

STATIC STRENGTH ANALYSIS OF PLATE STRUCTURES USING FINITE ELEMENT METHOD

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Abstract

The paper presents the issues regarding modelling and strength calculations for the plate structures including thin-walled tanks and water tubes in steam boilers or heat exchangers subject to thermal stresses. In this case, the subject of the analysis is not the stress-strain state due to the pressure in the structure cross-section but the conditions at the interface between plate and lifting lugs used for handling tanks decommissioned due to technical and economic factors or replaced with the new ones.

Keywords: *theory of plates, stresses in plates, stress concentration, Huber-von Mises energy hypothesis*

1. Introduction

The strength calculations for steel structures, regarded as the rotationally symmetric plates, have been in continuous development from 2010 and are based on the standard specifications defining three object classes: stacks, bulk material silos and cylindrical vertical liquid tanks. The rules applied in strength calculations for plate structures are available in the literature [1], [2], [3].

The current change in the approach to the issue of verification of strength of those structures as per standard [4] assumes a standardization of criteria for determining the limit states for which the specific methods of calculating the stress values in the cross-sections are valid. The states include plastic collapse (LS1), cyclic plasticity (LS2), buckling (LS3) and fatigue (LS4).

The calculation rules are strictly related to the nature of plate stresses in operation, although do not include a method to determine the stress threshold limit values in the plate during transport and assembly. It can be assumed, that a suitable procedure in those cases is to perform calculations based on a general theory of plates, which in a numerical method comes down to a plate finite element modelling of the structures.

The finite element method provides accurate solutions not only within the scope of linear plate statistics, although in some cases, e.g. concentrated loads, non-continuous boundary conditions it is difficult to select the element type and structure discretization method and thus the method requires some improvements.

The basic finite element groups used in the analysis are flat elements, curvilinear elements and three dimensional isoparametric elements [5], although other elements are also available and used in the analysis of special cases. None of the above groups can be considered best when it comes to the accuracy of obtained results or the hardware requirements determined by the operating memory limitations of the computer systems used.

The three-dimensional solid elements can be used in simple strength calculations, although these can be problematic in case of the thin plates, which require use of systems with a large number of equations.

2. Problem description

The analysis deals with the strength issues at the interface between a thin-walled tank shell and the lifting lugs for handling during disassembly. In numerical calculations using the finite element method, the lifting lugs are modelled using standard solid elements, whereas the tank walls are modelled both using 3D and plate elements. Technically complex tank hoisting and handling procedures require a multi-threaded method of strength calculations. To reduce the column replacement time, it was assumed that the column will be removed as a whole with its ceramic lining still inside, which is a somewhat bold decision, since its nominal column shell thickness of 10 mm at the height of 20,200 mm makes it a very slender structure. The lifting lugs as well as the reinforcing ribs are the points with the highest wall stresses and thus the areas of stress accumulation. An alternative solution is to disassemble the column components after removing the ceramic lining.

