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Stress analysis of a tank for bulk materials

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Abstract. The paper deals with a stress analysis of the existing tank trailer for bulk materials as well as with the effects of bulk materials on the tank trailer wall. Technical parameters: Volume 62m^3, Max. working pressure 2 bar, Max. load weight 32 000 kg, Material EN AW-5083 0/H111. Designed according to AD 2000 Merkblatt. Analysis is based on extreme load conditions of the structure identified from the trailer working cycle. Based on its results, design optimization is made so as to eliminate the places with increased stress and, if possible to reduce the weight of the structure.

Introduction

Cargo transport is nowadays the most widespread and growing type of transport of goods. With its development, the amount of conveyed bulk materials is also growing, with increasing number of tank trailers being used. With increasing demands on ecology, traffic economy and safety, there is a growing demand for weight reduction and increased safety and lifespan of tank structures.

Due to the number and complex shapes of tank trailers and the specific types of transported materials, classical analytical computational procedures are inadequate. For newly designed tanks and optimization of the existing ones, the accuracy of the design is often verified by FEM analysis.

The aim of this article is design optimization based on a stress analysis (FEM) of the tank trailer for bulk materials (see Fig.1) made of EN AW-5083 0/H111.

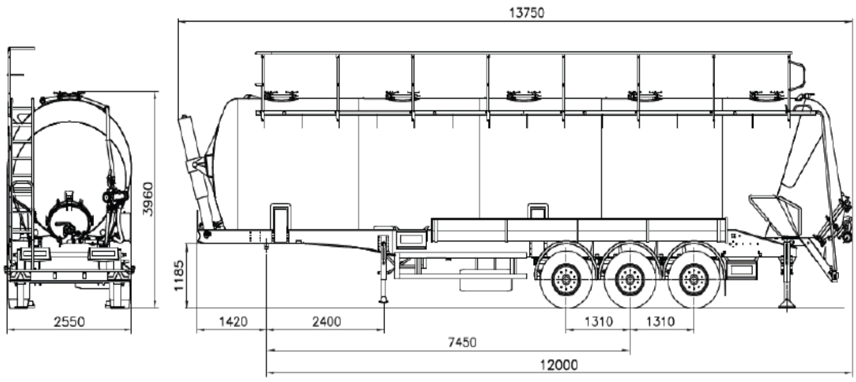

Fig. 1: Tank trailer for bulk materials [2]

Analysis and evaluation

From the tank working cycle three extreme load conditions were identified (see Table 1) of the structure, it was proved to be crucial to define the effects of bulk material on the tank trailer wall.

Table 1: Extreme load conditions

Condition:	Media pressure [MPa]:	Media density [kg/m3]:	Tank tilt angle: [deg]	Material type:
Start of tilting	0,2	516	0	bulk
End of tilting	0,2	516	45	bulk
Pressure test	0,3	1000	0	fluid

The effect of bulk material was simulated by commonly used Janssen´s theory [1] for the shallow bins (see Fig.2). The chosen theory was applied to the wall of the tank and was transformed for the case where the gravity is acting in reversed y-direction (1,2).

