SARGENT & LUNDY
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CHICAGO

ASSESSMENT OF STITCH WELD STRENGTH IN HVAC DUCTWORK CONSTRUCTION

LA SALLE COUNTY STATION

UNITS 1 & 2

Prepared by

Component Qualification Division

for

COMMONWEALTH EDISON COMPANY

Report No. CQD-003490

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INTRODUCTION

This report presents a summary of Sargent & Lundy Engineers (S&L) assessment and evaluation of the strength of quality control rejectable stitch welds, used in ductwork construction in LaSalle County Nuclear Station (LSCS) units 1 & 2. The stitch welds under consideration join the duct to the companion angle flange in some safety-related HVAC systems. The overall scope of this report is addressed in the following sections:

I - Background
II - Objective
III - Design Consideration
IV - Test Program
V - Observation & Interpretation of Test Results
VI - Conclusions
Appendix A - Representative Design Cases
Appendix B - Test Results
Appendix C - Photographs of Test Samples

I. BACKGROUND

The HVAC ductwork construction and installation for LSCS is contracted to the ZACK Company. Their ducts are constructed in the shop in four feet sections with companion angle flanges welded on both sides of the section (see fig. 1). Then the duct sections are joined together in the field by means of flange bolts or Huck screws. All duct sections constructed are shipped to the site after passing the ZACK Quality Control Procedure CQP-20 which is approved by the Commonwealth Edison Company (CECo) and their Architect/Engineer (S&L). It was discovered that an unqualified welder has performed some work on Safety-Related ducts for units 1 & 2. Therefore, CECo has initiated a field inspection program for the affected HVAC duct systems in accordance with QCP-20.

The program was conducted by personnel from CECo Q.C., ZACK Q.C. and CECo's independent Q.C. reviewer (CONAM). It resulted in finding some rejectable stitch welds in accordance with ZACK CQP-20. These welds fall under the following four major categories:

- undercut
- porosity
- bad profile
- lack of fusion

A test program was authorized by CECo for the assessment and evaluation of the adequacy of Q.C. rejectable stitch welds. 64 random samples of Q.C. rejectable stitch welds were selected from different duct sizes taken from the affected duct systems in unit 2. The samples comprise all previously mentioned four categories of weld deficiencies in addition to some Q.C. acceptable stitch welds for comparison.

II. OBJECTIVE

The objective of this assessment program is to correlate the design aspects of the stitch welds as documented at S&L to the strength of Q.C. rejectable welds based on the test program and the margin of safety existing, if any. In other words, to find out whether or not the Q.C. rejectable stitch welds can resist the postulated design loads with adequate margin of safety and maintain the structural integrity of the affected Safety-Related HVAC systems.

III. DESIGN CONSIDERATIONS

The stitch welds under consideration join the duct sheet metal to the companion angle flange (see fig. 1). They are fillet types with a nominal length of 1.0" and throat dimension of 0.125" (1/8) and 0.1875" (3/16) depending upon the duct size. The welds are spaced every 8" along the duct to companion angle flange joint periphery.

Spacing and sizing of the welds are governed primarily by leak tightness requirements for the joint and by usual construction practice, not by the required weld strength. In addition, the design of duct systems is based solely on the governing sheet metal stresses. It is obvious from duct construction that (see fig. 1) the vertical and transverse shear forces and out-of-plane bending moments at the joint cross-section will be transmitted to the stitch welds as shear force.

