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# Static Structural Analysis of Water Tank

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**Abstract** The paper is devoted to the static analysis water tank. Three different thicknesses of walls of the water tank are proposed and the structure is analysed in order to find appropriate stress and deformation states of structure. The maximal stress level was higher than the yield strength of stainless steel used in structure so seven different variants of stiffeners were proposed for improving stability and strength of structure.

***Keywords:*** *water tank, container, static analysis, finite element method*

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## 1. Introduction

The tanks are often used for storage and transportation of liquids, mostly for transport or storage of drinking water, industrial water, petrol, dangerous toxic substances, acids, etc. The questions of strength and stability of such structures are very important in order to insure safe operation of those devices [1-10].

In the following we will deal with a water tank designed for transportation on a truck. The structure was modelled according to drawing documentation and demands of producer (Figure 1). The container will be used for transportation of water and accordingly stainless steel is used as a base material of the structure. The maximal length of the water tank is 4533 mm, the width in the top and bottom part of the body is 2422 mm,1005 mm, respectively and the height of structure is 1241 mm.

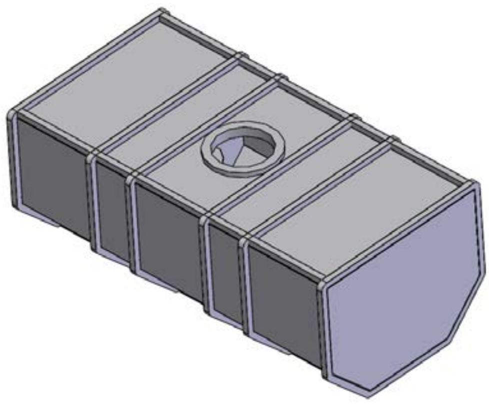

**Figure 1**. The 3D model of the water tank

## 2. Theoretical Background

Nowadays, the finite element method (FEM) is the most popular and spread method of computation in continuum mechanics. A deformation variant has been expanded in practice. From numerical point of view it is numerical method of approximation of boundary problem. The body (Figure 2) is replaced by union of set of subregions, which we call finite elements [1,3,4,6].

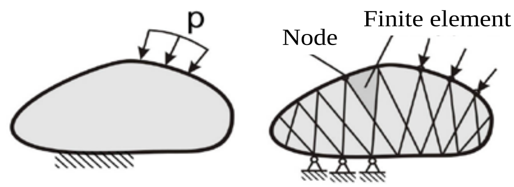


**Figure 2.** Solution of boundary problem [1]

The finite element method can be based e.g on the principle virtual displacements. At the element level we can write equation

$$\iiint_V \delta\boldsymbol{\varepsilon}^T \boldsymbol{\sigma} dV = \iiint_V \delta\mathbf{u}^T \mathbf{X} dV + \iint_A \delta\mathbf{u}^T \mathbf{p} dA, \qquad (1)$$

where $\delta\boldsymbol{\varepsilon}$, $\boldsymbol{\sigma}$, $\delta\mathbf{u}$, $\mathbf{X}$, $\mathbf{p}$, $dV$, $dA$ is variation of strain vector, stress vector, variation of displacement vector, body force vector, pressure vector, infinitesimal volume and infinitesimal area, respectively [1,3].

Displacement $\mathbf{u}$ can be expressed as

$$\mathbf{u} = \mathbf{N} \cdot \mathbf{d}, \qquad (2)$$

where $\mathbf{N}$ is matrix containing the shape functions and $\mathbf{d}$ is vector of node displacement.

Now we have equation

$$\boldsymbol{\varepsilon} = \mathbf{B} \cdot \mathbf{d}, \qquad (3)$$

which expresses the dependence of the strain vector $\boldsymbol{\varepsilon}$ on the node displacement vector $\mathbf{d}$ and $\mathbf{B}$ is matrix containing derivatives of shape functions.

