INLAND STEEL COMPANY
OPERATING TECHNOLOGY DEPARTMENT

# INRYCO POST TENSIONING DIVISION
# JOSEPH M. FARLEY NUCLEAR PLANT
# ANCHOR HEAD INVESTIGATION

METALLURGICAL LABORATORY INVESTIGATION NO. 20617

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TABLE OF CONTENTS

## INTRODUCTION

THE JOSEPH M. FARLEY NUCLEAR PLANT - DOTHAN, ALABAMA, FOUND INDICATIONS OF CRACKING IN FIELD ANCHOR HEADS FN 025 AND FE 059. THE INDICATIONS WERE DISCOVERED THROUGH MAGNETIC PARTICLE INSPECTION BY ALABAMA POWER COMPANY (APCO) DURING AN ONGOING INSPECTION OF ALL ANCHOR HEADS. ANCHOR HEAD FN 025 REVEALED A NETWORK OF CRACKS IN A RADIAL OR DIAGONAL DIRECTION THROUGH THE HONEYCOMB WEB AREA ON THE BOTTOM (SHIM) FACE. CONVERSELY, ANCHOR HEAD FE 059 SHOWED ONE SMALL INDICATION BETWEEN TWO WIRE HOLES NEAR THE CENTER OF THE HONEYCOMB WEB ON THE TOP (BUTTONHEAD) FACE, AN ATYPICAL FRACTURE LOCATION.

ON JULY 9, 1985, BOTH ANCHOR HEADS WERE RECEIVED AT INLAND METALLURGICAL LABORATORY TO DETERMINE THE PROBABLE CAUSE OF CRACKING AND FOR TESTING AND METALLURGICAL EVALUATION. IN ADDITION, EIGHT OTHER ANCHOR HEADS, HV 036, HP 014, HU 019, FE 026, FL 049, FN 097, FK 016, AND FM 028, WHICH WERE DETENSIONED AND REMOVED FROM THE CONTAINMENT VESSEL, WERE ALSO RECEIVED. THE EIGHT SELECTED ANCHOR HEADS REPRESENT DIFFERENT HEATS AND WERE SUBMITTED FOR TESTING AND METALLURGICAL EVALUATION ONLY. ALL EIGHT ANCHOR HEADS WERE MAGNETIC PARTICLE INSPECTED BY APCO AFTER DETENSIONING AND NO INDICATIONS WERE NOTED. ONE ADDITIONAL ANCHOR HEAD, TFD 24, WHICH WAS FROM THE LOT USED FOR REPLACEMENTS, WAS ALSO TESTED.

ALL OF THE SUBMITTED ANCHOR HEADS WERE OF THE FIELD ANCHOR TYPE AND WITH THE EXCEPTION OF ANCHOR HEAD TFD 24, ALL WERE IN SERVICE APPROXIMATELY EIGHT TO TEN YEARS. REPORTEDLY, THE ANCHOR HEADS WERE FROM VERTICAL WALL TENDONS LOCATED IN THE GALLERY OF THE BASE OF BOTH CONTAINMENT VESSELS, UNITS NO.1 AND NO.2. THE EXACT LOCATION OF EACH ANCHOR HEAD WITHIN THE VESSELS WAS NOT PROVIDED.

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 O 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. NOMINALLY, THERE ARE 358 TENDONS IN EACH OF THE CONTAINMENT STRUCTURES (UNITS NO.1 AND NO.2) OF WHICH 130 ARE VERTICAL, 135 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 ANCHOR HEADS WERE REPORTEDLY PRODUCED FROM STEEL PURCHASED BY WESTERN CONCRETE FROM E. M. JORGENSON, WHO PURCHASED IT FROM REPUBLIC STEEL COMPANY. 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 ANALYSES OF ANCHOR HEADS FN 025 AND FE 059 TO DETERMINE THE PROBABLE CAUSE OF CRACKING AND THE METALLURGICAL EVALUATION OF THESE ANCHORAGES ALONG WITH ANCHORAGES HV 036, HP 014, HU 019, FE 026, FL 049, FN 097, FK 016, FM 028 AND TFD 24. PRIOR INLAND STEEL INVESTIGATIONS COVERING ANCHORAGE FAILURES ARE INVESTIGATIONS NO. 06775 AND 19975 DATED MAY 28, 1980 AND MARCH 27, 1985, RESPECTIVELY.

