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A Study on the Postweld Heat Treatment Requirements for the Reactor Containment Building Liner Near Penetrations

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ABSTRACT

The steel liner for an ASME Subsection CB concrete reactor pressure vessel and an ASME Subsection CC concrete containment serve the same function of providing a leaktight membrane effectively stopping the release of radioactive material. However, the exemptions to mandatory Postweld Heat Treatment (PWHT) requirements specified for the steel liner in these two subsections are different. The PWHT exemptions outlined in ASME Subsection CC are more limiting than those outlined in ASME Subsection CB and appear to be equivalent to those specified for steel pressure vessels in ASME Subsection NE.

Since it is difficult to perform PWHT in some field situations (welding of liner plate segments is performed in the field for the Korea Standard Nuclear Power Plant, UCN 3&4), an exemption was requested by the designer with the following justifications and subsequently approved by the ASME committee: 1) ASME CC liners are leaktight membranes only and are not considered as a strength element in the design of the containment pressure vessel; 2) Design per ASME CC code limits reinforcing bar and liner strains to conservative allowables; 3) Sandia Laboratory concrete containment test results demonstrate that the liner design per CC code is conservative and provides a large margin against liner tearing.

The focus of this paper is to show that PWHT is not necessary for welded joints between the containment liner plate and penetration sleeves for the sleeve type used on the UCN 3&4 project. For this purpose the paper presents three separate justifications for waiving the PWHT. These are: 1) The design concept of the UCN 3&4 penetration sleeves is presented and it is qualitatively demonstrated that weld stresses and strains are inherently low for this design. The UCN 3&4 sleeve design is contrasted with a different design Yonggwang nuclear power plant Unit 1&2(YGN 1&2) which has larger weld stress and strains; 2) An analysis of the residual weld stresses and strains in the penetration-to-liner welds using a 3-D finite element method is presented; and 3) The results of the Sandia Laboratory concrete containment model test are presented.

1. INTRODUCTION

Leaktightness of the containment structure is generally provided by a steel liner plate (1/4 inch thick ASME SA516 Grade 55), which is attached to the entire inside surface of the concrete containment building. The liner for the containment shell and dome acts as concrete formwork for the interior surface of the structure during the construction phase of the project. To facilitate fabrication and installation, the liner is erected ring by ring, where each ring is made from numerous curved panels approximately 10 feet high and 37 feet wide. All liner joints are full penetration butt-welded. All penetration sleeves including barrels for the equipment hatch and personnel airlocks are welded to the liner using full penetration T-joint welds. The function of the welds between the liner panels and penetration sleeves is to join all liner plate panels and penetrations together thereby providing a continuous leaktight membrane on the inside surface of the containment building.

The liner design and construction requirements are in accordance with the Subsection CC of Section III, Division 2 of the ASME Code(1). In accordance with Subsection CC-3841 the welded joints connection the penetration nozzles to the liner are not exempt from PWHT. However, these same welds are exempt from PWHT if used for a concrete reactor vessel designed per ASME Subsection CB. It should be noted that the steel liner for a Subsection CB concrete reactor pressure vessel and a Subsection CC concrete containment serve the same function of providing a leaktight membrane. To seek relief from the mandatory PWHT requirement for the welds in a CC liner, a Code Case(2) was submitted to the ASME/ACI Joint Committee for consideration. Based on the committee's review of submitted documentation and justification, the code case was approved.

In this paper, we present three justifications for exemption from PWHT, These are: 1) The design concept of the UCN 3&4 penetration sleeves is presented and it is qualitatively demonstrated that weld stresses and strains are inherently low for this design. The UCN 3&4 sleeve design is contrasted with a different design (YGN 1&2) which has larger weld stresses and strains; 2) An analysis of the residual weld stresses in the penetration-to-liner welds using a 3-D finite element method is presented; and 3) The results of the Sandia Laboratories concrete containment model tests are presented.

2. PWHT REQUIREMENTS

2.1 ASME CC Requirement

In accordance with ASME Section III, Division 2, Subsection CC (CC-3841), the welded joints connecting penetration nozzles to the liner are defined as "Category D" joints. Figure 1(a) shows typical welded joints falling under this category. All "Category D" joints shall be postweld heat treated per the requirements of Table 1 except for those welds which meet the requirements for exemption from mandatory PWHT as shown in Table 2. As indicated in Table 2, penetration sleeves (nozzles) with an inside diameter over 2 inches are not exempt from PWHT. Thus, for nozzles with a diameter over 2 inches, PWHT is required by ASME

CC irrespective of the sleeves' anchorage detail or load carrying mechanism. These requirements appear to be equivalent to those specified for a steel pressure vessel (ASME NE Table NE-4622.7 (b)-1). Unlike the NE steel pressure vessel, however, the steel liner for a concrete containment is not designed as a strength element.

