APPENDIX 3G

CONTAINMENT LINER ANCHOR LOAD TESTS

The information contained in this appendix was not revised, but has been extracted from the original FSAR and is provided for historical information.

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FINAL REPORT

CONTAINMENT LINER ANCHOR LOAD TESTS

by

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Tests Performed for

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1. INTRODUCTION

The containment structure for the Public Service Company of New Hampshire's Seabrook Nuclear Power Station consists of a right vertical cylinder, a hemispherical dome, and a thick, flat base. In order to meet leak-tightness requirements for the containment acting as a pressure vessel, the entire inside surface of the concrete is covered with a steel liner. This liner is anchored to the concrete by embedded structural tees, angles, or studs which are welded to the steel liner plate. The containment is designed to resist the high temperature and pressure associated with the most severe break in a reactor coolant pipe. Under this postulated loading condition, the liner anchors must be adequate to maintain the structural integrity of the liner-liner anchor system. In order to evaluate, analytically, the adequacy of the liner anchors to perform their required function, experimental load-deflection data for individual anchors are needed for shear loads and displacements along the surface of the containment wall.

The results of load tests on liner anchors have been reported in References 2, 3 and 4. Of particular interest relative to the tests reported herein are the results reported in Reference 2 of tests performed at the University of Tennessee. These test results provide considerable information on load-deflection behavior of angles and a smaller amount of data on structural tees, both angles and tees being attached to 1/4 inch thick liner plates. The tests reported herein utilized the same test equipment and essentially the same test procedure as those tests in Reference 2 and were designed to provide experimental data directly applicable to the containment liner at Seabrook.

1.1 Objective

The objective of the tests aeported here is to obtain the shear load-displacement relationships for a) the Japanese Tee 100x100mm with 1/4 inch fillet welds which was used to anchor the containment liner at Seabrook and b) for 3/4 inch diameter x 12 inch long studs. The boundary support conditions for the liner plate test specimens were designed to represent, as nearly as practicable, those existing in the field; if an accurate simulation of field conditions was not practical, the support conditions were designed to produce conservative results.

1.2 Scope

A total of six shear tests were performed to accomplish the stated objective three tests on the Japanese Tee 100x100mm and three tests on 3/4 inch diameter x 12 inch long studs. Information was obtained in each test to plot the load-deflection curve for the anchor being tested.

1.3 Acknowledgment

The work reported herein was performed as a part of United Engineers and Constructors, Inc., Purchase Order No. H.O. 56971, Change Order No. 1. The facilities of the Department of Civil Engineering at the University of Tennessee, Knoxville, were used to perform the tests. A number of Civil Engineering students participated in the performance of the tests, with special commendation due to Steve Stethen, graduate student in charge, and to James Haley.

2. TEST SPECIMENS

All of the test specimens were prepared on the Seabrook plant site using procedures and materials approved for construction of the containment structure. A complete description of the test specimens with appropriate drawings is contained in Reference 1, and a sketch showing the dimensions of the test specimens is shown in Figure 1 herein. The concrete blocks in which both the tees and the studs were embedded were 3'-4" x 3'-0" x 2'-3" high with the liner attached to the 3'-4" x 3'-0" top face. The embedded tees were 12 inches long, and the two studs were spaced 12 inches apart. The welds for the tees were 1/4 inch continuous fillets on both sides of the stem. The embedded anchors were located 20 inches from the loaded front face of the test block, a distance equal to the horizontal spacing of the structural tee anchors. The length of the liner plate beyond the front edge of the concrete test block was determined by the dimensions of the test rig. After the specimens were cast, they were shipped to the University of Tennessee via flat-bed truck for testing.

At the time of casting, concrete cylinders representative of the concrete in each specimen were cast and stored at the Seabrook site. On the day a particular specimen was tested at the University, three corresponding cylinders were tested at Seabrook to obtain the compressive strength of the concrete.

Four specimens were cast with embedded tees and four with embedded studs. The test plan called for the testing of three specimens of each type. The fourth specimen of each type was cast as a safety measure; if one specimen was damaged in shipment or if the results of the first three tests suggested a revised testing procedure, the extra specimen would then be tested. It turned out that there was no reason to test the extra specimens; thus, three tee and three stud specimens were tested.

3. METHOD OF TESTING

3.1 Test Apparatus

The concrete block with the liner plate anchored to its top face was restrained by bearing against an abutment beam. The liner plate was fastened to a moveable head beam which was driven by two, 200kip capacity hydraulic rams. The driving of this head beam produced tension in the liner plate and, in turn, a shear load in the anchor. A hydrocal cap was placed between the leading top edge of the concrete block and the top 3 inches of the abutment beam. Calibration curves for the two load cells are included in Appendix C.

The test instrumentation consisted of the following key elements:

1. An LVDT was attached to the liner plate in the vicinity of the anchor. In the first test the LVDT was located behind the anchor - that is, on the side away from the applied load - but the rotation of the anchor and the resulting uplift of the plate behind the anchor caused some inaccuracies in LVDT readings at deflections beyond peak load (see Plates B1 and B2). Thus, for all later tests the LVDT was attached to the liner plate several inches in front of the anchor where there was no vertical movement of the liner plate (see Plate B8).
2. A Gilmore console was used to control the closed loop testing system. A voltage input at the console causes the pump to drive the hydraulic ram until a voltage output from the LVDT sends a feedback signal that precisely matches

the voltage input signal, at which point the system is in equilibrium.

3. Load cells are attached to the head beam which pulls the plate in such a way that the rams act directly against the cells. The signal from the load cells is transmitted to a digital strain indicator which is calibrated to read the load directly in kips.

4. An XY plotter is keyed into the system in such a way that it receives signals from both the LVDT and the load cells. These two signals cause the XY plotter to produce a continuous plot of load versus deflection while a test is in progress.

3.2 Test Procedure

The tests proceeded as follows:

1. A small input voltage, corresponding to a small deflection, was "dialed in" at the console. The pumps then drove the rams until sufficient movement of the anchor resulted in an output voltage from the LVDT which matched the input voltage. The load required to produce that deflection was read and recorded, and the XY plotter made a continuous record of load and deflection up to that point.

2. The procedure just described was repeated for increments of deflection small enough to obtain an accurate plot of the measured data. Measurement of load and deflection continued until the full 0.5 inch travel of the LVDT was reached or failure of the anchor occurred. For those tests where failure had not occurred at the limit of travel of the LVDT, the LVDT was disconnected from the specimen, and the test was continued to failure to observe the mode of failure of the embedded anchors. A dial gage was attached to the specimen to provide a check on the deflections measured by the LVDT.

3.3 General Comments

Two aspects of the testing procedure merit special comment:

1. The load was applied to the anchors in the tests through a pull on the plate rather than a push on the plate as used in the tests in Reference 4. This type of load application obviated the need for any bending stiffeners on the liner plate, permitting a realistic representation of the rotation of the liner plate at the anchor. However, the fact that the unloaded end of the liner plate was unrestrained permitted it to lift off the test block as a result of the anchor rotation. In an actual liner-liner anchor system, this lift-off would be restrained by another embedded tee or row of studs, restraint that would add to the stability of the system. This effect is particularly important in the tee tests. Therefore, the method of testing these specimens was such that the load-deflection curve obtained for an anchor would be a conservative representation of the actual load-deflection relationship for an anchor in an actual field installation.
2. The tests were controlled by deflection rather than by load. The input voltage corresponded to a deflection and the rams acted to produce this deflection; the load required to produce this deflection was then read from the multimeter. This method of controlling the tests permitted the definition of the descending portion of the load-deflection curve for an anchor.

4. TEST RESULTS

The test results are summarized in Tables 1 and 2, and load-deflection curves are shown in Figures 2 and 3. Original data, including XY plots, are included in Appendix C. Selected photographs are presented in Appendix B to illustrate the testing operations and the mode of failure of the anchors.

