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CAUSES AND RESOLUTION OF THROUGH-WALL CRACKING IN A COLD REHEAT PIPING SYSTEM

William Thurley, P.E., Senior Mechanical Engineer
Thielsch Engineering, Inc.

Anthony Carrino, Mechanical Maintenance Supervisor
Illinois Power Company

ABSTRACT

Unit No. 6 at the Havana Station of Illinois Power Company underwent two forced outages in a period of 15 months. These forced outages were both a result of through-wall cracking which occurred in circumferential welds of the Cold Reheat piping system.

Support system deficiencies were suspected at the time of the first forced outage. A stress analysis of the piping system was then initiated to identify high stress locations. The information generated by this analysis was later used to modify the supporting system, thereby lowering system operating stresses. It was also used to identify areas of high stress for inspection purposes.

Nondestructive examinations were then performed to identify any additional cracking and confirm the cause or causes of the through-wall leaks. The detailed nondestructive examinations performed during the November, 1991 planned outage revealed two additional cracked circumferential welds which required repairs by welding. Metallurgical examinations were performed to identify the nature of cracking, thereby confirming the cause.

This paper describes the mechanism which resulted in the failures in the Cold Reheat piping system, the program utilized to determine that mechanism, and the corrective measures taken to return the system to its intended level of integrity for continued service.

INTRODUCTION

Unit No. 6 of the Havana Station went into service in 1978. The 420 MW coal-fired unit normally operates during peak-load periods, typically experiencing five starts per week. As of the November, 1991 outage, the unit had experienced approximately 2,000 starts.

The Cold Reheat piping system was designed to the

ASME B31.1 Code for Pressure Piping on "Power Piping". The system design temperature is 675°F and design pressure is 650 psig. The pipe for the system was produced to ASTM Specification A-155, Grade KC60, Class I, covering "Electric Fusion Welded Carbon Steel Pipe". The piping consists of a single 33.625 inch outside diameter lead with a minimum wall thickness of 0.8423 inch. The two turbine leads consist of 26.125 inches outside diameter, 0.6795 inch minimum wall thickness piping.

COLD REHEAT PIPING SYSTEM HISTORY

The first leak occurred in the Cold Reheat piping system in March of 1990. It developed at the 6:00 o'clock position of the girth weld immediately upstream of the riser. This is denoted as location 1 on the system isometric sketch, Fig. 1.

At this location, the girth weld intersects a seam weld on the extrados of a clam shell elbow. Along the outside diameter of the pipe, the circumferential crack was 9 inches in length. As the repair excavation progressed through the cross-sectional thickness, it was observed that the crack grew longer. Along the inside diameter surface, the crack was 14-1/2 inches in length. This would indicate that the cracking initiated along the inside diameter of the pipe.

A failure analysis performed in 1990 attributed the failure primarily to cyclic bending stresses, with crack propagation occurring over several years. A system walkdown also revealed evidence of water hammer loading on the system, mainly in the form of damage to east/west lateral restraint 6CR01008R, Fig. 2.

Discussions with Illinois Power Company personnel confirmed that water hammer events had occurred, particularly in the late 1970's. An attemperator valve located along the upper riser piping had leaked, allowing water entry. A low point drain was subsequently added downstream of the

tee connection. This drain now remains open during start-up. By the time the failure occurred in 1990, the Cold Reheat piping system contained no known water pockets or points of water entry.

The discussions with plant personnel also revealed that the west turbine flange connection had leaked and been replaced on three occasions since 1978. When the flange was unbolted, the turbine lead sprung out of position, mainly due to the absence of restraint 6CR01008R. The restraint had been designed to guide thermal piping movement away from the turbine to minimize turbine loading.

A stress analysis was initiated to investigate whether operating loads could be reduced. The analysis recommendations would be implemented during the major outage in November, 1991.

On June 27, 1991, a second through-wall leak occurred in the Cold Reheat piping system, denoted as location 2 on the system isometric sketch. The failure occurred in the upper horizontal lead at the 12:00 o'clock position of the first circumferential weld downstream of the riser. The cracking at this location had initiated on the inside diameter of the pipe. The crack length along the inside diameter of the pipe was approximately 26 inches. Like the 1990 failure, the crack was located on the side of the pipe in greatest tension due to bending stresses.

STRESS ANALYSIS

A stress analysis of the Cold Reheat piping system was performed after the 1990 failure. The highest thermal stresses prior to hanger modifications are listed in order in Table 1. The corresponding thermal stress after hanger modifications are also provided. The most significant modification involved replacing rigid hanger 6CR01007R with a pair of constant support hangers to allow greater flexibility.

TABLE 1

Thermal Stresses Before and After Hanger Modifications

Data Point	Location	Before Modifications	After Modifications
310	Bottom of riser	11,471 psi	8,364 psi
450	Turbine connection	10,940 psi	2,936 psi
220	Top of riser	8,830 psi	8,669 psi

The highest thermal stress, 11,471 psi, was found to be at the circumferential weld which had developed a through-wall crack in 1990. Note that failure occurred after approximately 1,800 cycles, even though the thermal stress was approximately 50% of the allowable stress set forth in the ASME B31.1 Code for Pressure Piping on "Power Piping".¹ The relatively high bending stress resulted from the downward expansion of the riser, in conjunction with the limited movement of the lower horizontal lead. The expansion had been restricted by rigid hanger 6CR01007R.