Table 1. Mandatory Requirements for PWHT of Welds

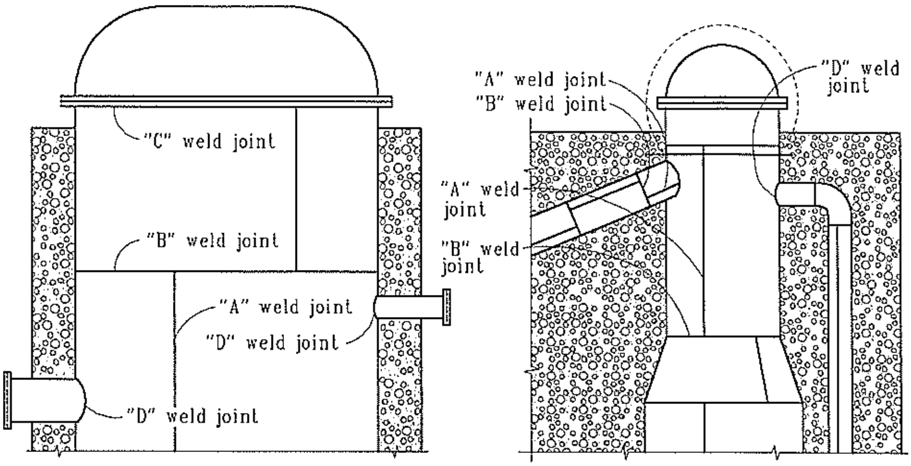
P-Number	Holding Temperature Range, °F	Minimum Holding Time at Temperature for Weld Thickness (Nominal)		
		1/2 in. or less	Over 1/2 in. to 2 in.	Over 2 in.
1	1100-1250	30 min	1 hr/in.	2 hr plus 15 min for each additional inch over 2 in.
8		PWHT neither required nor prohibited		

Table 2. Exemptions to Mandatory PWHT (ASME CC)

P-Number	Type of Weld	Nominal Thickness (CC-4552.2.3)	Properties of Pressure Retaining Material(s) Being Joined	
			Max. Reported Carbon, %	Min. Preheat Required, °F
1	All welds, including repair welds, in material 1-1/2 in. and less, exclusive of welds joining nozzles or penetrations with an I.D. greater than 2 in.	1-1/4 in. or less	0.30 or less	...
		Over 1-1/4 in. to 1-1/2 in.	0.30 or less	200
		3/4 in. or less	0.30 or less	...
		Over 3/4 in. to 1-1/2 in.	0.30 or less	200
	All fillet, partial penetration, and repair welds in material over 1 1/2 in., exclusive of welds joining nozzles or penetrations with an I.D. greater than 2 in.	3/4 in. or less	...	200

2.2 ASME CB Requirement

The mandatory requirements for PWHT of welds in accordance with ASME CB are similar to ASME CC. Figure 1(b) shows the Category D weld joint per ASAME CB. As shown in the figure, these are the penetration-to-liner welds which serve the same purpose as ASME CC Category D weld joints. However the exemptions for the penetration to liner welds are different. As shown in Table 3, if the base material thickness is less than 1-1/4 inches, PWHT is waived without excluding welds joining nozzles or penetrations with an inner diameter greater than 2 inches.



(a) ASME CC (b) ASME CB

Figure 1. Typical Weld Joints (ASME CC vs. ASME CB)

Table 3. Exemptions to Mandatory PWHT (ASME CB)

P-Number	Type of Weld	Nominal Thickness (CC-4552.2.3)	Properties of Pressure Retaining Material(s) Being Joined	
			Max. Reported Carbon, %	Min. Preheat Required, °F
1	All welds, including repair welds, in material 1-1/2 in. and less	1 1/4 in. or less Over 1-1/4 in. to 1-1/2 in. 3/4 in. or less Over 3/4 in. to 1-1/2 in.	0.30 or less 0.30 or less 0.30 or less 0.30 or less	. . . 200 . . . 200
	Fillet, partial penetration, and repair welds in material over 1-1/2 in	3/4 in. or less	. . .	200

3. JUSTIFICATIONS FOR EXEMPTION TO ASME CC PWHT REQUIREMENT

3.1 Design Concept

Two methods of sleeve anchorage are presented. The first anchorage method, referred to as Type 1 in this paper and shown in Figure 2, is the type used on UCN 3&4 for which the PWHT exemption was requested. This detail has ring and fin lugs welded to the body of the sleeve at concrete wall mid-depth. The load transfer mechanism for this type of configuration is from the pipe head fitting to the sleeve, then to the sleeve anchorage lugs, and finally to the confining concrete element. The seam weld between the thin 1/4-inch liner and sleeve plays a passive role for this type of anchorage since the load path is not through the weld.