4.1 Discussion of Results

The irregularities present in the load-deflection curves shown in the XY plots in Appendix C are due, for the most part, to relaxation of the concrete causing a reduction in load under a constant deflection. When the test was stopped to take readings or, for that matter, when the person dialing in the voltage hesitated a bit, the system responded by maintinaing constant deflection; and the load required to maintain this deflection immediately decreased.

The load-deflection curves for the tees, shown in Figure 2, drop off sharply immediately after peak load is reached. At peak load the rotation of the tee in the concrete produces a crack on the back side of the flange of the tee. The local instability of the anchor results in a sharply reduced load-carrying capacity; in fact, the only load-carrying capacity remaining is that required to fail the concrete wedge directly in front of the embedded tee.

The drop-off in load beyond the peak was so sudden that, for T-1 and T-3, the testing equipment was incapable of tracking it accurately. The sudden load instability of the concrete around the tee would permit the anchor to move too far forward, "overshooting" the dialed in voltage. The rams would then try to rectify the situation by retracting; however, the rams were not connected to the head beam, so their retraction allowed the load to go to zero. This situation is illustreted by the load-deflection curves obtained from the XY plotter and included in Appendix C. This loss of load presented no particular problem; a new, higher voltage was dialed in, the test was continued, and a continuation of the load-deflection curve was obtained. In an actual containment liner-liner anchor system, the restraint provided by an adjacent anchor would almost certainly reduce the sharpness of the drop-off of the load-deflection curve and enhance the ductility of the tee anchors.

The distinctly different shapes of the load-deflection curves for the tees and for the studs reflect the different modes of failure for the two anchor systems. The fillet welds joining the tee's to the liner plate were of sufficient strength to prevent a failure of the steel embedment; thus, the shear strength of the anchor was limited by concrete tension acting to resist the rotation of the tee produced by the applied shear. Ductility of the embedded tees resulted from the development of a secondary mode of failure, namely, the diagonal tension failure of the wedge of concrete directly in front of the tee. Conversely, the limiting strength element in a stud test was the shear strength of the studs. In each case the studs sheared just below the weld which attached them to the liner plate. The resulting load-deflection relationship resembles the stress-strain curve for steel, with a corresponding high degree of ductility. Interestingly, the maximum shear stress in the studs for an average of the three tests was 60 ksi.

5. CONCLUSIONS

The load-deflection curves shown in Figures 2 and 3 represent, in the opinion of this writer, a reasonable description of the shear load-deflection behavior of the anchors tested. Because of the absence of any hold-down restraint on the free ends of the liner plates in the tests, the descending portions of the curves for the tees should be somewhat higher. Thus, the curves in

Figure 2 may be thought of as reasonable but somewhat conservative representations of the behavior of actual embedded tee anchors.

REFERENCES

1. Galunic, Branko, "Procedure for Containment Liner Anchor Load Test", United Engineers and Constructors, Inc., Philadelphia, PA 19101, Revised August 25, 1980 (attached to Purchase Order No. H.O. 56971, Change Order No. 1).

2. Burdette, Edwin G. and Rogers, Larry W., "Liner Anchorage Tests", Journal of the Structural Division, ASCE, Vol. 101, No. ST7, Proc. Paper 11432, July 1975, pp 1455-1468.

3. Lee, T. and Gurbuz, O., "Assessment of Behavior and Designing Steel Liners for Concrete Reactor Vessels", Final Report, Engineering Research Institute, Iowa State University, Ames, Iowa, Nov. 1973 (prepared for the U.S. Atomic Energy Commission Under Contract No. AT(11-1)-2267).

4. "Liner Plate Anchorage Tests", Bechtel Corporation, San Francisco, California, for Arkansas Nuclear One, Arkansas Power and Light Co., April 18, 1969.

APPENDIX A

TABLES AND FIGURES

Table 1

Test Data for Tee Specimens

Specimen	Concrete Age (Days)	Concrete f'_c (psi)	Peak Load (kips)	Peak Load (k/in)	Defl. Peak Load (ins.)	Load at Δ = 0.25 in. (kips)
T-1	20	5,710	152	12.67	0.070	36
T-2	24	5,770	156	13.0	0.070	34
T-3	28	5,950	144	12.0	0.060	32
Avg.		5,810	150.7	12.6	0.067	34

Table 2

Test Data for Stud Specimens

Specimen	Concrete Age (Days)	Concrete f'_c (psi)	Peak Load (kips)	Peak Load (k/stud)	Defl. at Peak Load (Ins.)	Load at Δ = 0.25 in. (kips)
S-1	42	6,100	51.5	25.8	0.390	48
S-2	56	6,060	54.8	27.4	0.620	46
S-3	67	6,500	52.5	26.3	0.395	49
Avg.		6,220	52.9	26.5	0.468	47.7

