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Stress Analysis of Deformed Storage Tank Shell

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Shell plate material deformations appeared when storage tank operation. Material deformations were significant and may affect the loss of stability for the future operation. The assessment was made on the basis of performed measurements for examination the strength of existing deformations in the current wall thicknesses. Corrective actions and optimal method of operation including regular inspections was proposed. According to the measurements taken were assessed major geometry deformations. These deformations were subjected to a detailed stress analysis and assessed in terms of standards in use.

1. Storage tank design

Analysed tank is used for storage of fuel oil needed for energy industry or for storage of heavy hydrocarbons needed for petrochemical industry. The current operating level of the liquid is kept at a height of 8.5 m and the operating temperature is 90 °C. The inner diameter of the storage tank is 24 m and the height of the cylindrical shell is 12 m. The wall thicknesses of the individual shell parts are according drawings between 8 to 20 mm Values of main dimensions are illustrated at Figure 1.

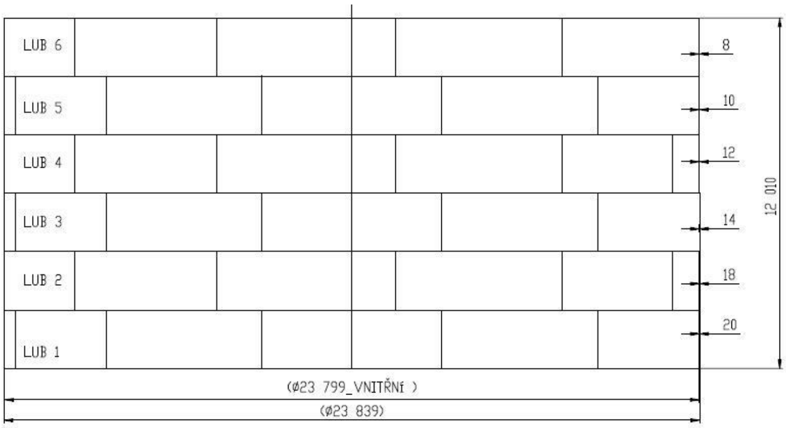

Figure 1: Scheme of analysed storage tank shell design

1.1 Shell deformations examination

During operation control were detected visible deformations of tank shell. It was decided to expose and check the walls of the tank shell. In the selected region a significant deformations of the shell were revealed. These deformations were in the vertical and the circumferential direction. The tank wall was deformed inward and outward. Figure 2 illustrates deformations at shell.

1.2 Performed measurements of deformation and shell thickness

To map the current state of the deformed shell the necessary measurements of shell thickness and shell deformations were made. Measurements were performed in between shell levels 4 - 6 according marking at Figure 1. Specific measuring points are shown in Figure 3. Measurement results were used to create FEA model. The maximum deformation value corresponds to point X, which is 42 mm inward of shell circumferential neutral axis and point Y, which is 25 mm outward shell circumferential neutral axis.

Figure 2: Photo of shell deformation points

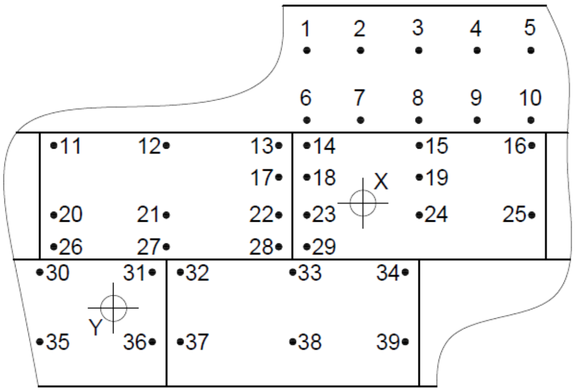

Figure 3: Scheme of thickness measuring

2. Performed tank analysis

Based on analysed shell thickness and supplied drawings of storage tank was developed computational model for FEM analysis. It was also carried out detailed modelling of the identified deformation of the shell in order to analyse stress in this area.