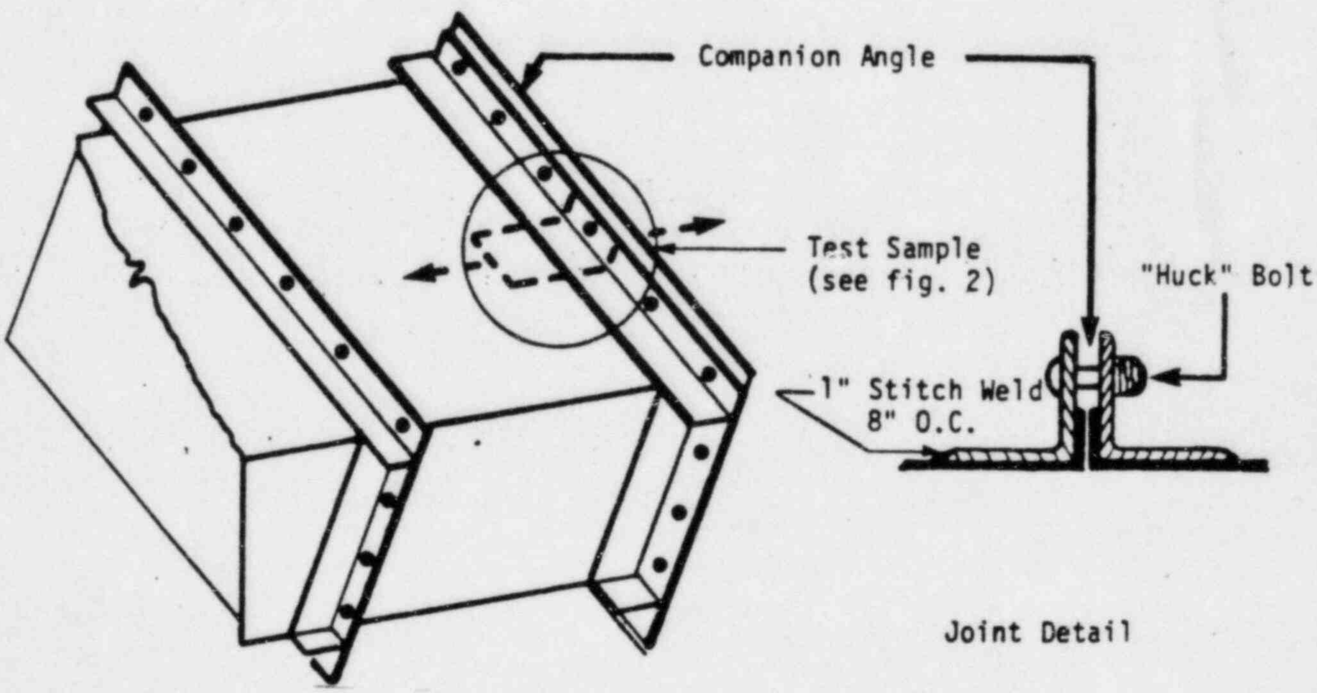


Figure 1
Typical Duct Section

Appendix A delineates the four most representative cases for LSCS ducts. One can easily observe that the maximum load/stitch weld due to internal pressure, weight and postulated dynamic loads does not exceed 400 lbs. In other words, the stitch weld is not resisting more than 400 lbs regardless of the duct size and spacing. This load translates to a stress of 3200 psi in the weld. The design load for 1/8" throat fillet weld is 2400 lbs/in per AISC design specicification for E70 welding electrode.

The aforementioned discussion attests to the fact that the duct design is governed by sheet metal strength. Hence, in a hypothetical case of failure the duct sheet metal will reach the material ultimate stress long before the stitch weld reaches its design load.

IV. TEST PROGRAM

The purpose of this program is to determine the strength of "Q.C. rejectable stitch welds" based on random sampling. The test has been conducted at Pittsburg Testing Lab., Hillside, IL on 8/16/82.

Test Specimen Configuration

Figure 2 depicts a typical dimension of the random test samples in order to simulate the existing installation condition.