The second highest thermal stress prior to hanger modifications was at the west turbine connection. The absence of lateral restraint 6CR01008R resulted in a thermal

stress of 10,940 psi, in addition to leakage of the turbine flange.

The third highest thermal stress, 8,830 psi, occurred at the top of the riser. This condition resulted from the piping layout, which consists of a long, single riser without an expansion loop. With the existing layout, moving the location of rigid hanger 6CR01005R up the riser would not lower stresses at the upper elbow without increasing stresses at the lower elbow. The thermal stresses "after modifications" in Table 1 illustrate that the rigid hanger location is in an optimum position, as the stresses are nearly equal.

To lower system operating stresses, it was recommended that a pair of constant support hangers be installed to replace rigid hanger 6CR01007R. The constant support hangers would allow for the desired downward movement of 2.64 inches, as opposed to no downward movement. The pair of constant support hangers at 6CR01006C, near the bottom of the riser, would also require replacement to accommodate the greater downward movement. The repair of lateral restraint 6CR01008R would decrease the loading at the turbine flange by directing thermal expansion away from the turbine.

A detailed scope of work was planned for the November, 1991 outage. This included the installation of constant support hangers 6CR01006C and 6CR01007C, and the repair of lateral restraint 6CR01008R. System walkdowns and thorough nondestructive examinations of the horizontal piping runs were also planned. The Cold Reheat riser, which was not subjected to significant bending moments, was scheduled for nondestructive examination in 1992.

HANGER WALKDOWNS AND MODIFICATIONS

Cold system walkdowns were performed during the November, 1991 outage, before and after setting the new constant support hangers. Constant support hanger 6CR01006C is shown after installation in Fig. 3. Lateral restraint 6CR01008R was repaired and reinforced.

After modifying the supports, a final cold system walkdown and measurements for slope were made. The cold position slope of the lower horizontal piping had been downward away from the drain, causing localized low points. The slope was measured to be 0.0 inches after the final hanger adjustments. Any downward slope away from the low point drain may have necessitated the addition of a second drain or further system modifications.

Subsequent hot position hanger readings, including readings of new constant support hangers 6CR01006C and 6CR01007C, indicated that the system expanded as predicted by the stress analysis. Thermal operating stresses are lower as a result of the hanger modifications, reducing the potential for pipe cracking in the future.

NONDESTRUCTIVE EXAMINATIONS AND WELD REPAIRS

At the beginning of the November, 1991 outage, a third through-wall crack was discovered. Water leakage was apparent while the lower portion of the system was under hydrostatic pressure. Failure location No. 3, as indicated on

the system isometric sketch of Fig. 1, was located at the 6:00 o'clock position of the girth weld, Fig. 4. The lower photograph illustrates the crack as viewed during the wet fluorescent magnetic particle examination.

Ultrasonic shear wave examinations were performed on 100% of the circumferential and longitudinal welds of the horizontal piping runs. A significant indication was detected at the 6:00 o'clock position of the girth weld at location No. 4 on the system isometric sketch. The indication was approximately 0.4 inches deep, 5 inches long, and initiated along the inside diameter of the pipe.

FAILURE ANALYSES

Three boat shaped samples were removed prior to welding at repair locations 2, 3, and 4, as identified in the system isometric sketch.

Sample No. 2 was removed transverse to the Cold Reheat circumferential weld at the top of the riser at the 12:00 o'clock pipe position, Fig. 5. Primary and secondary cracking transverse to the girth weld was evident along the inside pipe diameter. The cracks were aligned in the direction of the longitudinal seam. The cracking associated with the circumferential through-wall crack was not included with the sample No. 2 failure analysis.

The primary transverse crack progressed from the inside diameter, Fig. 6. The crack measured 0.325 inches in depth. Secondary cracking was also evident, as shown in the lower left hand photograph. The secondary cracking appeared "tight" and was filled with scale. This condition is typical of slowly progressing cracks which are exposed to oxidizing conditions. The microstructure consisted primarily of ferrite with pearlite grains, typical of a carbon steel pipe material.

Sample No. 3 was removed from the through-wall crack at location No. 3. Circumferential cracking initiated from the inside diameter of the pipe at the 6:00 o'clock position. Views of sample No. 3 are provided in Fig. 7, before and after liquid penetrant examination. Fissuring transverse to the weld was evident throughout the internal diameter of the sample.

A cross section of the through-wall crack is shown in Fig. 8. The photomicrographs illustrate the crack progression from the inside base metal, into the heat-affected zone, and then to the weld fusion line. The linear transgranular progression is typical of fatigue cracking. Secondary cracks were evident along the internal diameter surfaces and along the primary crack. Laboratory measurements of scale thickness confirmed the presence of heavy scale at the initiation point and lesser scale near the final stages of crack progression.

After metallurgical evaluation, the remaining portion of sample No. 3 was separated to examine the fracture surface using Scanning Electron Microscopy (SEM). Fractographs of the examined areas are shown in Fig. 9. Beach marks are apparent, which are characteristic of fatigue cracking stages. Due to heavy scaling, fatigue striations could not be resolved. This is not uncommon when materials are exposed to thermal fatigue conditions.