Fluid level in the tank is maintained at a height of 6 to 7 meters. Density of storage fluid mixture is between 1,150 to 1,250 kg/m^3. For stress analysis was considered state level at 6 metres and liquid density 1,150 kg/m^3.This situation is less favourable to the deformed area of the shell. This situation is necessary for stability analysis. The results of stress analysis are shown in Figures 4, 5 and 6.

Material of storage tank shell is carbon steel S235JRG2. Allowable material stress at working temperature is 215 MPa. Permitted stress value according to EN 1993-4-2 is 195.4 MPa. Achieved values of stress on the surface of the shell reach a value of 98.4 MPa, which is considerably lower value than permitted stress value.

In place of deformed area achieved stress on surface a value around 9.4 MPa. From the analysis therefore implies that the deformed area due to the inducted stress is not dangerous, but it was necessary to evaluate the stability of storage tank. Results of stability analysis are in Chapter 4.

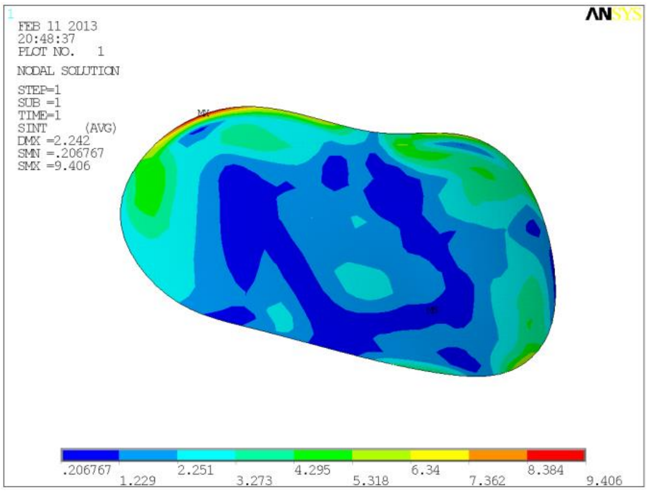

Figure 4: Surface stress in deformed area

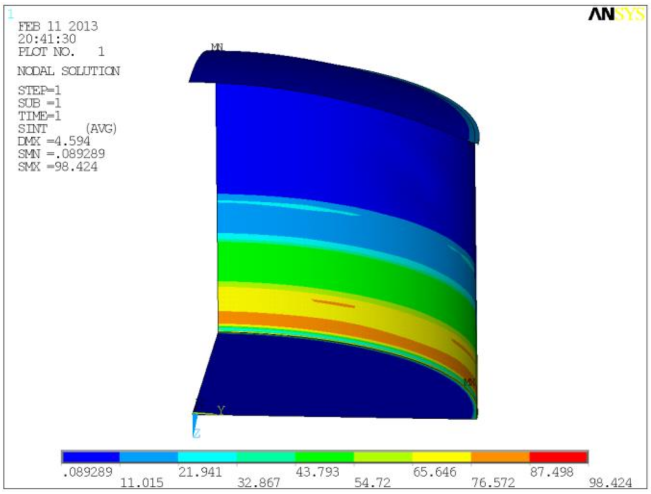

Figure 5: Surface stress in the tank shell

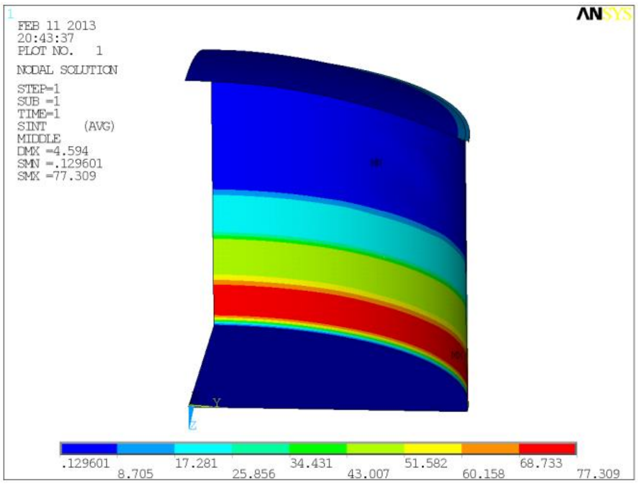

Figure 6: Membrane stress in the tank shell

3. Case of rise level analysis

To ensure the continued safe operation was examined the possibility of increasing the level of fluid. The assumption was increased level from 6 to 8 m. Density of storage fluid is 1,150 kg/m^3. In case of rise of level in the tank has been reached higher values of surface stress in the lower part of the deformed area. However, these values satisfy the condition of allowable stress according to EN 1993-4-2. During the operation of tank in the future will lead to repeated level fluctuations in the range of 1 to 2 m. It could occur in the deformed area fatigue damage which is quite undesirable for safety. The results of stress are shown in Figures 7 and 8.