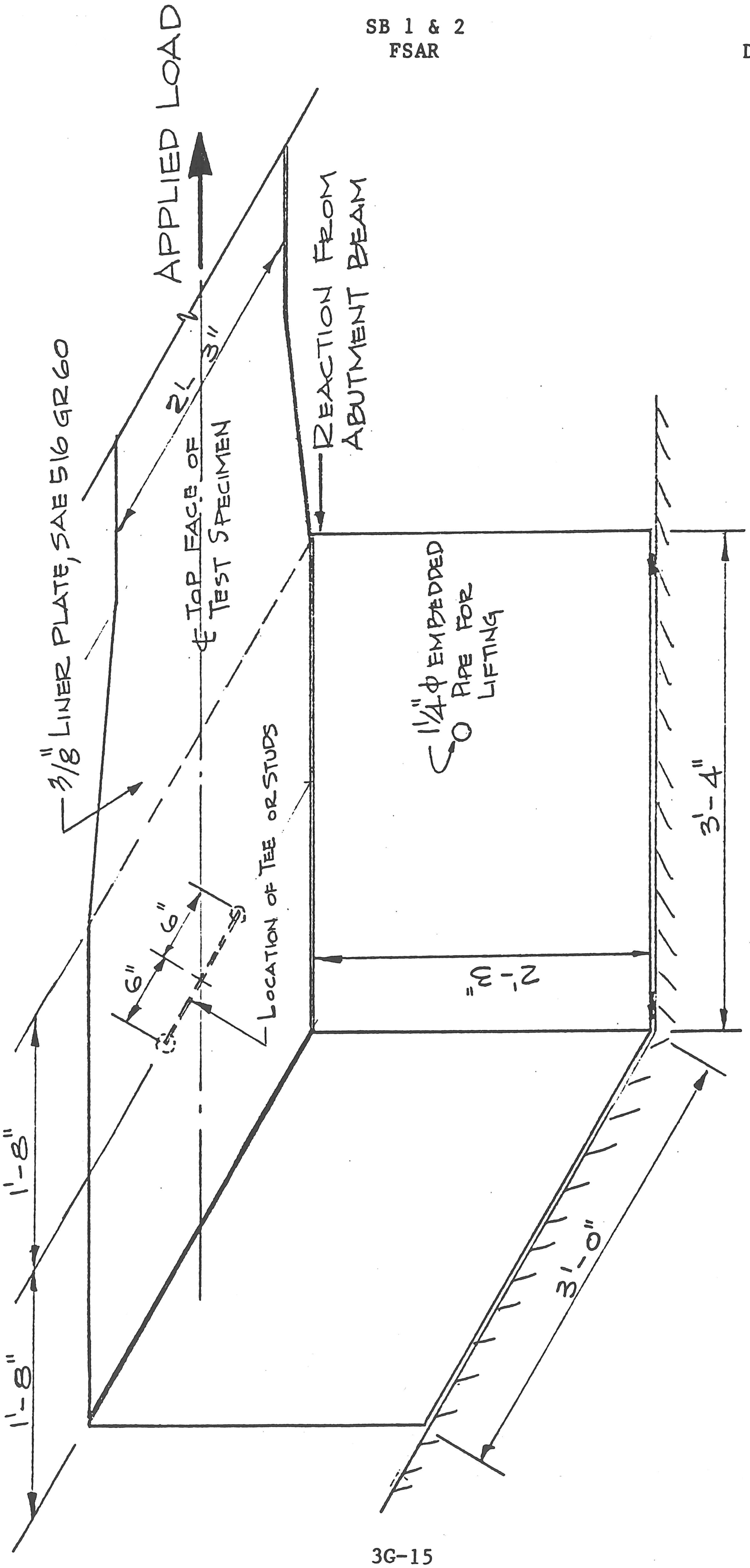

FIGURE 1. SKETCH SHOWING DIMENSIONS OF TEST SPECIMENS

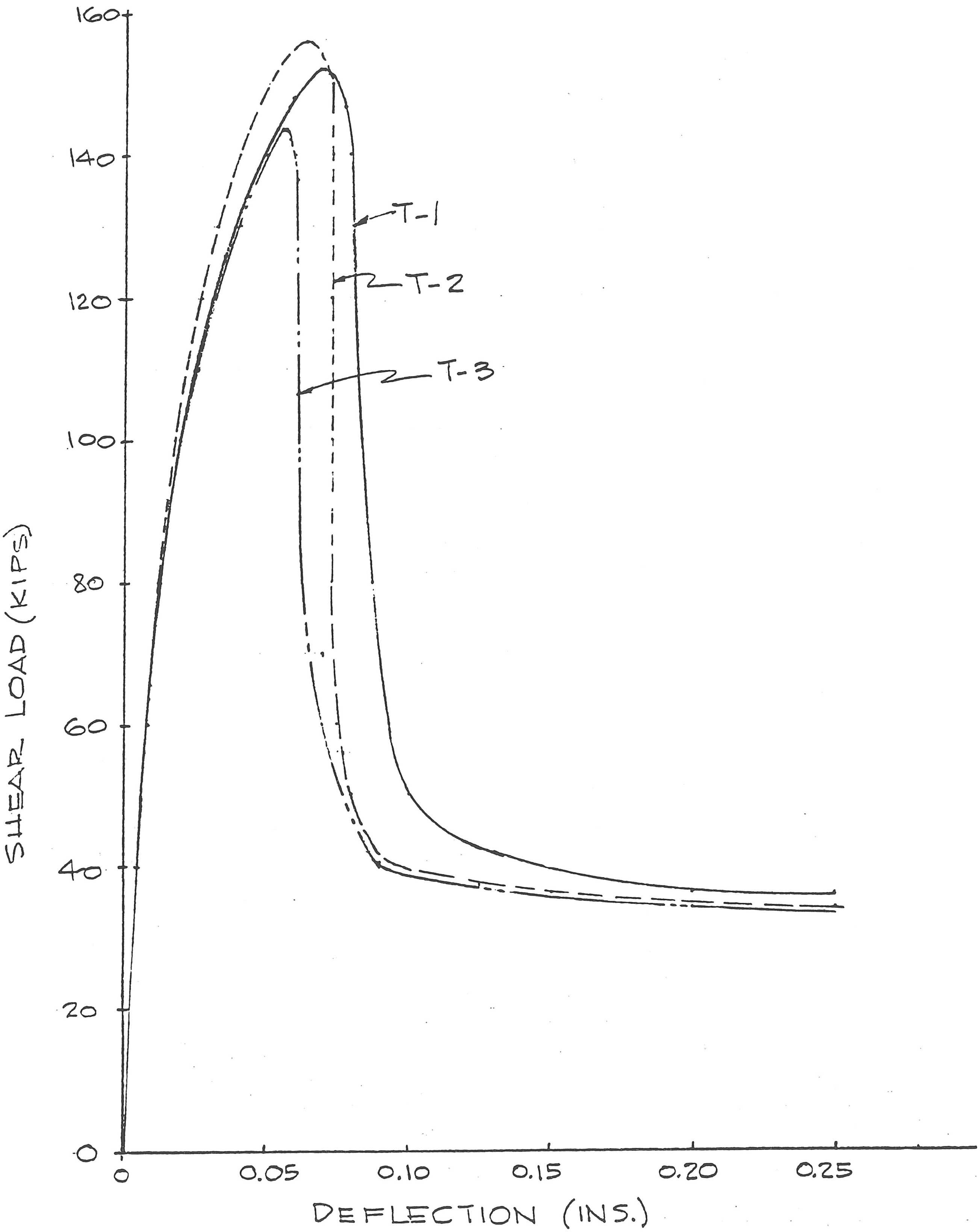

FIGURE 2. LOAD-DEFLECTION CURVES ~ TEE SPECIMENS
~ JAPANESE TEE 100 x 100 MM w/ 1/4" WELDS -

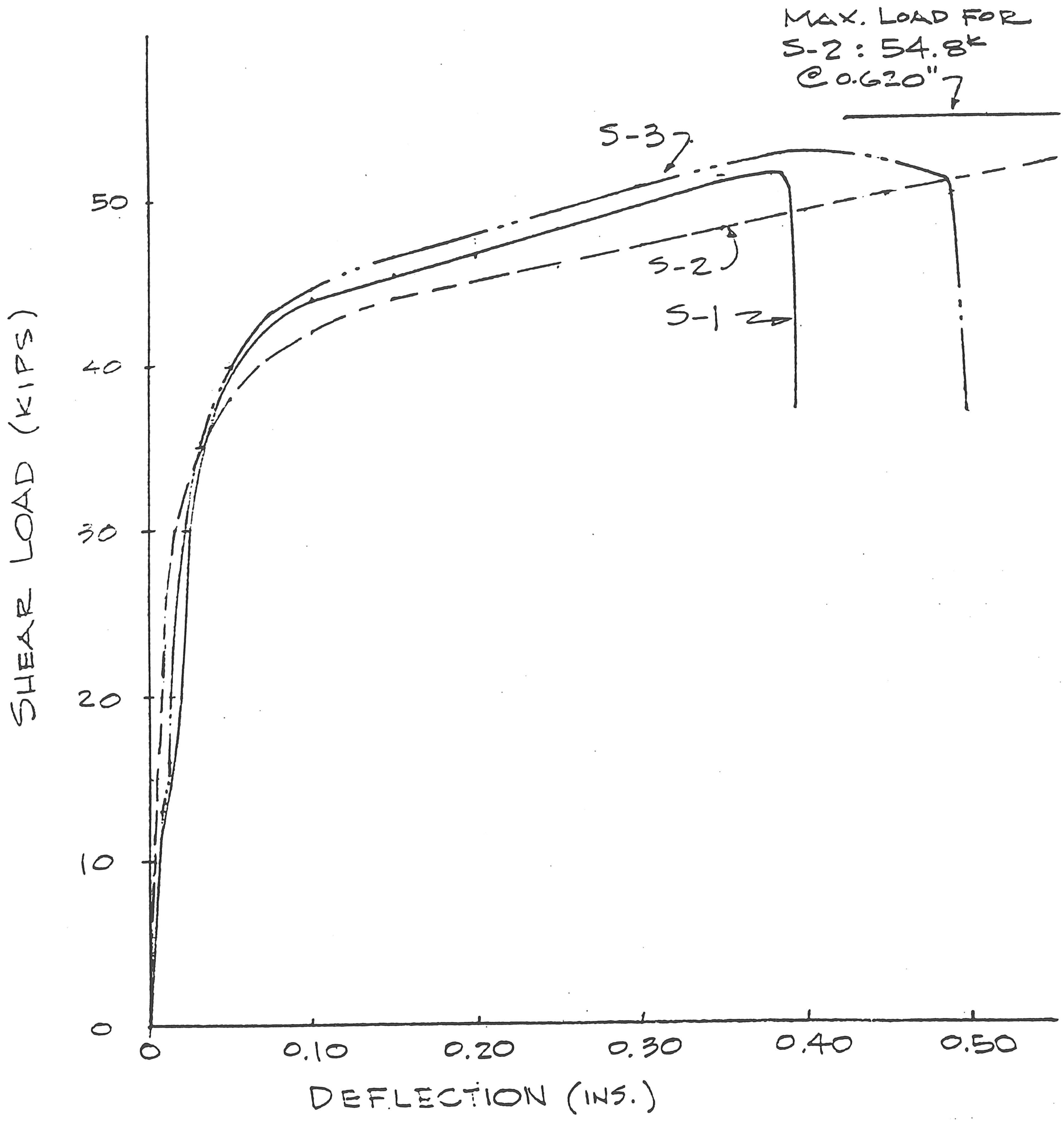

FIGURE 3. LOAD-DEFLECTION CURVES ~ STUD SPECIMENS
- 2, 3/4" Φ × 12" LONG STUDS -

APPENDIX B

PHOTOGRAPHS

