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WELD OVERLAY DESIGN

FOR THE INDICATIONS IN THE DUANE ARNOLD

RECIRCULATION AND RESIDUAL HEAT REMOVAL PIPING SYSTEMS

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GENERAL ELECTRIC

CONTENTS

1. INTRODUCTION

During in-service inspection at the Duane Arnold site, crack indications were discovered in 7 of the 8 recirculation loop risers and a tee located in the Residual Heat Removal (RHR) line. Figures 1 and 2 show the locations of the indications in loops A and B respectively.

Iowa Electric Light and Power has requested a weld overlay design at all locations where indications were found. Iowa Electric has requested that the weld overlays be designed for longevity and inspectibility. Therefore, the weld overlays were designed to provide full structural reinforcement and thus maintain ASME Code safety margins. The weld overlay consists of a continuous 360° band of weld metal applied to the outside surface of a pipe directly above the crack indication. In addition, the weld overlay designs were determined by assuming circumferential cracks at all locations even if the detected flaws were axially oriented. The overlay weld metal is Type 308L stainless steel containing low carbon and high ferrite, deposited using a high quality gas tungsten arc welding technique (GTAW) with water inside the pipe. This process deposits a high toughness weld consisting of material resistant to IGSCC and typically produces a compressive residual stress at the inside surface of the pipe and through a substantial portion of the inner wall.

Sizing of the weld overlay was determined using GE recommended minimum thicknesses along with consideration for future in-service inspectability. The overlay designs also meet the requirements for being a full structural (type 1) overlay and maintains the ASME Code intended safety margins for a 360° through-wall circumferential flaw. This report provides the basis for the weld overlay design and the detailed geometric considerations.

2.0 WELD OVERLAY DESIGN ANALYSIS

This evaluation conservatively assumes that the flaws are fully circumferential and will extend through the original pipe wall. The overlay thickness is selected such that it provides the Code margin for the applied loading without taking credit for the uncracked wall thickness. Also, no credit is taken for the beneficial compressive residual stresses induced by the heat sink weld overlay process that would oppose crack extension through the thickness. The assumption of a through-wall crack also provides assurance that the overlay design is independent of the crack size as determined by the ultrasonic testing. Finally, the selection of IGSCC-resistant material assures that IGSCC crack growth into the weld overlay material beyond the first layer does not occur.

3.0 DESIGN CONSIDERATIONS FOR CIRCUMFERENTIAL CRACKS

3.1 METHODOLOGY FOR DETERMINING THE MINIMUM REQUIRED WELD OVERLAY THICKNESS

The minimum weld overlay thickness necessary to achieve full structural reinforcement of the flaw is that thickness which provides the appropriate factor of safety against net section collapse of the adjacent material for a postulated 360° through-wall crack. The depth at which net section collapse occurs is a function of the material flow stress, the overall wall thickness including the weld overlay, and the applied primary membrane and bending stresses. The primary membrane stress is produced by pressure, and the primary bending stress is the sum of the dead weight and seismic stresses.

3.1 METHODOLOGY FOR DETERMINING THE MINIMUM REQUIRED WELD OVERLAY THICKNESS (Continued)

Paragraph IWB-3642 of the ASME Code, Section XI (Reference 1), can be used to determine the allowable flaw size using a safety factor of 3.0 on applied loading. Assuming that the indications are fully circumferential, the method described in Reference 2 can be used. In Reference 2 a relationship between the applied loads, the flow stress, and the critical crack depth to thickness ratio is defined by Equations (1) and (2).

$$\beta = \frac{\pi\left(1 - a/t - \frac{P_m}{\sigma_f}\right)}{2 - a/t} \qquad (1)$$

where $$P_b = \frac{2\sigma_f}{\pi}\left(2 - a/t\right)\sin\beta$$

σ_f = material flow stress = 3 S_m (2)

P_m = primary membrane stress

P_b = primary bending stress

a = crack depth

t = total thickness (pipe wall + weld overlay thickness)

These equations cannot be solved directly for the allowable flaw depth to thickness ratio, thus an iterative approach must be used. In the iteration scheme, a weld overlay thickness is assumed and the primary stresses are adjusted to the new total thickness. The allowable primary stress is compared with the applied stress for that thickness. The iteration is performed until the the allowable and applied stresses are equal. This defined the minimum required weld overlay thickness. A factor of safety of 3.0 is used in accordance with IWB-3642.