In case of linear elastic material we have relation

$$\boldsymbol{\sigma} = \mathbf{D} \cdot \boldsymbol{\varepsilon}, \qquad (4)$$

where $\mathbf{D}$ is matrix of elastic constants. Further we use equation (3) and we get

$$\boldsymbol{\sigma} = \mathbf{D} \cdot \mathbf{B} \cdot \mathbf{d}, \tag{5}$$

and final relation

$$\mathbf{k} \cdot \mathbf{d} = \mathbf{f}, \tag{6}$$

where $\mathbf{k}, \mathbf{f}$ is element stiffness matrix and nodal load vector, respectively. For the whole body we have equation

$$\mathbf{K} \cdot \mathbf{x} = \mathbf{F}, \tag{7}$$

where $\mathbf{K}$ is global stiffness matrix, $\mathbf{F}$ is resultant vector of load forces and $\mathbf{x}$ is displacement vector of the whole structure [1], [3].

## 3. Static Analysis

The water tank was modelled in SolidWorks. The walls were modelled as 3D bodies with ribs. Ribs are created from square tubes with dimensions $50 \times 50 \times 4$ mm. Thickness of wall as set to 8 mm for the first model. The boundary conditions for the structure are shown in Figure 3. The loading due to water was modelled by pressure with the maximal value 20 kPa. The pressure is applied as nonuniform loading (i.e. hydrostatic pressure) with minimal value on the top and maximal value in the bottom (Figure 3) [2-10].

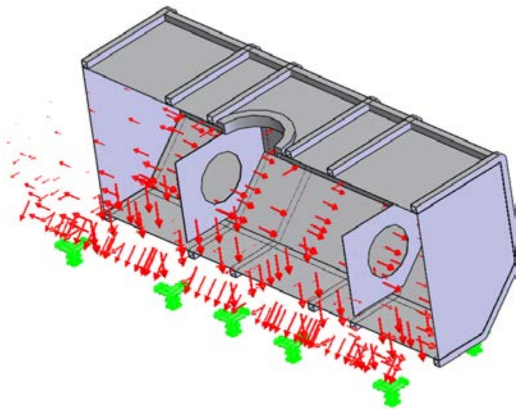

**Figure 3**. Boundary conditions applied on model

The mesh of finite elements (Figure 4) was generated automatically with predefined maximal length of element 10 mm. The material properties of used material are: Young's modulus $E = 1.95x10^5$ MPa, Poisson's ratio $\mu = 0.27$, mass destiny $\rho = 8000$ kg/m$^3$ and yield point $Re = 275$ MPa.

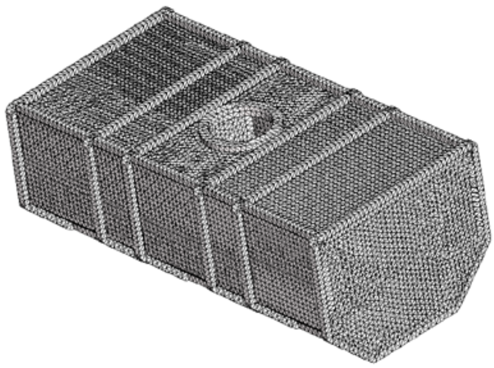

**Figure 4**. Finite element mesh

The results of static analysis are given in the following figures. In Figure 5 is given field of displacements and in Figure 6 the field of equivalent von Mises stresses. The maximal displacement is 24.857 mm and the maximal von Misses stress is 370.635 MPa. The maximal displacement (Figure 5) is on the front and the back side of structure, respectively. The maximal von Misses stress is again on these sides at the bottom part of rib in location of weld.

The maximal values of stress exceed yield point of stainless steel ($Re = 275$ MPa). Accordingly, seven modifications of structure were proposed. In Figure 7 is shown the first basic model of the water tank without modifications.