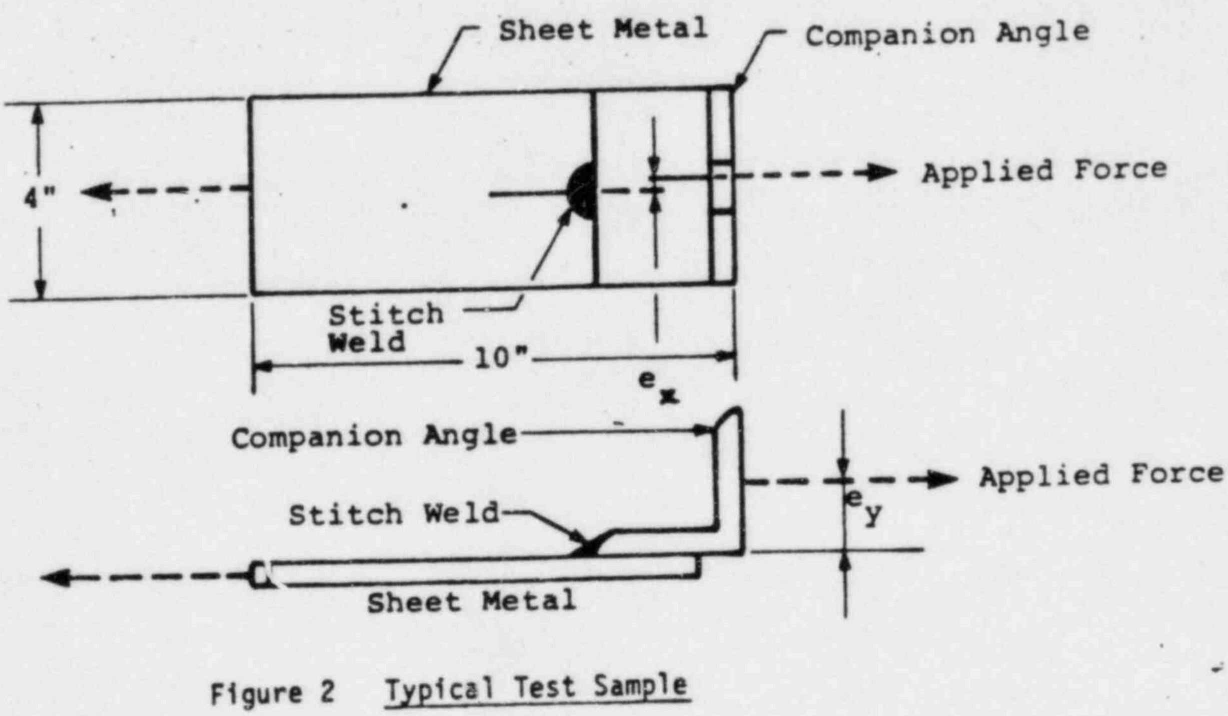


Figure 2 Typical Test Sample

Determination of Test Samples

There are a wide range of variation in the sizes of companion angles as well as the thickness of sheet metal in ductwork construction, coupled with various defective or rejectable welds per E70 Electrode weldment for ductwork joint construction.

The following Lists-(a) & (b) show the representation of test samples for "Pull" test:

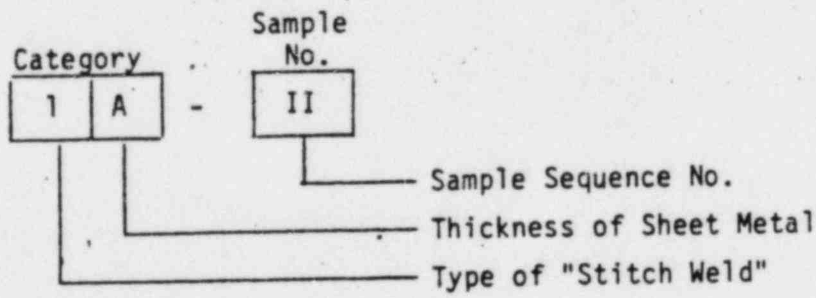
(a) Type of "stitch welds" Sample

1. Q.C. acceptable weld
2. Undercut weld
3. Porous weld
4. Bad profile weld
5. Lack of fusion in weld

(b) Thickness of Sheet Metal for Ductwork Construction

A. 22 GA (0.0312")
B. 20 GA (0.0375")
C. 18 GA (0.050")
D. 16 GA (0.062")

Thus, the designation of test sample shall be shown as follows:



The total of 64 test samples has been subjected to "Pull" test for reflecting proper representation of physical cases.

Test Description

Each sample was clamped to the stationary jaw of the test machine at the sheet metal section (see fig. 2). The pull load (shear force on the weld) applied to the weld via 3/8" bolt attached to test fixture which in turn is connected to the moving jaw of the test machine. The applied load was increased gradually till failure is indicated either by sheet metal separation or yielding of the companion angle (bolt punching through).

V. OBSERVATION & INTERPRETATION OF TEST RESULTS (see Appendix B)

1. Failure of the tested samples were either cracking of the sheet metal or yielding of the companion angle. in either case the welds were still intact after the test.

2. A summary of the governing results is shown in Table 1 of Appendix B, where the highest (upper bound) and lowest (lower bound) failure loads are listed for all weld categories.

   It is clear from Table 1 that variation of the upper/lower bound loads exist for all weld categories including Q.C. accepted weld.

   These ranges of variation are not of a concern because of the following reasons:

   a. Variation in the actual weld sizes from the minimum specified. In other words, the actual weld sizes are usually larger than the specified value.

   b. Variation of eccentricty e_x (see fig. 2). This leads to imposed additional moment on the weld coupled with stress concentration (stress riser) which in turn causes premature failure of the welded connection.

However, for conservatism, Q.C. rejectable weld allowable will be based on the lower bound failure loads.

3. A conservative pseudo allowable load per Q.C. rejectable stitch weld can be interpreted as the Statistical Average of the lower bound failure Load (SAL) for the four rejectable weld categories (2 → 5) for 22 gage sheet metal case which is the governing case.

$$\text{Hence, SAL} = \frac{2050 + 1930 + 1890 + 2200}{4} = 2018 \text{ lbs} \sim 2000 \text{ lbs.}$$

Therefore, the pseudo Allowable Load for "Q.C. rejectable weld" is 2000 which compares very favorably with the minimum lower bound load of 1890 lbs.

CONCLUSIONS

In Section III we established that the actual design load per stitch weld does not exceed 400 lbs regardless of duct size. In addition, we stated that the duct design is governed by duct material strength.

In Section V we established a conservative pseudo "Q.C. rejectable stitch weld" allowable load of 2000 lbs. This allowable is based on actual test data regardless of duct sheet metal thickness or companion angle size. Furthermore, the test program proved the fact that the weakest link in the duct joint is the sheet metal or the companion angle but not the Q.C. rejectable welds.

Based on the above stated facts we can deduce that the strength of "Q.C." rejectable stitch weld" is far higher than the postulated design loads with a margin of safety of 5.0 (2000/400).