Photographs of the cross section of sample No. 4 are provided in Fig. 10. The cracking progressed to a depth of

0.363 inches from the inside pipe diameter. This crack was detected by ultrasonic shear wave examination, as it had not progressed through-wall. Secondary cracking was apparent adjacent and parallel to the primary crack. Thermal fatigue conditions similar to the through-wall failures were observed.

Chemical analyses were performed on each sample by Optical Emission Spectroscopy (OES). The results confirmed that all of the samples met the requirements of ASTM Specification A-155, Grade KC-60 "Electric-Fusion-Welded Steel Pipe for High-Pressure Service".

Hardness testing was also performed on each of the samples, indicating that the weld joints were most likely not stress relieved during the original fabrication. For the pipe wall thickness of 0.8423", a stress relief heat treatment would have been required by the ASME B31.1 Code. The higher residual welding stresses have increased the propensity for cracking to initiate. The weld repairs performed at these locations have been stress relieved.

CONCLUSIONS

Each of the failure analyses revealed conditions indicative of fatigue cracking. The circumferential cracking progressed mainly as a result of cyclic conditions associated with the thermal expansion of the piping system. Secondary cracking, numerous but shallow in depth, resulted from thermal fatigue associated with intermittent wetting from water in the system.

Contributing to the initiation of the failures were "notches", or stress risers on the inside diameter of the pipe, due to pipe beveling for the original fabrication fit-up. This was most evident at failure locations Nos. 3 and 4, Figs. 8 and 10, respectively. Cracking initiated at the notch and progressed in a straight path through the base metal. This is typical of fatigue cracking, which is highly sensitive to notch conditions. Nevertheless, even in the absence of the notches, the fatigue related cracking could eventually have occurred at essentially the same locations. Although through-wall piping failures more commonly progress from the outside pipe diameter, particularly when sustained stresses are the cause, cracking initiated at the inside diameter at all four locations.

The thermal fatigue associated with intermittent wetting in the system would not, in itself, have caused the through-wall failures to occur in twelve years. Thermal expansion bending stresses combined with cycling of the system caused the through-wall crack propagation. The stress analysis indicated that the failures occurred at high thermal stress points in the system.

As of November, 1991, the system had experienced approximately 2,000 starts, whereas the highest thermal stress was only 50% of the ASME B31.1 Code allowable stress. Failures may occur in piping systems that meet the ASME B31.1 Code allowable stress and fatigue reduction requirements, particularly when additional factors such as stress risers, residual stresses, and transient loading conditions are present.

Limiting the number of cycles the unit experiences would prolong the life of the Cold Reheat system. This option is generally not feasible. The fatigue life has instead been in-

creased by lowering operating stresses. The reduction of thermal bending stresses through hanger modifications reduces the probability of crack initiation and progression in the future. While stress analyses are necessary in meeting the requirements of applicable piping codes during initial system design, they do not ensure that failures will not later occur. With existing systems, stress analyses remain useful in determining high stress areas or in modifying supporting systems to reduce operating stresses. Hanger walkdown and nondestructive examination programs are effective means of predicting and detecting conditions which could ultimately lead to piping failures or degradation.

ACKNOWLEDGEMENTS

The cooperation of Havana Station personnel of the Illinois Power Company is acknowledged in allowing for the publication of this case study. The failure analyses performed by Susan Freeman as well as the efforts of Matthew Dowling, Steven Flowers and Florence Cone of Thielsch Engineering, Inc. were also necessary in the investigation and problem resolution.

REFERENCES

- 1 ASME B31.1 Code for Pressure Piping on "Power Piping", 1989 Edition.