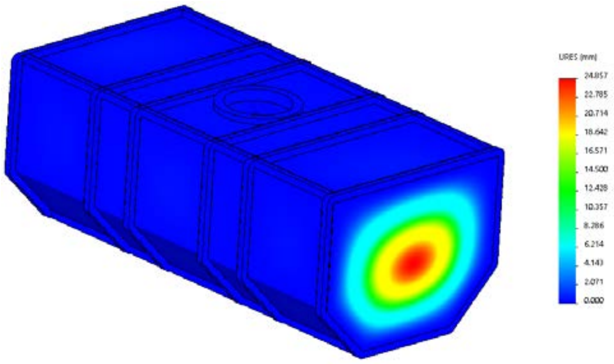


**Figure 5**. Displacement plot

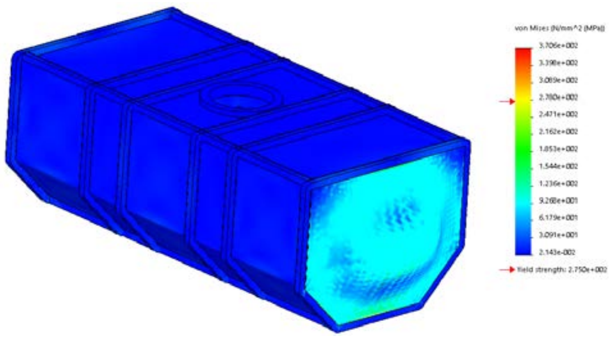


**Figure 6**. Stress plot for 8 mm wall

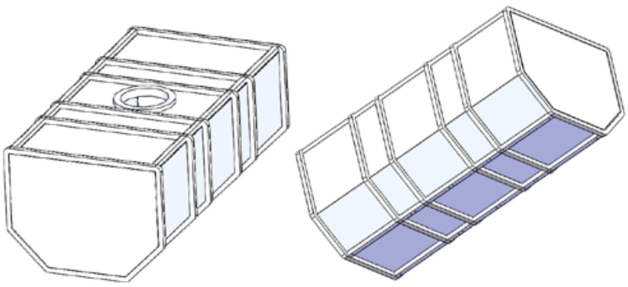

**Figure 7**. The basic variant (zero)

The modifications were made step by step by adding ribs in order to ensure for smaller deformations and better stability. New ribs are shown in figures with grey colour. The static analysis has been performed for each variant with one quarter model and symmetric boundary conditions. Each analysis has been performed for three different thicknesses of walls 3 mm, 5 mm, 8 mm, because producer of the water tank has such sheets in deposit. The mass of variant zero for each thickness of sheet, but without water, are $V_{0-3mm} = 716.13$ kg, $V_{0-5mm} = 930.69$ kg and $V_{0-8mm} = 1251.25$ kg, respectively.

The first variant (Figure 8) is made by adding a rib on the front and the back part of the water tank, which should decrease the maximal deflection on these parts of body.

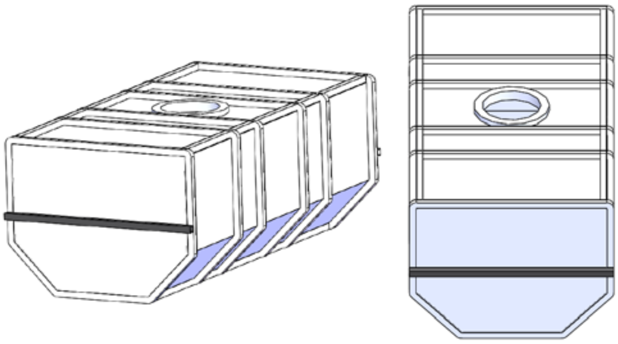

**Figure 8**. The 1st variant, the front and the back rib

The next ribs are added on the bottom of the water tank and this design is shown in Figure 9.

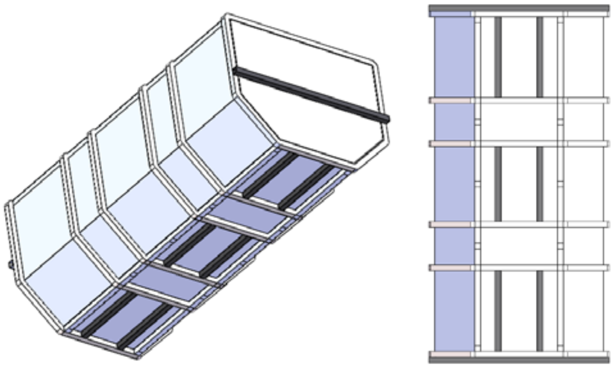

**Figure 9**. The 2nd variant, bottom ribs

Additional ribs are added to the top of water tank and these should improve stability of structure (Figure 10).