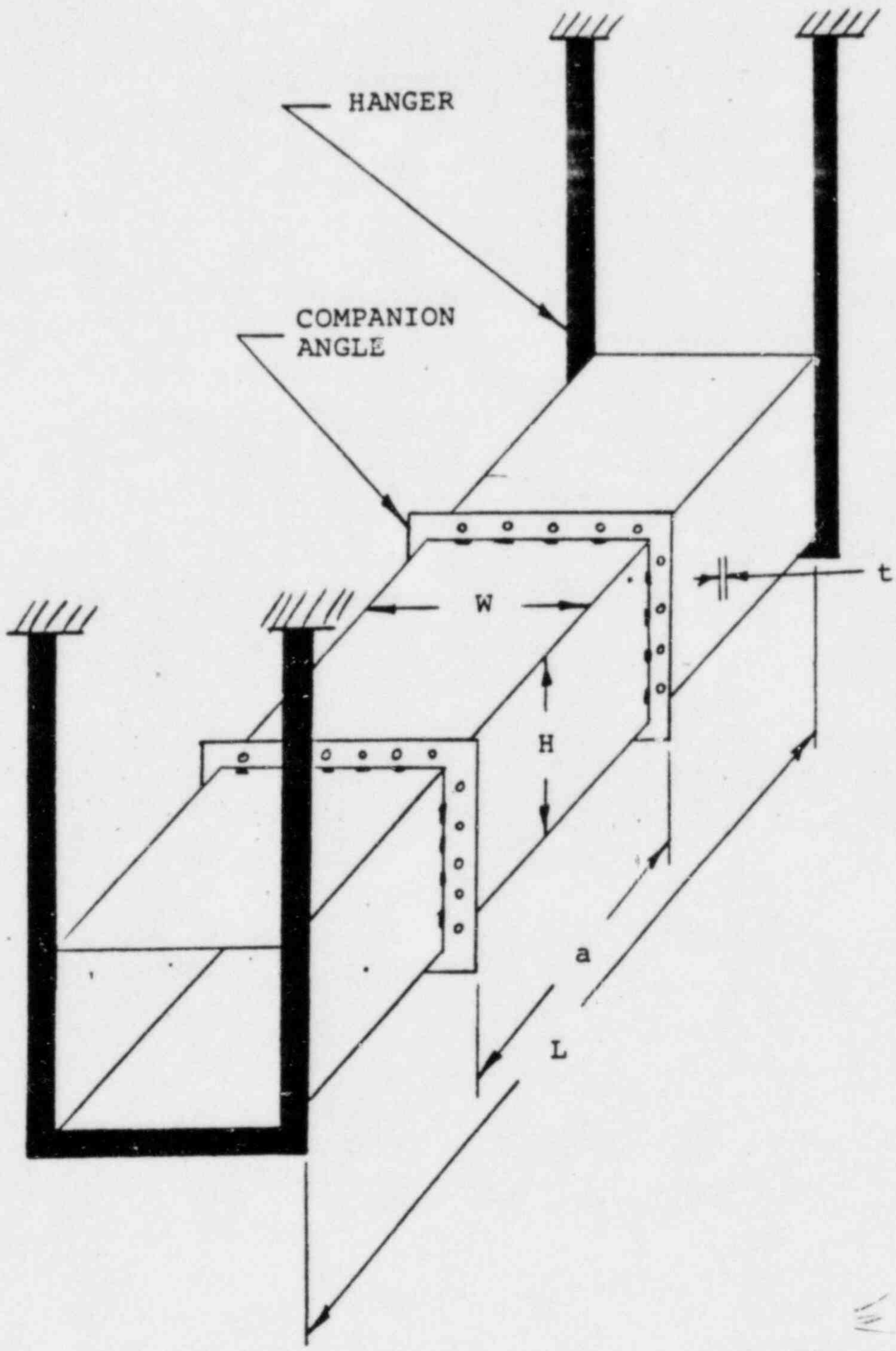
Therefore, it is concluded that the "Q.C. rejectable stitch welds" shall be able to withstand the postulated design loads and maintain the structural integrity of the duct to companion angle flange joints in LSCS HVAC safety-related duct assemblies.