3.2 APPLIED STRESSES AT THE WELD OVERLAY LOCATION

The applied stresses at the weld overlay locations were determined from the Duane Arnold Recirculation System Piping Stress Report (Reference 3). The pressure in the recirculating line was assumed to be 1325 psi, and the pressure in the RHR line was assumed to be 1150 psi. The primary membrane stress is due to pressure stress. The primary bending stress is the sum of the dead weight and seismic stress. Table 1 shows the stresses at each weld overlay location. The stresses were calculated based on the limiting diameter and thickness due to the variation in diameter and thickness with azimuthal variation.

3.3 WELD OVERLAY THICKNESS

The iterative calculations described in Section 3. 1 were performed using the stresses described in Section 3. 2. The weld overlay thickness generated by this calculation is the minimum necessary for the overlay to maintain the required 3.0 factor of safety. Calculations were performed for each of the various reported diameters and thickness at each weld overlay location. A weld overlay thickness (calculated for RRE-J4A) of .215 inches which bounds all other riser calculations was selected to be applied at all riser weld overlay locations. Figure 3 shows the results of the iterative analysis for the riser bounding case. Iterative calculations were also performed for the RHR RHB-J1 weld overlay location. Figure 4 shows the results of the iterative analysis. A weld overlay thickness of .280 inches was calculated for the RHR.

The recommended weld overlay thicknesses are summarized below:

Weld Overlay Location	Weld Overlay Thickness
RRA-J4/J4A	.215"
RRB-J4/J4A	.215"
RRD-J4/J4A	.215"
RRE-J4/J4A	.215"
RRF-J4/J4A	.215"
RRG-J4/J4A	.215"
RRH-J4/J4A	.215"
RHB-J1	.280"

As discussed in References 4 and 5, to account for dilution on the ferrite level that may occur in the first overlay layer, the minimum weld overlay thickness does not include this first layer.

3.4 WELD OVERLAY WIDTH

Unlike the thickness requirements for weld overlay designs, which are based on satisfying the safety margins of the ASME Code, there are no guidelines for determining the weld overlay widths. Former overlay design specifications recommended a conservative width of one attenuation length $\sqrt{Rt}$ on either side of the weld material (total width of $2\sqrt{Rt}$). General Electric has performed finite element studies which compared the stresses obtained when modeling pipes with weld overlay widths of $\sqrt{Rt}$ to those of $2\sqrt{Rt}$ for fully circumferential through-wall cracks. Results showed that there is no significant difference between the stresses obtained for the two widths, however, the applied weld overlay width may be increased to accommodate weld ultrasonic inspectability.

3.5 WELD OVERLAY DESIGN

The specific overlay design shown in Figures 5 and 6 was based on consideration of such factors as the relative thicknesses of the butt welding members, the weld crown geometry, the extent of the original heat affected zone, the proximity of transition area, and the consideration of ultrasonic testing.

4.0 ACCEPTABILITY FOR MULTIPLE CYCLE OPERATION

The weld overlay design recommended here is based on the conservative assumption of a through-wall crack. Furthermore, the weld overlay design accounts for a potential circumferential indication by providing adequate thickness for an assumed 360° circumferential crack. Thus the weld overlay sizing considers all potential crack sizes and orientations and still provides the required code margins. This, coupled with the fact that the overlay is made of a high ferrite low carbon weld material resistant to IGSCC, provides assurance for satisfactory long term performance. The results of the recent GE/EPRI degraded pipe program have confirmed that weld overlays of the type described here provide structural and IGSCC margins for several cycles. Recognizing this, the NRC has stated in NUREG 1061 that weld overlays for circumferential cracks are acceptable for at least two fuel cycles. Overlays for axial cracks are acceptable for longer periods of time. Based on this it can be concluded that the Duane Arnold overlays are acceptable for more than two operating cycles.

