strain conditions. No sulfides or other hydrogen-entry promoters were found which could have contributed to rapid SCC failure. However, there were medications that some zinc-filled coating was applied to the cans that contained the lime water. These cans were galvanically coupled to the heads and probably contributed to SCC by promoting hydrogen entry into the heads. Additional on-site studies appear to be needed to ensure that the failure occurred as postulated and that additional failures will not occur in the rest of the construction phase or during subsequent plant operation.

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Conclusions as to Cause of Failure

1. Introduction

The investigation into the possible causes for the failure of anchor heads JA89 and JA81 has been conducted in the following three different areas:

a. Investigation of the anchor head material.

b. Investigation of stresses in the anchor head.

c. Investigation of outside influences which caused conditions different and beyond the design parameters of the anchor head.

2. Investigation of Anchor Head Material

Extensive investigations have been made of the material of anchor head JA89. Investigations of JA81 are still under way, but preliminary results indicate a close relation to the findings of JA89. The tests were made by the following organizations:

a. Combustion Engineering (for TVA)

b. Inland Steel (who is not the supplier of the base material)

c. Kawin Laboratories

d. Magnetic Inspection Laboratory Inc.

All these investigations indicate that the steel quality is as specified and as to be expected. The degree of cleanliness could have been better, but it is not outside of tolerance. Tensile test specimens indicate adequate strength as related to the hardness of the material and the prototype test.

Heat treatment has been found to be adequate, and the possibility of existing quench cracks has been investigated and discarded.

2. Investigation of Anchor Head Material - Continued

Charpy V notch impact tests both in the longitudinal and transverse directions at temperatures from -80°F to +212°F indicate behavior as expected for the material in question (see Aerospace Structural Metals Handbook, Revision March, 1963, Code 1203 Page 1; Metals Handbook Volume 1, Page 231; Structural Alloys Handbook, Pages 14 and 15).

In conclusion , the material in question is of sufficient quality to meet design and specifications requirements.

3. Investigation of Stresses in the Anchor Head

170 wire prototype anchor head design and test information have been submitted to TVA together with the bid proposal. The anchor head used for the rock anchors is slightly modified from the prototype, featuring a 1.4 inch center hole for passage of the grout pipe. The wires anchored in the center portion in the prototype head were relocated to the periphery of the wire bundle in the rock anchor head. The anchorage is the same as was used on the Ocoee Dam Project, a TVA contract carried out in 1974 - 1975.

Due to the complexity of the system, instead of trying to approximate the stress field with an analytical model, direct strain measurements on the anchor head under load were conducted. These tests were carried out at Inryco's test facility. The instrumentation of the anchorages and strain measurements, as well as witnessing the tests, were performed by an outside laboratory, namely Wiss, Janney, Elstner & Associates of Northbrook, Illinois.

Data reduction of measurements for different support conditions yielded the following results:

a. Anchor head under normal bearing conditions on shims, supported on an annulus around the entire perimeter of the anchor head. Maximum principal stress next to the large center hole, at 70% of GUTS = 100 KSI.

b. Anchor head held in a coupling engaged thru the outside thread of the anchor head. Maximum principal stress next to the large center hole at 70% of GUTS [illegible] KSI.

3. Investigation of Stresses in the Anchor Head - Continued

The material heat treated to a Rockwell hardness of RC 42 ± 2 has the following physical properties:

Ultimate tensile strength:	190 KSI
Yield strength:	170 KSI

These stress measurements indicate that under service loads the anchorage performs well within the material strength limits, and should not cause premature failure as experienced on heads JA89 and JA81.

4. Investigation of Outside Influences

Measurements taken of the bearing plate of rock anchor in hole #147 (anchor head JA81) when the failure was discovered, revealed a substantial amount of deformation (dishing) of the bearing plate.

The deformation (curvature) was larger in direction perpendicular to the shim joint than parallel to the joint. Also it was noted that some rotation of the two half shim stacks had taken place, following the deflection of the bearing plate.

Upon removal of the bearing plate and examination of the supporting mortar, for both failed anchorages, it was discovered that the mortar was of such quality that it could not support the pressure imposed by the bearing plate. Examination results of the grout by Dr. L. Copeland of Wiss, Janney, Elstner & Associates are given in the letter Report WJE No. 75582 dated January 8, 1976, enclosed in Section 6 of the Documentation.

The lack of support, and in particular the time dependent creeping of the mortar bed allowed the bearing plate to deflect over time beyond the elastic deformation at the time of stressing. This time dependent deformation, and rotation of the two half shim stacks, changed the bearing condition of the anchor head from condition (a) described in the previous section to a bridging over the shims and only a two-sided support. This change in support condition causes a different stress pattern to develop, where at 70% of GUTS, the principal stresses next to the large center hole exceed 200 KSI.

4. Investigation of Outside Influences - Continued

Such mechanism would cause a crack to form above the shim joint, which was observed in both cases. Cracks in other radial directions would form after the initial break occurred, due to the loading conditions prevailing in the fragments.