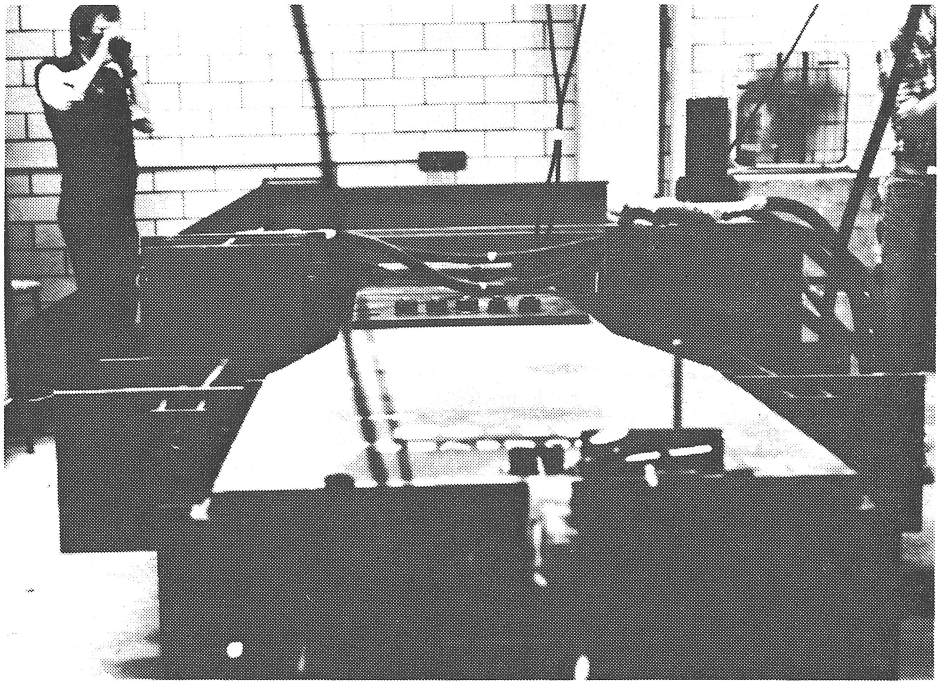

Plate B1: Specimen T-1. Test Assembly at Start of Test

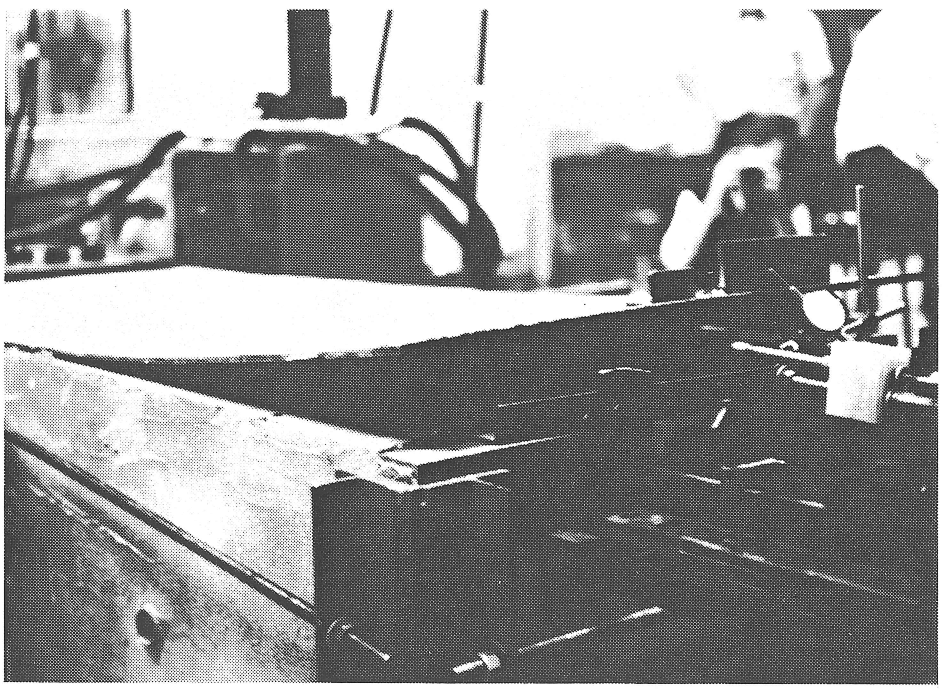

Plate B2: Specimen T-1. Plate Deformation During Final Stages of Testing

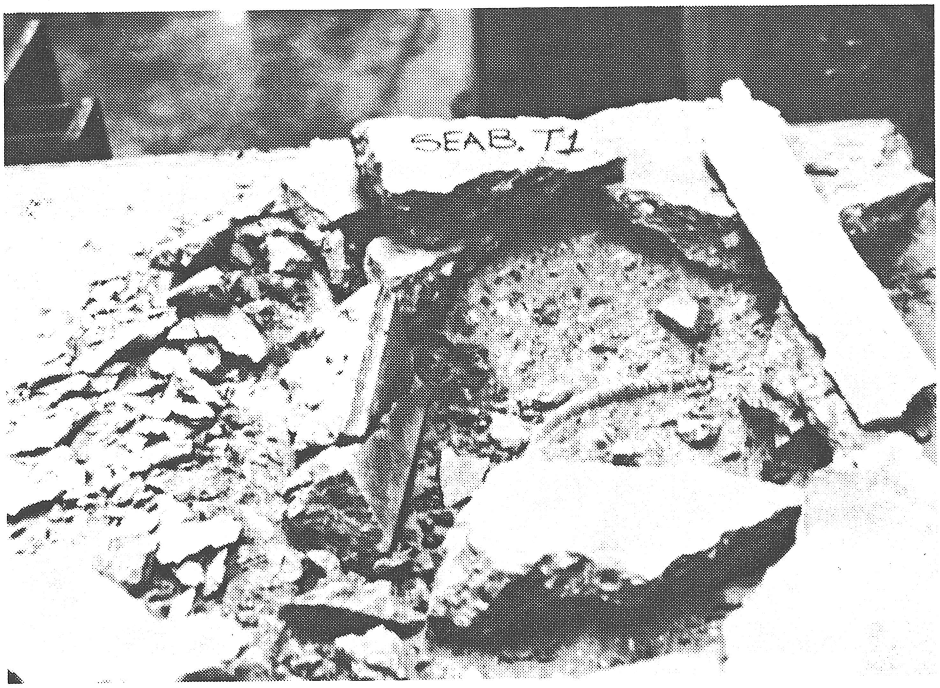

Plate B3: Specimen T-1. Concrete Surface After Removal of Liner Plate

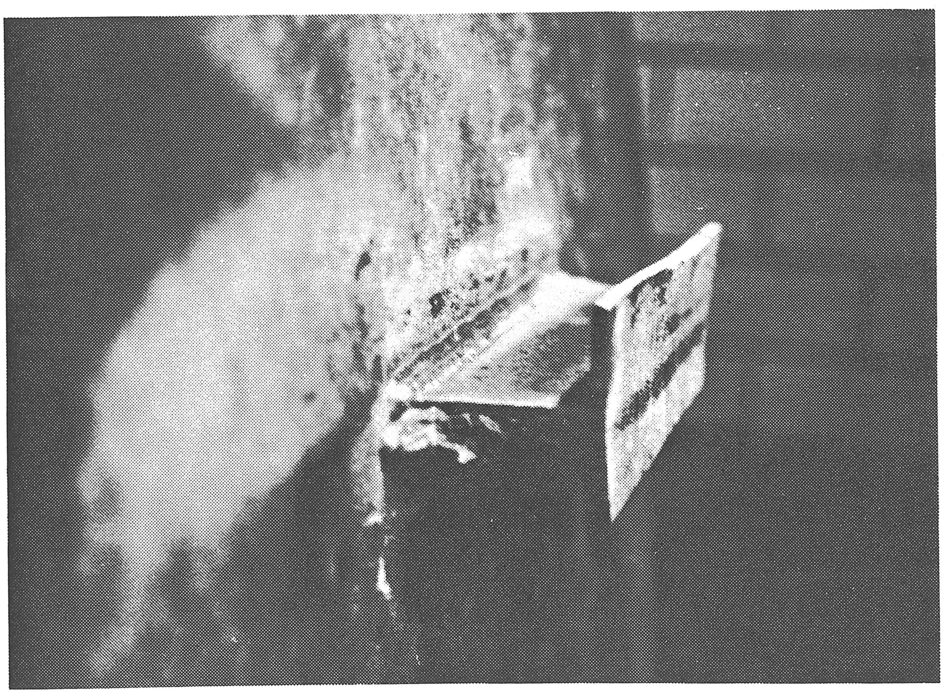

