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Assessment of Steel Tanks Exposed to Corrosion

Vit Krivy, Monika Kubzova and Viktor Urban
Department of Building Structures, Faculty of Civil Engineering, VSB-TU Ostrava,
Ludvika Podeste 1875, 70800 Ostrava-Poruba, Czech Republic

Abstract: The initiative for a study regarding the influence of corrosive weakening came at the request of the company CEZ, a.s. to process methodical procedure that is used to evaluate measured residual thickness of walls of reservoirs in operation. This study, is introduced a part of the methodical procedure dealing with the way how the corrosion weakening affects the value of circumferential tensile stress in the wall of cylindrical tank.

Key words: Corrosion, assessment of steel tanks, circumferential tensile stress, internal pressure, cylindrical tank, methodical

INTRODUCTION

During the production of electric energy in a typical thermal power station there is a need to store different kinds of liquid materials such as demineralized water, light fuel oil, NaOH solution, limestone and gypsum suspension. Liquid materials are usually stored in cylindrical steel tanks with different diameters, height of construction and thickness (Fig. 1). Historical, development of weathering steels was described in detail (Albrecht and Hall, 2003). Specific corrosion properties of steels containing larger amounts of copper were systematically observed already in 1910 (Buck, 1913). The walls of these steel tanks and other structures (especially bridges) are often attacked by atmospheric corrosion (Morcillo *et al*., 2016; Urban *et al*., 2014). Atmospheric corrosion causes a really significant corrosive weakening which can influence the reliability of a construction. Researchers of this study, developed a methodical procedure to evaluate the relevance of corrosive weakening for the operators of tanks. The procedure can be easily used for a conservative decision whether the identified corrosive weakening can significantly decrease the mechanical resistance (and requires a static analysis of this construction in detail) or not.

These steel tanks are often attacked equally by corrosive weakening on their whole area. The development of corrosion products is long-term monitored such as on bridges (Urban *et al*., 2016; Krivy *et al*., 2013). In some cases this weakening can be only on the local area (corrosive weakening is only on a limited part of the wall). Because of that, it is needed to evaluate not only the value of corrosive damage but also the size effect of the area which is attacked by corrosion during processing methodical documents. There are some basic types of the stress of cylindrical tanks, primarily it is circumferential tensile stress from the loading of store liquid materials and buckling from meridional and circumferential pressure stress. This present, study is introduced only basic aspects related with the assessment of the corrosion weakening and its effects on the circumferential tensile stress.

Fig. 1: Steel tank for the storage of limestone suspension

CALCULATION OF CIRCUMFERENTIAL TENSILE STRESS

Effects of corrosion weakening on circumferential tensile stress: With the help of numerical modeling there were created models of steel tanks with the diameter from 1-10 m where the influence of differently sized areas with

Corresponding Author: Vit Krivy, Department of Building Structures, Faculty of Civil Engineering, VSB-TU Ostrava, Ludvika Podeste 1875, 70800 Ostrava-Poruba, Czech Republic

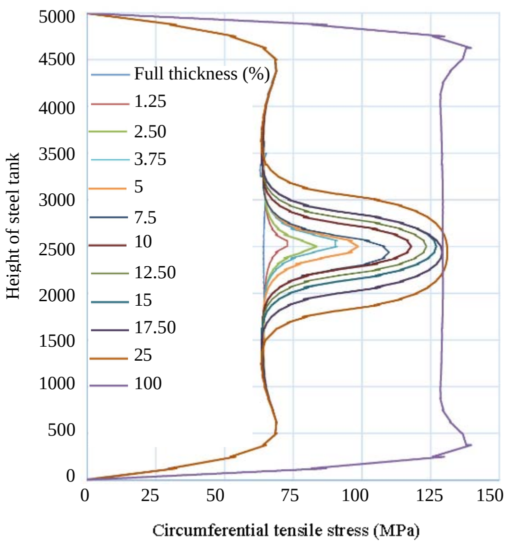

Fig. 2: Influence of height of the weakened area on a process of stress; weakening of vertical surface

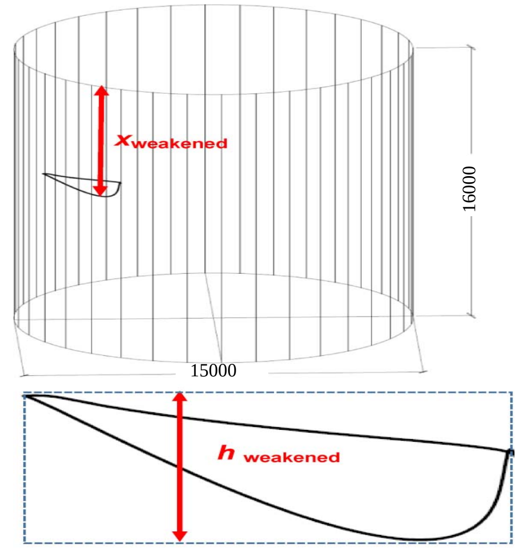

Fig. 3: Approximation of the weakened area by corrosion, determining $h_{weakened}$, determining the elevation coordinate of the weakened area $x_{weakened}$

corrosion attacks were systematically evaluated (size effect of the area with corrosive weakening and the shape of this area was monitored).

