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WELD OVERLAY DESIGN FOR THE INDICATIONS IN THE PEACH BOTTOM UNIT 3 4-INCH JET PUMP INSTRUMENTATION NOZZLE

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1. ABSTRACT

In June 1984 General Electric Company, in conjunction with Sonic Systems, Inc., performed ultrasonic examinations of the Safe End to Nozzle, Safe End to Penetration Seal, and Penetration Seal Assembly welds on the Peach Bottom #3 4-inch Jet Pump Instrumentation Nozzle. The examination revealed three circumferential indications, one in the #2 weld of the 'A' loop and two in the #2 weld of the 'B' loop. Due to minimum separation, the two indications in the 'B' loop were considered to be one continuous indication.

It was decided to weld overlay repair the welds in each loop. The weld overlay was designed using the criteria to provide full structural reinforcement of the cracked region while maintaining the ASME Code safety margins. The weld will consist of a sealing pass and a weld overlay 1/8-inch thick and 1.5 inches wide with a 3/1 transition.

2. INTRODUCTION

In June 1984 General Electric Company, in conjunction with Sonic Systems, Inc., performed ultrasonic examinations of the Safe End to Nozzle, Safe End to Penetration Seal, and Penetration Seal Assembly welds on the Peach Bottom Unit 3 4-inch Jet Pump Instrumentation Nozzle. The examination revealed three circumferential indications in the #2 weld: one in the 'A' loop and two in the 'B' loop. The configuration of the #2 weld does not allow complete examination, the scanning surface on either side of the weld is not large enough to examine the weld root and weld crown effectively. The configuration also prevents gathering data points needed to estimate the through-wall dimension of the indications. The through-wall dimension is, therefore, an estimate.

Analysis of the indications produced the following data:

'A' Loop, Weld #2

Length (l) = .75 inch
through-wall (a) = .175 inch
measured thickness (t) = .360 inch
a/l = .23
a/t = 48.6%

The 'A' loop circumferential flaw was later reexamined and the length was measured at 1.0 inch.

'B' Loop, Weld #2

Length (l) = 1.87 inches
through-wall (a) = .075 inch
measured thickness (t) = .340 inch
a/l = .04
a/t = 22%

The 'B' loop circumferential flaw was also reexamined and found to be leaking, indicating a through-wall flaw.

It was decided to weld overlay repair the weld in each loop. The overlay is designed to provide full structural reinforcement of the cracked region while maintaining the ASME Code safety margins. This report provides a recommendation for the design of the weld overlay to meet these Code safety margins and the specific geometric considerations for both welds.

3. WELD OVERLAY DESIGN ANALYSIS

The criterion used to design the weld overlay for the 4-inch Jet Pump Instrumentation Nozzle is to provide full structural reinforcement of the cracked region maintaining the ASME Code safety margins. This evaluation conservatively assumes that the flaws are fully circumferential and will extend through the susceptible material of the original pipe wall. With this assumption, 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 postulated through-wall cracks also provide assurance that the overlay design is independent of the crack size as determined by the ultrasonic testing. IGSCC crack growth into the weld overlay material beyond the first layer is not expected since the weld material away from the fusion line is not susceptible.

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 fully circumferential crack, the depth that net section collapse occurs is a funtion 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.

Paragraph IWB-3640 of Appendix X to Section XI, Reference 1, contains tables of the allowable circumferential flaw depth to pipe thickness ratios (a/t) for various applied primary stress ratios: $(P_m + P_b)/S_m$. The 4-inch Jet Pump Instrumentation Nozzle welds are subjected to primary loads where the $(P_m + P_b)/S_m$ ratios are less than 0.6 after weld overlay thickness adjustment (assuming a design stress intensity S_m of 16.9 ksi for 304 stainless steel). The tables of Reference 1 do not apply for these low stress ratios. Instead, the allowable flaw depth to thickness ratio must be calculated from the actual applied loads. Assuming that the indications are fully circumferential, the method described in Reference 2 can be used. In this report a relationship between the applied loads, the flow stress, and the critical crack depth to thickness ratio is defined by Equations (1) and (2).