## TESTING PROCEDURES

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

1. EACH SAMPLE WAS DEGREASED WITH STODDART'S SOLVENT AND/OR TRICHLOROETHYLENE.

2. VISUAL EXAMINATION AND NONDESTRUCTIVE TESTING (LIQUID DYE PENETRANT) WERE PERFORMED, IN THE DEGREASED CONDITION, ON ALL SUBMITTED ANCHOR HEADS.

3. SCANNING ELECTRON MICROSCOPE (SEM) FRACTOGRAPHY WAS PERFORMED ON ALL FRACTURE FACES OF ANCHOR HEAD FN 025 AFTER THE HEAD WAS SECTIONED TO A SUITABLE SIZE. IN ADDITION, ALL OF THE TRANSVERSE TENSILE SPECIMEN FRACTURE FACES AND SELECTED CHARPY V-NOTCH IMPACT SPECIMEN FRACTURE FACES WERE EXAMINED FOR FRACTURE MODES, I.E., DUCTILE, BRITTLE (CLEAVAGE), SHEAR OR INTERGRANULAR SEPARATION (IGS).

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

5. MECHANICAL PROPERTIES INCLUDED THE FOLLOWING:

   A. BRINELL HARDNESSES WERE OBTAINED ON THE RING SURFACE AND BRINELL AND ROCKWELL (HRC) HARDNESSES WERE OBTAINED ON THE RING CROSS-SECTION OF ALL ANCHOR HEADS.

   B. TRANSVERSE TENSILE PROPERTIES WERE OBTAINED FROM THE RING AREA OF EACH ANCHOR HEAD USING STANDARD .505" DIAMETER ROUND TENSILE SPECIMENS WITH 2" GAUGE LENGTHS.

      THE FOLLOWING PROPERTIES WERE OBTAINED:

      1. YIELD STRENGTH, KSI (0.2% OFFSET)
      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. DUPLICATE TESTS WERE PERFORMED.

C. CHARPY V-NOTCH IMPACT PROPERTIES USING FULL SIZE IMPACT SPECIMENS WERE OBTAINED FROM THE RING AREA OF THE ANCHOR HEADS AND WERE TESTED AT ROOM TEMPERATURE IN THE TRANSVERSE DIRECTION. THE FOLLOWING PROPERTIES WERE OBTAINED:

1. ENERGY ABSORPTION, FT.-LBS.
2. BRITTLE FRACTURE, %
3. LATERAL EXPANSION, INCHES

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

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 AND 2B.

## TEST RESULTS

### VISUAL EXAMINATION

ALL ANCHOR HEADS WERE VISUALLY EXAMINED. ANCHOR HEAD FN 025 REVEALED FINE CRACKS ALONG THE CENTRAL HONEYCOMB WEB ON THE INBOARD (SHIM) FACE. NO OTHER ANCHORAGES EXHIBITED CRACKS. TO ENHANCE VISUAL INSPECTION, LIQUID DYE PENETRANT WAS USED TO HIGHLIGHT ANY POSSIBLE CRACKS. AGAIN, INDICATIONS WERE ONLY FOUND ON ANCHOR HEAD FN 025.

REPORTEDLY, AN INDICATION OF A CRACK WAS FOUND IN ANCHOR HEAD FE 059 ACROSS TWO TENDON HOLES NEAR THE CENTER OF THE HONEYCOMB WEB ON THE OUTER (BUTTONHEAD) FACE. THE INDICATION WAS FOUND THROUGH MAGNETIC PARTICLE INSPECTION BY APCO. THE SAMPLE WAS THOROUGHLY EXAMINED BY INLAND, WITH AND WITHOUT THE AID OF A LOW POWER STEREO MICROSCOPE. THE SAMPLE WAS ALSO INSPECTED THROUGH THE USE OF LIQUID DYE PENETRANT AND FLUORESCENT MAGNETIC PARTICLE INSPECTION WITH ULTRAVIOLET LIGHT. NO CRACKS COULD BE FOUND.

THE ANCHORAGES SHOWED VARYING DEGREES OF CORROSION PITTING ON BOTH THE SHIM AND BUTTONHEAD FACES. FN 025 SHOWED A GREATER DEGREE OF PITTING THAN THE OTHER ANCHORAGES. HEAVY PITTING WAS NOTED AT SOME OF THE CRACKS ON THE SHIM FACE AS SHOWN IN FIGURES 3A AND 3B. THE CORROSION PITTING INDICATES THAT ACTIVE CORROSION HAD OCCURRED OR WAS OCCURRING AT SOME OF THE CRACKS.