5.0 REFERENCES

1. American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, 1983 and revisions.

2. Ranganath, S. and Mehta, H.S., "Engineering Methods for the Assessment of Ductile Fracture Margin in Nuclear Power Plant Piping," Elastic-Plastic Fracture: Second Symposium, Volume II - Fracture Resistance Curves and Engineering Applications, ASTM STP-803, 1983, pp. 309-330.

3. Duane Arnold Energy Center Piping Stress Analysis Recirculation Loops A and B. Prepared by Nuclear Services Corporation, Report Nos. NSC-IOW-4, NSC-IOW-3, October 1972, Campbell, CA.

4. BWR Owners Group Ad Hoc Committee, Continual Service Justification for Weld Overlay Pipe Repairs, EPRI, May 25, 1984.

5. Letter from William J. Dircks, NRC, to the Commissioners, NRC, "Staff Requirements for Reinspection of BWR Piping and Repair of Cracked Piping," November 7, 1983, SECY-83-267C.

Table 1 Applied Stress* (ksi)

	RHR RHB	RRD	RRB	RRA	RRH	RRG	RRF	RRE
Dead Weight	.85	.25	.43	.36	.83	.14	.83	.46
Seismic	1.9	2.44	1.29	2.6	2.52	1.24	1.25	2.34

*Stresses based on limiting diameter and thickness to produce maximum stress.