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

$$P_b = \frac{2\sigma_t}{\pi} \left(2 - \frac{a}{t}\right) \sin \beta \qquad (2)$$

where

σ_f = Material Flow Stress = 3 S_m

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, so 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 P_b corresponding to the new thickness and the adjusted primary membrane stress is calculated from Equations (1) and (2). The allowable $\left(\frac{P_m + P_b}{S_m}\right) \div$ Factor of Safety is then compared to the actual adjusted $\frac{P_m + P_b}{S_m}$. If the allowable is less than the actual, then the assumed weld overlay thickness is insufficient to provide full structural reinforcement and the procedure is repeated using a larger weld overlay thickness. The iteration is performed until the minimum required weld overlay thickness is determined. A factor of safety of 3.0 is used in accordance with the ASME Code, Section XI, Paragraph IWB-3640.

3.2 Applied Stresses at the Weld Overlay Locations

The design specification for the Peach Bottom Unit 3 4-inch Jet Pump Instrumentation Nozzle, Reference 3, did not provide information regarding normal operation stresses; therefore, the stresses were estimated. As discussed in Section 3.1, the primary membrane stress is produced by pressure, the pressure at normal operation is known to be 1.05 ksi resulting in a primary membrane stress of 3.5 ksi. The primary bending stress is the sum of the dead weight and seismic stress. However, since the dead weight and seismic loads are unknown, but expected to be small, the primary bending stress was conservatively chosen to be 4.5 ksi.

3.3 Weld Overlay Thickness Results

The iterative calculations described in Section 3.1 were performed using the stresses described in Section 3.2. The flow stress σ_f is taken as 3 S_m, and the pressure used in calculating the primary membrane stress is the normal operating pressure of 1050 psi. The thickness generated by this calculation is the minimum necessary for the overlay to maintain the required 3.0 factor of safety. As shown in Figure 1, a thickness of 1/8-inch is the recommended design thickness.

3.4 Weld Overlay Widths

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 one attenuation length to those of two attenuation lengths for fully circumferential through-wall cracks. Results showed that there is no significant difference between the stresses obtained for the two widths and it was concluded that the additional material of the wider overlay contributes little to the overall structural reinformcement of the weld. Therefore, a minimum weld overlay width of $\sqrt{Rt}$ is used as the basis for the recommended overlay designs. This reduction in width greatly reduces the time required for application of the weld overlays. Even though the width based on the criteria of $\sqrt{Rt}$ would be 1 inch, the width was chosen as 1.5 inch to assure that the overlay would cover the heat affected zone as well as the weld.

3.5 Weld Overlay Designs

The specific overlay design shown in Figure 1 was also 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, and the proximity to eccentricity in the reducer. The slope of the overlay end was set to three-to-one (width-to-thickness) to reduce stress concentration effects.

A further consideration was weld metal-base metal dilution in the first weld overlay layer. The overlay-base metal mixing results in a lessening of the weld material's resistance to IGSCC close to the fusion line. Thus an effective thickness (that thickness of overlay deposited after the first weld layer) was used as the specified overlay design thickness dimension, providing the minimum required overlay thickness plus margin, in accordance with Reference 4.

