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COMPARISON OF DESIGN METHODS FOR OPENINGS IN CYLINDRICAL SHELLS UNDER INTERNAL PRESSURE REINFORCED BY FLUSH (SET-ON) NOZZLES

Josip Kacmarcik
University of Zenica
Fakultetska 3, Zenica
Bosnia and Herzegovina

Nedeljko Vukojevic
University of Zenica
Fakultetska 3, Zenica
Bosnia and Herzegovina

ABSTRACT
In this paper a comprehensive comparison of three design methods for openings in cylindrical shells under internal pressure (pressure vessels) reinforced by flush (set-on) nozzles has been carried out. The design methods are used in EN 13445-3: Unfired pressure vessels-Part 3: Design, ASME pressure vessel code and PD 5500: Specification for unfired fusion welded pressure vessels. The calculation procedures used in the three methods are significantly different, so the comparison has been based on the maximum permissible design pressures for 45 specific geometries calculated using the three methods.
Keywords: flush nozzle, set-on nozzle, cylindrical pressure vessel

1. INTRODUCTION
In this paper three design methods for nozzle connections with flush (set-on) nozzles in cylindrical shells under internal pressure (pressure vessels) are investigated and compared. The methods are from EN 13445-3: Unfired pressure vessels-Part 3: Design, ASME pressure vessel code and PD 5500: Specification for unfired fusion welded pressure vessels.

Set-on nozzle is nozzle which is welded to the outside of the vessel with the weld that penetrates through the nozzle wall so the height of the weld is equal to the thickness of the nozzle wall. The characteristic dimensions of the nozzle and the vessel are: R – the external radius of a vessel, r- the external radius of a nozzle, T – the thickness of a vessel wall, t – the thickness of a nozzle wall, Figure 1. To define the geometry of the nozzle, three ratios are used in this paper: r/R, R/T, T/t. Limit values for the ratios, defining the range that includes geometries that are most likely to occur in practice, are selected as:

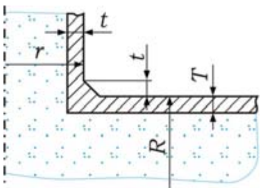

Figure 1. Cross section of flush (set-on)nozzle in cylindrical vessel.

$$0.02 \le \frac{r}{R} \le 0.3\,;\, 10 \le \frac{R}{T} \le 250\,;\, 0.5 \le \frac{T}{t} \le 2 \qquad (1)$$

In order to avoid uncommon or impossible designs the analysis range is narrowed with the following constraints:

$$\frac{r}{T} > 2\,;\, 2 < \frac{r}{t} < 50 \qquad (2)$$

2. DESIGN METHODS

In the following text a brief overview of the three investigated design methods is given.

2.1 EN 13445-3: Unfired pressure vessels-Part 3: Design

The method given in European standard is empirical and it is based on a simple load analysis. The reactive force provided by the material should be greater than, or equal to, the load from the pressure. The former is the sum of the product of the average membrane stress in each component and its stress loaded cross-sectional area (Figure 2). The latter is the sum of the product of the pressure and the pressure loaded cross-sectional areas. The general equation for the reinforcement by set-on nozzle connection of an isolated opening is given by:

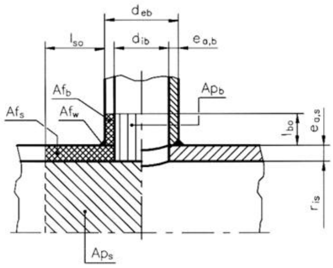

Figure 2. Configuration of set-on nozzle in EN 13345 [1].

$$(Af_s + Af_w)(f_s - 0.5P) + Af_b(f_{ob} - 0.5P) \geq P(Ap_s + Ap_b) \qquad (3)$$

If nominal design stresses for the materials of shell and nozzle are equal ($f_s = f_{ob} = f$) maximum permissible pressure is given by:

$$P_{\max} = \frac{(Af_s + Af_w + Af_b)\,f}{(Ap_s + Ap_b) + 0.5(Af_s + Af_w + Af_b)} \qquad (4)$$

2.2. ASME pressure vessel code

In American code area replacement method is used. Opening is reinforced by providing material near the hole in excess of the minimum thickness required for the individual components considered as unpierced shells. The area of additional material is required to be at least equal to the area removed by making the hole in a shell of minimum thickness. The common nozzle configuration used in the ASME Section VIII Division 1 Code is illustrated in Figure 3.