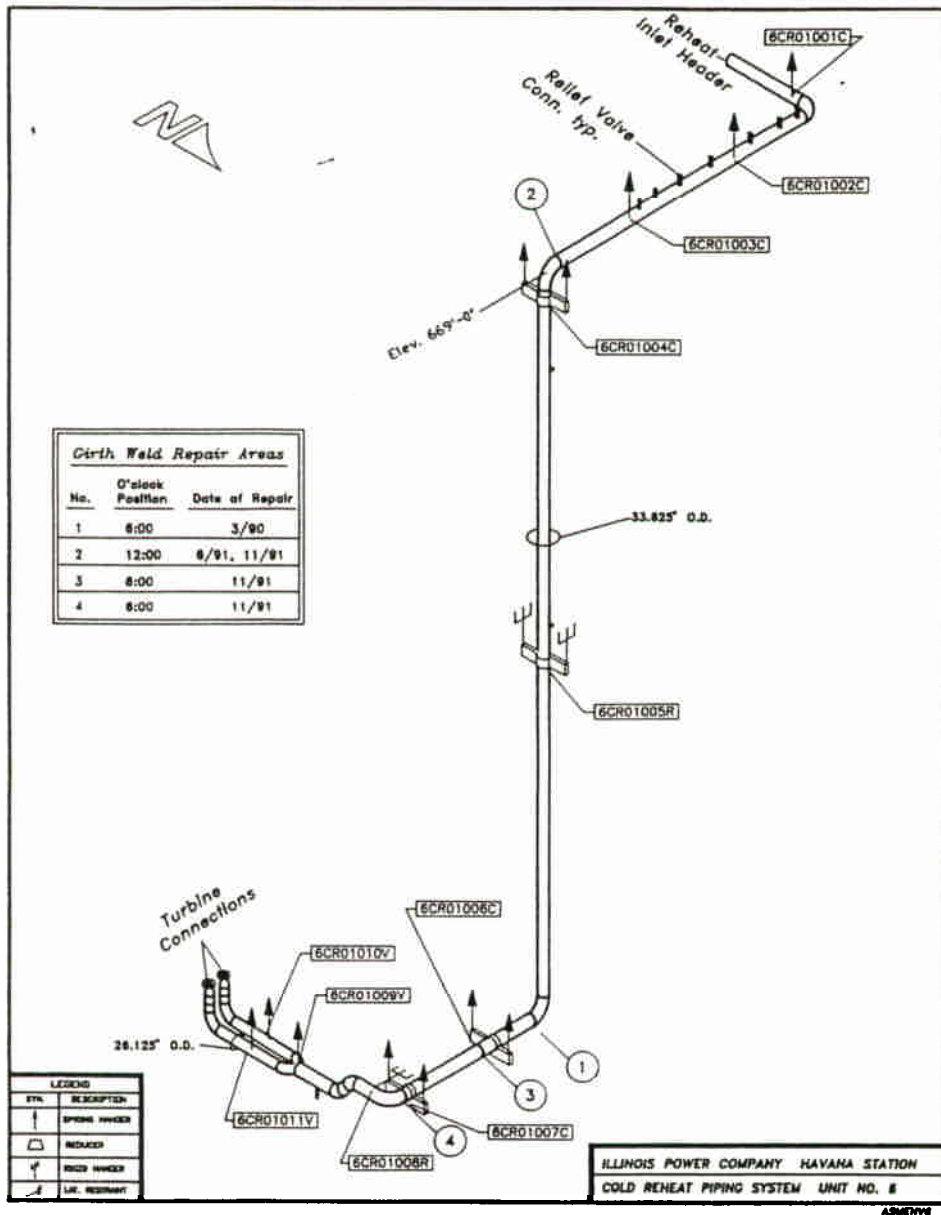


FIG. 1. COLD REHEAT PIPING SYSTEM AFTER HANGER MODIFICATIONS

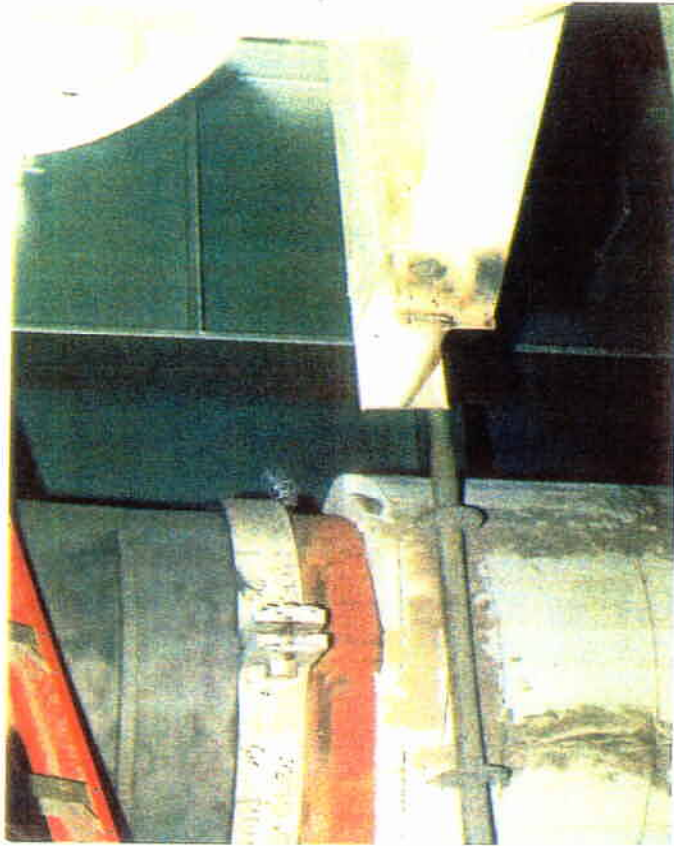


FIG. 2. VIEW OF DAMAGE TO LATERAL RESTRAINT 6CR01008R.