APPENDIX A

Representative Design Cases

APPENDIX - A

TYPICAL HVAC DUCT SYSTEM



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APPENDIX - A

REPRESENTATIVE DESIGN CASES	
CASE NO.: 1	
DATA	**FORCE/WELD IN LBS.**
Duct Size = W x H W = 48" H = 18"	
Length of Duct Section L = 10.66'	Weight + DL* 248.51
Component Weight P = 476.0	
Distributed Duct Weight Wd = 36.4 lbs/ft	Internal Pressure** < 150
Distance Between Stiffeners a = 30"	
Thickness of Duct (Gage) - 18 t = 0.05"	Resultant 398.51 ~400
Thickness of Companion Flange Angle T = 1/8"	

Note: For detail analysis see S&L CQD File No. CQD-003560

* DL - Dynamic Loads
** 9" Water Column

APPENDIX - A

REPRESENTATIVE DESIGN CASES	
CASE NO.: 2	
DATA	**FORCE/WELD IN LBS.**
Duct Size = W x H W = 32" H = 48"	
Length of Duct Section L = 7.833'	Weight + DL* 62.74 lbs.
Component Weight P = 198 lbs.	
Distributed Duct Weight Wd = 44 lbs/ft.	Internal Pressure** <170
Distance Between Stiffeners a = 30"	
Thickness of Duct (Gage) - 18 t = 0.05"	Resultant ~240
Thickness of Companion Flange Angle T = 1/8"	

Note: For detail analysis see S&L CQD File No. CQD-003560

* DL - Dynamic Loads
** 10" Water Column

APPENDIX - A

REPRESENTATIVE DESIGN CASES	
CASE NO.: 3	
DATA	FORCE/WELD IN LBS.
Duct Size = W x H W = 32" H = 30"	
Length of Duct Section L = 4.167"	Weight + DL* 74.44
Component Weight P = 398 lbs	
Distributed Duct Weight Wd = 25.66 lbs/ft	Internal Pressure** <170
Distance Between Stiffeners a = 36"	
Thickness of Duct (Gage) - 20 t = 0.0375"	Resultant ~250
Thickness of Companion Flange Angle T = 1/8"	

Note: For detail analysis see S&L CQD File No. CQD-003560

* DL - Dynamic Loads
** 10" Water Column

APPENDIX B

- A Summary of the Governing Samples (Table 1)
- Specific Failure Mode and Load for 64 Test Samples

Table 1

A Summary of the Governing Samples

Weld Category \ Thickness of sheet metal	A*	B	C	D
	22 (0.0312")	20 (0.0375")	18 (0.050")	16 (0.062")
1 (Acceptable Weld)	3020 IV / 1600 I	3760 VI / 2680 IV	3490 IV / 2810 I	5650 II / 4760 IV
2 (Undercut Weld)	2190 I / 2050 II	2040 I	3270 II / 2880 V	6180 II / [illegible]000 I
3 (Porous Weld)	3020 II / 1930 I	3530 I / 3150 V	3160 III / 2360 II	6620 I / 5530 IV
4 (Bad Profile Weld)	2720 I / 1890 II	3360 I / 2330 IV	3210 I / 3000 III	3070 I / **
5 (Lack of Fusion Weld)	2200 I / **	** / **	** / **	4820 I / **

* Governing Cases
** Not Available

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Specific Failure Mode and Load for 64 Test Samples

Category	Ductwork Gauge (GA)	Sample Number	Weld Size (inches)	Failure Mode	Failure Load (lbs)	Remarks
1.A	22	I	1-1/2x3/16	CS	1600.	e_x=1", e_y=7/8"
	22	V	1-9/16x3/16	CS	3130.	
	22	IV	1-1/2x3/16	CS	3020.	
	22	II	1-1/2x5/32	CS	3130.	
	22	III	1-7/16x3/16	CS	1770.	
1.B	20	III	1-9/16x7/32	PA	2800.	
	20	I	1-3/16x3/16	CS	3030.	
	20	II	2x3/16	PA	2480.	
	20	IV	1-3/16x7/16	CS	2680.	
	20	V	1-3/4x5/32	CS	2800.	
	20	VI	1-9/16x3/16	PA	3760.	
2.A	22	I	15/16x5/32	CS	2190.	
	22	II	1-9/16x5/32	CS	2050.	
2.B	20	I	1-1/4x7/16	CS	2040.	
3.A	22	I	1-7/8x5/32	CS	1930.	
	22	II	1-5/16x5/32	CS	2720.	
	22	III	1-7/32x5/32	CS	3020.	
	22	IV	1-1/2x3/16	CS	2560.	
3.B	20	I	1-1/8x7/16	CS	3530.	
	20	II	1-5/8x3/16	PA	3520.	
	20	III	1-1/4x3/16	CS	3410.	
	20	IV	1-3/16x3/16	CS	3310.	
	20	V	1-3/32x5/32	CS	3150.	

