CERTIFICATION OF ENGINEERING CALCULATION

STATION AND UNIT NUMBER Catawba Unit 2

TITLE OF CALCULATION Operability of Cracked Weld on KC Heat Exchanger 2B

CALCULATION NUMBER CNC-1201.04-01-0001

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THESE ENGINEERING CALCULATIONS COVER QA CONDITION 1 ITEMS. IN ACCORDANCE WITH ESTABLISHED PROCEDURES, THE QUALITY HAS BEEN ASSURED AND I CERTIFY THAT THE ABOVE CALCULATION HAS BEEN ORIGINATED, CHECKED OR APPROVED AS NOTED BELOW:

ORIGINATED BY J. F. Willis DATE 10-14-93

CHECKED BY Albert M. Dihu DATE 10-14-93

APPROVED BY D. L. Ward DATE 10-14-93

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1	1-4 (Vol. I)	N/A	5 (Vol. I)	N/A	N/A	Attach. B Pages 1 & 2	N/A	N/A	J F Willis 10/26/93	[signature] 10/26/93	D L Ward 10/26/93	

Form 101.2 Revision 1
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REVISION DOCUMENTATION SHEET

Revision Number	Review Frequency Changed Yes/No	Revision Description
1	N/A	This calculation was revised to incorporate attachment B, and to add a better description of the calculated crack growth.

Operability of Cracked Weld on KC Hx. 2B

Statement of Problem/Purpose

The cracked weld is located near the bottom center of the 2B KC Hx.. This weld is a circumferential butt weld between two cylinders. The crack consists of 4 distinct, parallel, discontinuous, overlaping cracks. The cracks run perpendicular across the weld. The approximate combined length of the crack is 1.0". Per attachment A the crack is due to an existing flaw in the weld and not due to fatigue. The crack will be repaired during the next Unit 2 refueling outage. The purpose of this calculation is to determine if the crack will remain stable until the next Unit 2 outage for its design loading conditions.

Quality Assurance Condition

This calculation is QA condition 1 because it serves as the basis for the qualification of a QA condition 1 structure, system or component.

Analysis Methods Used

Method 1

The above condition will be evaluated using hand calculation employing Linear Elastic Fracture Mechanics (LEFM) methodology (see pages 1-5).

Method 2 (See attachment B, pages 1and 2)

This condition will also be evaluated using Generic Letter 91-18 section 6.14 (Flaw Evaluation). Paragraph's 3 and 4 state that moderate energy Class 3 piping (maximum operating operating temperature less than 200 degrees F and a maximum operating pressure less than 275 psig) may be evaluated using Generic Letter 90-05. The component in question is however not a pipe but the shell side of a heat exchanger with a 64" diameter. Both of the components are long cylindrical vessel with thin walls. The crack is located at a distance of 4.5" from the only discontinuity in the region, which is a support saddle.

Analysis Methods Used (cont.)

This distance is greater than the square root of Rt (R = 64.125/2 = 32.06" and t = 0.5625" see ref. 3 page 2.3, $(Rt)^{0.5}$ = 4.25"). This would locate the crack in a region of low discontinuity stress. Based on the above similarities the accepted method of through wall flaw evaluation given in Generic Letter 90-05 will also be used to evaluate this condition.

References

1. Elementary Engineering Fracture Mechanics, By David Broek
2. 1992 ASME Code Section XI Appendix A and E
3. KC Hx. Stress report CNM-1201.06-0081 rev. 1
4. Flow Diagram CN-2573-1.0 rev. 14
5. Attachment A
6. NRC Generic Letters 90-05 and 91-18

Assumptions

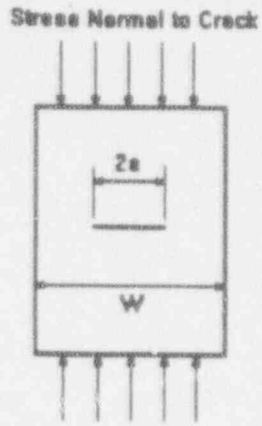
Listed as used in body of calculation

Evaluation

The crack will be evaluated using linear elastic fracture mechanics. The crack is known to be thru wall because the vessel is leaking. The leak consists of about 15 drips per minute which is not considered a significant amount. Based on a review of the stress report (See reference 3) the only significant loading normal to the crack is hoop stress. The center of the crack is also located at a distance of 4.5" from the closest discontinuity, this is greater than the square root of Rt (R = 64.125/2 = 32.06" and t = 0.5625" see ref. 3 page 2.3, $(Rt)^{0.5}$ = 4.25"), which would put the crack in a region of low discontinuity stress. The only significant cyclic loading will be that of pressurizing and depressurizing the vessel. The 4 cracks will be considered as one continuous crack 1.0" long. The stress intensity factor KI will be calculated using reference 1, page 76, table 3.1. The model assumes a crack of length 2a in a flat plate of width W. Since the vessel is a cylinder with a 5' diameter the width W was assumed to be infinite. This would make the equation for KI as follows.