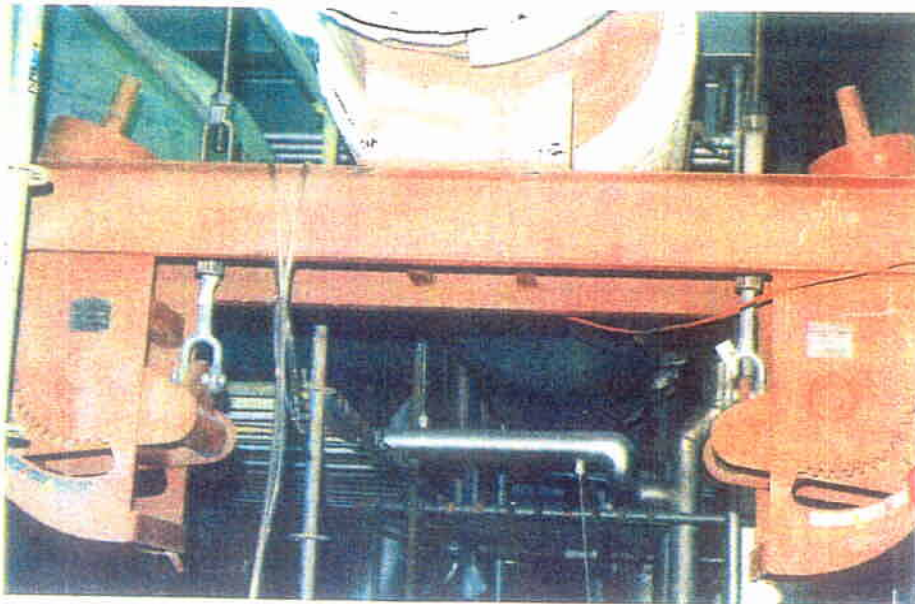


FIG. 3. VIEW OF NEW CONSTANT SUPPORT HANGER 6CR01006C.

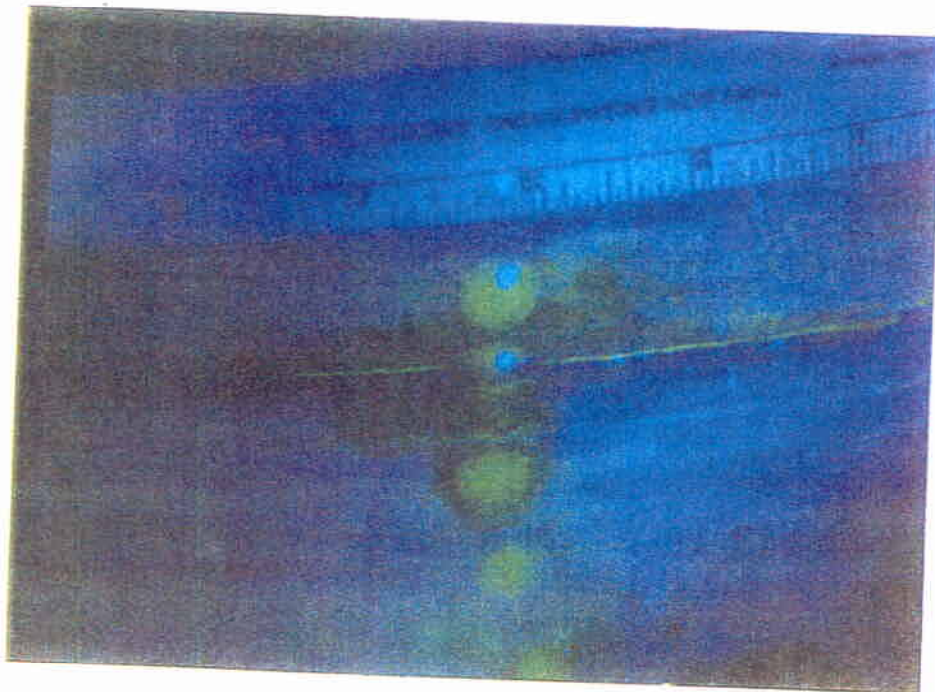
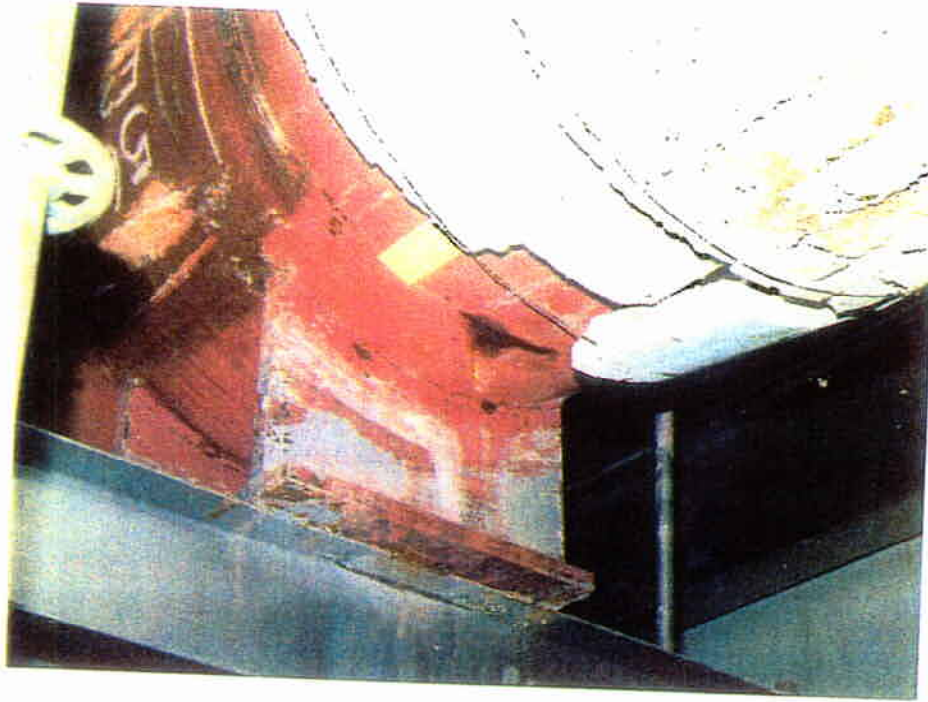


FIG. 4. VIEW OF THROUGH-WALL LEAK AT REPAIR LOCATION NO. 3.