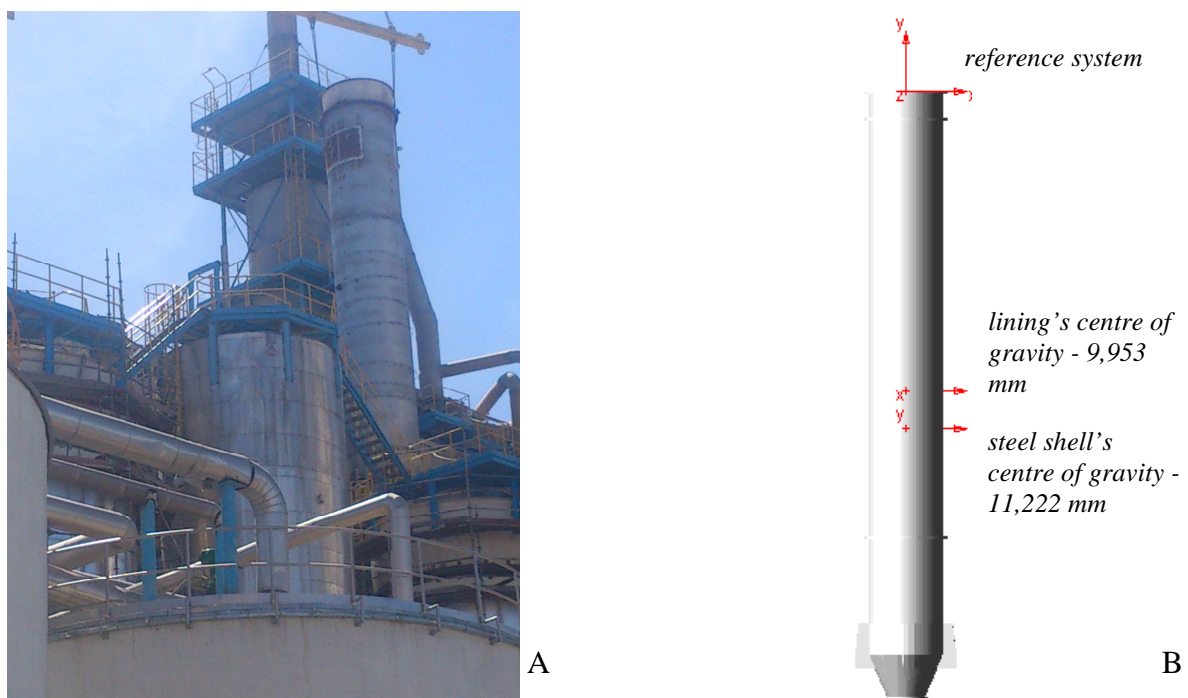


Fig. 1. View of a steel cylindrical plate structure during disassembly (A) and lining and shell centres of gravity (B)

Although the safety of the alternative disassembly method is greatly improved, the time required and thus standstills generate costs, which make the risk economically viable, even if using a 500 tonnes crane. The risks are due to the need to hoist the tank at the height of several meters over the roof of the production floor where the process line machines are installed. A lifted structure weight was 400,000 N including the weight of the shackles, reinforcing elements and a tank end securing the lining.

The centre of gravity of the steel section (Fig. 1B) is in the distance of 11,222 mm, and the centre of gravity of the lining is in the distance of 9,953 mm from the top edge. The lifting lugs must be above the system's centre of gravity in order to keep the column stable during hoisting. The lifting lugs will be installed in the distance of 2,500 mm from the top column edge. Apart from the weight of the column shell, the ceramic lining is a component's node load in the strength analysis. The method of fastening the ceramic lining to the column shell does not allow it to be treated as a shell reinforcement, but only as an additional column load.

The reduced stresses in the cross-section at the interface of the lugs and the column shell were determined based on the Huber-von Mises energy hypothesis. The maximum stress value results from the ultimate tensile strength of the steel reduced by a safety factor. The aim is achieved by adding a reinforcing pad having a size optimized by calculations. A satisfactory stress-strain state at the plate-pad interface with a simultaneous reduction of the reinforcing pad weight was achieved thus reducing a significant load to the column shell.

3. Plate strength calculation for the loads resulting from its own weight

The column weight will not cause any reduced stresses in its cross-section that may affect the structure strength, provided that a vertical axis is maintained during hoisting, whereas the effect of the gravity force during column storage is more significant since its moment may cause the plate to bend.