Evaluation (cont.)

$$KI = (\text{stress normal to the crack}) * (3.14 * a)^{0.5}$$



Calculate Stresses Normal to the Crack

Hoop stress = Pd/2t where: P = 135 psig (see ref. 4)
d = 64.125" (see ref. 3)
t = 0.5625" (see ref. 3)
= (135 * 64.125) /(2 * 0.5625) = 7700 psi or 7.7 ksi

Residual stresses due to fabrication - Per reference 2 appendix E table E-2 residual stresses due to fabrication may be assumed to be +/- 10 ksi. Based on the thin wall of this vessel and the direction of the crack a residual stress of 5 ksi should be sufficient.

Total stress normal to the crack = 7.7 + 5.0 = 12.7 ksi

Evaluation (cont.)

Calculate KI max. and KI min.

$KI\ max = 12.7 * (3.14 * 0.5)^{0.5} = 15.9\ ksi\ (in.)^{0.5}$

$KI\ min = 5.0 * (3.14 * 0.5)^{0.5} = 6.3\ ksi\ (in.)^{0.5}$

Determine delta KI

$delta\ KI = KI\ max. - KI\ min. = 15.9 - 6.3 = 9.6\ ksi\ (in.)^{0.5}$

Determine R

$R = Kmin. / K\ max. = 6.3 / 15.9 = 0.4$

Per reference 3 the tank material is carbon steel SA-515-70. Per reference 2 appendix A article A-4200(b) and A-4300(b-1) the lower bound curves contained in the appendix can be used if actual data is not available. Since this flaw is thru-wall, and is exposed to water, section A-4300(b-2) of reference 2 will be used. Using A-4300, equations 1, 3, and 4 of reference 2, with a delta KI of 9.6 and R = 0.4 calculate the crack growth (a) per cyc'..

Max. delta KI for low delta KI values $= 17.74[(3.75 \times R + 0.06) / (26.9 \times R - 5.725)]^{0.25}$
where: $R = 0.4$
$= 17.74[(3.75 \times 0.4 + 0.06) / (26.9 \times 0.4 - 5.725)]^{0.25}$

$= 13.24\ ksi\ (in)^{0.5} > 9.6$ use low curves

$da / dN = C_o \times (delta\ KI)^n$ Where: $Co = 1.02 \times 10^{-12} \times S$
$S = 26.9 \times 0.4 - 5.725 = 5.035$
$n = 5.95$
$= 1.02 \times 10^{-12} \times 5.035 \times (9.6)^{5.95} = 3.59 \times 10^{-06}$ in / cycle

Evaluation (cont.)

To conservatively estimate the crack growth without, growing the crack and recalculating delta KI for each cycle, the da / dN value will be multiplied by a factor of around 25, which would yield a value of 0.0001 in/cycle, which equals 0.0002 total crack growth per cycle (2a = 2 x .0001 = .0002). The above delta KI is based on a full pressure cycle, which is conservative, since while the unit is in operation the heat exchanger would remain pressurized even when not in service. Since this crack is going to be repaired during the next refueling outage the total crack growth will be conservatively estimated by assuming 100 full pressure cycles. This would make the crack growth equal 0.02" (0.0002 * 100 = 0.02) at the time of repair. The final crack length would be approximately 1.02". The critical crack length will be determined using KIc from Fig. A-4200-1 of reference 2. The value of (T-RTNDT) was conservatively assumed to be -100 degrees F, this yields a KIc of about 35 ksi $(in.)^{0.5}$. Using the previous equation for KI and solving for (a), with KI = 35, the critical crack length would be as follows. It should be noted that the total crack length is equal to 2a.

$$2ac = ((KIc)^2 \; / \; ((\text{total stress normal to the crack})^2 * 3.14) * 2)$$

$$= ((35)^2 / ((12.7)^2 * 3.14) * 2)$$

= 4.84" using a factor of safety 2, 2ac = 4.84/2 = 2.42" or ac

Since the crack length at the time of repair is less than the critical crack length the crack is acceptable (2.42" > 1.02").

Conclusion

Based on the above, the crack in the weld on the KC Hx. 2B, as documented in PIP 2C93-0824 will remain stable until the end of the next Unit 2 refueling outage.