Plate B4: Specimen T-1. Liner Anchor (Tee) After Test

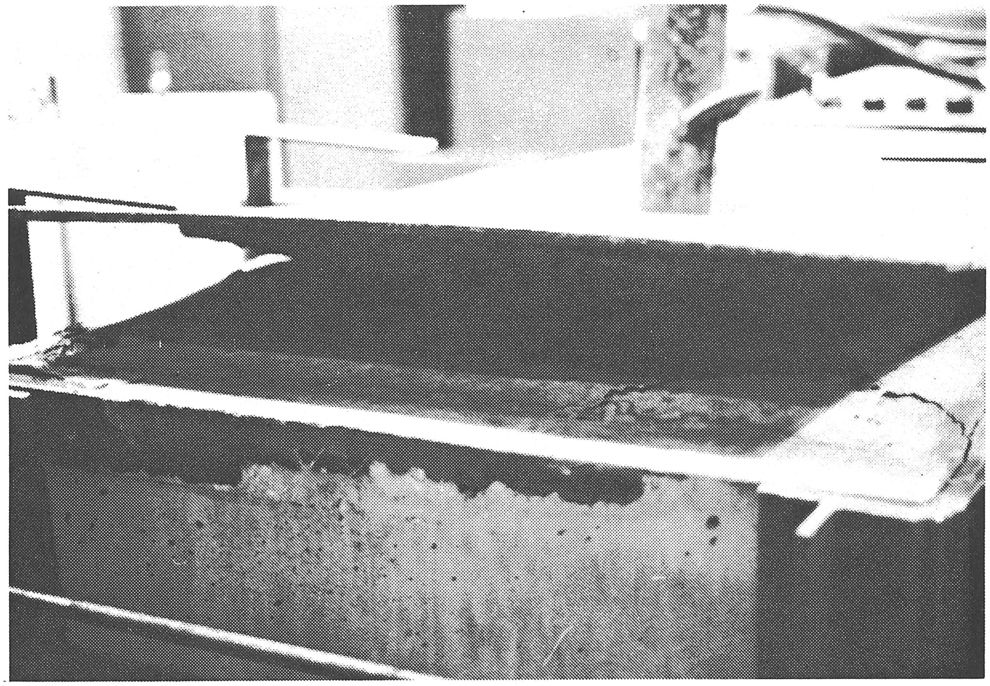

Plate B5: Specimen T-2. Liner Deformation at End of Test

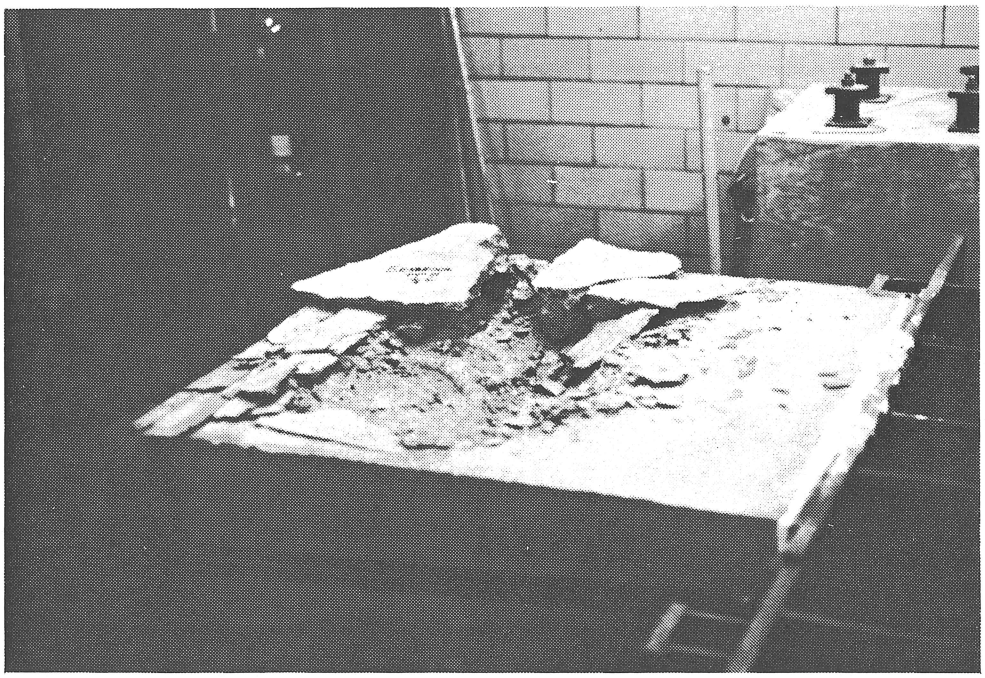

Plate B6: Specimen T-2. Top of Concrete at End of Test

Plate B7: Specimen T-2. Liner and Tee at End of Test

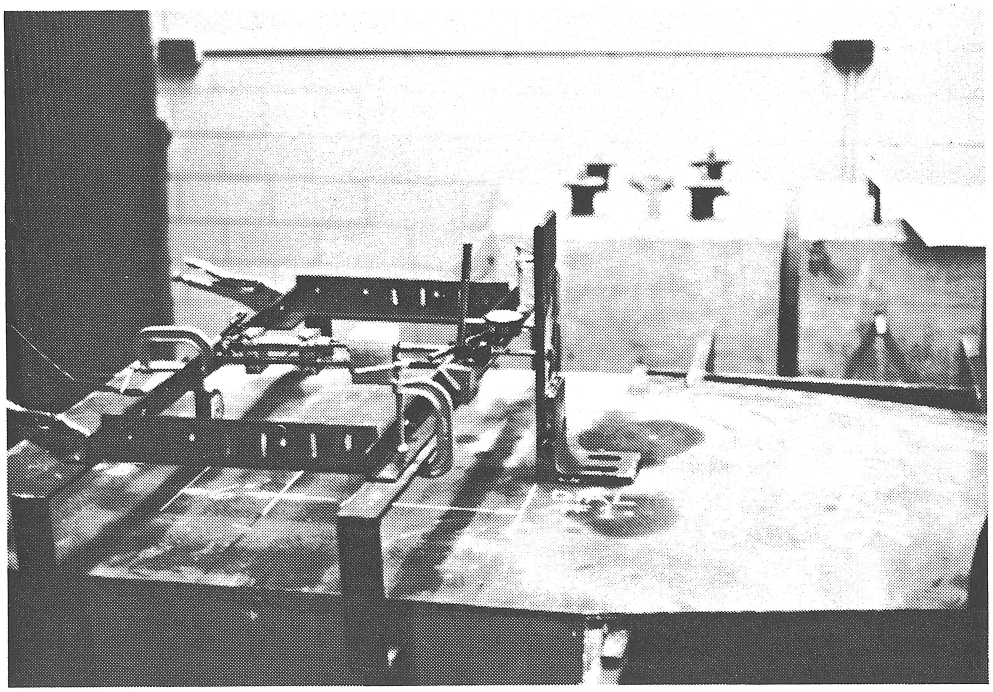

Plate B8: Specimen T-3. Instrumentation at Start of Test