Fig. 2. View of the column storage method

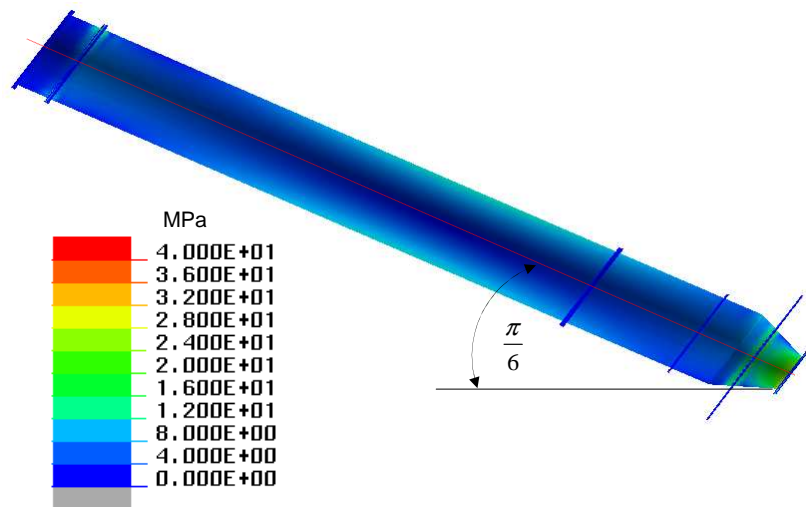


Fig. 3. Stress values and distribution in the column cross-section during storage

The calculated maximum stress values in the column cross-section for the angle of inclination of $\frac{\pi}{6}$ does not exceed 30 MPa. The stresses will not cause the tank to break, the more so as they are present near the support point.

4. Plate strength calculations at the lifting lug attachment point

Using only two lifting lugs for hoisting the column will result in a high bending moment exerted on each lifting lug. The solution is determined by the safety conditions if the column is tilted before lowering, and the lower end is hoisted by the second crane. With a larger number of lifting lugs, some of the slings might require detaching thus creating a hazard to the operator assisting in the column storage procedure.

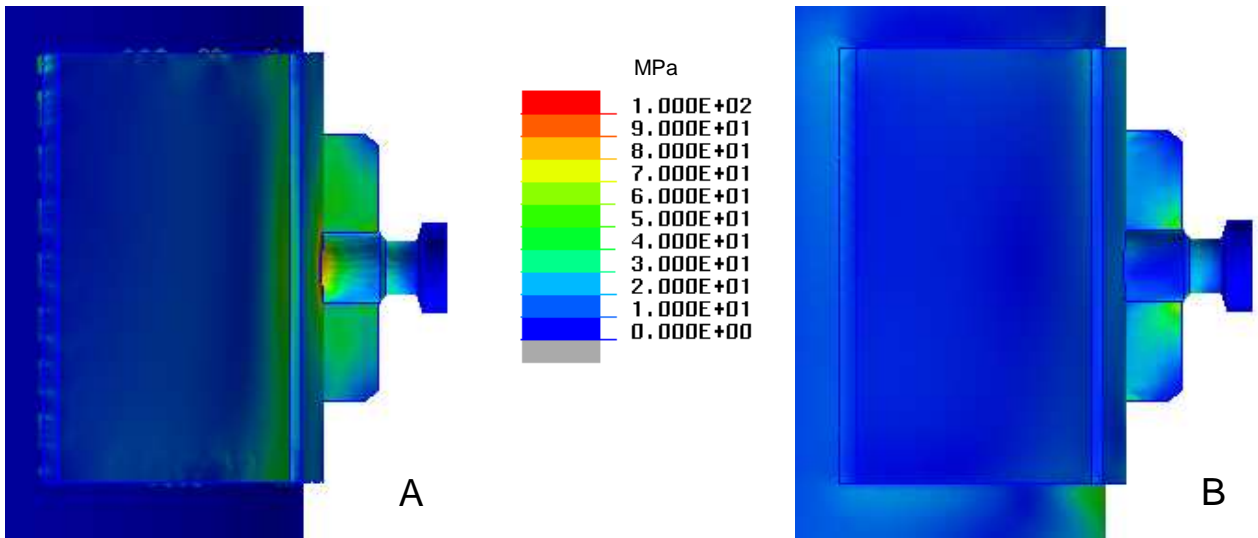


Fig. 4. Stress-strain state in the column cross-section near the lifting lug attachment points:
 A - determined based on the plate model, B - determined based on the 3D model

The stresses in the column shell cross-section were determined using two methods: The tank shell was discretized with 3D and 2D finite elements. The calculations for both models yielded interesting results. The stress values obtained using the plate model are close to 100 MPa. The maximum stresses can be observed at the point of welding the lifting lug pivot to the reinforcing pad (Fig. 4A).