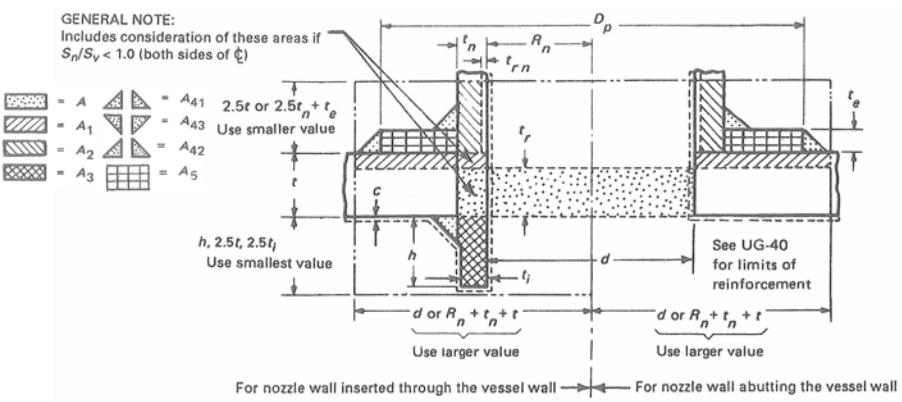

Figure 3. Configuration of flush nozzle in ASME cod [2].

The general requirement for the adequate reinforcement of the opening is given by:

$$A_1 + A_2 + A_3 + A_{41} + A_{42} + A_{43} + A_5 \geq A \qquad (5)$$

2.3. PD 5500: Specification for unfired fusion welded pressure vessels

PD (Publish document) 5500 is derived from British standard BSI 5500 which was withdrawn because its status as a national standard was incompatible with the development of the European Standard EN 13445. The design methodology in the document is based on various stress analysis studies and on photo-elastic tests reported between 1961 and 1974. The design procedure is iterative with several stages. Dimensions of the nozzle are selected and then tested through the design iterative procedure stages, repeating the procedure until the values converge.

3. COMPARISON OF DIFFERENT DESIGN METHODS

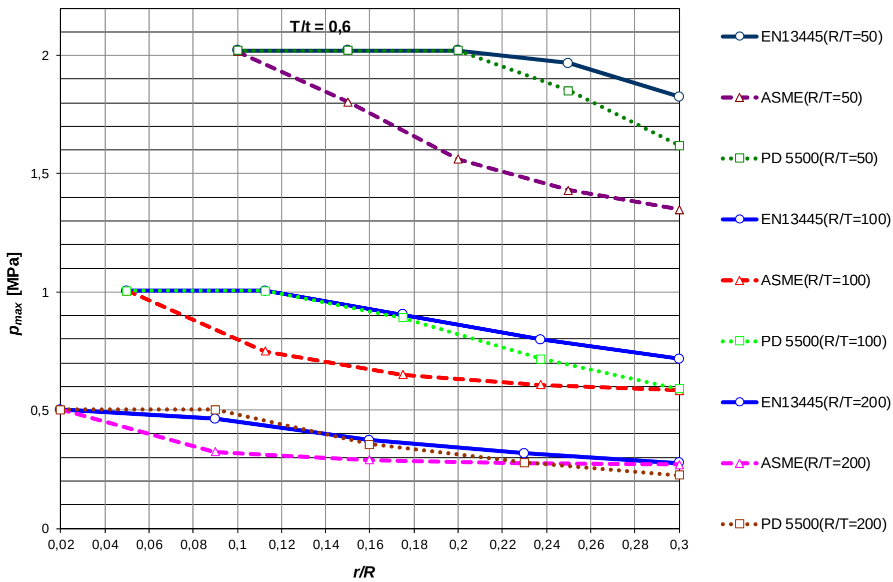

Figure 4. Maximum permissible design pressures according to different design methods (EN 13445, ASME, PD 5500) for different geometries of flush nozzle in cylinder with T/t = 0.6.

