Example 24 Design of a Tapped Opening

Design Task: A nominal four inch NPT 8 tapped inspection opening is to be cut in the shell of a pressure vessel that has a design pressure of 125 lb/in^2 that is in non-hazardous, non-lethal service The nominal (actual) thickness of the shell is ⅝ inch and the required minimum thickness has been calculated to be 0.507 inches. The shell material has a design allowable stress in tension of 13,750 lb/in^2. A corrosion allowance of 0.0938 inches is specified. Show all the design considerations for this opening.

Given: From the service conditions presented in the problem statement, it is safe to assume that the use of a tapped opening is Code acceptable and,

$$d_{\text{nom}} = 4 \text{ in} \;;\; n = 8 \;;\; P = 125 \text{ lb/in}^2 \;;\; t = 0.625 \text{ in} \;;$$
$$t_r = 0.507 \text{ in} \;;\; S = 13{,}750 \text{ lb/in}^2 \;;\; c = 0.0938 \text{ in}$$

The largest engagement diameter for a 4 inch NPT 8 thread series, while slightly smaller in value, will be conservatively assumed to equal the outside diameter of NPS 4 inch pipe, therefore d will be assigned the value of 4.500 inches.

Strategy: In order to facilitate the design and analysis of this particular type of opening connection while promoting consistency, the Code published nomenclature and formulas associated with opening reinforcement calculations will be judiciously applied to generate a pseudo-surrogate connection that can be thought of as simply a set-on (abutting) opening reinforcement element absent a projecting nozzle neck. The reader should refer to Chapter 9 for further explanations and defining mathematical expressions for the opening reinforcing equation variables that are used in this example.

Solution:

1. Referring to Table 8.14, a minimum host shell component thickness of 1¼ inches is stipulated for an 4 inch NPT tapped opening. Adjusting this thickness to account for corrosion results in,

$$t_{\text{min}} = 1.25 + 0.0938 = 1.344 \text{ in.}$$

2. The vessel's nominal thickness at the site of the tapped opening is therefore deficient in thickness by,

$$\Delta = t_{\text{min}} - t = 1.344 - 0.625 = 0.719 \text{ in.}$$

3. The addition of a minimum ¾ inch nominal thickness shell reinforcing plate of comparable mechanical properties (strength) is therefore needed at the tapped opening. In the fully-corroded condition, this now reinforced, new composite shell sectional thickness would become,

$$t_c = t_e + t - c = 0.75 + 0.625 - 0.09380 = 1.281 \text{ in.}$$

4. Table 8.14 also specifies that the minimum thread engagement for a 4 inch NPT tapped opening is eight threads. The fully-corroded composite section thickness will allow a thread engagement of,

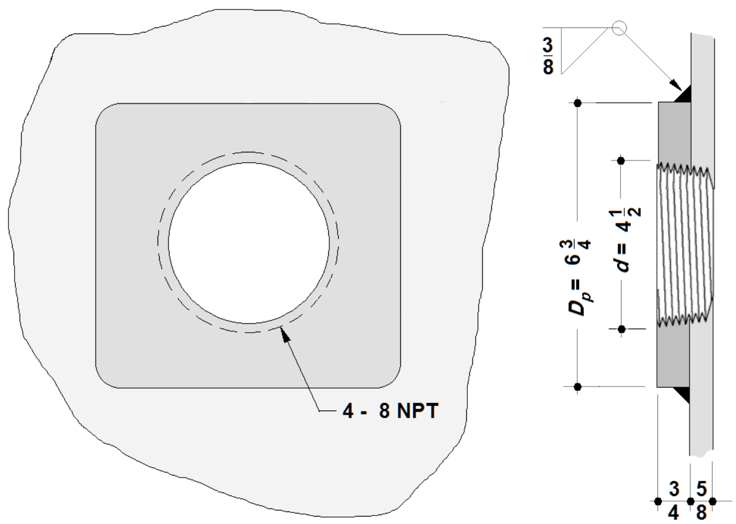
$$L_e = t_c n = \frac{1.281 \text{ in}}{1} \cdot \frac{8 \text{ threads}}{\text{in}} = \underline{\underline{10+ \text{ threads engaged,}}} \quad \therefore \text{ okay} \quad .$$

5. From Chapter 6, the shell reinforcing plates' minimum attachment weld size will be:

$$w_{4_{\text{leg}}} \geq \text{lesser of} \begin{cases} 9/16 \text{ inch } = 0.5625 \text{ in} \\ 0.7(t-c) = (0.7)(0.625-0.0938) = \underline{\underline{0.372 \text{ in}}} \\ 0.7\, t_e = (0.7)(0.75) = 0.525 \text{ in} \end{cases}$$

(Notes: 1. The Code does not assign a variable to the leg dimension of the attachment fillet weld. 2. The shell reinforcing plate is assumed to be exteriorly applied.)

6. Therefore, at a minimum, the use of a ⅜ inch fillet weld is indicated. Select a trial size for the shell reinforcing plate of 6¾ inches by 6¾ inches, resulting in one possible design configuration of,



7. By visual estimation the edge ligament indicated above appears to more than adequate for the internal design pressure of 125 lb/in^2; nevertheless, a check will be made considering it an ultra-short internally threaded projecting nozzle whose minimum thickness will be,

$$t_{rn} = \frac{P(R+c)}{SE-0.6P} + \frac{0.8}{n} = \frac{(125)(4.5/2+0.0938)}{(13{,}750)(1)-(0.6)(500)} + \frac{0.8}{8} = 0.121 \text{ in} \quad .$$

The ligament of (6.75–4.5) / 2 = 1.25 inches is therefore exceedingly adequate by orders of magnitude.