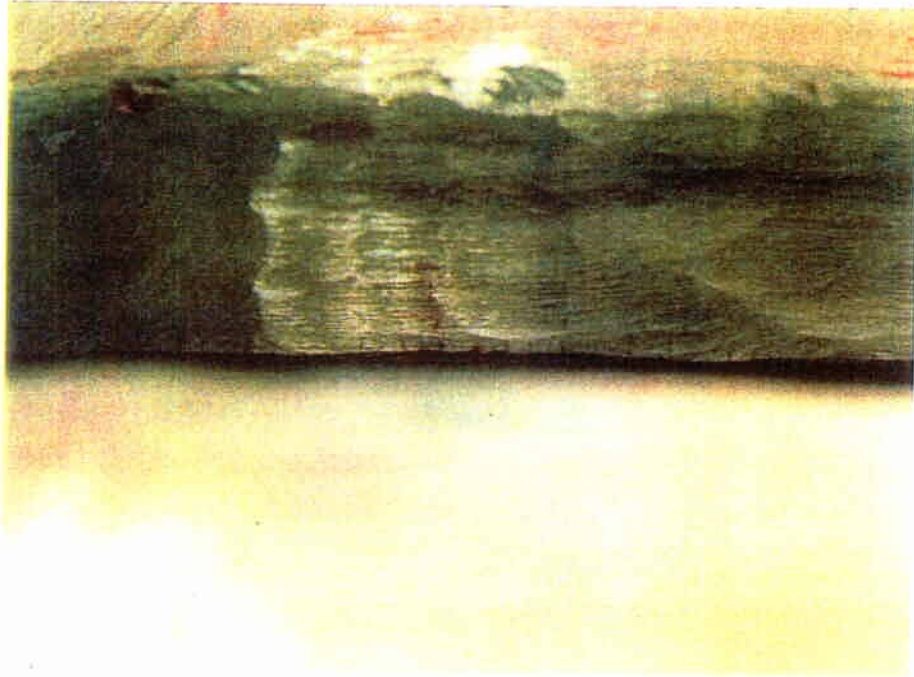
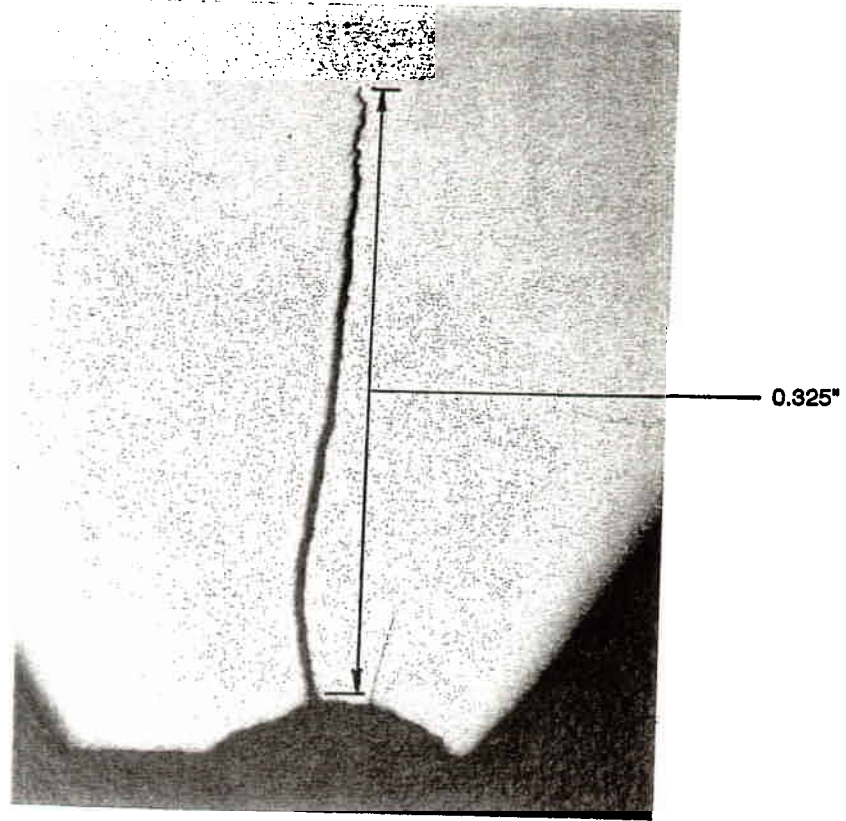
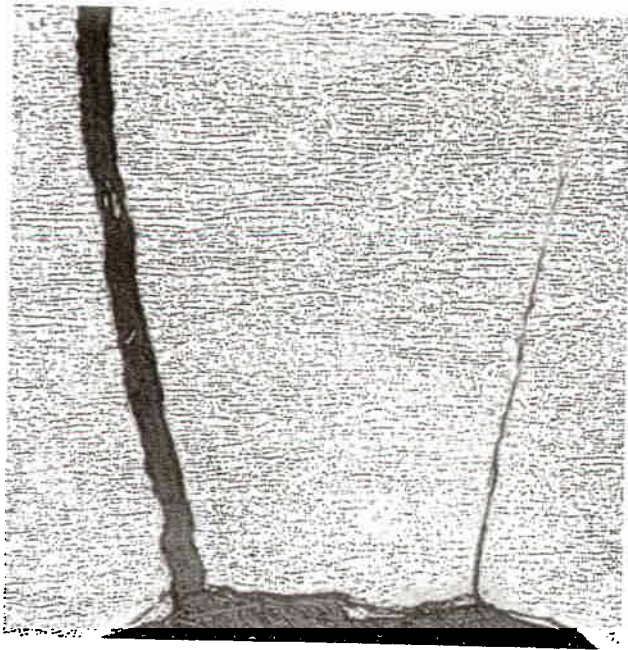