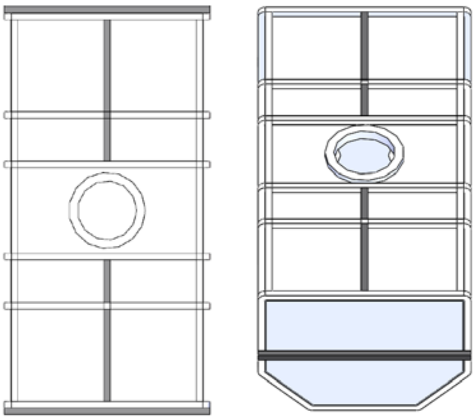

**Figure 10**. The 3rd variant, up ribs

The ribs on the left and the right side are shown in Figure 11. They have to ensure stability of container.

Because the maximal stress and deflection are on the front and the back side of the water tank, respectively, the ribs are located on the internally side as is shown in Figure 12.

The externally front and back rib are removed for better view and better fixing a protective skin (Figure 13).

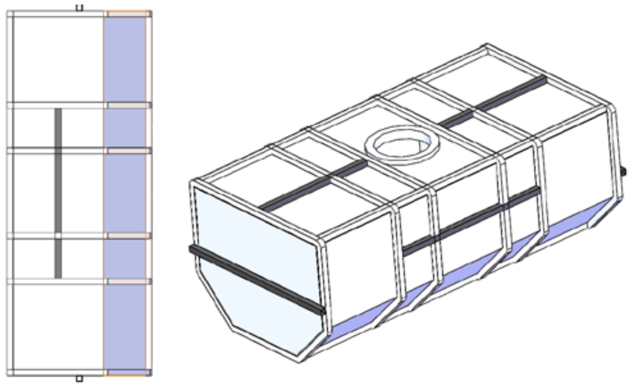

**Figure 11**. The 4th Variant, left and right rib

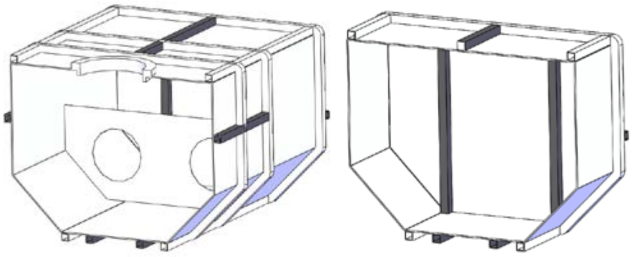

**Figure 12**. The 5th variant, the interior ribs

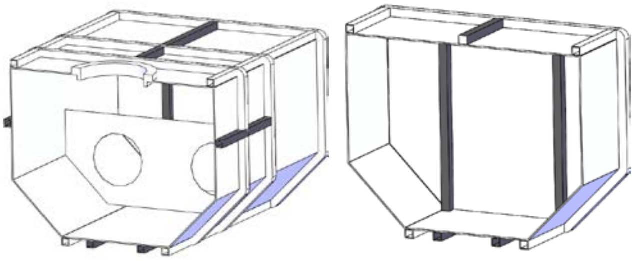

**Figure 13**. The 6th variant, the interior ribs without the front and the back externally rib

And finally, one transverse rib is added on the interior front side and on the interior back side as is shown in Figure 14.

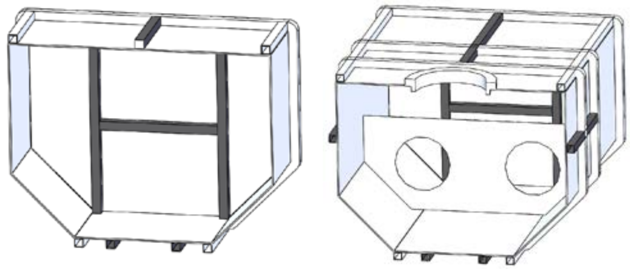

**Figure 14**. The 7th variant, the interior ribs

Displacements for the 7th variant (8 mm sheet thickness) are shown in Figure 15. The maximal value of displacement is 1.047 mm on the front and the back side, respectively. The maximal stress (Figure 16) is 49.252 MPa. This von Mises stress is smaller than yield point of material ($Re = 275$ MPa). The maximal displacement is now on the bottom part of the divided front and the back part of the water tank. The maximal von Mises stress is on the front and the back side of the water tank, respectively, but it is located in transverse rib welding.

