APPLICABILITY OF ASME CODE CASE N-284-1
TO BUCKLING ANALYSIS OF DRYWELL SHELL

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INTRODUCTION

The methods and assumptions contained in ASME Code Case N-284-1 were used in the buckling analysis of the drywell shell with local areas of corrosion. The NRC staff is questioning the application of these rules for a corroded shell.

DISCUSSION

The local buckling stress equations given in N-284-1 for spherical shells are a function of the applied stresses and the geometry of the sphere at any local area defined by L_c. The applied stresses are the average stresses over this local area and the thickness is the average thickness over this area. It would be quite conservative to use the minimum corroded thickness determined over a smaller area.

Typically the stress-strain curve for a corroded plate will be similar to that of the uncorroded plate. This was confirmed by tests for the drywell. Because the buckling stresses are elastic, the actual contour of the shell in the corroded area is not a factor in the buckling analysis. The buckling of the shell as a whole is not very sensitive to local variations in the shell. This is apparent from axial compression tests conducted by Miller (1980) on a cylindrical shell with a large unreinforced opening. The opening corresponded to a 30 degree central angle which was the largest opening that had been considered at that time for a containment vessel. The capacity reduction factor was 0.29 for the shell with no opening and 0.22 for the shell with the opening. The size of the hole was $12.6\sqrt{Rt}$.

There is also conservatism in the capacity reduction factor given in ASME N-284-1 which will be explained below. The following allowable stress equation is given for a spherical shell.

$$\sigma_a = \alpha\, \sigma_{th}/FS \qquad (1)$$

where σ_{th} is the theoretical buckling stress of a perfect sphere, α is a capacity reduction factor that accounts for the effects of initial shape imperfections and FS is a factor of safety. The capacity reduction factor for a sphere with biaxial stresses where one stress is compressive and the other stress is tensile is not given in N-284-1. The factor used in the drywell analysis for this stress state was

$$\alpha = \alpha_{1L} + \alpha_p \qquad (2)$$

where $\alpha_{1L} = \alpha_{2L}/0.6$

$$\alpha_p = \frac{1.752}{3.24 + \frac{1}{\overline{p}}} \qquad\qquad \overline{p} = \frac{\sigma_2 R}{Et}$$

α_{1L} is the capacity reduction factor for a sphere under uniaxial compression and α_{2L} is the capacity reduction factor for a sphere under equal biaxial compression. α_p is the capacity reduction factor due to the effect of tensile stress in the orthogonal direction. σ_2 is the tensile stress. The basis for Eq. 2 is given in Miller (1991). The factor α_p was found to be independent of $\alpha_{1L.}$ Equation 2 is now given in ASME Code Case 2286 which was approved July 17, 1998. A commentary on the Code Case is given in WRC Bulletin 462 (Miller 2001).

The application of Eq. 2 in stability analysis provides additional conservatism when applied to the drywell shell. The capacity reduction factors are a function of the deviation from true shape measured over a distance L_c. The relationships between shape imperfections and reduction factors for a sphere are given in Miller (1983).

$$L_c = 2.42\sqrt{R_1 t} \tag{3}$$

where R_1 is the local radius and t is the thickness of the shell at the area under investigation.

The Code Cases assume any imperfection in a spherical shell is the maximum permitted by the ASME Code which is e/t = 1.0. The maximum e/t for the drywell is much less than 1.0 and therefore the buckling stresses will be higher than those given by the Code Case equations. The capacity factor corresponding to the drywell imperfections can be determined from the following. The corroded shell can be treated as an added out-of-roundness with

$$\frac{e}{t} = \frac{t_n - t_c}{2t_c} \tag{4}$$

t_n = nominal thickness
t_c = corroded thickness

The relationship between R_1 and the maximum deviation e/t of a spherical shell from the theoretical radius R, when measured over the arc length of L_c, can be determined from the approximate relationship

$$R_1 = (1 + 1.36\ e/t)\ R \qquad \text{for} \quad R/t > 100 \tag{5}$$

The following values of α_{2L} were determined as the lower bound of available tests which failed by elastic buckling (Miller, 1983). The e/t values varied from about 0.10 to 3.22.

$$\alpha_{2L} = 0.70 - 1.75\ e/t \qquad \text{if} \quad e/t \leq 0.2 \tag{6a}$$

$$\alpha_{2L} = 0.09 + 0.0326(e/t)^{-1.29} \qquad \text{if} \quad 0.2 < e/t < 3.2 \qquad (6b)$$

$$\alpha_{2L} = 0.097 \qquad \text{if} \quad e/t \geq 3.2 \qquad (6c)$$

The maximum e/t ratio permitted by the ASME Pressure Vessel Code is 1.0. For this value α_{2L} = 0.123 from Eq. 6b and $L_c = 3.72\sqrt{Rt}$ from Eqs. 3 and 5. Code Case N-284-1 gives α_{2L} = 0.124. The value for α_{1L} = 0.207 for e/t = 1.0. As an example, if e/t = 0.8 rather than 1.0, the value of α_{1L} = 0.222.

CONCLUSION

The capacity reduction factors given in ASME Code Case N-284-1 and the added factor given by Eq. 2 are applicable to both the corroded areas and the uncorroded areas of the drywell shell if the reduced thickness and local deviation from true shape as determined over the distance L_c are used to determine the factors. This statement is based on the assumption that the material properties in the corroded area are nearly the same as the uncorroded shell.

REFERENCES

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