CS - Cracking of Sheet Metal
PA - Punch through Angle

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Category	Ductwork Gauge (GA)	Sample Number	Weld Size (inches)	Failure Mode	Failure Load (lbs)	Remarks
4.A	22	I	1-1/4x3/16	CS	2720.	
	22	II	1-1/8x5/32	CS	1890.	
	22	III	1-3/16x5/32	CS	2250.	
4.B	20	I	1-9/32x5/32	CS	3360.	
	20	II	1-1/2x3/16	CS	2890.	
	20	III	1-3/8x5/32	CS	3250.	
	20	IV	1-7/8x3/16	CS	2330.	
5.A	22	I	1-5/8x3/16	CS	2200.	e_x=3/4", e_y=7/8"
1.C	18	I	1-3/4x1/8	PA	2810.	
	18	II	1-5/8x5/32	PA	3070.	
	18	III	1-1/2x5/32	PA	3230.	
	18	IV	1-9/16x5/32	PA	3490.	
	18	V	1-11/16x5/32	PA	3430.	
2.C	18	I	1-11/16x7/32	PA	3020.	
	18	II	1-3/4x3/16	PA	3270.	
	18	III	1-1/2x3/16	PA	3010.	
	18	IV	1-5/16x3/16	PA	2920.	
	18	V	1-1/4x7/16	PA	2880.	
3.C	18	I	1-3/8x5/32	PA	2940.	
	18	II	1-1/2x3/32	PA	2360.	With 3/8" hole nearby
	18	III	1-5/16x5/32	PA	3160.	
	18	IV	1-5/16x5/32	PA	2920.	
	18	V	1-5/16x5/32	PA	2890.	

Category	Ductwork Gauge (GA)	Sample Number	Weld Size (inches)	Failure Mode	Failure Load (lbs)	Remarks
4.C	18	I	1-11/32x5/32	PA	3210.	Plug weld in back side
	18	II	1-5/32x1/8	PA	3040.	
	18	III	2-1/4x3/16	PA	3000.	
1.D	16	I	1-15/32x5/32	CS	5370.	
	16	II	1-3/8x3/16	PA	5650.	
	16	III	1-17/32x3/16	CS	5430.	
	16	IV	1-7/16x3/16	CS	4760.	
	16	V	1-13/32x3/16	CS	5350.	
2.D	16	I	1-5/8x3/16	PA	6000.	
	16	II	1-1/2x3/16	PA	6180.	
3.D	16	I	1-5/8x3/16	CS	6620.	3/8" of crater
	16	II	1-1/2x3/16	CS	6280.	
	16	III	1-5/8x3/16	PA	6630.	
	16	IV	1-9/16x3/16	CS	5530.	
4.D	16	I	1-5/8x5/32	PA	3070.	with 1/8" thickness L
5.D	16	I	1-1/2x3/16	CS	4820.	1/2" of crater