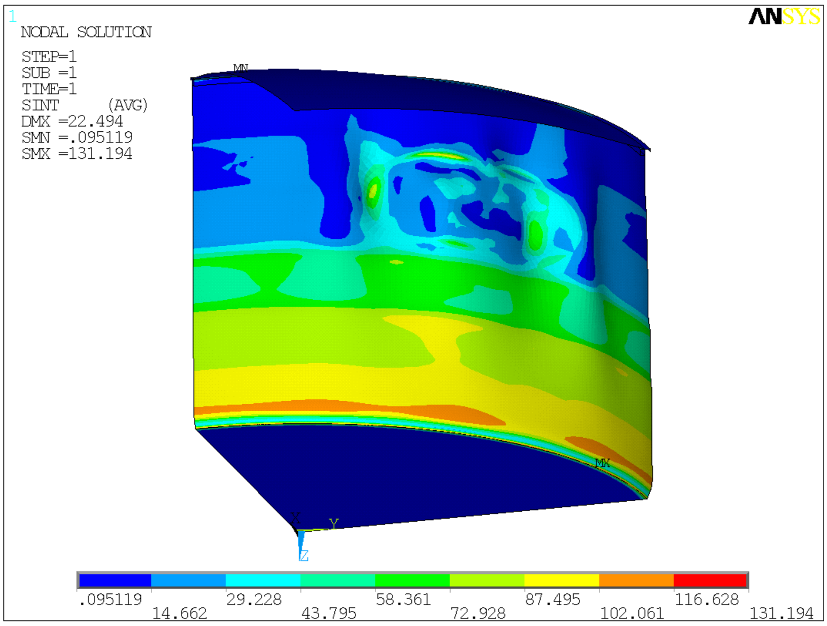

Figure 7: Surface stress in the tank shell

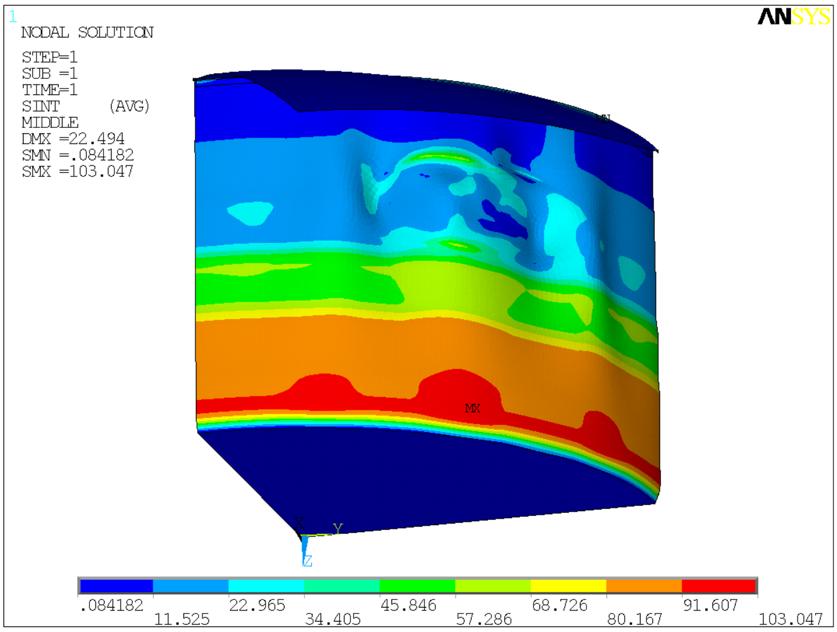

Figure 8: Membrane stress in the tank shell

4. Assessment of deformed shell stability

Based on standards EN 1993-4-2 and EN 1993-1-6 have been assessed stability of detected deformation. In spots where maximal deformation appeared are supposed only axial loads, while considered level of fluid at 6 meters. Value of the shell plate thickness in the area of deformation was considered 5.2 mm, which was the smallest thickness measured. Table 1 shows input data for stability calculation. Table 2 shows results of stability calculation.

Table 1: Input data for stability calculation

Mark	Name	Value	Unit
f_y	Yield strength of steel at 20 °C	235	MPa
f_{yT}	Yield strength of steel at 90 °C	215	MPa
Y_{M0}	Safety coefficient for allowable stress	1.1	-
f	Allowable stress	195.4	MPa
ω	Relative length parameter for shell	24.1	-
$\sigma_{x, Rcr}$	The critical elastic axial buckling tension	54.4	MPa
C_x	Buckling coefficient	1	-
α_x	Axial buckling parameter	0.061	-
ΔW_k	Tolerance normal to the shell surface	15.5	mm
γ_{x0}	Partial factor of buckling resistance	0.2	-
β	Plastic range factor in buckling strength assessment	0.6	-
η	Interaction exponent for buckling	1	-
$\sigma_{x, Ed}$	Axial membrane stress	2.68	MPa

Table 2: Results of stability calculation

Mark	Name	Value	Unit
f_y	Yield strength of steel at 20 °C	235	MPa
λ_p	Plastic limit relative slenderness	0.391	-
λ_x	Relative slenderness of shell	1.988	-
k_X	Reducing factor of buckling influence	1.261	-