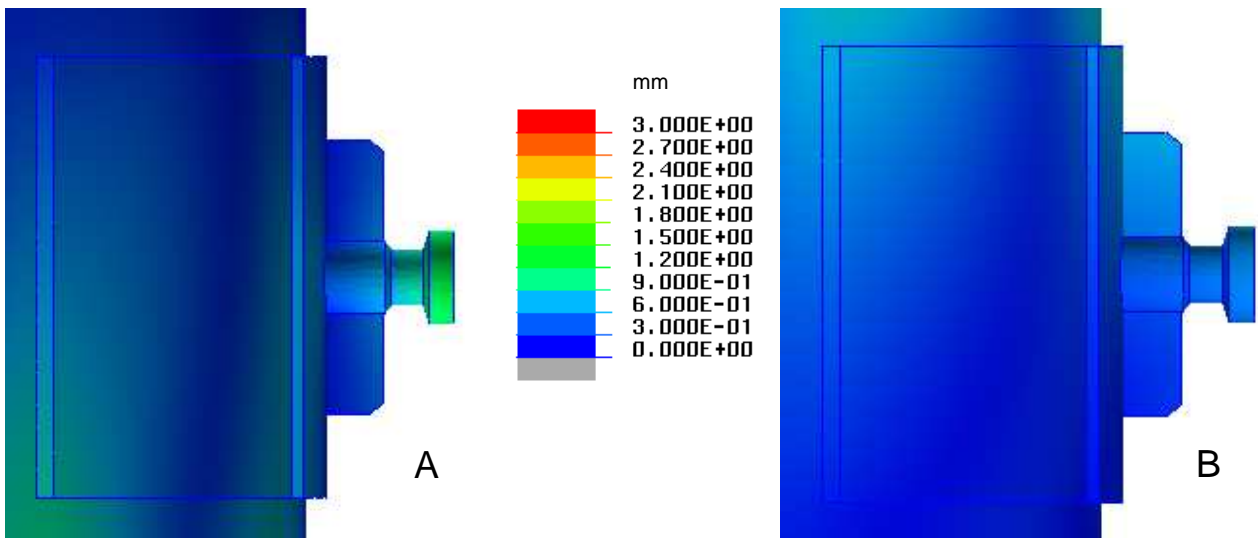


Fig. 5. Strain state in the column cross-section near the lifting lug attachment points:
 A - determined based on the plate model,, B - determined based on the 3D model

The stress values determined using 3D finite elements were slightly different. The values do not exceed 60 MPa and were recorded at the point of contact between the lifting lug pivot and the reinforcing ribs (Fig. 4B). The plate strain in the lifting lug attachment point using 2D finite elements reaches maximum values up to 1.5 mm (Fig. 5A). A division of the column into tetragonal elements yields a result, where the strain values does not exceed 1 mm (Fig. 5B).

The boundary conditions are a fundamental prerequisite, since the static calculations require valid constraints. In the previously discussed cases, the forces exerted during column hoisting are applied in the rope fixing points whereas the plate is stationary. Fig. 6 shows the stress pattern (A) and plate strain at the lifting lug attachment point, where the load is a tank weight and the restraint is present in the lug attachment points.