A test has been conducted attempting to simulate the above by resting the instrumented anchor head on two parallel diametrically opposed T1 shims. The measured stress level at 70% of GUTS force (principal stress) next to the large center hole was 206.2 KSI. The fact that the bearing plate deformation increased with time provides an explanation for the delayed failure - rather than during the stressing operation when the maximum force is applied to the tendon.

5. Summary

From all the investigations and tests conducted relative to the anchor head failures (JA89 and JA81) it is Inryco's conclusion that the only identifiable cause of the failures is the lack of adequate supporting strength of the mortar under the bearing plates.

Stress measurements conducted on the anchor head indicate that the stress levels under normal bearing conditions and at load levels actually obtained during stressing and at lock-off will not produce failure of the anchor head. The quality of the anchor head material is adequate and has no detectable influence on the anchor head failure.

No conclusions have been drawn on the possible influence of shock waves from nearby blasting could have on the anchor head failures.

Tennessee Valley Authority
Bellefonte Nuclear Plant
Contract 75C53-85380

Proposed Course of Action for Anchors Installed

Preliminary Installation Procedure for Heat Shrunk Couplers on Tendon Anchor Heads

1. Field measure all anchor head threads.

   a. Remove protective covers.

   b. Clean up anchor head threads.

   c. Field measure all anchor heads recording measurements for later determination of coupler thread sizes.

   d. Replace protective covers.

2. Fabricate couplers.

   a. From field measurements determine size of coupler threads required.

   b. Fabricate two or three sizes of close thread tolerance couplers and mark to match drawing made from field measurement of anchor head threads.

   c. Ship couplers to TVA inside storage warehouse.

3. Install couplers.

   a. Load over and bring coupler to heat.

   b. Remove appropriate grease cans according to drawing, tendon marks and coupler size.

   c. Chase threads of anchor head with ring gauge.

3. Install couplers - continued.

   d. When recorder indicates proper heat, remove coupler, place in insulated cart and transport to tendon.

   e. Install heated coupler on anchor heads.

   f. Replace protective covers.

   g. Fill with treated water (allow coupler to cool 4 hours prior to filling can with treated water).

4. Proceed with second stage grouting according to specifications.

LADLE ANALYSIS AND ASTM CHEMICAL REQUIREMENTS

Description	C	Mn	P	S	Si	Cu	Ni	Mo	Cr	Al	O_2 N	O_2 (ppm)
→ Ladle, Heat 6061524 (HV)	.44	.96	.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. Identical to INRYCO Specification 1649 dated July 15, 1972, with the exception of the carbon range of .40/.45% on the INRYCO spec.

ENCLOSURE 7

METALLURGICAL PROPERTIES OF FIELD ANCHOR HEAD HV 016

C	Mn	P	S	Si	Cu	Ni	Mo	Cr	As	Cb	V	Ti	Al	N	O2	Sn	Sb
.43	.97	.014	.028	.24	.10	.13	.22	1.10	.016	-.008	.01	.004	.018	.008	58 PPM	.01	.008

Microanalysis:

Cleanliness (J-K Rating)	A-34H, B2H
Carbide Morphology	Temper Martensite

Macroanalysis: Sound

Hardness: 444-429 BHN, 45-47 HRC

Tensile Properties:

Sample	Gauge (In)	Yield Strength (KSI)	Tensile Strength (KSI)	Total Elong. (% in 2 in.)	% Reduction In Area
Trans.	.503	163.6	201.3	11.0	18.6
Trans.	.498	168.2	198.5	8.0	13.9
Long.	.498	174.6	206.2	13.0	35.9
Long.	.499	169.2	200.2	13.0	35.5

Impact Properties:

	Room Temperature		212^{o} F	
	Long	Trans	Long	Trans
Ft-Lbs	12	6	20	8
% Brtl	95%	95%	90-95%	95%
Ft-Lbs	13	8	20	10
% Brtl	95%	95%	90-95%	95%

APCO PROGRAM   ENCLOSURE 3

The present phase for the FNP Unit 2 containment tensioning system inspection and repair program consists of the following activities:

(1) Detension all tendons with **HV** heat code field anchors (49).

(2) Remove all **HV** heat code field anchors and replace with new anchors.

(3) Retension all **HV** tendons.

(4) Inspect a sufficient quantity of non-**HV** heat code field anchors to establish a 95% probability with a 95% confidence level that no further problems exist.

(5) Continue analysis of failed components to provide assurance that corrective actions being taken correct the cause of failure.

To accomplish these activities in a timely manner, APCo has contracted with Inryco (the tensioning system supplier and installer) to provide equipment, procedures, supervision and Quality Control. Current plans call for utilization of seven hydraulic rams and six work platforms to maneuver the rams up and down the containment wall. Equipment and technical manpower are being assembled from numerous locations. With the delay of the Callaway Surveillance Program, Inryco equipment and manpower dedicated to Callaway have been diverted to Farley. Other equipment is being refurbished and calibrated in Inryco's home shop. The site currently has two work platforms that are normally used for tendon surveillance. The remaining four platforms needed were procured from Braidwood Nuclear Plant. These four platforms will require complete refurbishment and checkout prior to being placed in service again. Depending upon their actual condition, this may take five to ten days after they arrive at FNP (currently scheduled for 2/8/85). As additional work platforms are placed in service, rams and other equipment will be available for use. Meanwhile, the program will continue at a reduced pace with the two FNP platforms.