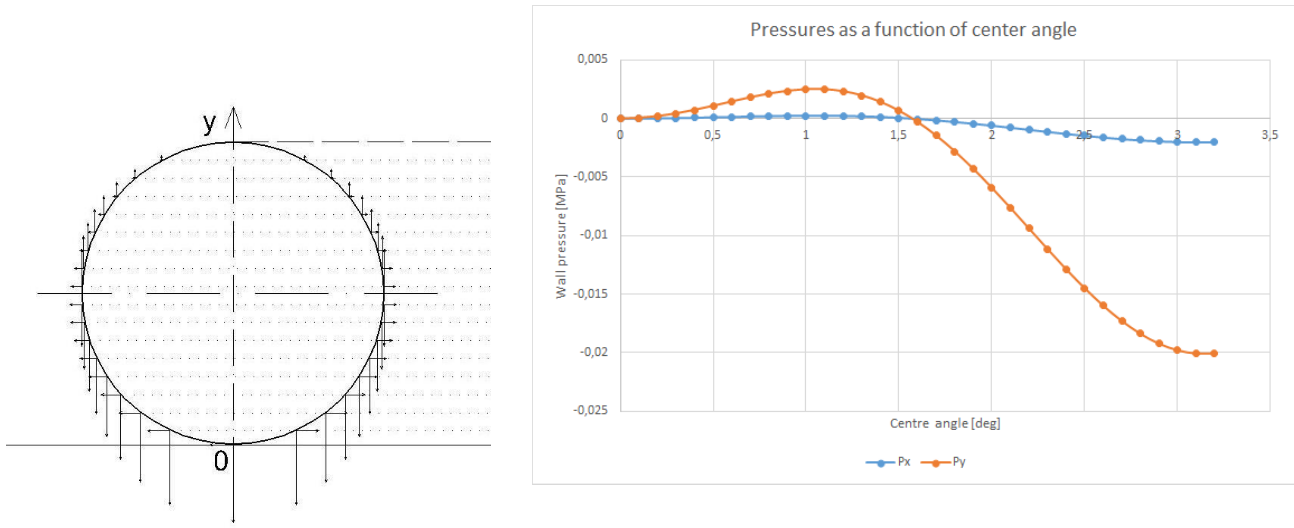

Fig. 2: Simulated pressure distribution on a circular wall

$$p_y = p_H \cdot \cos\varphi = R \cdot \rho \cdot g \cdot (1 - \cos\varphi) \cdot \cos\varphi \tag{1}$$

$$p_x = p_y \cdot tg^2 \left(\frac{\pi}{4} - \frac{\rho}{2}\right) \tag{2}$$

Verification of correctness of transformation and the application of Janssen's theory to the FEM program environment was performed by two examples for which it was possible to determine the results using FEM analysis as well as by classic analytical procedures, and these results were compared.

The first verification example was to determine total weight of the bulk material in cylindrical wall as the resulting force of simulated wall pressures (1,2)
The second example was comparison of the Mises stress (see Fig.3) on a half circular curved beam (0;π) with one end built-in and the other end free.

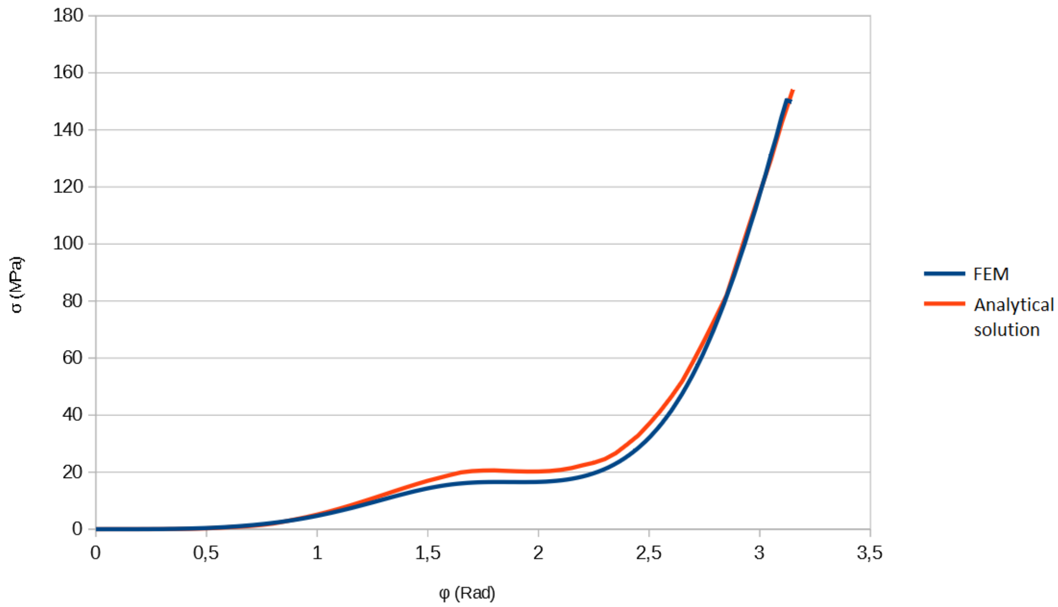

Fig. 3: Comparison of Mises stress on a curved beam as a function of center angle