DESCRIPTION OF FLAW

The flaw is located in the circumferential weld adjacent to the smaller middle support of the 2B KC Heat Exchanger. Specifically, the flaw is located in the circumferential vessel weld 4 1/2" from the vessel support weld and approximately 5 degrees from the bottom center of the vessel or 25 inches from the upper edge of the support.

The flaw was first identified by a drip of water. The paint was removed from the vessel surface and an inspection was performed by Engineering Personnel (TL Mauldin, HD Mason, and SS Lefler) and also by Personnel from the Metallurgy Lab (Sue Anderson and David Bartlett). These inspections revealed two pinhole indications that resembled porosity in the weld and possibly a crack. UT examination was performed and these results indicated there was a crack approximately one inch in length. UT examinations on either side of the crack found the actual thickness met or exceeded the nominal vessel wall thickness of 9/16".

Grinding of the surface of the weld was then performed to aid in examining and evaluating the defect. This further surface preparation found the defect to consist of four discontinuous cracks spaced closely together. Surface examination found the cracks to be limited entirely to the weld bead and approximately 3/4" in length. One of the original pinhole indications was still visible in the middle of one of the cracks. All of the cracks are located in a longitudinal orientation with respect to the vessel centerline or transverse to the circmferential weld.

EVALUATION

Visual inspection of the defect concluded that this is a defect in the manufacturer's weld. The cracks resulted from the pinholes or porosity that were observed. The vessel welds were spot radiographed by the manufacturer. (Reference drawing CNM 1201.06-0051) As a result, this defect would not have been found in one of the areas of the vessel that did not receive radiography. It appears that this weld was made by the vendor using a submerged arc welding process. This is a common welding process used for fabricating pipe and vessel sections in the shop. Discussions with Brian Kruse and Clyde Freeman revealed that some defects have been found in vendor submerged arc welds in other vessels.

CONCLUSIONS

This defect was present in the weld when the vessel was fabricated. The spot radiography performed in accordance with ASME Section III

did not find this defect. The nominal wall thickness measured by UT on either side of the defect is nominal wall thickness or greater indicating that the defect is not the result of corrosion.

The small amount of water loss from the drip through the crack in the vessel wall does not cause a problem with system inventory and operability.

Reference attached 10/13/93 summary of field examination from Sue Anderson.

Summary By: [signature] Date: 10-14-93

From: SXA3347 --PRDC   Date and time   10/13/93 08:42:19

To: HDM9312 --PRDC   H. Dennis Mason   SSL1401 --PRDC   Samuel S. Lefler,
TMM9378 --PRDC   Tony M. Mauldin   JFW8363 --PRDC
BJK1331 --PRDC   Brian Kruse

From: Sue Anderson   875-5326/5275   SXA3347   6:30-5 M-Th
Analytical & Predictive Technologies - Metallurgy Lab
Generation Services Department

Subject: Leaking weld in 2B KCHX

The Metallurgy Lab examined the leaking weld near the bottom center of the 2B KCHX at Catawba on 10/11 and 10/12. First, the observations:

- Leak as found was a weeping pinhole. Difficult to see anything else due to heavy grinding marks.

- Station personnel ground weld flat and did some buffing - axial crack became visible. Leak rate increased.

- Met lab did some fine polishing in area and examined crack w/5X magnifier:
    - o crack was actually 4 distinct, discontinuous cracks
    - o cracking confined entirely to weld bead
    - o weld 1-1/4" wide; crack tip visible 5/16" from edge of weld, ran axially for 3/4"
    - o original pinhole leak visible as wide part of one of the cracks

From these observations, some thoughts:

- Fatigue cracking is virtually ruled out, as fatigue cracks do not form step-wise on parallel planes. However, must consider possibility that if parallel cracks existed as flaws, each could have grown independently.

- Most likely explanation is that cracks existed for some time as weld flaws. The nature of the flaw is not obvious; the cracks are not in the direction in which hot cracking might occur, and hot cracking is not common in plain carbon steel. Due to the size of the structure, stresses generated during fabrication could have been significant.

- The pinhole (original leak) at one crack is further evidence of weld flaws; pinhole leaks can sometimes result from interconnected porosity. In this case, the pinhole may instead be a spot of localized corrosion: flaws/cracks open to the KC water would have acted as a crevice. Although the KC water contains corrosion inhibitors, the environment in a crevice is different from the bulk water and is usually more hostile.

If you have any questions concerning these thoughts or would like to discuss further, please call.