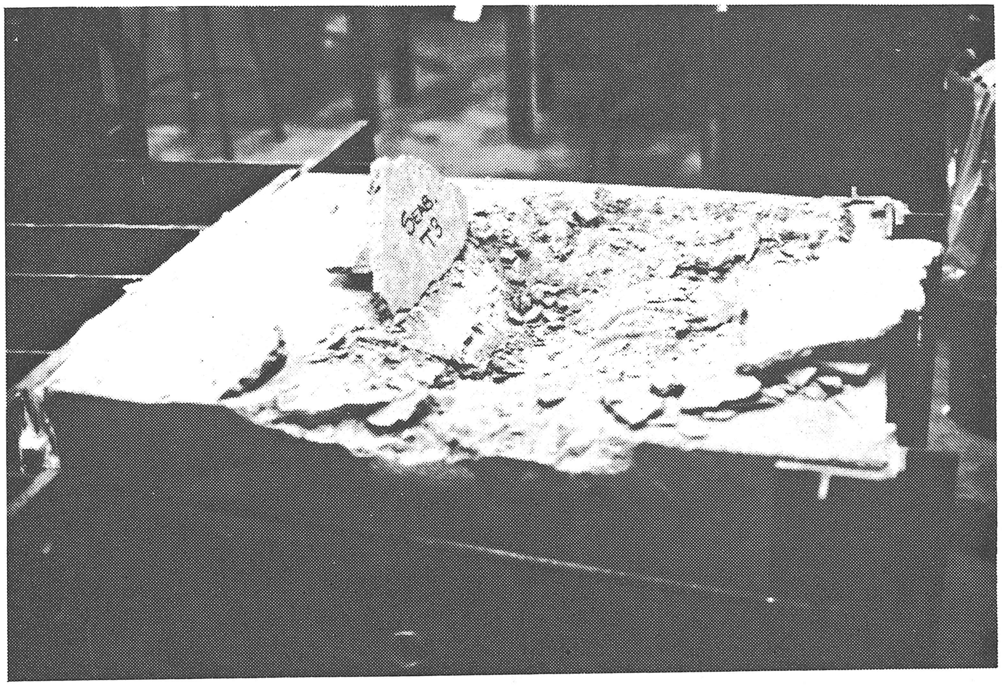

Plate B9: Specimen T-3. Concrete Surface After Removal of Liner Plate

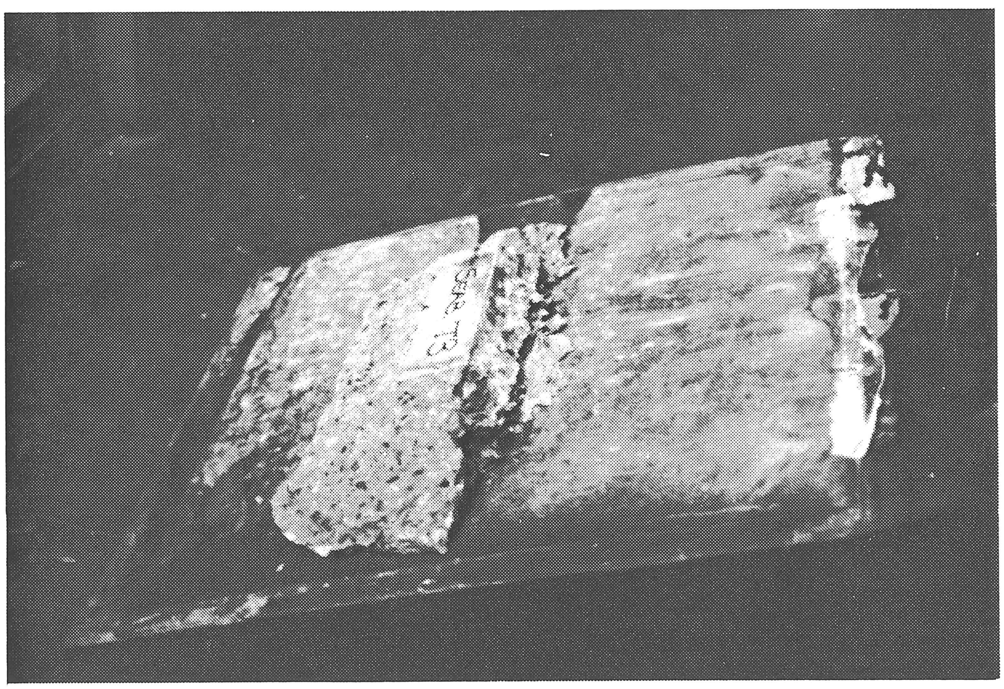

Plate B10: Specimen T-3. Liner and Tee After Removal of Liner Plate

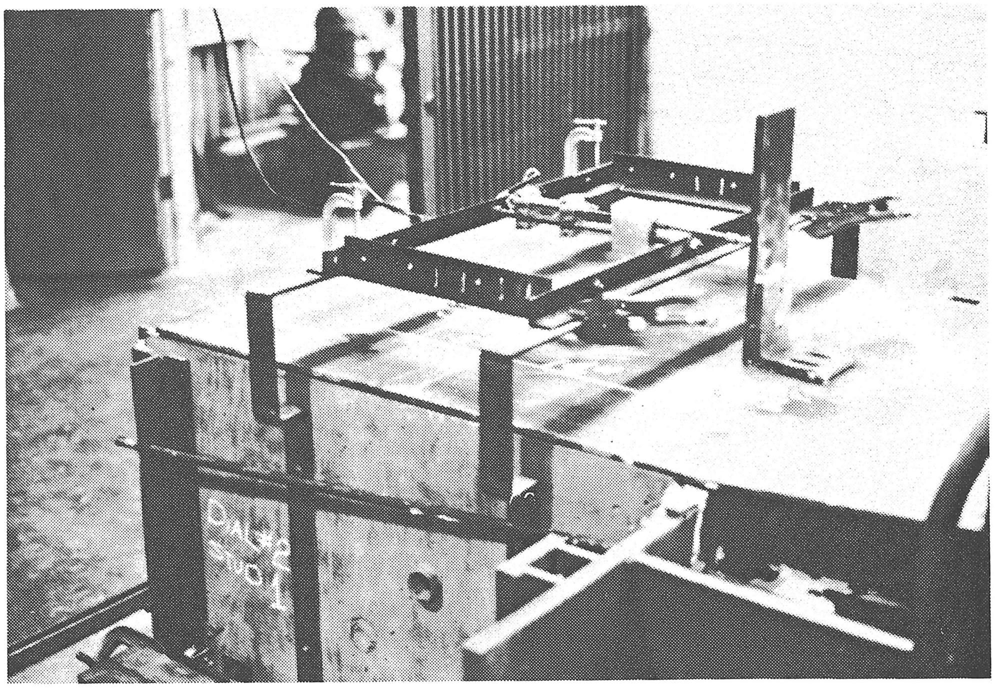

Plate B11: Specimen S-1. Start-up of Test

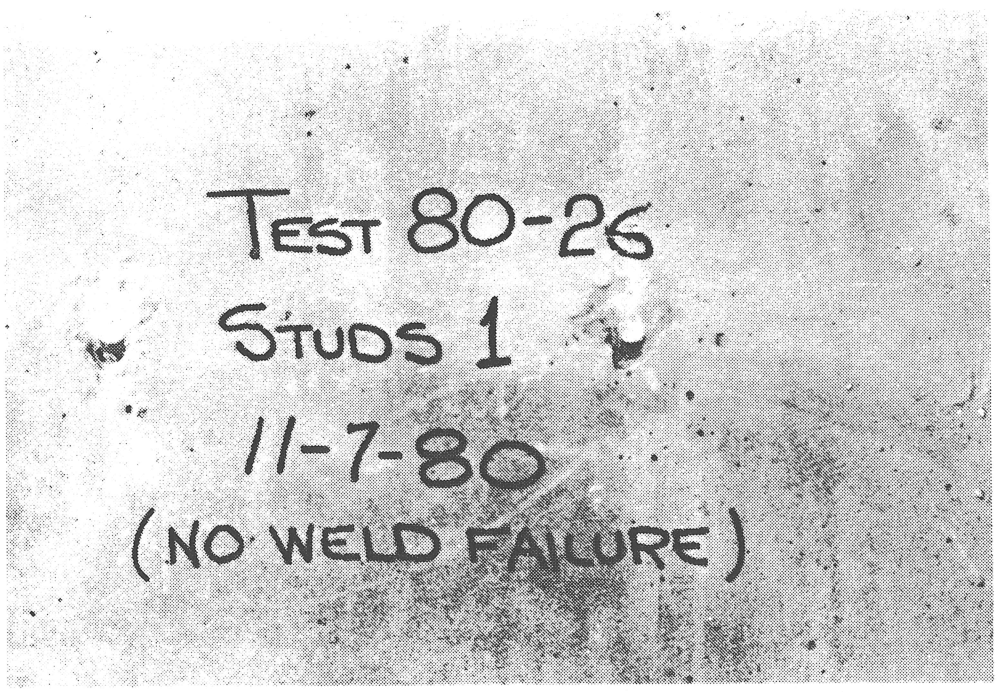