Pressure in Recirculation piping = 1325. psi
Pressure in RHR system = 1150. psi

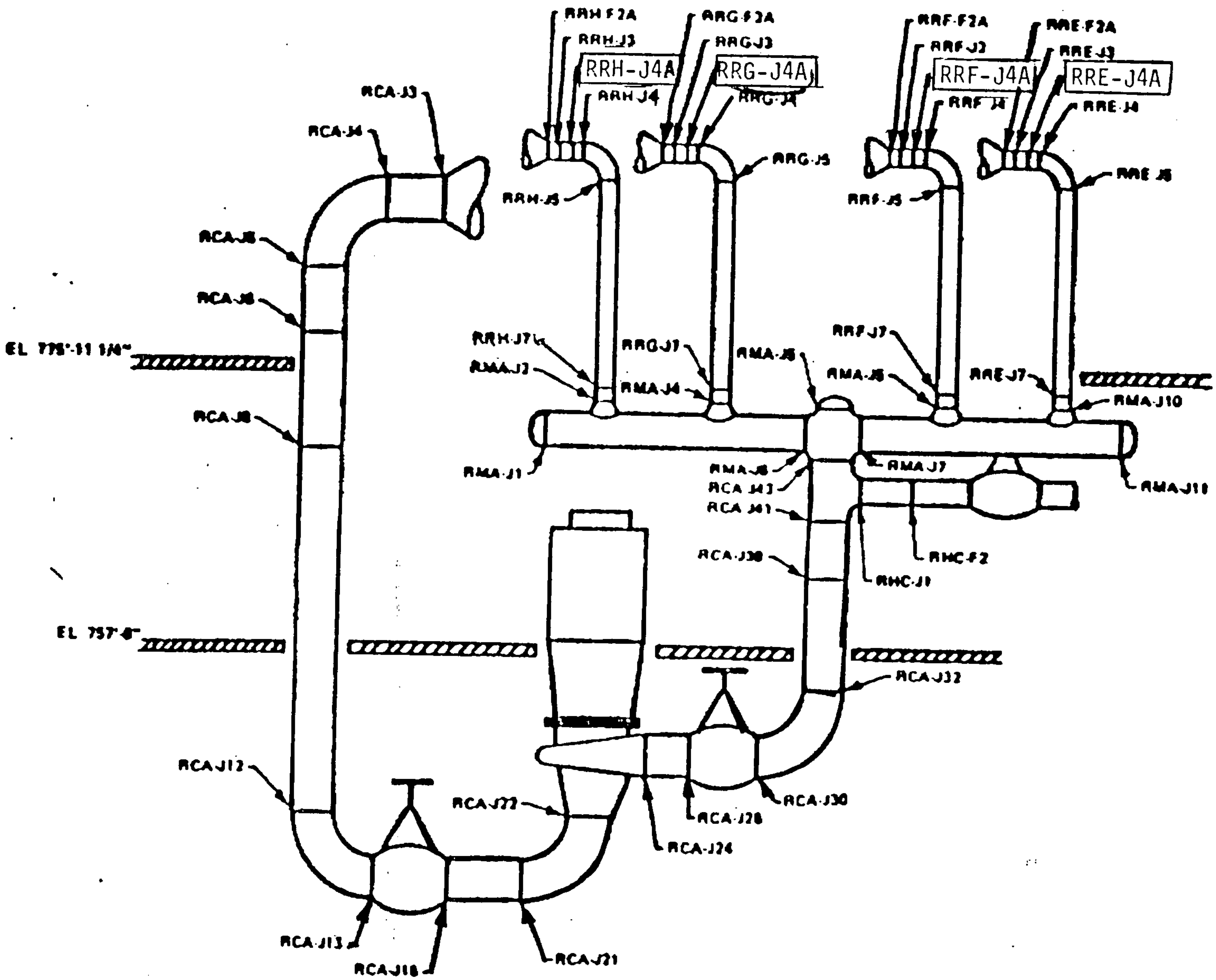


FIGURE 1

REACTOR RECIRCULATION SYSTEM
LOOP A – DUANE ARNOLD ENERGY CENTER

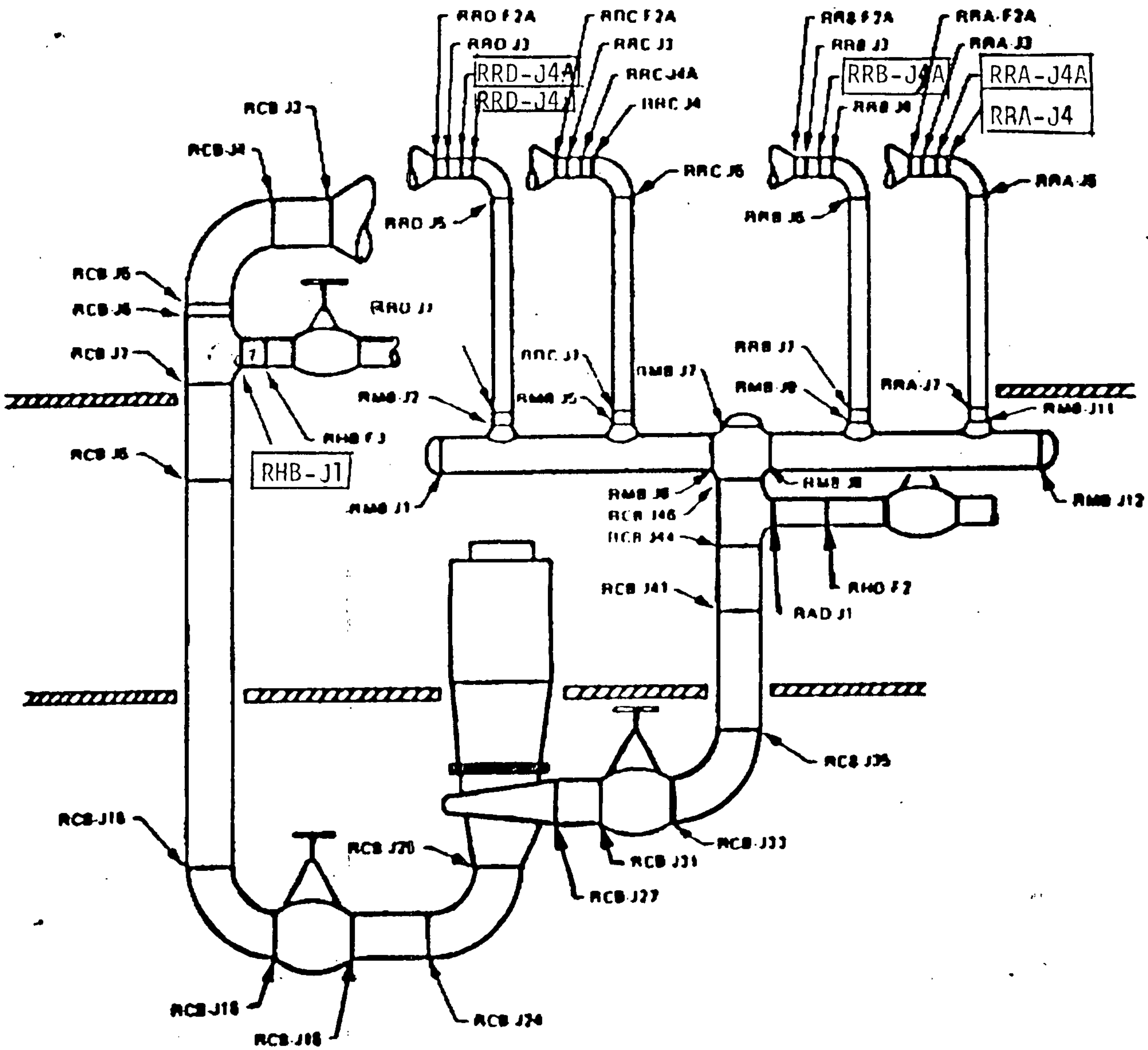


FIGURE 2

REACTOR RECIRCULATION SYSTEM
LOOP B – DUANE ARNOLD ENERGY CENTER

FIGURE 3 ITERATIVE CALCULATION
FOR BOUNDING CASE

WELD ID: RRE J4A

PIPE THICKNESS = 0.78 INCH
PIPE DIAMETER = 10.9 INCH

PRIMARY LOADS (STRESS):
PRESSURE = 4.38 KSI
DEAD WEIGHT = 0.83 KSI
SEISMIC = 2.34 KSI

WOT	I / T+WOT	PM (KSI)	PB (KSI) ACTUAL	PB (KSI) CALC	PM+PB / SM (ACTUAL)	PM+PB / 3SM (CALC)
0.215	0.784	3.444	2.485	14.658	0.351	0.357