APPENDIX C

Photographs of Test Samples

Figure 1 - Test Fixture

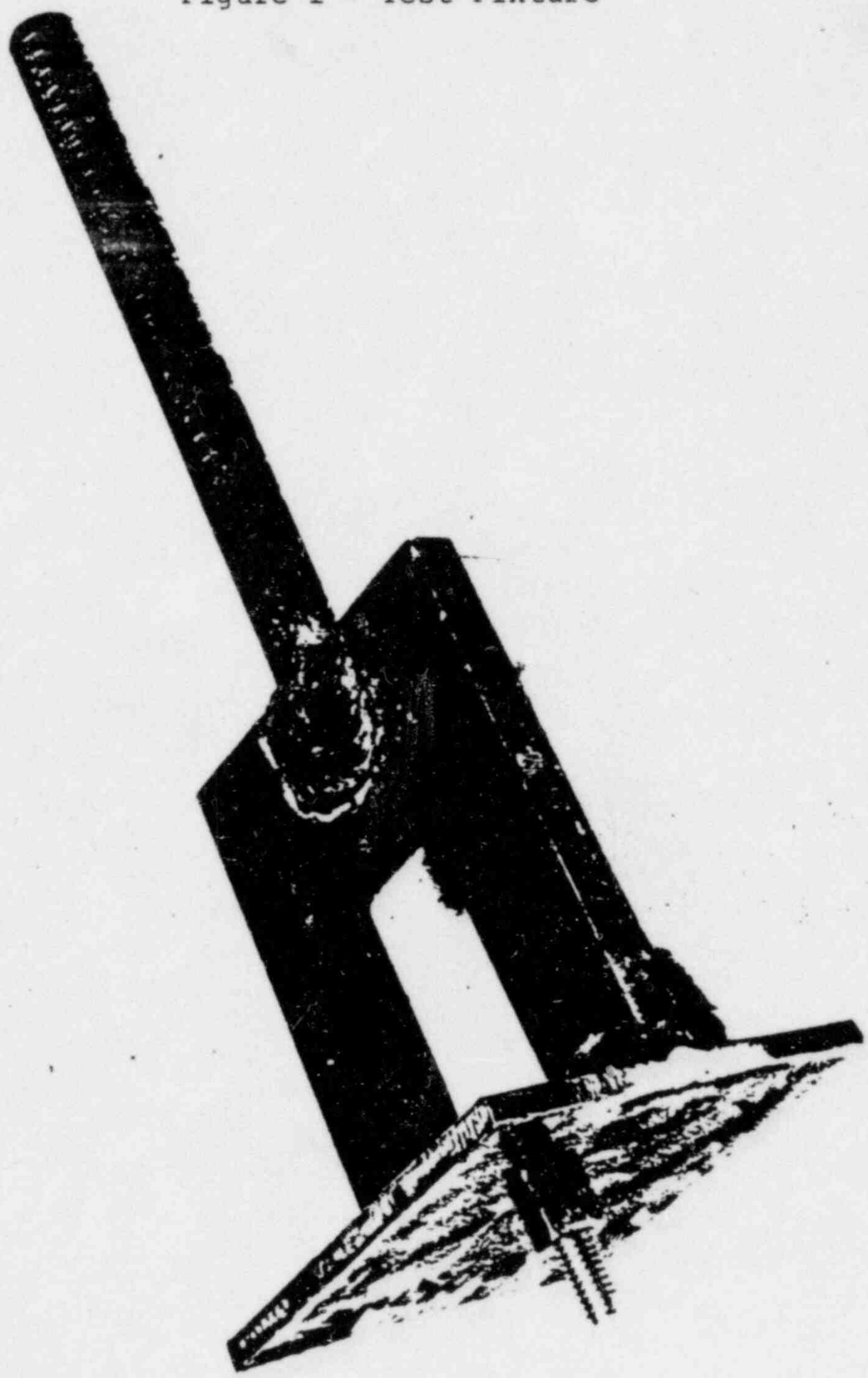

Figure 2 - Test Sample I-4C
Bad Profile 18 Gage

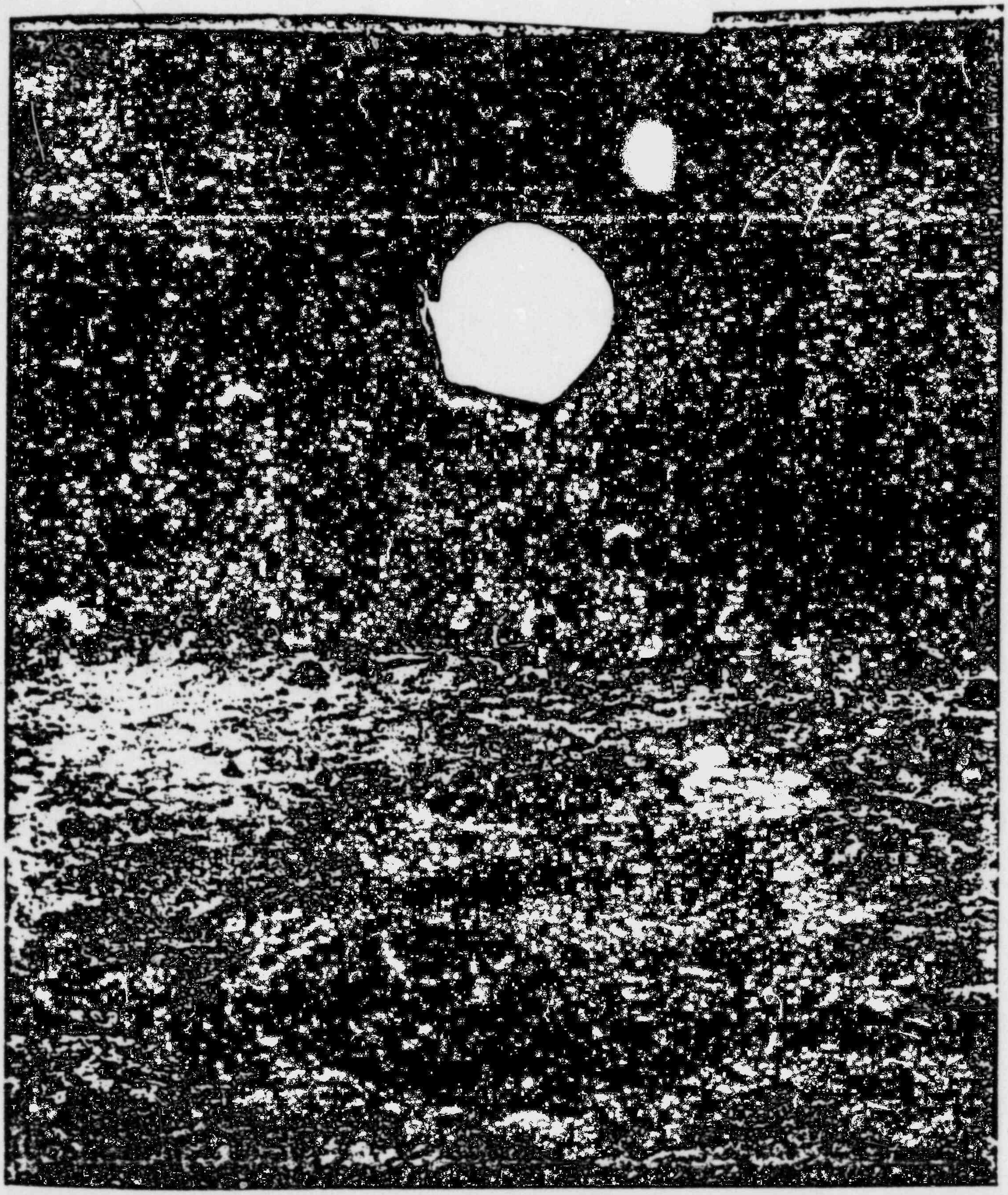

Figure 3 - Test Sample II 3C