After verification of application of Janssen's theory, FEM analysis was made, which shown that several places can be found, where minimum yield stress of material was exceeded (see Fig.4). (EN AW-5083 0/H111 - MinRp$_{0,2}$ =125 N/mm^2)

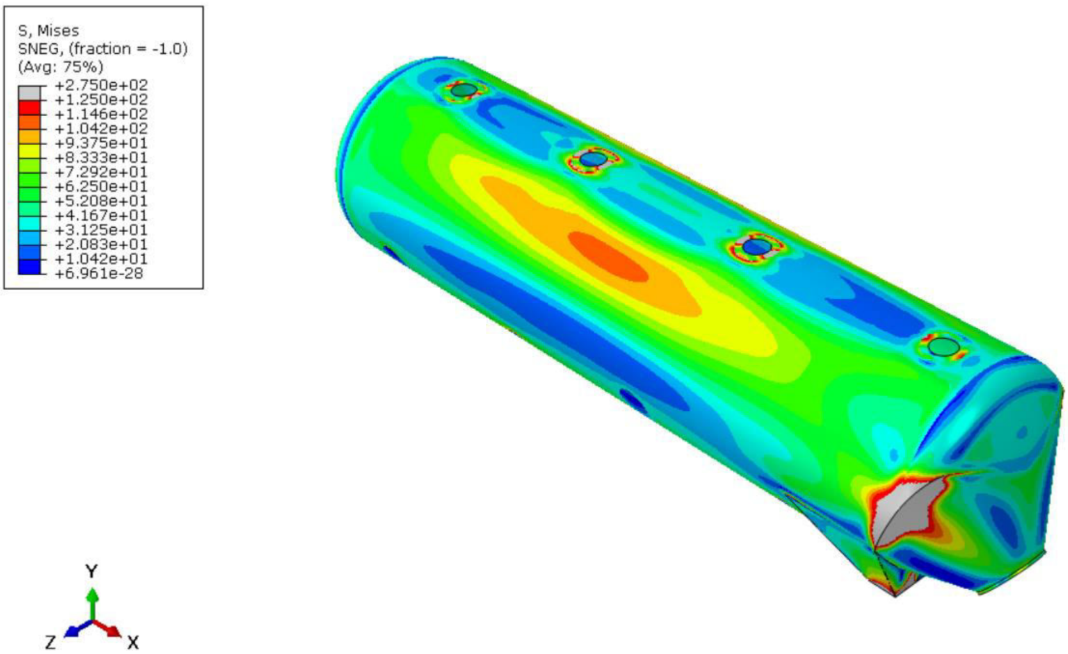

Fig. 4: Structural stress - start of tilting (general)

The first place was in the circular mid-section of tank, symmetrically on both sides the stress increased up to 125 N/mm^2. This stress was caused by combination of boundary conditions of tank and pressure fields of bulk material acting along tank wall.
The second place was connection between circular section and conical end section (see Fig.4), where the increased stress was caused by incorrect geometry of joint, as well as low tank toughness in the ZY plane caused by reduced shell thickness.

Design optimization

As a result of several analyses, design optimization was made (see Fig.5). After consultation with manufacturer only joint between mid and end section was optimized. Material used for tanks has significantly higher yield stress $RealRp_{0,2}$ =164 N/mm^2, so design modification of circular mid-section wasn´t necessary.