The second sleeve anchorage method designated as Type 2 and shown in Figure 3, is the type used on earlier projects (i.e. YGN 1&2). This detail has a thick collar plate welded around the sleeve at the inside and outside surface of the concrete wall. Stiffener plates are welded between the sleeve and collar at equally spaced intervals around the circumference of the sleeve. In this method, the collar weld to the sleeve plays a critical role in the load transfer to the concrete and must be designed as a strength element based on all applied loads. The weld is then post weld heat treated.

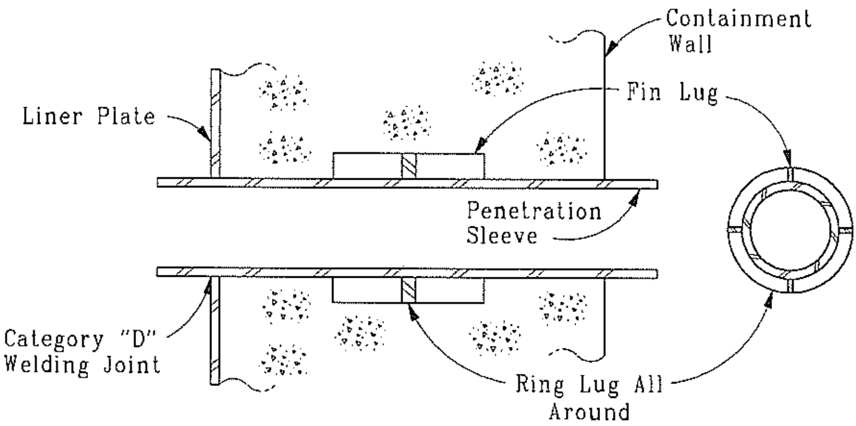


Figure 2. Configuration of Type 1

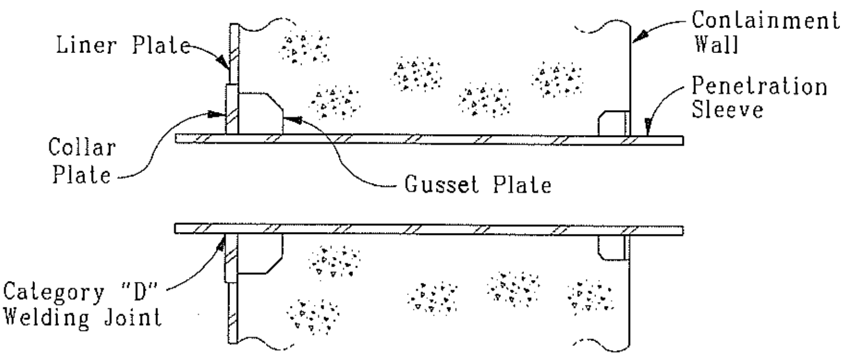


Figure 3. Configuration of Type 2

As noted above, the sleeve to liner weld for the Type 1 detail is not required as a strength element, however strains must be kept within acceptable limits to preclude failure of the weld or liner. In support of the code case to waive PWHT for CC "Category D" welds for the penetrations sleeves used for Type 1, mechanical properties of the liner material are compared with ASME Code allowable liner strains. ASME SA516 Grade 55 is used as the liner material due to its superior ductile behavior. Per material specifications, this mild carbon steel has a minimum ultimate elongation at rupture in 8-inch test specimen equal to 21%. That is, ultimate strain of the liner material is 21%. Assuming that the strain at peak load (ultimate load) is equal to half the ultimate strain, the design margin against liner strain at ultimate load can be calculated as the ratio between the strain at peak load and the code allowable strain. These calculated margins are summarized in Table 4. Since tensile strain governs liner tearing and leakage, the minimum design margin against liner tearing based on liner material properties is 10.5.

Table 4. Design Margin in Strain at Peak Load

	Compressive Strain Margin	Tensile Strain Margin
Membrane	21.0 (=10.5% / 0.5%)	35.0 (=10.5% / 0.3%)
Membrane + Bending	7.5 (=10.5% / 1.4%)	10.5 (=10.5% / 1.0%)

2.3 3.2 Finite Element Analysis

In this study, two three-dimensional finite element models were developed using the ABAQUS computer program to analyze and determine the stresses and strains at the sleeve-liner junction for the two types of penetration details (Type 1 and Type 2).

Since it is assumed that the Type 1 design is not post weld heat treated, a thermal analysis of the Type 1 penetration was performed to determine the residual thermal stresses which result from the welding process. This thermal analysis considered the change in the sleeve and liner material properties according to the temperature history. The welding bead was assumed symmetric along the welding axis, and in determining the heat transfer during welding, the welding current, voltage and travel speed were assumed to be 170 amperes, 26 volts and 0.61 cm/sec, respectively. An arc efficiency is assumed to be 0.7 for the SMAW.[3,4].