Porsity 18 Gage

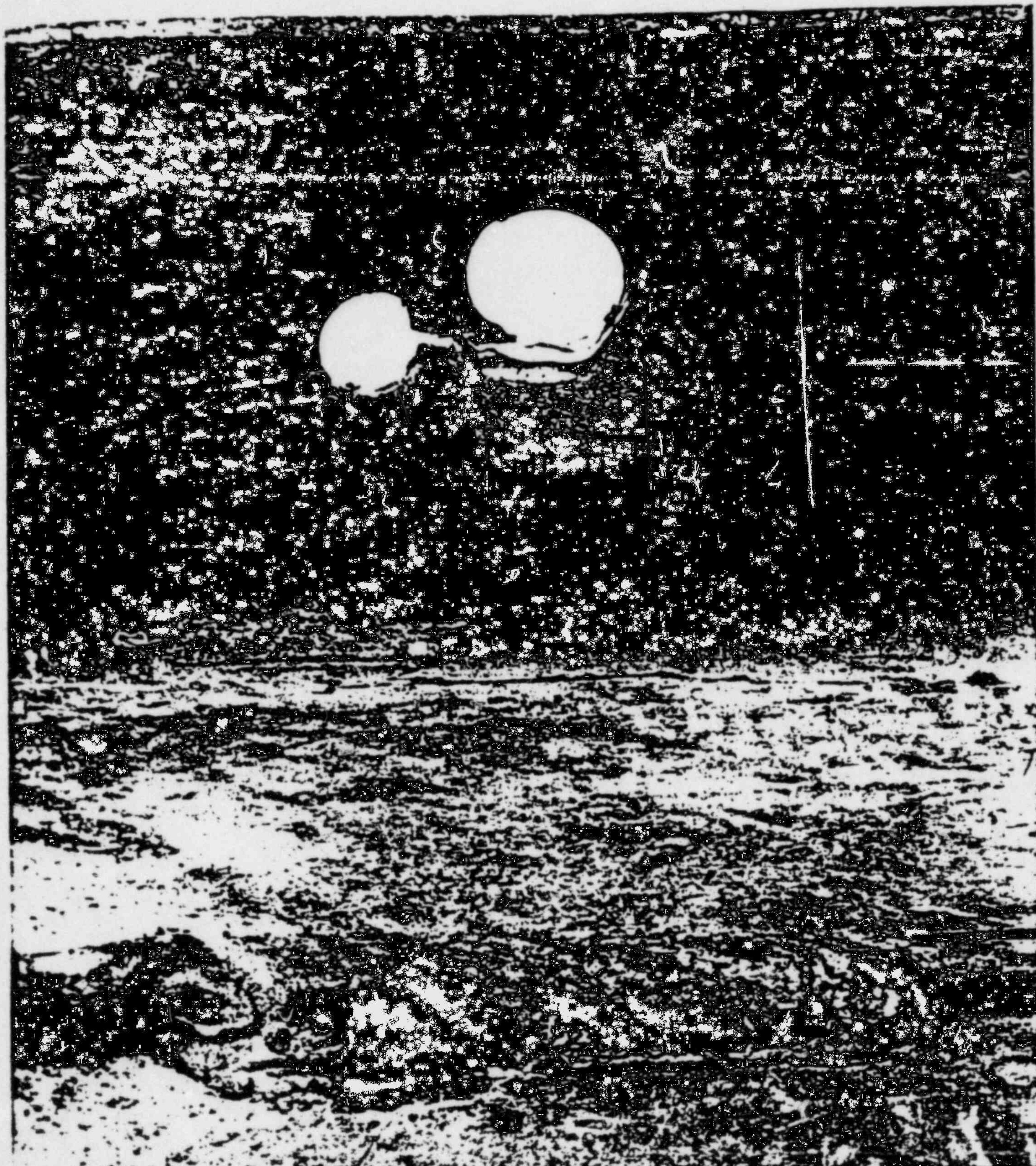

Fig. 4 - Test Sample I-2B
Weld Undercut
20 Gage

Fig. 5 - Test Sample I-4C
(back)

Bad Profile 1

Fig. 6 - Test Sample I-4C
Bad Profile 18 gage