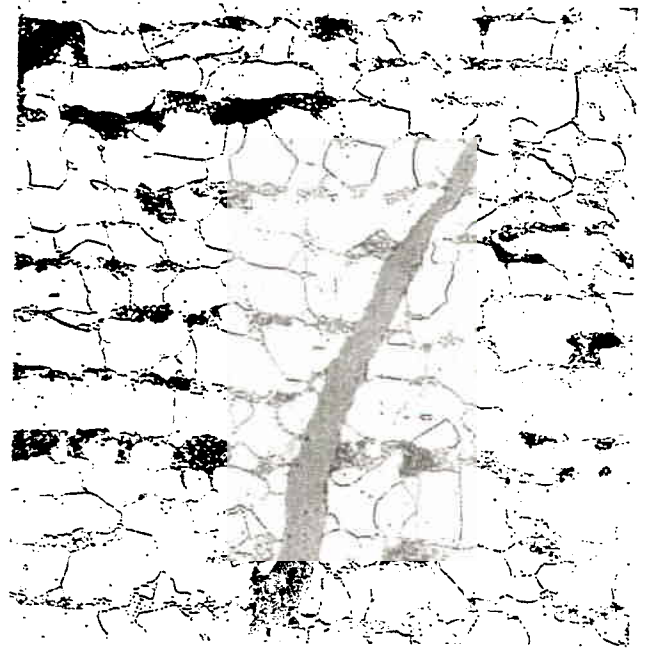
FIG. 5. VIEWS OF TRANSVERSE CRACKS AT BOAT SAMPLE NO. 2.



10X



50X



500X

FIG. 6. PRIMARY AND SECONDARY CRACKING, LOCATION NO. 2.

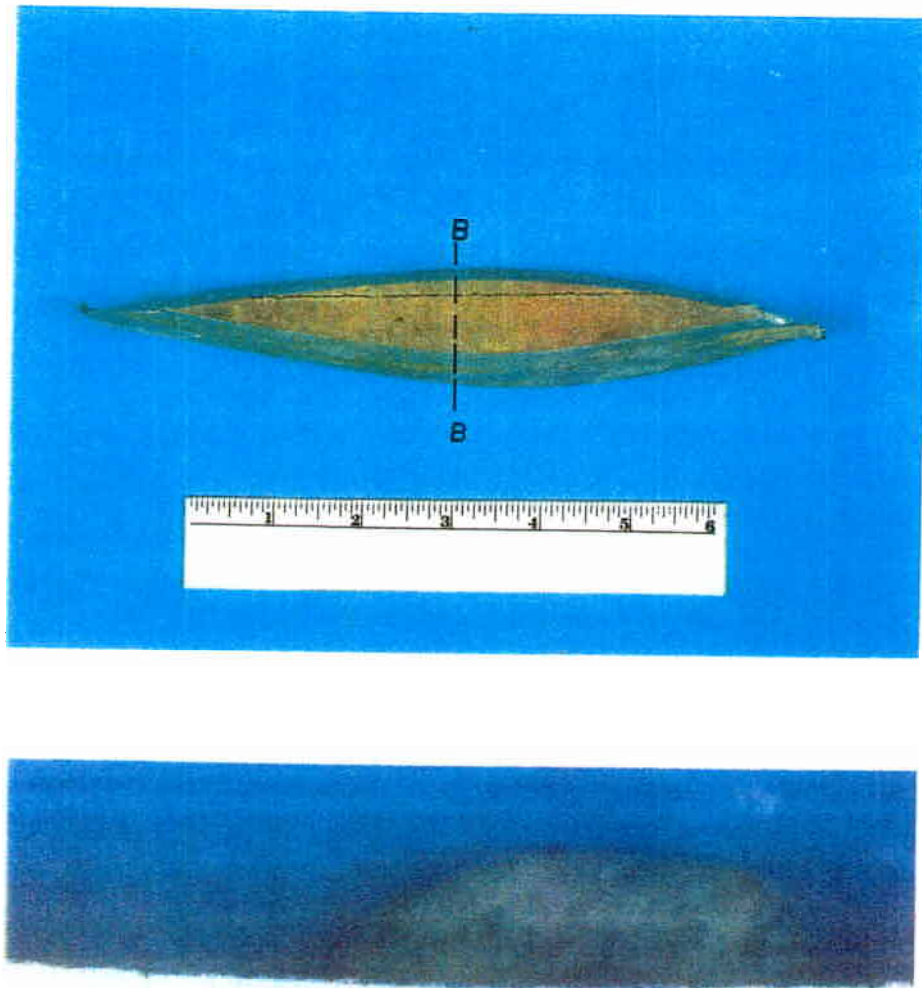


FIG. 7. SAMPLE NO. 3 BEFORE AND AFTER LIQUID PENETRANT EXAMINATION.