A SECTION THROUGH THE HONEYCOMB WEB CONTAINING THE CRACKS IN ANCHOR HEAD FN 025 WAS CUT OUT AND THEN SEPARATED TO REVEAL THE FRACTURE FACES. CARE WAS TAKEN IN SECTIONING FN 025 TO INCLUDE BOTH PRECRACKS (CRACKS EXISTING ON THE AS-RECEIVED ANCHOR HEAD) AND POST-CRACKS (FRESH FRACTURES RESULTING FROM THE OPENING OF THE PRE-CRACKS IN THE METALLURGICAL LABORATORY). THE FRACTURE FACES, SHOWN IN FIGURES 4-8, EXHIBITED A WOODY, FIBROUS-TYPE PRECRACK FRACTURE APPEARANCE. THE POST-CRACKED AREAS OF THE WEB HAD A SMOOTHER, CRYSTALLINE APPEARANCE. IN ADDITION, THE PRECRACKED FRACTURE FACES EXHIBITED VARYING DEGREES OF CORROSION. THE FRACTURES ADJACENT TO THE SHIM FACE EXHIBITED THE GREATEST DEGREE OF CORROSION. THE FRACTURES WERE NORMAL TO THE 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; HOWEVER, IT IS APPARENT THAT THE FRACTURE(S) ORIGINATED AT THE SHIM FACE OF THE HEAD IN THE HONEYCOMB WEB.

## SCANNING ELECTRON MICROSCOPY (SEM)

FRACTOGRAPHS OF FN 025, FIGURES 5-7, HAVE ACCOMPANYING OVERLAYS. THE OVERLAYS SHOW BOTH THE POSITIONS AT WHICH SEM ANALYSES WERE OBTAINED, I.E., THE OUTLINED AREAS, AND THE POSITIONS AT WHICH INTERGRANULAR SEPARATION (IGS) WAS NOTED, I.E., THE CROSS-HATCHED 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.

## CRACKED ANCHOR HEAD FN 025

SCANNING ELECTRON MICROSCOPIC (SEM) ANALYSES WERE PERFORMED ON SELECTED FRACTURE FACE AREAS OF THE HONEYCOMB; REFER TO FIGURES 5-7. THE PRECRACKED FRACTURE FACE AREAS EXHIBITED PREDOMINANTLY INTERGRANULAR SEPARATION (IGS); SEE FIGURES 9-12. IGS INDICATES THAT THE FRACTURE OCCURRED WHILE THE HEAD WAS IN A PARTIALLY EMBRITTLED CONDITION. IN ADDITION, VARYING DEGREES OF CORROSION WERE NOTED ALONG THE PRECRACKED FRACTURE FACES. IN SOME AREAS, ESPECIALLY NEAR THE SHIM FACE, HEAVY CORROSION PRECLUDED DETERMINATION OF THE FRACTURE MODE. HOWEVER, FRACTURE AREAS ADJACENT TO AND/OR SURROUNDED BY CORROSION EXHIBITED IGS. THE CRACK TIPS AT THE INTERFACE BETWEEN THE PRECRACKED AND POST-CRACKED AREAS EXHIBITED A TRANSITION FROM PREDOMINANTLY IGS TO PREDOMINANTLY CLEAVAGE; SEE FIGURE 13. THE POST-CRACKED FRACTURE AREAS, WHICH WERE SEPARATED WITH THE AID OF LIQUID NITROGEN, EXHIBITED PREDOMINANTLY CLEAVAGE; SEE FIGURE 14.

THE WOODY FIBROUS NATURE OF THE FRACTURES WAS CAUSED BY THE PREFERENTIAL ALIGNMENT OF THE NONMETALLIC INCLUSIONS IN THE ROLLING DIRECTION.

ANCHOR HEAD FE 059

TO FURTHER EXAMINE THE POSSIBILITY OF A CRACK WHICH WAS REPORTEDLY DETECTED BY APCO ON THE BUTTONHEAD FACE THROUGH MAGNETIC PARTICLE INSPECTION, A SECTION OF THE SAMPLE CONTAINING THE SUPPOSED CRACK WAS EXAMINED WITH THE AID OF THE SEM. NO INDICATION OF A CRACK COULD BE FOUND AT THE SURFACE.