Plate B12: Specimen S-1. Studs in Concrete After Shear Failure

Plate B13: Specimen S-1. Detail of Sheared Stud in Plate

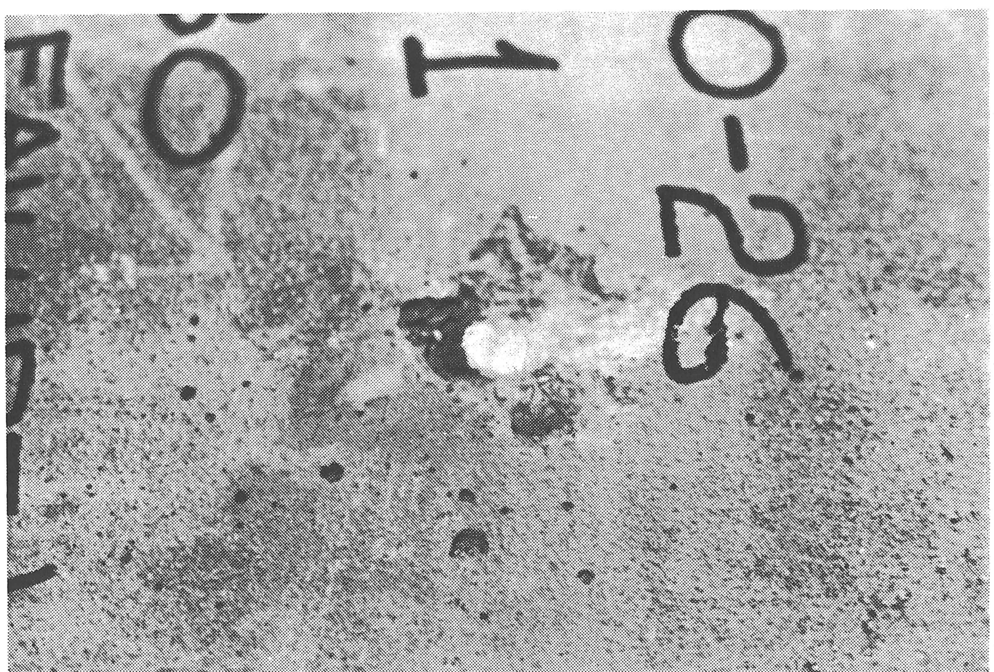

Plate B14: Specimen S-1. Detail of Sheared Stud in Concrete

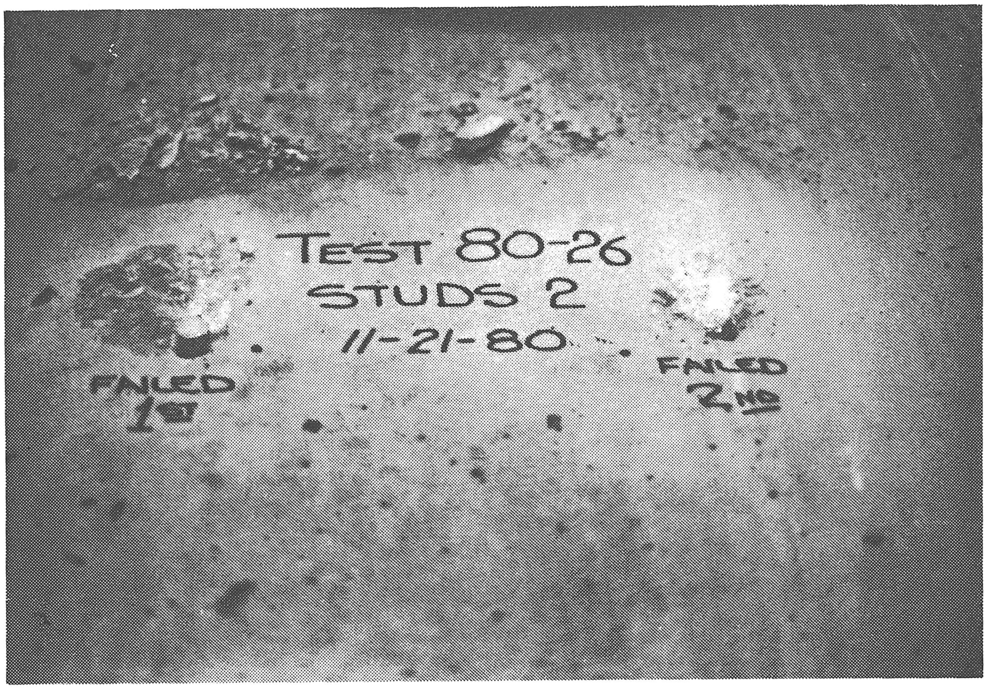

Plate B15: Specimen S-2. Concrete Surface After Failure of Studs

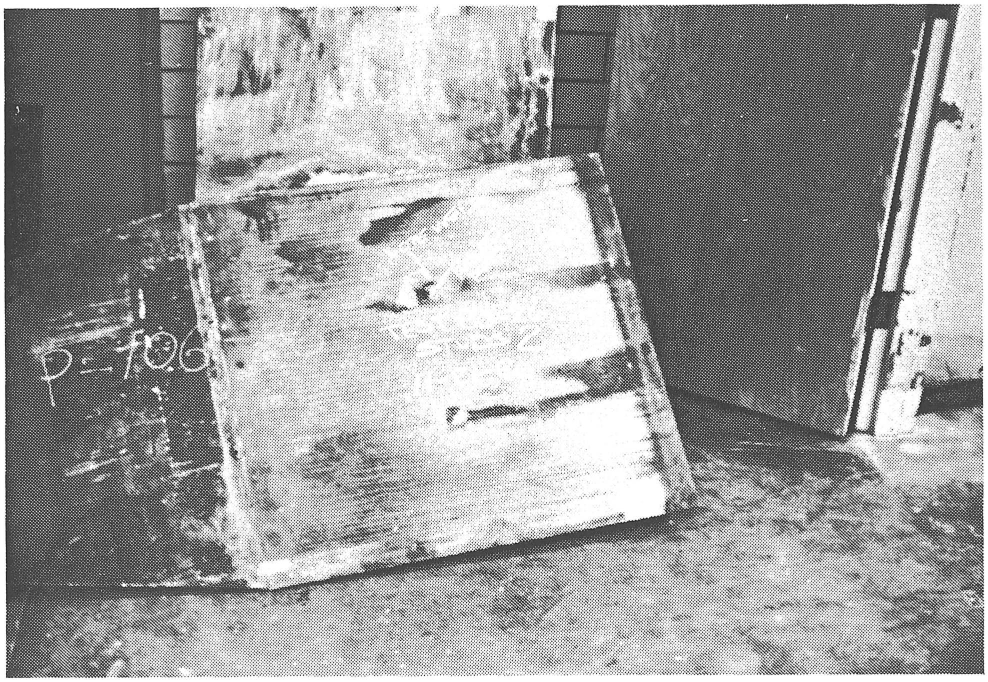

Plate B16: Specimen S-2. Liner After Stud Failure