PRIMARY STRESS RATIOS (ADJUSTED):
PM/SM = 0.204
(PM+PB)/SM = 0.351

MINIMUM REQUIRED WELD OVERLAY THICKNESS = 0.215 INCH
MINIMUM REQUIRED WELD OVERLAY WIDTH = 2.1 INCH

FIGURE 4 ITERATIVE CALCULATION
FOR RHB-J1

WELD ID: RHB-J1

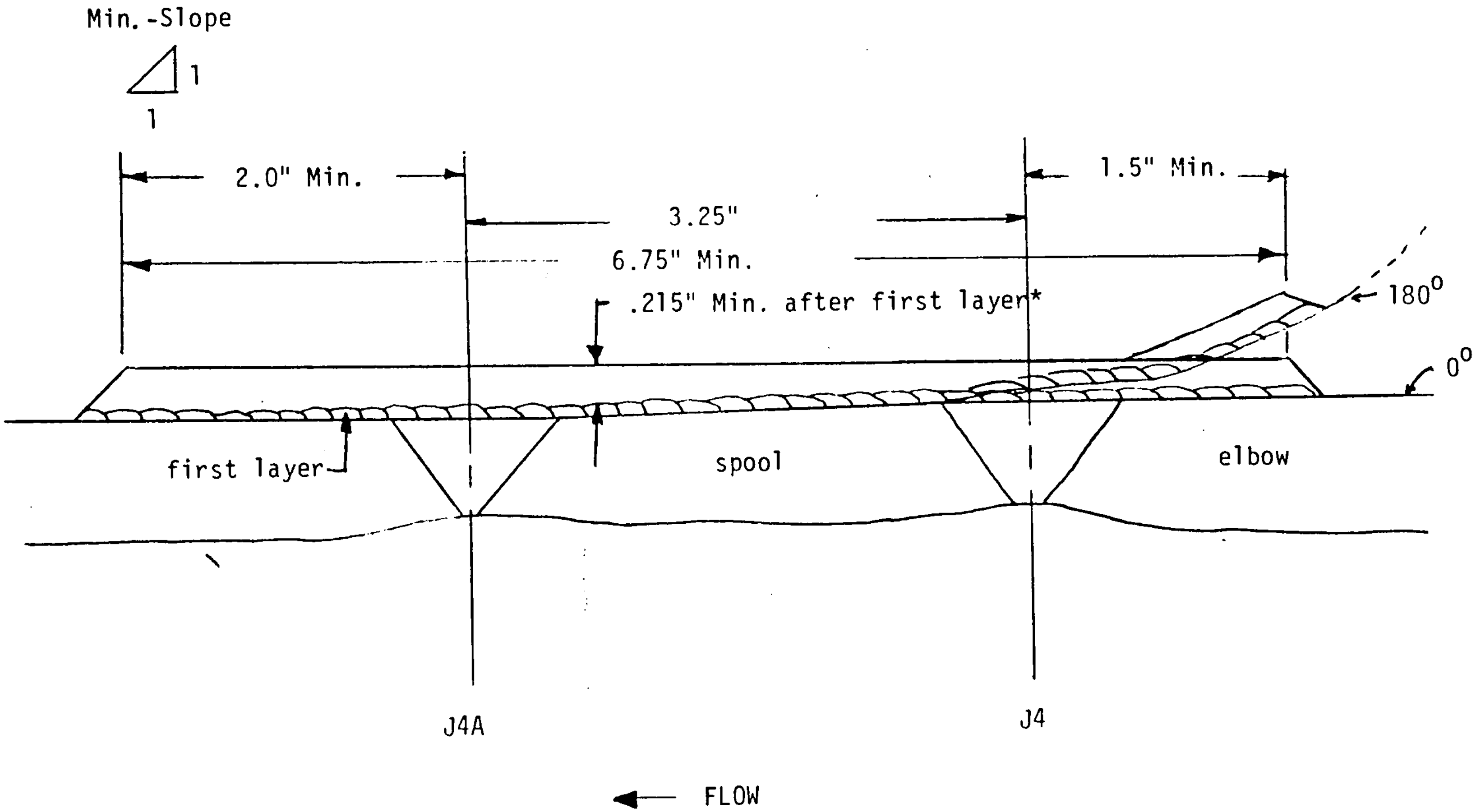
PIPE THICKNESS = 0.91 INCH
PIPE DIAMETER = 18.1 INCH

PRIMARY LOADS (STRESS):
PRESSURE = 5.42 KSI
DEAD WEIGHT = 0.85 KSI
SEISMIC = 1.90 KSI

WOT	T / T+WOT	PM (KSI)	PB (KSI) ACTUAL	PB (KSI) CALC	PM+PB / SM (ACTUAL)	PM+PB / 3SM (CALC)
0.280	0.766	4.192	2.106	14.996	0.373	0.378