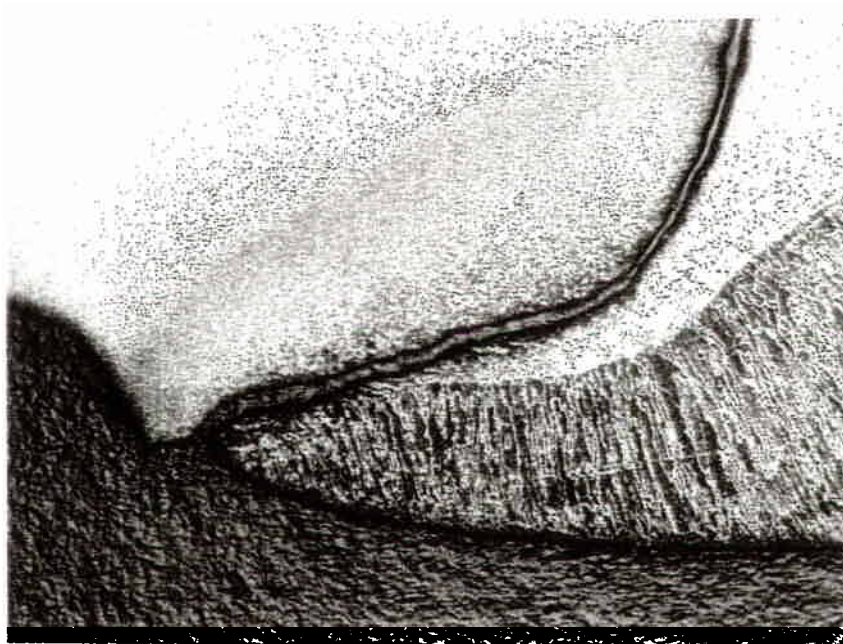
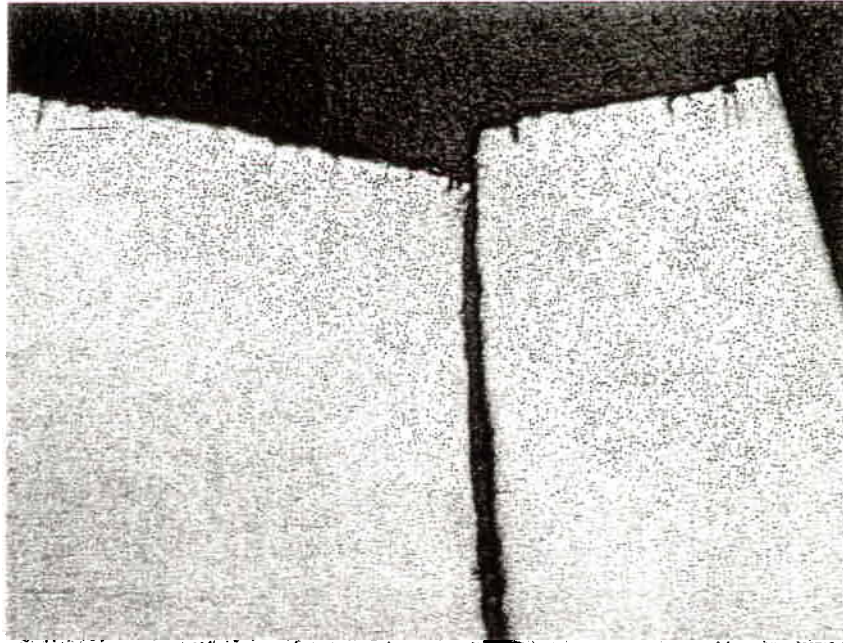


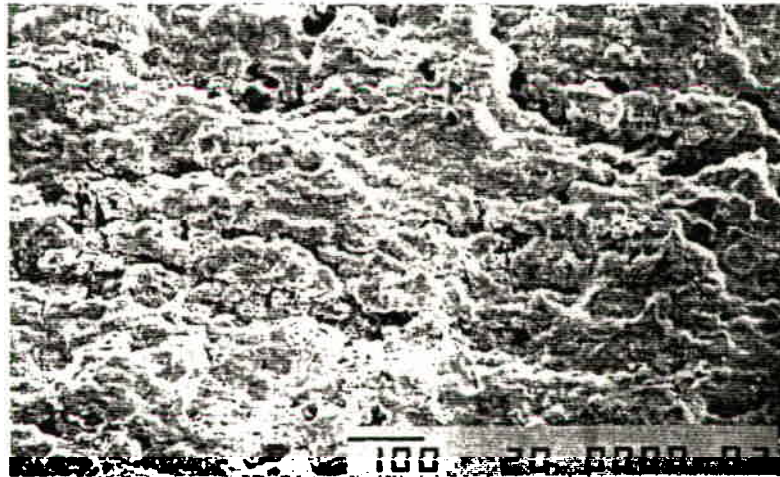
FIG. 8. PHOTOMICROGRAPHS OF SUBSEGMENT CUT AT CROSS SECTION "B-B".



35X



35X



100X

FIG. 9. SCANNING ELECTRON MICROGRAPHS (SEM) OF SAMPLE NO. 3 AFTER SEPARATION.