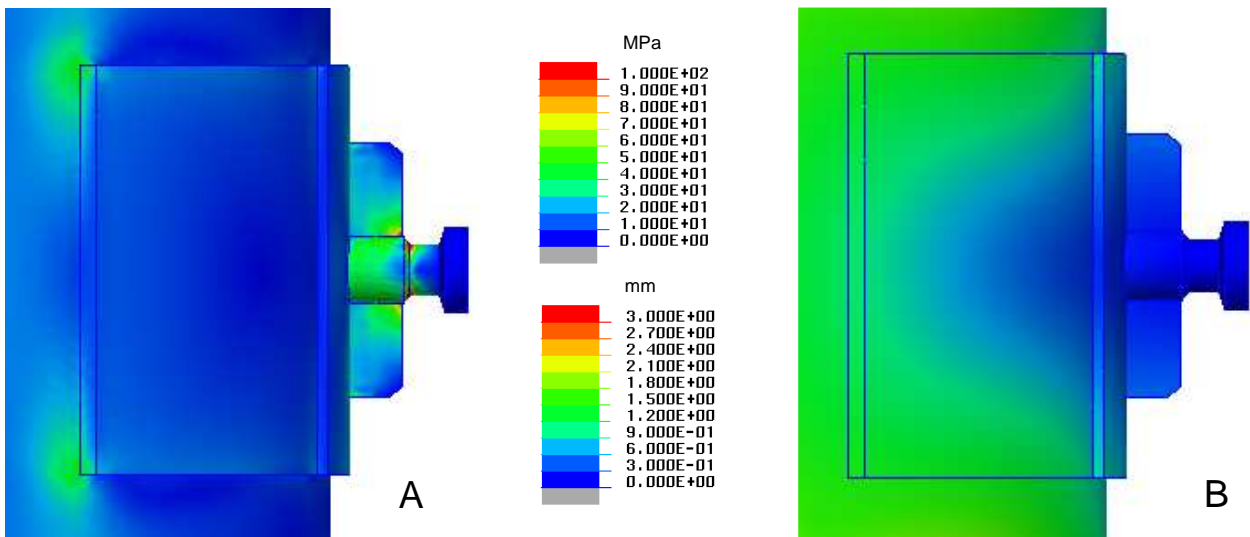


Fig. 6. Stress (A) and strain (B) state of the column determined based on the 3D model for the support in the lug attachment point

The stress values determined based on the calculations for the specified boundary conditions are higher than shown in Fig. 4B. The maximum values can be observed at the point of contact between the lifting lug pivot and the reinforcing rib, although the values are twice as high (up to 120 MPa). A similar ratio applies to the plate strain. The strain values at the reinforcing pad edges reached up to 2 mm (Fig. 6B).

5. Conclusions

The method to determine the plate structure strength using a finite element method is easy to use. The main problem is the unfavourable conditions resulting from the small thickness in relation to the other two plate dimensions. The use of the 3D finite elements requires division of a structure into a large number of elements, which in turn requires very large weight, rigidity and suppression matrices. It affects not only the calculation time but also requires high computing power and memory resources.

The solution to the problem is to use the 2D elements in the plate model. The calculation results presented in this paper both for the plate strength under its own weight and at the point of connection between the solid elements and the plate shows, that despite significant differences, both methods give good estimation of the stress values.

The plate model yields higher stress values in the cross-section than obtained by the discretization of the column shell using the 3D finite elements. The similar trend can be observed for the column shell strain.

The calculation results are strongly affected by the boundary conditions determining the forces applied. The column support in the sling attachment point yields the stress values twice as high as when the active forces with the module corresponding to the sling tension are applied at the same point.

The stress values in both cases were almost two times lower than the ultimate tensile strength of the steel. Although the calculations relate to an actual case, an experimental verification of the stress values and stress distribution has not been performed due to a complex measuring technique required. An ultrasonic testing of welds and locations indicated as relevant due to an anticipated stress-strain level did not show any micro cracks, whose location might have been compared with the stress plot obtained using a numerical simulation approach. It can thus be concluded that for the assumed safety factor, the method of plate reinforcement meets the strength criterion for both calculation models used.

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