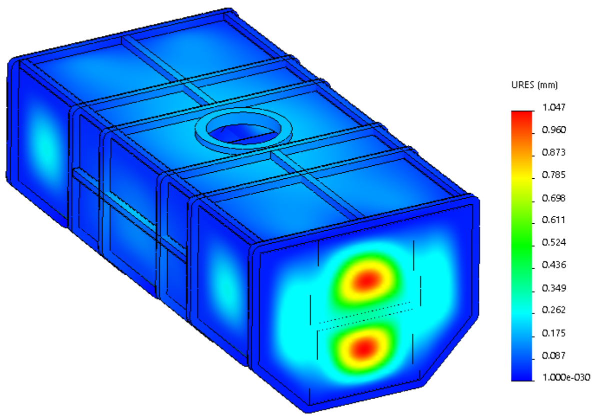


**Figure 15**. Displacement plot of the 7th variant (8 mm wall)

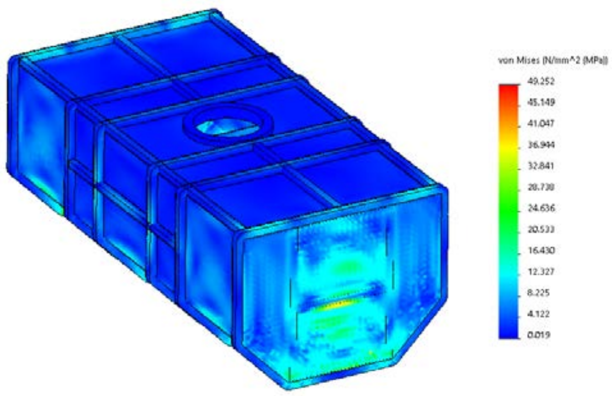


**Figure 16**. Stress plot of the 7th variant (8 mm wall)

All other computed values of all modified structures are given in Table 1. All new variants have values of maximal stress smaller than yield strength.

**Table 1. Computed maximal values of displacements and von Mises stresses for all variants**

| Var. | Thickness of sheets | | | | | |
|---|---|---|---|---|---|---|
| | 3 mm | 5 mm | 8 mm | 3 mm | 5 mm | 8 mm |
| | max. displacement (mm) | | | max. von Mises stress (MPa) | | |
| 0. | 30.992 | 28.724 | 24.857 | 393.7 | 380.541 | 370.635 |
| 1. | 7.828 | 3.361 | 2.468 | 183.872 | 127.277 | 108.066 |
| 2. | 3.609 | 3.342 | 2.457 | 176.976 | 128.764 | 108.150 |
| 3. | 3.609 | 3.342 | 2.457 | 176.369 | 128.290 | 108.031 |
| 4. | 3.609 | 3.342 | 2.457 | 176.939 | 128.328 | 107.977 |
| 5. | 2.788 | 1.623 | 1.261 | 145.764 | 68.471 | 54.047 |
| 6. | 6.442 | 5.619 | 4.611 | 165.334 | 98.691 | 77.657 |
| 7. | 2.791 | 1.480 | 1.047 | 145.379 | 68.091 | 49.252 |

In Table 2 are compared maximal results of all computations. Variant 0 serves as a base for percentage computation.