From the analyses, it is evident that values of circumferential tensile stress $\sigma_\theta(x)$ emerging along the high variable internal pressure $p_n(x)$ depend on the height of area with the weakening. From certain "compensatory height" there are already maximum values in the local corrosion of steel tank reaching values of the circumferential tensile stress such as in case when the whole area of the wall with corrosion weakening has the same values of corrosion loss. The width of weakened area doesn't have significant influence on values of the stress.

For a specifically selected case (e.g., tanks with diameter R = 10 m, original thickness of wall tanks with a value of 10 mm, weakened thickness 5 mm, loaded by even internal pressure with a value of 43 kNm^2) values of circumferential tensile stress grow up into the compensatory height value which is around 20% of the tank's height. At higher heights of weakening, the maximum value of circumferential tensile stress does not already grow up and remains equal to the value of the whole weakened area of the wall with a thickness of 5 mm (Fig. 2).

From the parametric studies based on numerical modeling were derived analytical relations and graphic aids for an accurate calculation of circumferential tensile stress in weakened area of cylindrical shell. This procedure can be used for circular cylindrical tanks with the diameters from 1-10 m. The design value of circumferential tensile stress in weakened areas of wall tank can be calculated by relationship:

$$\sigma_{\theta,\ d,\ weakened} = \sigma_{\theta,\ d,\ original} \times (1 + k_s) \quad (1)$$

where, the multiplier for circumferential tensile stress k_s was derived on the basis of evaluation of parametric studies in which was monitored a dependence among height corrosion attack area, values of corrosion losses and the diameter of tank. Coefficients k_s specified for corrosion losses of 10, 25, 50, 75 and 90% and for diameters of circular cylindrical tanks from 1-10 m. For determining factors were processed graphical aids (Fig. 4) where the interpretation for corrosion weakening by 25 and 50% is evident). Intermediate values are determined by interpolation.

Sample calculation-determining the height of the weakened area: The height of the weakened area $h_{weakened}$ is conservatively determined on the basis of approximation of a measured weakened area by corrosion according to Fig. 3. The height of weakened area is expressed by depending on diameter of shell R by relationship:

$$h_{weakened,rel} = a.R = \frac{h_{weakened}}{R}.\ R \quad (2)$$

For example for the height of approximate rectangle $h_{weakened}$ = 375 mm and diameter R = 7500 mm, we will receive:

$$h_{weakened,\ rel} = \frac{375}{7500}.\ R = 0.05R \quad (3)$$

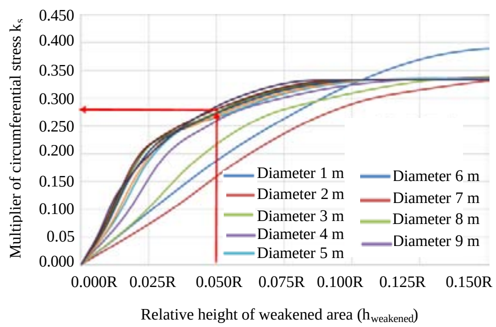

Fig. 4: Multiplier for corrosion loss 25%; multiplier of circumferential stress (detail)-corrosion loss 25%

Calculation of internal pressure for original not weakened tank: The internal pressure is calculated with respect to maximal operating height of suspension h_{operat}, elevation coordinate value of corrosion weakened area $x_{weakened}$ and unit weight storage liquid γ. Dynamic coefficient δ is introduced into the calculation if dynamic effects of storage liquid are expected for example if the agitators are in the tank. Elevation coordinate value of the area with corrosion loss is conservatively determined to the lowest measured part of weakened area (Fig. 3).