Both models were subjected to applied mechanical loads. A total of four cases were analyzed:

Case 1) Type 1 with residual thermal stresses only

Case 2) Type 1 with mechanical loading only

Case 3) Type 2 with mechanical loading only

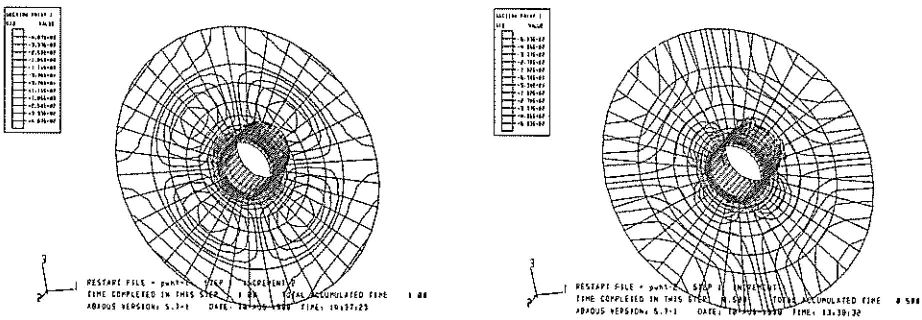
Case 4) Type 1 with mechanical loads plus residual thermal stresses

The finite element models and shear stress contours are shown in Figure 4. Results of the analysis are summarized in Table 5 and the following conclusions are noted:

1) A comparison of the results shows that the effects of mechanical load on the weld joint of the Type 1 penetration are less significant than on the Type 2 penetration.
2) The results of the analysis indicate that the combined stresses under mechanical loading plus residual stresses for the Type 1 penetration are lower than those for the mechanical loads only for the Type 2 penetration.
3) In all cases, strains meet the allowable strain limits of the ASME Code

Table 5. Stress analysis result at the critical location along the weld

Cases	Stress(lb/in^2)			Strain(in/in)		
	S11	S22	S12	E11	E22	E12
Case 1	-1208.0	-1239.0	-707.8	3.049E-4	2.89E-4	-7.19E-4
Case 2	551.0	549.3	-225.4	1.33E-4	1.32E-4	-2.02E-4
Case 3	1968.0	1969.0	-1400.0	4.75E-4	4.75E-4	-1.25E-3
Case 4	-657.0	-689.7	-933.2	-4.38E-4	4.21E-4	-9.21E-4



(a) Case 4 (for Type 1) (b) Case 3 (for Type 2)

Figure 4. Shear stress contour in liner of Type 1 and Type 2

3.3 Sandia Laboratory Test Results

A 1/6 scale model of a steel lined containment building was tested by Sandia Laboratory which provides empirical data regarding the strains in the penetration-to-liner weld area. A detailed description of the testing is described in Reference 5. In this test, the design pressure for the model was 46 psig. The test results indicated very little leakage until approximately 140 psig where a leakage of 10 scfm was measured. The leakage grew to 50scfm at 143psig, and at 145psig leakage increased tremendously to 5000scfm. The leakage was primarily due to a 22 inch long tear in the liner near a piping penetration which occurred due to the strain concentration near penetration[(6)].

The design margin based on the test results can be computed as the ratio between the strain concentration value at tear initiation reported in Reference (6) and code allowable strains. As aforementioned, no significant leakage occurred prior to reaching 140 psig which is over three times the design pressure 46 psig. Reference 5 reported that in liner areas away from penetrations, the average liner hoop strain at the final pressure (145 psig) was 1.72%. It was also reported that in the area of the liner tear, the strain concentration was nearly 11 times the average liner strain values at pressures in the range of 100psig to 130psig. Therefore, the liner strain at tear location can be estimated to 18.9% (=11.0 x 1.72%) and design margin against liner tear can be summarized as shown in Table 6. Since tensile strain governs liner tear and leakage, the minimum design margin based on Sandia model test is 18.9. This indicates that the allowable liner strains specified in ASME CC-3720.1 are conservative and provide a large safety margin against liner tear and leakage.

Table 6. Design Margin against Liner Tear (from Sandia Model Test)

	Tensile Strain Margin
Membrane	63.0 (=18.9% / 0.3%)
Membrane + Bending	18.9 (=18.9% / 1.0%)

4. CONCLUSIONS

The following conclusions can be drawn from this investigation:

1) The liner and welds around the penetration sleeves for Type 1 are intended to provide leak-tightness and not required for strength.
2) The design arrangement of the Type 1 penetration results in relatively low stresses and strains at the weld joint.
3) PWHT need not be mandatory for the welded joint between the containment liner and penetration sleeves in a Type 1 arrangement.

Therefore, exemption from CC Code requirements for PWHT is justified.

REFERENCES

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