GENERAL COMMENTS ON THE SEM FRACTOGRAPHY

THE PRESENCE OF IGS INDICATES THAT THE STEEL WAS IN THE EMBRITTLED CONDITION. SEVERAL FAILURE MECHANISMS SUCH AS A TEMPER EMBRITTLEMENT PHENOMENON, STRESS CORROSION CRACKING (SCC) OR HYDROGEN STRESS CRACKING (HSC) CAN RESULT IN IGS OF HIGH STRENGTH STEELS.

THE PREDOMINANCE OF IGS WITHIN THE PRECRACKED FRACTURE FACES AND NOT IN THE POST-CRACKED FRACTURE FACES INDICATES AN EXTERNAL EMBRITTLING AGENT RATHER THAN A TEMPER EMBRITTLING AGENT. THE PRE-CRACKED AND POST-CRACKED FRACTURE FACES EXHIBITED A SHARP CONTRAST IN FRACTURE MODES, WHEREAS TEMPER EMBRITTLEMENT SHOULD RESULT IN A MORE UNIFORM DISPERSION OF IGS. IN ADDITION, SEM ANALYSES WERE PER-FORMED ON THE FRACTURED TRANSVERSE TENSILE SPECIMENS OF ALL ANCHOR HEADS AND SELECTED FRACTURED TRANSVERSE IMPACT SPECIMENS. 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 PRE-SENT.

THE PRECRACKED FRACTURE FACES EXHIBITED VARYING DEGREES OF CORROSION WITH THE AREAS OF HEAVIEST CORROSION BEING EVIDENT NEAR THE SHIM FACE OF FN 025. THE PRESENCE OF CORROSION IS AN INDI-CATION THAT THE FRACTURES MAY BE RELATED TO AN ENVIRONMENTAL-MECHANICAL PROCESS SUCH AS SCC OR HSC. ENERGY DISPERSIVE QUALIT-ATIVE SEM X-RAY ANALYSES OF THE FRACTURE FACES SHOWED NO SIGNIFIC-ANT IDENTIFIABLE CORROSION PRODUCTS OR EMBRITTLING SPECIES. HOWEVER, IT SHOULD BE NOTED THAT THE X-RAY UNIT IS NOT CAPABLE OF DETECTING HYDROGEN, CARBON, NITROGEN OR OXYGEN.

HYDROGEN STRESS CRACKING OCCURS IN HIGH STRENGTH STEELS DUE TO THE INTERACTION BETWEEN APPLIED TENSILE STRESS AND HYDROGEN DISSOLVED IN THE METAL LATTICE. WHILE TENSIONED, THE ANCHOR HEADS ARE SUBJECTED TO SUSTAINED TENSILE STRESSES AND ENCLOSED BY GALVANIZED GREASE COVERS. THE GREASE COVERS ARE FILLED WITH A CORROSION PROTECTION GREASE WHICH COMPLETELY ENCASES THE ANCHOR HEADS. IT IS UNLIKELY THAT REACTIONS WITH THE GREASE WOULD PRODUCE HYDROGEN. HAD THIS BEEN THE CASE, FN 025, WHICH WAS IN SERVICE APPROXIMATELY 8-10 YEARS, WOULD HAVE FAILED SHORTLY AFTER INSTALLATION. HOWEVER, IF THE GREASE WAS CONTAMINATED WITH WATER AND ACTED AS A CONDUCTOR, IT IS POSSIBLE THAT A CORROSIVE REACTION BETWEEN THE WATER AND THE STEEL ANCHOR HEAD, OR GALVANIC COUPLING BETWEEN THE GALVANIZED ZINC COATING AND THE STEEL ANCHOR HEAD COULD LIBERATE ATOMIC HYDROGEN AT THE STEEL SURFACE. SINCE A SAMPLE OF THE GREASE SURROUNDING FN 025 DURING SERVICE WAS NOT RETAINED FOR ANALYSIS, IT IS NOT KNOWN IF THE GREASE WAS CONTAMINATED WITH WATER; HOWEVER, SIGNIFICANT CORROSION PITTING WAS NOTED AT THE SURFACE OF FN 025 INDICATING AN OXIDATION-REDUCTION PROCESS HAS OCCURRED. FURTHERMORE, INLAND STEEL INVESTIGATION NO. 19975, DATED MARCH, 1985, REGARDING FAILURE ANALYSES OF JOSEPH M. FARLEY POWER PLANT ANCHOR HEADS DETERMINED THROUGH ANALYSES OF USED GREASE SAMPLES THAT THE GREASE WAS CONTAMINATED WITH WATER.