**Table 2. Comparison of individual variants**

| Var. | Thickness of sheets | | | | | |
|---|---|---|---|---|---|---|
| | 3 mm | 5 mm | 8 mm | 3 mm | 5 mm | 8 mm |
| | Decreasing of max. displacement (%) | | | Decreasing of max. von Mises stress (%) | | |
| 1. | 74.74 | 88.30 | 90.07 | 53.30 | 66.55 | 70.84 |
| 2. | 88.36 | 88.37 | 90.12 | 55.05 | 66.16 | 70.82 |
| 3. | 88.36 | 88.37 | 90.12 | 55.20 | 66.29 | 70.85 |
| 4. | 88.36 | 88.37 | 90.12 | 55.07 | 66.28 | 70.87 |
| 5. | 91.01 | 94.35 | 94.93 | 62.98 | 82.01 | 85.42 |
| 6. | 79.21 | 80.44 | 81.45 | 58.01 | 74.07 | 79.05 |
| 7. | 90.99 | 94.85 | 95.79 | 63.07 | 82.11 | 86.71 |

On the basis of results the 7th variant is selected for manufacturing. The masses of the 7th variant for different thicknesses of sheets are $V_{0-3mm} = 839.05$ kg, $V_{0-5mm} = 1053.47$ kg and $V_{0-8mm} = 1373.83$ kg, respectively.

**Figure 17**. The made water tank on the truck

The seventh variant with thickness 5 mm was chosen for production. The mass increasing for the seventh variant with thickness 5 mm is 13.19%. The mass increasing for the seventh variant with thickness 3 mm and 8 mm is 17.16 % and 9.80 %, respectively. The water tank is shown in Figure 17.

## 4. Conclusion

Static structural analysis of the water tank as part of the truck body was performed. The water tank was modelled from the stainless steel as 3D body. The finite analysis was performed by commercial computer program. Three different thicknesses (3 mm, 5 mm and 8 mm) were taken into account. The displacement plots and the von Misses stress plots served for comparison of results. Displacements and stresses were very high in basic design so seven modified structures were proposed in order to find the best one. All results of these variants were given in tables. For the 7th variant, which was chosen for manufacturing, we got the maximal displacement 2.791 mm, 1.480 mm, 1.047 mm and the maximal von Mises stress 145.379 MPa, 68.091 MPa, 49.252 MPa for thicknesses 3 mm, 5 mm and 8 mm, respectively.

## Acknowledgement

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## References

[1] Trebuňa, F., Šimčák, F. *Odolnosť prvkov mechanických sústav*, Emilena, Košice, 2004, 911-940.

[2] Bocko, J., Frankovský. P., *Nosné konštrukcie automobilov*, Technická Univerzita, Košice, 2015.

[3] Zienkiewicz, O.C., Taylor, R.L., Zhu, J.Z., *The Finite Element Method: Its Basis and Fundamentals*, Butterworth-Heinemann, United Kingdom, 2013.

[4] Tertel, E., Kurylo, P., Papacz, W., The stress state in the three-layer open conical shell during of stability loss, Acta Mechanica Slovaca, 18 (2). 56-63. Aug.2014.

[5] Wang, Y., Liew, J.Y.R, Lee, S. Ch., "Structural performance of water tank under static and dynamic pressure loading," *International Journal of Impact Engineering*, 85. 110-123. Nov.2015.

[6] Pacana, J., Pacana, A., Bednárová, L., "Strength calculations of dual-powerp gearing with FEM," *Acta Mechanica Slovaca*, 18 (2). 14-19. Aug.2015.

[7] Liu, W.K., "Finite element procedures for fluid-structure interactions and application to liquid storage tanks," *Nuclear Engineering and Design*, 65. 221-238. 1981.

[8] Mistríková, Z., Jendželovský, N., "Static analysis of the cylindrical tank resting on various types of subsoil," *Journal of Civil Engineering and Management*, 18 (5). 744-751. Sep.2012.

[9] Samangany, A.Y., Naderi, R., Talebpur, M.H., Shahabifar, H., "Static and Dynamic Analysis of Storage Tanks Considering Soil-Structure Interaction," *International Research Journal of Applied and Basic Sciences,* 6 (4). 515-532. 2013.

[10] Ustaoglu, H.B., et al., "Static and Dynamic Analysis of Plastic Fuel Tanks Used in Buses," *3rd International Conference on Material and Component Performance under Variable Amplitude Loading*, Elsevier, 509-517.