4. REFERENCES

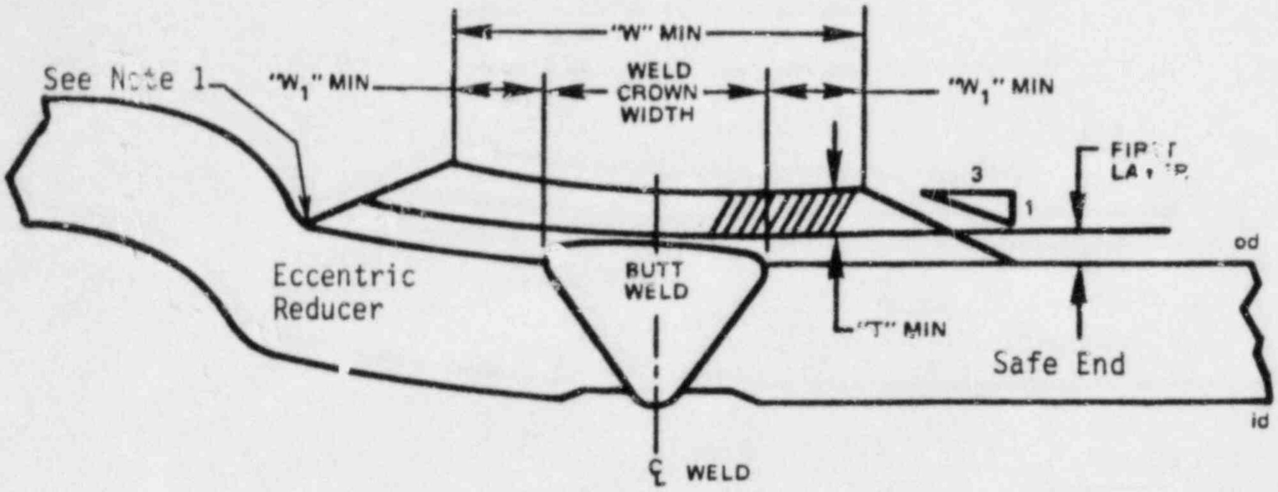
1. ASME Boiler and Pressure Vessel Code, Section XI, 1980 Edition, including Appendix X, 'Acceptance Criteria for Flaws in Austenitic Piping,' approved April 1983.

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.

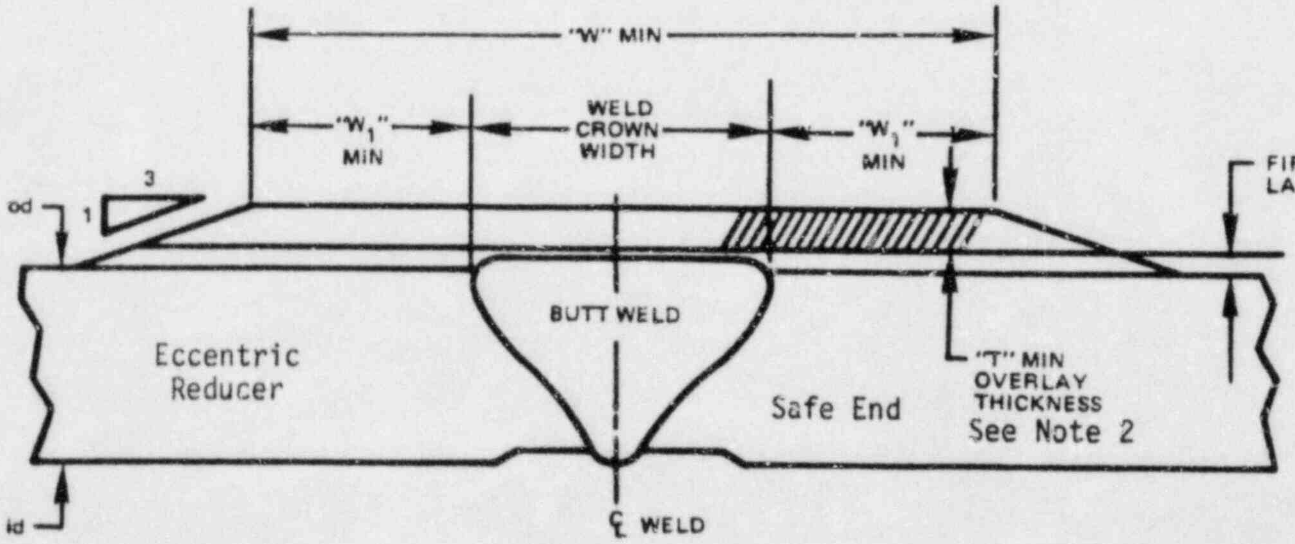
3. Peach Bottom III Stress Report prepared by Babcock and Wilcox Co.

4. 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.

Figure 1



Eccentric Reducer to Safe End



W_1 = 0.5 inch
W = 1.5 inches
T_{min} = 0.125 inch

Notes:

1. Weld may be blended in area of transition.
2. Weld metal must be deposited in a minimum of two layers beyond the first layer.