## MECHANICAL PROPERTIES

THE MECHANICAL PROPERTIES ARE PRESENTED IN THE ATTACHED TABLES 1-11. BRINELL HARDNESS TESTS WERE PERFORMED ON THE TRANSVERSE RING SURFACES, AND BRINELL AND ROCKWELL (HRC) HARDNESS TESTS WERE PERFORMED ON THE RING CROSS-SECTIONS TO OBTAIN HARDNESS PROFILES FOR EACH OF THE 11 SUBMITTED ANCHOR HEADS. THE SPECIFIED HARDNESS RANGE WAS HRC 40-44. HOWEVER, DUE TO INHOMOGENETIES IN THE STEEL, I.E., FERRITE PATCHES, INCLUSIONS OR SEGREGATION, BRINELL HARDNESS SHOULD BE MORE REPRESENTATIVE THAN ROCKWELL HARDNESS AND IT IS RECOMMENDED THAT BRINELL HARDNESS BE USED FOR FUTURE REFERENCE. IT WAS NOTED THAT THE ACTUAL ROCKWELL HARDNESSES WERE ON AVERAGE 2-3 POINTS LOWER THAN THE BRINELL HARDNESS CONVERTED TO ROCKWELL HARDNESS VALUES. IN ACCORDANCE WITH ASTM SPECIFICATION E-140-83 REGARDING STANDARD HARDNESS CONVERSION TABLES, THE APPROXIMATE BRINELL HARDNESS CONVERSION FOR HRC 40-44 ARE BHN 392-434. WITH RESPECT TO ACTUAL BRINELL SURFACE HARDNESS, ANCHORAGES FE 026, FM 028 AND TFD 24 HAD AVERAGE SURFACE HARDNESSES WHICH WERE 4 TO 40 BHN POINTS BELOW THE MINIMUM HARDNESS. ALL OTHER ANCHORAGES HAD AVERAGE SURFACE HARDNESSES WITHIN THE SPECIFIED RANGE. WITH RESPECT TO ACTUAL BRINELL CROSS-SECTIONAL HARDNESS, ONLY ANCHORAGE HV 036 HAD AN AVERAGE HARDNESS ABOVE (7 BHN POINTS) THE MAXIMUM HARDNESS. ANCHORAGES HU 019, FL 049, FE 059, FK 016, FM 028 AND TFD 24 HAD AVERAGE HARDNESS 9 TO 77 BHN POINTS BELOW THE MINIMUM HARDNESS. HOWEVER, THIS WOULD BE EXPECTED DUE TO SLIGHT SLACK QUENCH EXPERIENCED WITH THE STEEL GRADE AND PART SECTION INVOLVED. WITH RESPECT TO ACTUAL ROCKWELL CROSS-SECTIONAL HARDNESS, ANCHORAGE HV 036 HAD AN AVERAGE HARDNESS FOR THE NINE HARDNESS POSITIONS TESTED WHICH WAS SLIGHTLY ABOVE (0.3 HRC POINT) THE MAXIMUM HARDNESS. ANCHORAGES HU 019, FL 049, FE 059, FN 097, FK 016, FM 028 AND TFD 24 HAD AVERAGE CROSS-SECTIONAL HARDNESSES WHICH WERE 0.1 TO 8.8 HRC POINTS BELOW THE MINIMUM HARDNESS, WHICH IS ALSO ASSOCIATED WITH THE SLACK QUENCH. ALL OTHER ANCHORAGES HAD AVERAGE CROSS-SECTIONAL HARDNESSES WITHIN THE SPECIFIED RANGE.

THE TENSILE PROPERTIES WERE OBTAINED FROM MACHINED .505" DIAMETER TRANSVERSE SPECIMENS WITH 2" GAUGE LENGTHS FROM THE RING AREA OF THE HEADS. TEST 1 WAS TAKEN ADJACENT TO THE SHIM FACE AND TEST 2 WAS TAKEN APPROXIMATELY 1-1/2" ABOVE THE SHIM FACE. NO SIGNIFICANT DIFFERENCE OR TREND IN TENSILE PROPERTIES WAS NOTED BETWEEN TEST 1 AND TEST 2. HOWEVER, A WIDE RANGE OF PROPERTIES BETWEEN DIFFERENT HEATS WAS NOTED, WHICH MIGHT BE EXPECTED WITH THE USE OF BATCH HEAT TREATING PROCESSES. THE TENSILE STRENGTH RANGED FROM 141.1 KSI TO 204.8 KSI. THE REDUCTION IN AREA RANGED FROM 11.6% TO 38.8%, WHICH ARE CONSIDERED GOOD TO EXCELLENT.