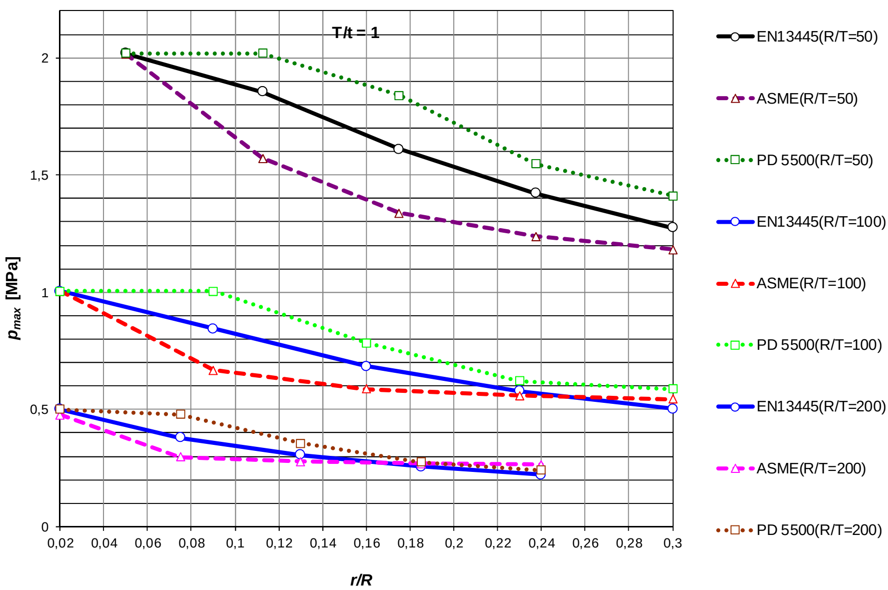

Figure 5. Maximum permissible design pressures according to different design methods (EN 13445, ASME, PD 5500) for different geometries of flush nozzle in cylinder with T/t = 1.

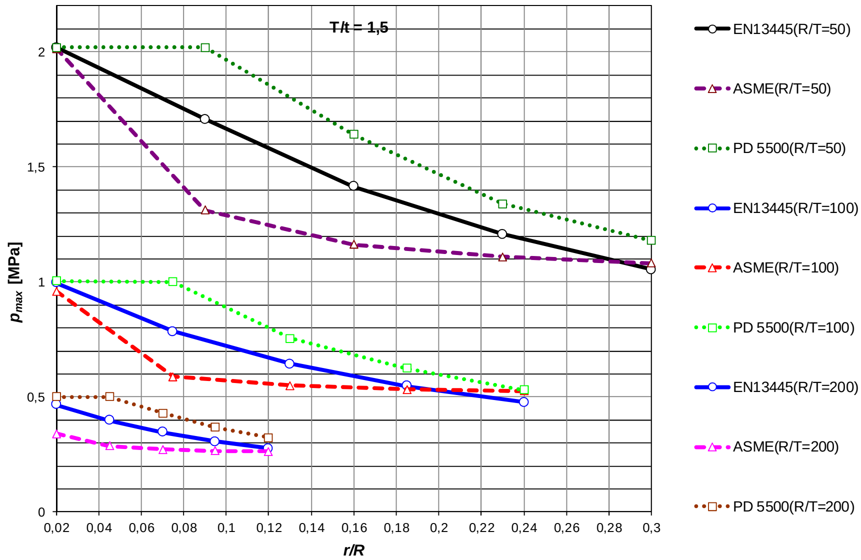

Figure 6. Maximum permissible design pressures according to different design methods (EN 13445, ASME, PD 5500) for different geometries of flush nozzle in cylinder with T/t = 1.5.

The calculation procedures used in the three methods are significantly different, so the comparison has been based on the maximum permissible design pressures for specific geometries calculated using the three methods. The calculations and the result representations are done with MS Excel. Three charts for three levels of ratio T/t (values of 0.6, 1 and 1.5) are made (Figure 4, 5 and 6), representing relationship between the geometric ratio r/R and maximum permissible design pressure. In every chart there are series for three levels of R/t ratio, for values of 50, 100 and 200. Every series has five points, for five different values of r/R ratio, thus making in sum forty five calculation points (3x3x5) for every design method. The selection of the values is made so that the selected values are evenly distributed within the range define with (1) and (2), not necessarily to cover the limit values of the range.

The design stress of 100 MPa is used in the calculations, for materials of a nozzle and a shell. In the ASME and PD 5500 calculations a direct method to calculate the maximum permissible pressure is not given so Goal Seek command from Excel is used on expressions that define the requirements for the adequate reinforcement in order to obtain the maximum permissible pressure value.

4. CONCLUSIONS

With many years of good experience with all of these methods it can be concluded that a safe nozzle design can be provided whichever method is used. However, from the comparison charts it is noticeable that the different methods can give significantly different results, for some geometries even up to 1.75 times greater values according to one method than the other. It can be observed that ASME design method mostly gives the smallest values of permissible design pressure, which shows that this method provides the greatest design safety but requires the largest amount of reinforcement material. At the opposite, PD 5500 design method mostly gives the greatest values, thus requiring the smallest amount of reinforcement material but providing the least safety.

5. REFERENCES

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