$\sigma_{x, Rk}$	Characteristic buckling stress	3.23	MPa
$\sigma_{x, Rd}$	Buckling resistance	2.94	MPa

4.1 Control of membrane stress and resistance to buckling

$$\sigma_{x,Ed} \leq \sigma_{x,Rd}$$

$$2.68\ MPa \leq 2.94\ MPa$$

$$\left(\frac{\sigma_{x,Ed}}{\sigma_{x,Rd}}\right)^{k_x} = \left(\frac{2.68}{2.94}\right)^{1.261} = 0.89 \leq 1$$

Performing stability calculations was evaluated that the current manner of loading tank not lose its stability.

5. Conclusions

Based on the analyses it can be stated that the current state of deformation of the tank shell is not hazardous and can be operated at the current level height from 6 to 7 m. During increased levels to 8 m (flooding deformed area) appeared a higher stress values at deformed area, however stress values meet the allowable stress values. The advantage of increasing the level in tank would result higher toughness of deformed area to loss of stability.

It can be concluded that the current method of storage tank operation meets the requirements of used standards and there is no loss of stability of the tank shell. It would be necessary to perform control checks quarterly and measure wall thickness and at a value of 5 mm end operation and wean tank out of service. When considering longer-term storage tank operation would be preferable to increase the level of fluid at least 8 m.

Acknowledgments

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Reference

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EN 1993-1-6 Design of steel constructions, Part 1-6: Strength and stability of shell constructions