THE IMPACT PROPERTIES WERE OBTAINED FROM TRANSVERSE FULL SIZE CHARPY V-NOTCH SPECIMENS ALONG THE SHIM FACE IN THE RING AREA OF THE HEADS WHICH WERE TESTED AT ROOM TEMPERATURE. THE ABSORBED ENERGIES ARE ALL NORMAL FOR THE ALLOY STEEL PRODUCT IN THE QUENCHED AND TEMPERED CONDITION.

## CHEMISTRY

THE CHEMICAL CHECK ANALYSES OF THE ANCHOR HEADS WERE OBTAINED FROM THE OUTER RING AREAS AND ARE REPORTED IN TABLES 1-11. ALL ANCHORAGES WERE TO MEET THE CHEMICAL REQUIREMENTS OF ASTM A-322 GRADE AISI 4140 OR 4142 HOT ROLLED ALLOY STEEL BARS. THE CHEMICAL REQUIREMENTS ARE GIVEN BELOW:

| DESCRIPTION | C | MN | P | S | SI | MO | CR |
|---|---|---|---|---|---|---|---|
| ASTM A 322-82* | .38/ | .75/ | .035 | .040 | .15/ | .15/ | .80/ |
| GRADE 4140-4142 | .45 | 1.00 | | | .35 | .25 | 1.10 |
| PERMISSIBLE VARIATIONS | +/-.02 | +/-.04 | +.005 | +.005 | +/-.02 | +/-.02 | +/-.05 |

* 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. IN ADDITION, CU, NI, AL, N, O2, AS, TI, B, CB, V, SN AND SB CHECKS ARE AT A SATISFACTORY RESIDUAL LEVEL. THE RESIDUAL ELEMENTS IN ALL CASES INDICATED A PROBABLE ELECTRIC FURNACE STEELMAKING ORIGIN. HEAT ANALYSES FOR THE HEATS INVOLVED IN THIS INVESTIGATION WERE NOT PROVIDED AND, THEREFORE, NO COMPARISON OF HEAT VERSES CHECK ANALYSES COULD BE MADE.

MICROANALYSES

LONGITUDINAL MICROSECTIONS WERE TAKEN THROUGH THE OUTER RING AREA AND HONEYCOMB TENDON HOLES FOR EACH ANCHORAGE. THE MICRO-CLEANLINESS WAS RATED A2-4H AND B2-4H ON THE AVERAGE, PER THE J-K RATING SYSTEM, AND RATED ON APPEARANCE ONLY. ALL ANCHORAGES CONSISTED OF A TEMPERED MARTENSITE MICROSTRUCTURE INDICATING A QUENCHED AND TEMPERED CONDITION. VARYING DEGREES OF WIDMANSTATTEN FERRITE AND LIGHT REMNANTS OF BANDING WERE NOTED IN MOST ANCHOR HEAD MICROSTRUCTURES. IN ADDITION, MOST ANCHORAGES SHOWED A LIGHT PARTIAL SURFACE DECARBURIZATION, USUALLY <.001" DEEP. SOME CLUSTERING OF SULFIDES WAS EVIDENT. NO CHROMIUM CARBIDES WERE NOTED.

A MICROSPECIMEN TRAVERSING THE SUPPOSED CRACK IN ANCHOR HEAD FE 059 WAS METALLURGICALLY PREPARED TO CONFIRM OR DENY THE EXISTENCE OF A CRACK. METALLOGRAPHIC EXAMINATION REVEALED A SEQUENCE OF MANY NONMETALLIC INCLUSIONS ADJACENT TO THE BUTTONHEAD FACE OF THE ANCHORAGE IN A LINEAR PATTERN BETWEEN TWO TENDON HOLES. ENERGY DISPERSIVE QUALITATIVE SEM X-RAY ANALYSES INDICATED THAT THE INCLUSIONS CONSISTED OF VARIOUS COMPOSITIONS OF AL, CA, MG AND FE.

A TRANSVERSE MICROSECTION INTERSECTING THE FRACTURE FACE OF ANCHOR HEAD FN 025 WAS OBTAINED. THE FRACTURE APPEARED TO BE BRITTLE AND INTERGRANULAR. NO EVIDENCE OF PRIOR CRACKING WAS APPARENT.

