Stresses from Applied Loadings
for Level A, B, C and D Conditions
Considered in the
Core Spray Line Fracture Mechanics Evaluation

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INTRODUCTION

A fracture mechanics evaluation of the indications identified by the IVVI and UT inspection of the core spray internal piping during the current refueling outage at Cooper Nuclear Station, was documented in Reference 1. This report provides the details on the calculated stresses for various loads, load combinations for various operating conditions and allowable flaw calculations for the indication identified at weld # 1 on A-Loop (worst case).

STRESSES AND LOAD COMBINATIONS

The significant loads on the internal core spray line during various operating conditions are the following: weight, flow load during core spray operation, internal pressure during core spray operation, seismic inertia, seismic and thermal anchor motions and fluid drag during LOCA.

The weight, flow, pressure, fluid drag and OBE/SSE (Inertia) loadings are primary loadings (i.e., membrane stress is classified as P_m and the bending stress is classified as P_b). The OBE/SSE and thermal displacement loadings are classified as secondary. Therefore, the bending stresses from these loadings were added together to obtain the P_e stress magnitude. The P_e stress was then conservatively added to P_b for the purpose of allowable flaw calculations.

The calculated values of stresses for various operating conditions are summarized next.

Level A (Normal Operation)

During the normal operation, the core spray line does not have any flow or internal pressure. The only loading other than the weight is the thermal anchor displacement loading. The stresses from applicable loadings are tabulated below.

Load	Stress (psi)	
	Membrane	Bending
Weight	0	52
Flow	0	0
Pressure	0	0
OBE (Inertia) Horz. 5g Eq. Static	0	0
OBE (Inertia) Vert. 1g Eq. Static	0	0
OBE (Disp)	0	0
Thermal (Disp)	5	39

The P_m, P_b and P_e stresses for the normal condition are then obtained as follows:

P_m = 0 psi

P_b = 52 psi

P_e = 39 psi

Level B (Upset) Condition

It is conservatively assumed that the core spray operation and the seismic (OBE) event occur at the same time. The stresses are as summarized below:

Load	Stress (psi)	
	Membrane	Bending
Weight	0	52
Flow	250	0
Pressure	733	0
OBE (Inertia) Horz. 5g Eq. Static	117	1116
OBE (Inertia) Vert. 1g Eq. Static	0	52
OBE (Disp)	51	250
Thermal (Disp)	5	39

The P_m, P_b and P_e stresses for the upset condition are then obtained as follows:

P_m $= 0 + 250 + 733 + 117$
$= 1100$ psi

P_b $= 52 + 0 + 0 + \sqrt{(1116^2 + 52^2)}$
$= 52 + 1117$
$= 1169$ psi

P_e $= 250 + 39$
$= 289$ psi

Level C (Emergency) Condition

The emergency condition loads are essentially the same as those specified for upset condition except that the seismic stress calculations are based on SSE. The USAR of Cooper station states that the horizontal ground acceleration for OBE is 0.1g and that for SSE is 0.2g. Therefore, the stresses for the SSE event (both inertia and displacement) were obtained by doubling the corresponding OBE values. This is conservative because the damping during the SSE event is expected to be higher than that during the OBE event.

Load	Stress (psi)	
	Membrane	Bending
Weight	0	52
Flow	250	0
Pressure	733	0
SSE (Inertia) Horz. 10g Eq. Static	234	2232
SSE (Inertia) Vert. 2g Eq. Static	0	104
SSE (Disp)	102	500
Thermal (Disp)	5	39

The P_m, P_b and P_e stresses for this condition are then obtained as follows:

$$P_m = 0 + 250 + 733 + 234$$
$$= 1217 \text{ psi}$$

$$P_b = 52 + 0 + 0 + \sqrt{(2232^2 + 104^2)}$$
$$\approx 52 + 2234$$
$$= 2286 \text{ psi}$$

$$P_e = 500 + 39$$
$$= 539 \text{ psi}$$

Level D (Faulted) Condition

A simultaneous occurrence of LOCA and SSE events is considered in developing the load combinations for the Level D condition. A postulated occurrence of a recirculation or main steam line double-ended break is expected to generate drag forces from the escaping fluid. It was determined that fluid drag forces from the main steam line break will be more severe than those produced by the recirculation line break. The fluid drag forces are expected to peak in the first few seconds after the break. Because the core spray initiation would occur at a later time and the full flow is established in 10 seconds, it is reasonable to assume that the core spray initiation loads and the fluid drag loads are not additive and that the two loads should be considered individually. Thus, there are two cases to consider for the faulted condition. In the first case, the fluid drag loads are considered along with the SSE loads. The second case is essentially the same as the emergency condition in which core spray initiation loads are considered along with the SSE loads.