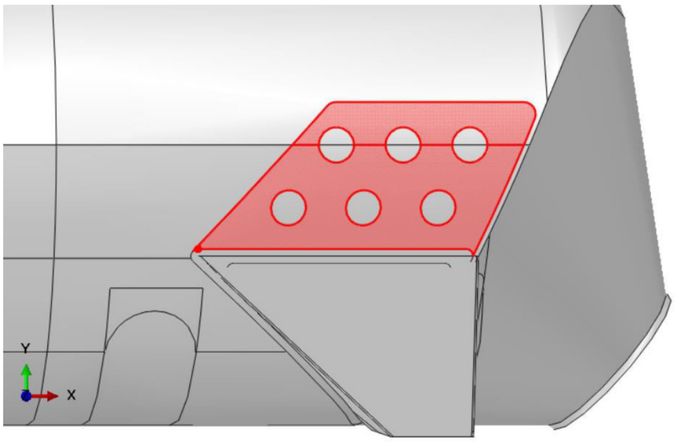

Fig. 5: Structural stress comparison – strengthening of joint

Optimization consisted of strengthening tank toughness in the ZY plane by extension of reinforcing plates from back support legs and rounding of cone section in joint for smooth transition. The designed modifications were compared with the existing design. As it can be seen (see Fig.6;7;8) modifications resulted in a considerable reduction of stress in tank wall.