## CONCLUSIONS

1. CRACKING OF ANCHOR HEAD FN 025 WAS DUE TO IN-SERVICE PARTIAL EMBRITTLEMENT AS INDICATED BY THE PRESENCE OF SIGNIFICANT AMOUNTS OF INTERGRANULAR SEPARATION (IGS) ON THE PRECRACKED FRACTURE FACES. IT WAS CONCLUDED THAT THE EMBRITTLEMENT RESULTED FROM EITHER HYDROGEN-STRESS CRACKING (HSC), STRESS CORROSION CRACKING (SCC) OR A COMBINATION OF BOTH.

2. THE CRACKS OF ANCHOR HEAD FN 025 ORIGINATED AT THE SHIM FACE AND PROPAGATED NORMAL TO THAT FACE IN A STRAIGHT AND PARALLEL ORIENTATION TO THE ROLLING DIRECTION.

3. THE ANCHORAGES EXHIBITED VARYING DEGREES OF CORROSION PITTING AT THE SHIM AND BUTTONHEAD FACES INDICATING THAT ACTIVE CORROSION WAS OCCURRING OR HAD OCCURRED. FN 025 SHOWED HEAVY CORROSION PITTING AT SOME CRACKS ON THE SHIM FACE. IN ADDITION, ALL PRECRACKED FRACTURE FACES OF FN 025 SHOWED VARYING DEGREES OF CORROSION.

4. OTHER POSSIBLE SOURCES OF 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.

5. ANCHOR HEAD FE 059 DID NOT CONTAIN A CRACK CONTRARY TO AN INDICATION FOUND BY ALABAMA POWER COMPANY (APCO). HOWEVER, A SEQUENCE OF MANY NONMETALLIC INCLUSIONS ADJACENT TO THE BUTTONHEAD FACE OF THE ANCHOR HEAD IN A LINEAR PATTERN BETWEEN TWO TENDON HOLES WAS NOTED WHICH CORRESPONDED TO THE LOCATION OF THE SUPPOSED CRACK AS SITED BY APCO.

6. ANCHOR HEAD HV 036 EXHIBITED A MEAN CROSS-SECTIONAL ACTUAL HRC HARDNESS ABOVE THE SPECIFIED HARDNESS RANGE, AND ANCHORAGES HU 019, FL 049, FE 059, FN 097, FK 016, FM 028 AND TFD 24 HAD MEAN CROSS-HARDNESSES BELOW THE RANGE. ALL OTHER ANCHORAGES EXHIBITED MEAN CROSS-SECTIONAL HARDNESSES WITHIN THE SPECIFIED RANGE. IT SHOULD BE NOTED THAT LOWER HARDNESS WOULD BE BENEFICIAL IN REDUCING THE SUSCEPTIBILITY TOWARD HSC OR SCC. THE STRENGTHS AND DUCTILITIES APPEARED NORMAL FOR THE STEEL ALLOY GRADE AND CONDITION AND WERE CONSISTENT WITH THE HARDNESSES.

7. ALL ANCHORAGES MET THE CHEMICAL REQUIREMENTS OF THE ASTM AND INRYCO SPECIFICATIONS. ALL RESIDUAL ELEMENTS WERE AT ACCEPTABLE LEVELS.

8. THE MICROSTRUCTURES AND MICROCLEANLINESSES OF THE SAMPLES WERE AS EXPECTED FOR THE STEEL GRADE AND CONDITION.

## LIST OF REFERENCES *


1. INRYCO BROCHURE ON POST TENSIONING SYSTEMS FOR CONTAINMENT BUILDINGS.

2. INRYCO MATERIAL SPECIFICATION 1649 DATED JULY 15, 1972.

3. ASTM SPECIFICATION A 322-64A (1970).

4. INRYCO MATERIAL SPECIFICATION 1322-40, "POST TENSIONING ANCHOR HEAD," DATED JUNE 24, 1980.

5. INRYCO MATERIAL SPECIFICATION 1001-40, "GUIDE FOR PREPARATION AND CERTIFICATION OF TEST INFORMATION," DATED JUNE 24, 1980.

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* THE ABOVE REFERENCES ARE NOT FOOTNOTED IN THE REPORT.

DTK:CMB
ATTACHMENTS
PHOTOGRAPHS