This program is being scheduled on Project II Computer Scheduling System. Dedicated managers and engineers have been appointed to oversee this program.

(1) DETENSION ALL TENDONS WITH HV HEAT CODE FIELD ANCHORS (49).

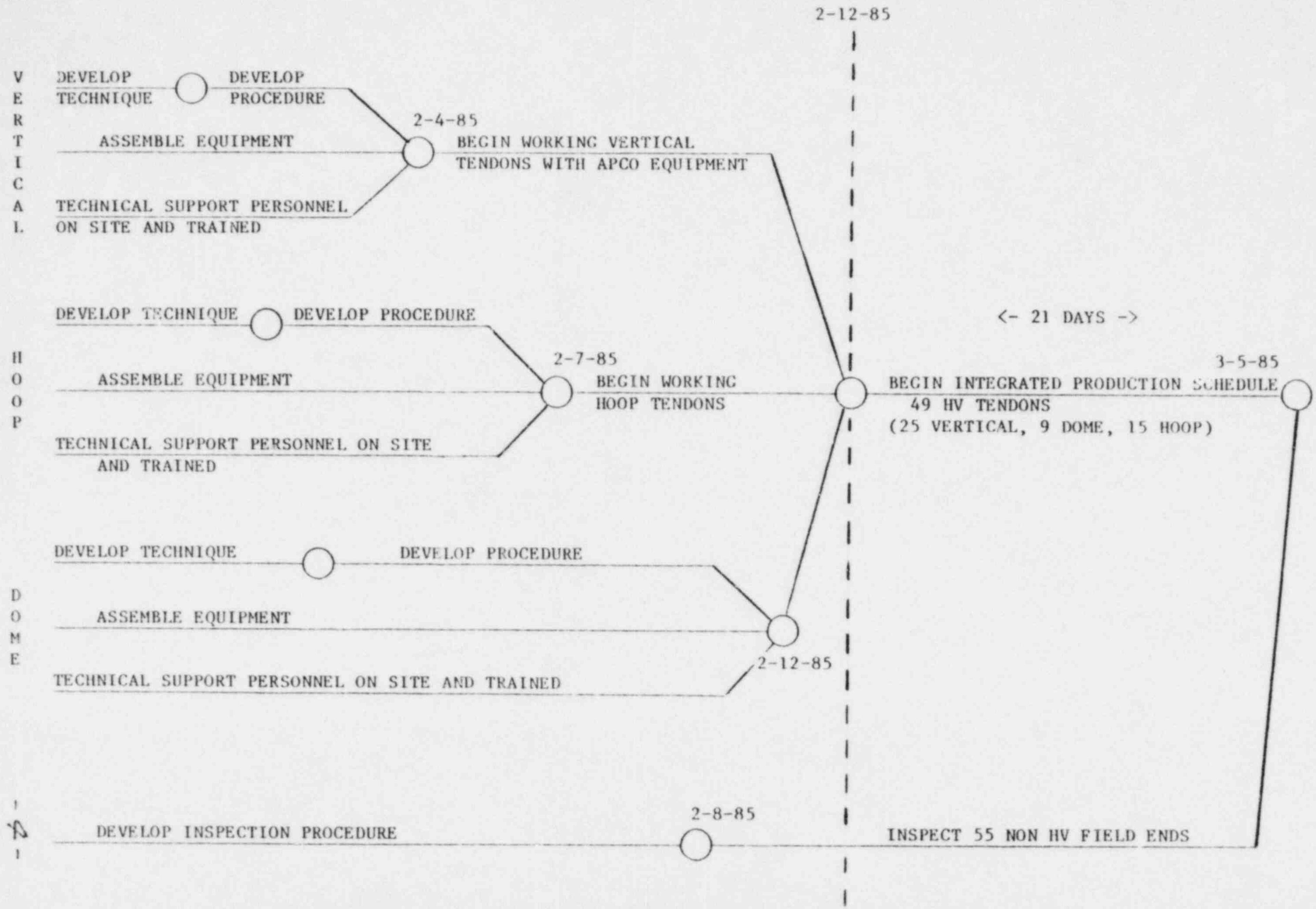
(2) REMOVE ALL HV HEAT CODE FIELD ANCHORS AND REPLACE WITH NEW ANCHORS.

(3) RETENSION ALL HV TENDONS.

(4) INSPECT A SUFFICIENT QUANTITY OF NON-HV HEAT CODE FIELD ANCHORS TO ESTABLISH A 95% PROBABILITY WITH A 95% CONFIDENCE LEVEL THAT NO FURTHER PROBLEMS EXIST.

(5) CONTINUE ANALYSIS OF FAILED COMPONENTS TO PROVIDE ASSURANCE THAT CORRECTIVE ACTIONS BEING TAKEN CORRECT THE CAUSE OF FAILURE.

UNIT II - TENDON WORK SCHEDULE



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