Thanks - Sue

Evaluation of Train B KC Heat Exchanger Leakage

Since KC has redundant independent trains which are each capable of bringing the plant to a complete shutdown, and since KC trains automatically isolate upon lo-lo surge tank level in either tank, assured makeup from nuclear service water (RN) is not needed to mitigate an accident. Per the Standard Review Plan (NUREG-0800), an assured makeup source must still be provided, however. If a most limiting pipe rupture occurs (the assumed single failure) on 2B, then that train is unavailable. RN makeup will not suffice, but may help mitigate a less severe break. Per CNC-1223.24-00-0013, about 346 gpm can be delivered to each train of the KC system. In this scenario, a leak on the order of drops per minute will not make any difference in the ability to achieve train separation before depleting the surge tanks during a pipe rupture. Also, since for this case it is being assumed that the pipe rupture has occurred on train B, this leakage will not matter, since the train is assumed to be rendered ineffective anyway. If the pipe break occurs on train A, there is still 346 gpm of makeup on train B with very little demand, since train B is assumed to be intact. Compared to the ability to make up, the train B heat exchanger leak can be considered inconsequential.

90-05 Evaluation of Cracked Weld

(Attachment B)

Evaluation

Per section C, part 3, of generic letter 90-05, the structural integrity of a through wall crack like flaw may be evaluated using, part 3.a ("Through-Wall Flaw" Approach). The following is an evaluati on using this method.

Determine t_{min} (Ref. ASME Code Section III Division I - Subsection ND, ND-3324.3)

$t_{min} = P * R / (S * E - 0.6 * P)$ Where: P = Design Pressure (135 psig, see ref. 4)
R = Inside radius before corrosion allow. (31.5", see ref. 3 page 2.3)
S = Allowable Stress (17500 psi, see ref. 3)
E = Joint efficiency (Assumed to be 0.8 per ND-3352 and Dwg. CNM-1201.06-51)

$t_{min} = 135 * 31.5 / (17500 * 0.8 - 0.6 * 135)$

$= 0.306"$

Flaw relation to t_{min} as shown in figure 2b of 90-05 - The maximum flaw length was conservatively assumed to exist at t_{min} .

The length 2a for the flaw in question is 1.0" which is less than 3.0". The crack is less than 15% of the circumference by inspection.

Stress at the flawed location - Based on a review of the stress report (See reference 3) the tangential stress produced by internal pressure is greater than the longitudinal stress produced by the combination of all other loadings, this stress equal 7.7 ksi (see page 3).

Evaluation (cont.)

Determine Stress Intensity Factor K

$K = 1.4 * S * F * (3.1416 * a)^{0.5}$

Where: $F = 1 + A * c^{1.5} + B c^{2.5} + C c^{3.5}$

$c = a / (3.1416 * R) = 0.5 / (3.1416 * 31.78) = 0.005$

R = mean radius ((64.125 - 0.5625)/2 = 31.78")

$r = R / t_{min} = 31.78 / 0.306 = 103.86$

$A = -3.26543 + 1.52784 * r - 0.072698 * r^2 + 0.0016011 * r^3$

$B = 11.36322 - 3.91412 * r + 0.18619 * r^2 - 0.004099 * r^3$

$C = -3.18609 + 3.84763 * r - 0.18304 * r^2 + 0.00403 * r^3$

a = flaw length / 2 = 1.0 / 2 = 0.5"

$A = -3.26543 + 1.52784 * 103.86 - 0.072698 * 103.86^2 + 0.0016011 * 103.86^3 = 1165.0$

$B = 11.36322 - 3.91412 * 103.86 + 0.18619 * 103.86^2 - 0.004099 * 103.86^3 = -2979.0$

$C = -3.18609 + 3.84763 * 103.86 - 0.18304 * 103.86^2 + 0.00403 * 103.86^3 = 2936.9$

$F = 1 + 1165.0 * 0.005^{1.5} - 2979 * 0.005^{2.5} + 2936.9 * 0.005^{3.5} = 1.407$

$K = 1.4 * 7.7 * 1.407 * (3.1416 * 0.5)^{0.5} = 19.01$ ksi(in)$^{0.5}$

Conclusion

Since the vessel is made of carbon steel, which is a ferritic steel, the critical stress intensity factor K will be 35.0 ksi(in)$^{0.5}$. Since the above calculated stress intensity factor is less than the critical value the requirements of generic letter 90-05 have been met (K = 19.01 < 35.0 ----------> OK).

By: JFW Date: 10/26/93 Check: [signature] Date: 10/26/93

ATTACHMENT 2

LEAKAGE EVALUATION