8. As part of the total design, the load carrying capacity of the opening connection must be determined. To accomplish this, the opening created in the composite shell section must be checked for the possible need for additional inforcement required by Code rules (Chapter 9). The required amount of cross-sectional reinforcement area is,

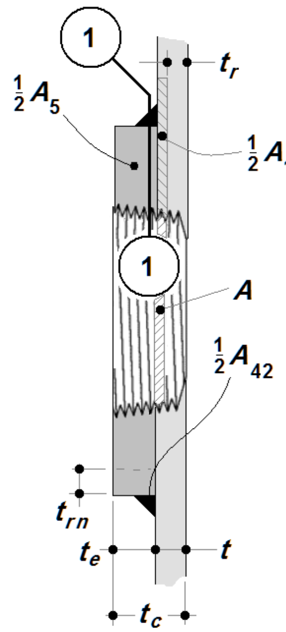
$$A = (d+2c)\, t_r = (4.5+2\cdot 0.0938)(0.507) = 2.377 \text{ in}^2 \quad .$$

This required amount will be compared to that available for reinforcement consideration. The constituent additive areas attributable to available excess shell thickness, the ¾ inch thick shell reinforcing plate, and its ⅜ inch attachment fillet weld are respectively,

$$A_1 = \text{the larger of } \begin{cases} (d+2c)(t-c-t_r) = (4.5+2\cdot 0.0938)(0.625-0.0938-0.507) = \underline{\underline{0.113 \text{ in}^2}} \\ 2(t-c)(t-c-t_r) = (2)(0.625-0.0938)(0.625-0.0938-0.507) = 0.026 \text{ in}^2 \end{cases}$$

$$A_5 = (D_p - d + 2c)t_e = (6.75 - 4.5 + 2\cdot 0.0938)(0.75) = 1.547 \text{ in}^2$$

$$A_{42} = w_{4_{leg}}^2 = 0.375^2 = 0.141 \text{ in}^2 \quad .$$



9. The total cross-sectional area available for reinforcement consideration is then,

$$A_t = A_1 + A_5 + A_{42} = 0.113 + 1.547 + 0.141 = 1.801 \text{ in}^2.$$

10. Because $A_t < A$, 1.801 < 2.377, the initially selected design is not of adequate strength. At this juncture the opening connection can be strengthened by either increasing the thickness of the shell reinforcing plate, or alternatively increasing the size of the plate. Clearly the largest constituent area is that associated with A_5. One approach to determine the second trial size for the shell reinforcing plate is to transpose the cross-sectional area equation for A_5 in terms of D_p and solve the resulting expression for the value of $A_5 = A$. Thus,

$$D_p = \frac{A_5}{t_e} + d - 2c = \frac{2.377}{0.750} + 4.5 - 2\cdot 0.0938 = 7.481 \text{ in} \quad .$$

11. Therefore, make the second trial size for the shell reinforcing plate 7½ inches by 7½ inches and determine the revised values of A_5 and A_t to be,

$$A_5 = \left(D_p - d + 2c\right)t_e = (7.500 - 4.5 + 2 \cdot 0.0938)(0.75) = 2.109 \text{ in}^2$$

$$A_t = A_1 + A_5 + A_{42} = 0.113 + 2.109 + 0.141 = 2.363 \text{ in}^2 \quad .$$

The total area available is now greater than the required area; therefore, the opening is adequately reinforced.

12. The required load to be carried by the attachment weld is,

$$W = \left(A - A_1\right)S = (2.377 - 0.113)(13{,}750) = 31{,}130 \text{ lb} \quad .$$

13. The weld load for strength path 1-1 will be,

$$W_{1-1} = SA_t = (13{,}750)(2.363) = 32{,}490 \text{ lb} \quad .$$

In accordance with the Code, the lesser value of W or $W_{1\text{-}1}$ will be used in comparing weld capacity to weld load.

14. Based on the reduction factors for shear stress presented in Chapter 8, the maximum allowable unit shear stress in the attachment fillet weld will be,

$$S_a = (0.875)(0.55)S = 0.49S = (0.49)(13{,}750) = 6{,}740 \text{ lb/in}^2 \quad .$$

15. Analyzing based on half-symmetry about the axial line of penetration of the opening connection, the load capacity of the attachment fillet weld is,

$$C_{1-1} = \frac{\pi}{2} D_p \, w_{4_{leg}} S_a = (\pi/2)(7.5)(0.375)(6{,}740) = 29{,}775 \text{ lb} \quad .$$

The selected attachment fillet weld size of ⅜ inch is therefore unsatisfactory because its load capacity of 29,775 pounds is less than the required load to be carried by the weld of 31,130 pounds. Increase the fillet weld size to 7/16 and calculate the new load capacity to be,

$$C'_{1-1} = \frac{\pi}{2} D_p \, w_{4_{leg}} S_a = (\pi/2)(7.5)(0.438)(6{,}740) = 34{,}780 \text{ lb} \quad .$$