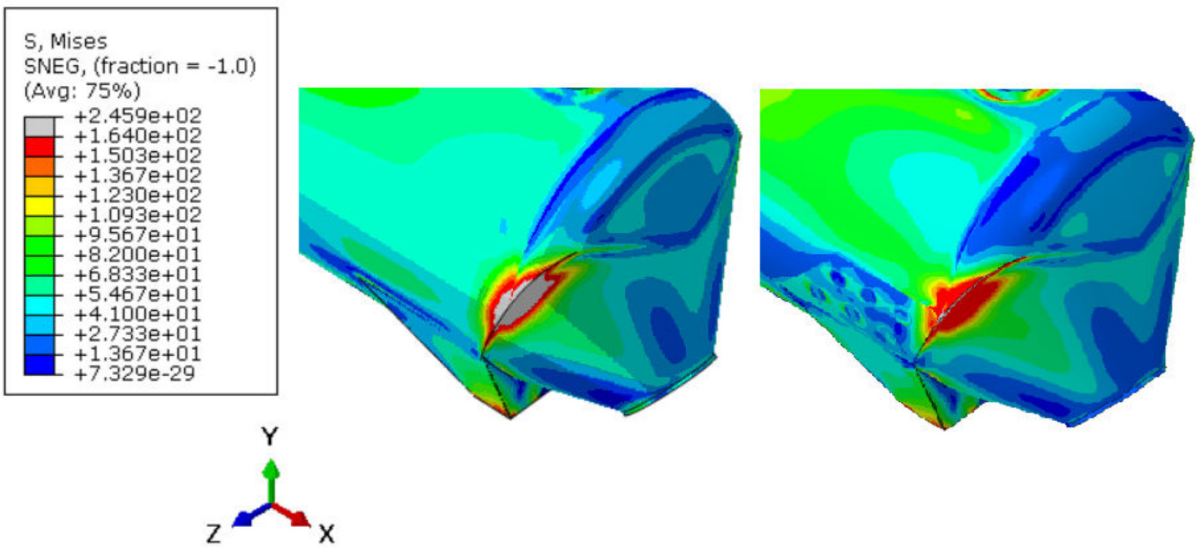

Fig. 6: Structural stress comparison - start of tilting

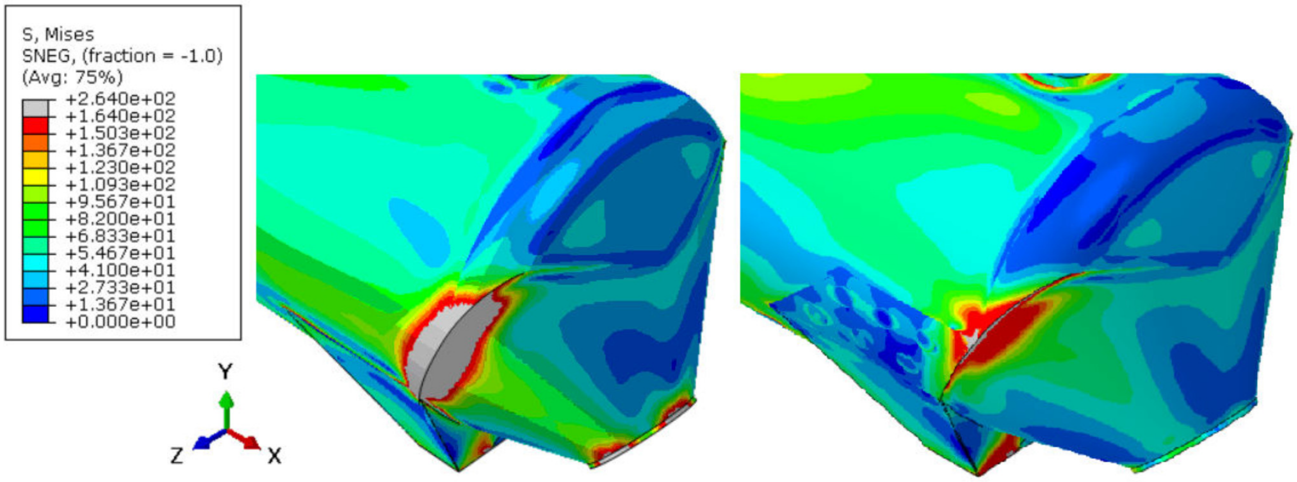

Fig. 7: Structural stress comparison - end of tilting

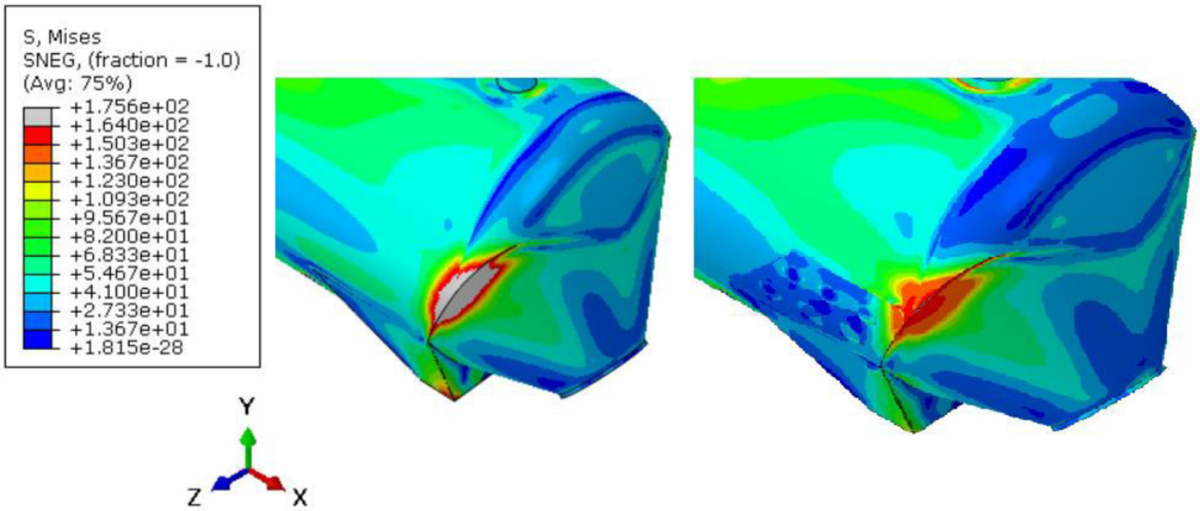

Fig. 8: Structural stress comparison - pressure test

Conclusion

Series of FEM analysis of tank construction showed that there can be found locations where the yield strength of material was exceeded (see Fig.4). Based on the analysis, the locations were selected and the possible causes were discussed. After that the design of the structural modifications were made, according to the manufacturer's technical requirements.

References

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[2] Přepravníky | ZVVZ a.s. - dodavatel zařízení pro ekologii. ZVVZ a.s. - dodavatel zařízení pro ekologii [online]. Copyright © 2017, ZVVZ a.s. [cit. 21.06.2017]. Dostupné z: http://www.zvvz.cz/zvvz-machinery/vyrobky/cisternove-navesy.html.