PRIMARY STRESS RATIOS (ADJUSTED):
PM/SM = 0.248
(PM+PB)/SM = 0.373

MINIMUM REQUIRED WELD OVERLAY THICKNESS = 0.280 INCH
MINIMUM REQUIRED WELD OVERLAY WIDTH = 2.9 INCH



* Thickness after final surface finishing

Figure 5 WELD OVERLAY DESIGN FOR RECIRCULATION RISERS

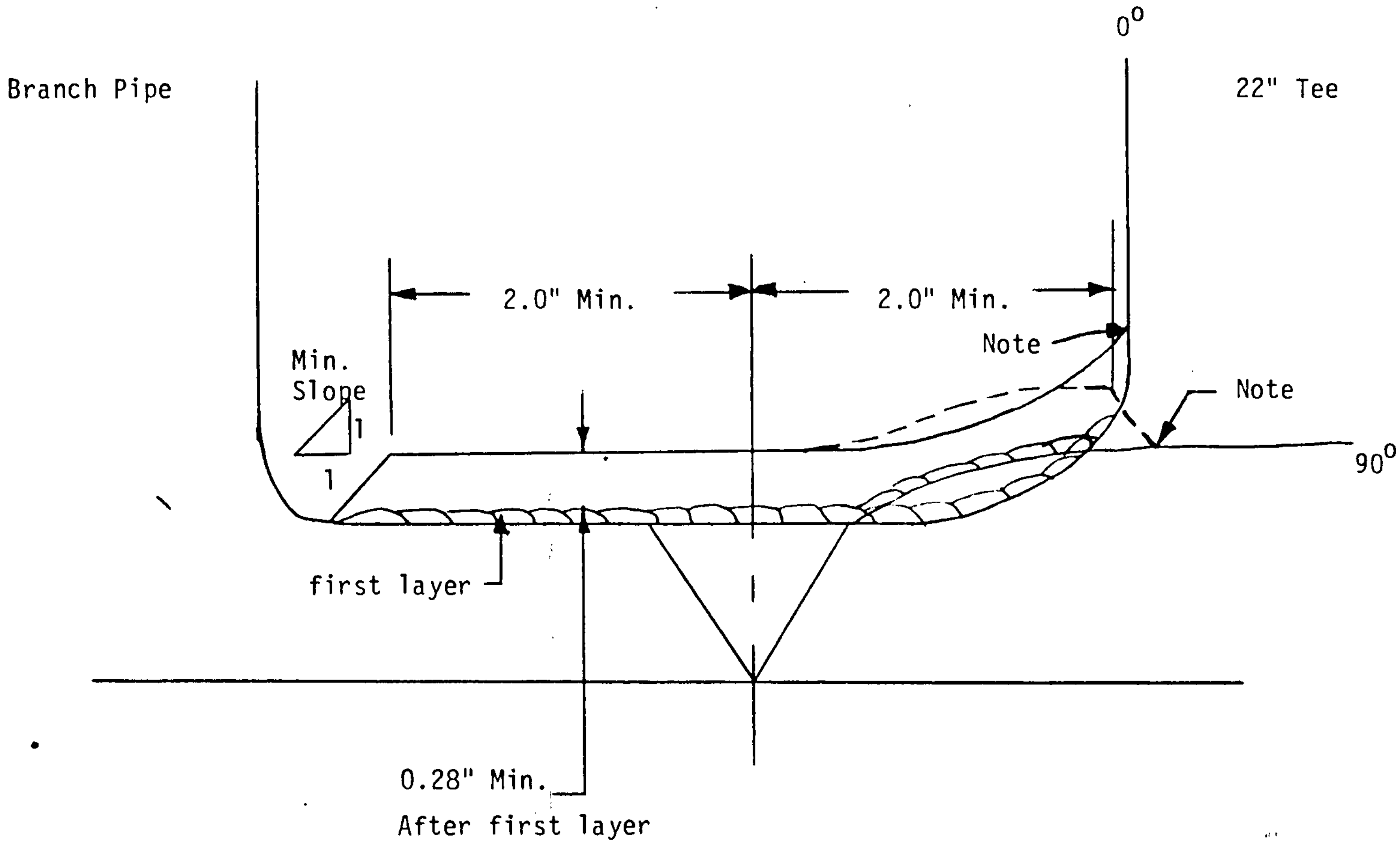


FIGURE 6 WELD OVERLAY DESIGN FOR WELD RHB-J1

* Note- Angle between weld and base metal-135° min.
or 0.25" Radius Min.