Case 1: LOCA Fluid Drag Loads

Load	Stress (psi)	
	Membrane	Bending
Weight	0	52
Flow	0	0
Pressure	0	0
Fluid Drag	0	1128
SSE (Inertia) Horz. 10g Eq. Static	234	2232
SSE (Inertia) Vert. 2g Eq. Static	0	104
SSE (Disp)	102	500
Thermal (Disp)	5	39

The P_m, P_b and P_e stresses for this condition are then obtained as follows:

P_m $= 0 + 0 + 0 + 234$
$= 234$ psi

P_b $= 52 + 0 + 0 + \sqrt{(2232^2 + 104^2)} + 1128$
$= 52 + 2234 + 1128$
$= 3414$ psi

P_e $= 500 + 39$
$= 539$ psi

Case 2: Core Spray Initiation

Load	Stress (psi)	
	Membrane	Bending
Weight	0	52
Flow	250	0
Pressure	733	0
SSE (Inertia) Horz. 10g Eq. Static	234	2232
SSE (Inertia) Vert. 2g Eq. Static	0	104
SSE (Disp)	102	500
Thermal (Disp)	5	39

The P_m, P_b and P_e stresses for this case 2 of the faulted condition are then essentially the same as those for the emergency condition.

Determination of Limiting Condition

A review of calculated P_m, P_b and P_e values for various operating conditions shows that between the normal and upset conditions, the upset condition is governing (i.e., has higher stresses). The stresses for the emergency and faulted condition case 2 are the same. Therefore, the allowable flaw values for the upset condition and the two faulted condition cases were determined to ascertain as to which one gives the smallest allowable flaw value. The allowable flaw calculations were conducted using the equations given in Appendix C of ASME Section XI. This weld was made by GTAW process which is a nonflux welding procedure. Therefore, the equations corresponding to base metal or nonflux welds were used which do not involve the use of a 'z' factor. For conservatism, the P_e stress was added to the P_b stress for the purpose of allowable flaw calculation. The core spray line material is Type 304 stainless steel. The S_m value was taken as 16.9 ksi, corresponding to the design temperature of 550°F. It should be noted that the use of 550°F temperature is conservative (a more appropriate temperature is 406°F, the temperature at which the core spray injection initiates).

ALLOWABLE FLAW LENGTH CALCULATIONS

The allowable flaw lengths for the upset condition and the two faulted condition cases were calculated using equations (1) and (3) of Appendix C, ASME Section XI. These equations are applicable to throughwall flaw configurations also as discussed in References 2 and 3.

The allowable flaw length in terms of angle θ was obtained using a circumference of 20.03 inch, corresponding to a sleeve diameter of 6.375 inches. The Appendix C equations are restated below:

(For neutral axis located such that $\theta + \beta < \pi$)

$$P_b' = (6S_m/\pi)(2 \sin\beta - a/t \sin\theta)$$

$$\beta = [(\pi - \theta a/t) - (P_m/3S_m)\pi]/2$$

where, t = pipe thickness, inches
θ = crack half-angle
β = angle that defines the location of the neutral axis
P_m = membrane axial stress
P_b' = failure bending stress
a = crack depth (assumed = t for this evaluation)

The safety factor is then incorporated as follows:

$$P_b' = SF(P_m + P_b) - P_m$$

<u>Upset Condition</u>

P_m = 1100 psi
P_b = 1169 +289 = 1458 psi
S_m = 16900 psi
Safety factor = 2.8

Assume θ = 1.8488 radians
Then,

β = 0.612 radians
P_b' = 6065 psi
P_b = 1459 psi

The above value of P_b is close enough to the load combination value of 1458 psi, indicating that the assumed value of θ is correct.

Allowable flaw length = (θ/π)xCircumference
= $(1.8488/\pi)$x20.03
= 11.8 inches

<u>Faulted Condition (Case 1)</u>

P_m = 234 psi
P_b = 3414 + 539 = 3953 psi
S_m = 16900 psi
Safety factor = 1.4

Assume θ = 1.9635 radians
Then,

β = 0.5818 radians
P_b' = 5654 psi
P_b = 3972 psi

The above value of P_b is close enough to the load combination value of 3953 psi, indicating that the assumed value of θ is correct.

Allowable flaw length = (θ/π)xCircumference
= $(1.9635/\pi)$x20.03
= 12.5 inches

<u>Faulted Condition (Case 2)</u>

P_m = 1217 psi

P_b = 2286 + 539 = 2825 psi
S_m = 16900 psi
Safety factor = 1.4

Assume θ = 1.9321 radians
Then,

β = 0.5671 radians
P_b' = 4482 psi
P_b = 2853 psi

The above value of P_b is close enough to the load combination value of 2825 psi, indicating that the assumed value of θ is correct.

Allowable flaw length = (θ/π)xCircumference
= (1.9321/π)x20.03
= 12.3 inches

Among the two faulted condition cases, the allowable flaw length is the least for case 2. Between the upset condition case and the faulted condition case 2, the upset condition allowable length of 11.8 inches is the least and thus governing.

REFERENCES

[1] "Internal Core Spray Line Flaw Evaluation at Cooper Nuclear Station," Report No. GENE-523-A121-1195, November 1995.

[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, C.F. Shih and J. P. Gudas, Eds., American Society for Testing and Materials, 1983, pp. II-309 - II-330.

[3] "Evaluation of Flaws in Austenitic Steel Piping," Journal of Pressure Vessel Technology, Transaction of ASME, Volume 108, August 1986, pp. 352-366.

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