Plate B17: Specimen S-2. Detail of Sheared Stud in Concrete

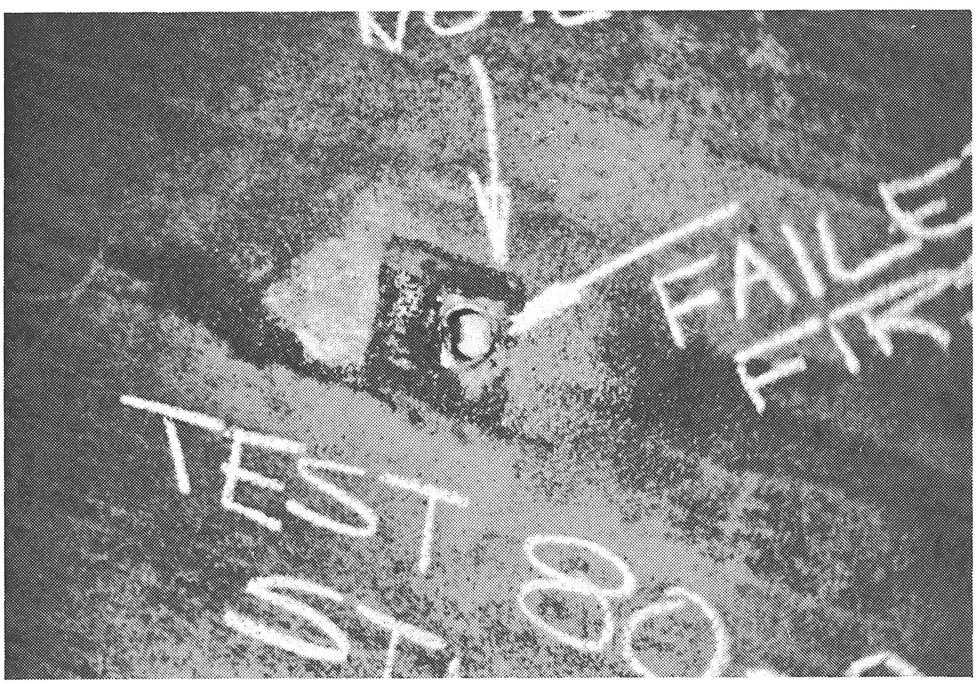

Plate B18: Specimen S-2. Detail of Sheared Stud in Plate

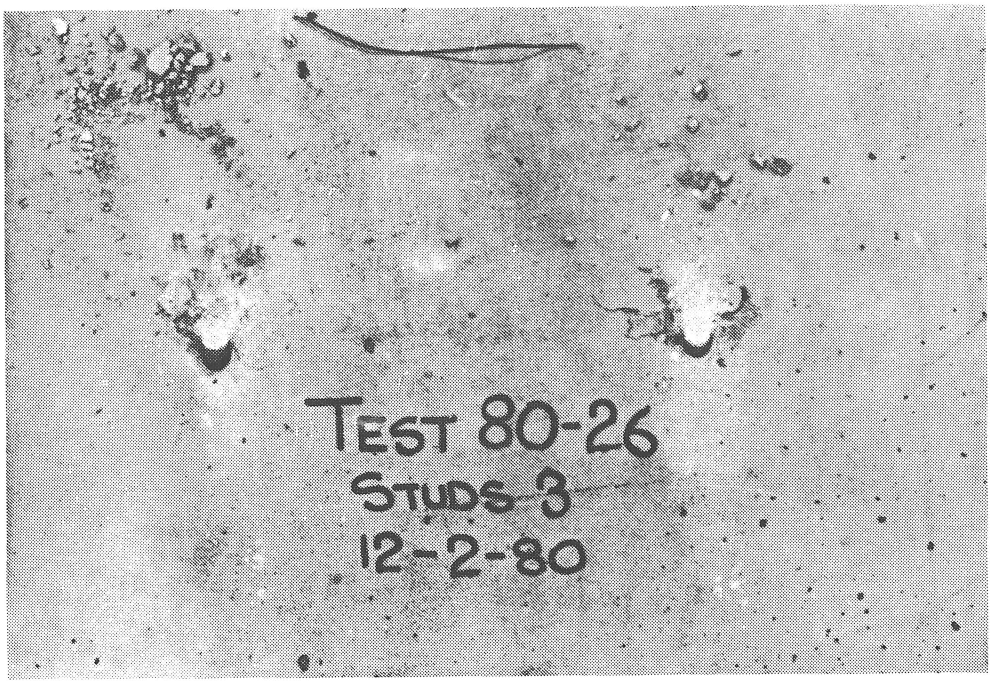

Plate B19: Specimen S-3. Sheared Studs in Concrete After Test

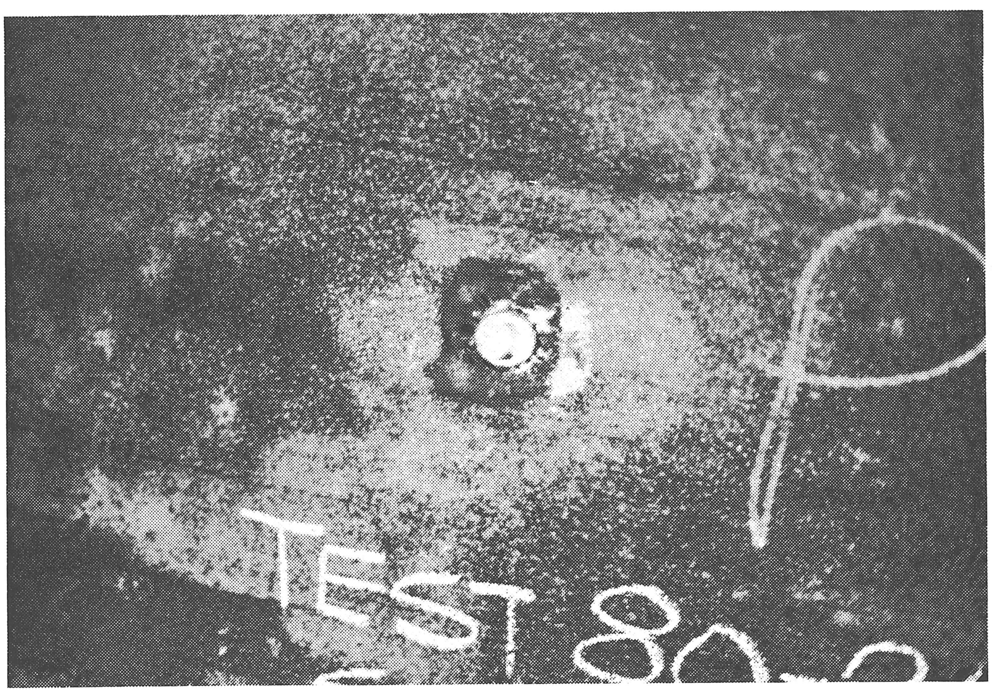

Plate B20: Specimen S-3. Sheared Stud in Plate After Test