For example, for cylindrical tank with height h = 16 000 mm, maximum height of storage suspension h_{max} = 13 000 mm, elevation coordinate value of weakened area $x_{weakened}$ = 8 000 mm, storage limestone suspension with unit weight 120 kN/m^3 and with the agitators in the tank which are introduced into calculation by using dynamic coefficient δ = 1.2 the internal pressure in the weakened area can be calculated by relationships (Fig. 5). The difference between the tank height and operational levels:

$$h_{operate} = h - h_{max} = 16 - 13 = 3.0 \text{ m} \quad (4)$$

Ordinates for calculation of stress in the place with corrosion weakening:

$$x = x_{weakened} - h_{operate} = 8 - 3 = 5.0 \text{ m} \quad (5)$$

The internal pressure (characteristic value) in the weakened area:

$$\begin{aligned} p_{n,k}(x = 5.0\text{m}) &= \delta \times 10^{-3} = \\ 12 \times 5{,}0.\ 1{,}2 \times 10^{-3} &= 0.072 \text{ MP}\alpha \end{aligned} \quad (6)$$

The internal pressure (design value) in the weakened area with γ_F = 1.2 according to Eq. 7:

$$\begin{aligned} p_{n,d}(x = 5\text{m}) &= \gamma_F \cdot p_{n,k}(x) = \\ 1{,}2 \times 0.072 &= 0.086 \text{ MP}\alpha \end{aligned} \quad (7)$$

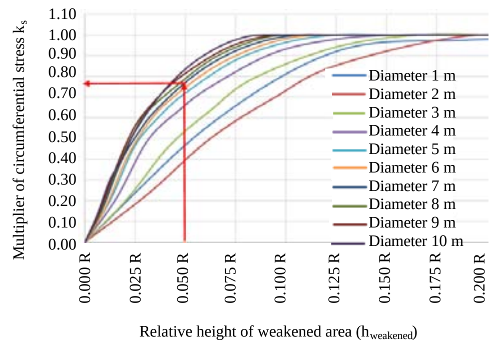

Fig. 5: Multiplier for corrosion loss 50%; multiplier of circumferential stress (detail)-corrosion loss 50%

Calculation of circumferential tensile stress: Design value of circumferential tension for original thickness of wall tank with diameter R is determined according to Eq. 8:

$$\sigma_{\theta,\,d,\,original}(x) = p_{n,\,d}(x)\,\frac{R}{t} \quad (8)$$

For the above example, the result follows:

$$\begin{aligned} &\sigma_{\theta,\,d,\,original}(x = 5\,m) = p_{n,\,d}(x) \\ &\frac{R}{t} = 0.086 \times \frac{7500}{10} = 64.5 \text{ MP}\alpha \end{aligned} \quad (9)$$

The value of coefficient k_s is determined in the following manner when for height approximating rectangle $h_{weakened}$ = 375 mm, diameter of tank R = 7500 mm and corrosion loss for example at 35% the value of coefficient k_s is determined by subtracting from the chart for corrosion losses 25 and 50% (Fig. 4 and 5):

$$h_{weakened,\,rel} = \frac{375}{7500} \times R = 0.05\,R \quad (10)$$

$$k_{s,\,25} = 0.28, k_{s,\,50} = 0.78$$

The value of coefficient $k_{s,\,35}$ is determined by using linear interpolation:

$$\begin{aligned} k_{s,\,35} &= k_{s,\,25} + \frac{35-25}{50-25}(k_{s,\,50} - k_{s,\,35}) = \\ &0.28 + \frac{35-25}{50.25}(0.78 - 0.28) = 0.48 \end{aligned} \quad (11)$$

The stress in weakened area is calculated by using coefficient k_s:

$$\begin{aligned} \sigma_{\theta,\,d,\,original}(x = 5m) &= p_{n,\,d}(x)\frac{R}{t} \\ &= 0.08 \times \frac{7500}{10} = 64.5 \text{ MPa} \end{aligned} \quad (12)$$

$$\sigma_{\theta,\ d,\ weakened} = \sigma_{\theta,\ d,\ original}(1+k_{s,35})64.5\times(1+0.48) = 95.5 \text{ MPa} \quad (13)$$

CONCLUSION

The results obtained by parametric studies can be used in two ways. The first way is creating Software at Microsoft Office Excel with values of wall stress and their dependences obtained by geometrically linear analysis and linear elastic bifurcation analysis for buckling of wall in software Scia engineer. The second way is creating graphical aids which are presented in this study. The software can be easily used by workers of company CEZ a.s. such as fast tool for assessment of tanks with corrosion attacks. The results of parametric studies showed that corrosion has significant influence on stress and it need to make experimental tests of corrosion loss and factors that can influence the development of corrosion products on the surfaces of construction. Experimental tests of atmospheric corrosion were mainly prepared to specify the prediction model for calculation of the design value of corrosion losses of weathering steels (Krivy *et al*., 2016). The maximum corrosion loss for the using Software and graphical aids is 90% of original thickness. If the corrosion loss is higher it can mean collapse of structures. The software and graphical aids can be used only for walls of tank not influenced by circumferential and meridional stiffeners. If tank has any stiffeners it is appropriate used for assessment static software with numerical 3D Model, may be Scia Engineer and others. In this case is necessary use geometrically nonlinear elastic analysis with imperfections included.

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