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ANALYSIS OF THE EXHAUST TRACT OF THE TURBOCOMPRESSOR LOADED BY HIGH TEMPERATURE

Abstract

By designing of technological structures which are loaded with temperatures we are often oblivious to the situation when the structure reaches operating temperature, such as the start-up of the machines. Then structures are loaded by uneven temperature effects and thus the effect of different thermal movement generates considerable additional stress. The amplitude of these tensions may cause low cycle fatigue. This paper describes this type of structure, its failure, analysis and refurbishment.

Keywords

Thermal stress, low-cycle fatigue, uneven temperature, gas-turbine chimney.

1 INTRODUCTION

Low cycle fatigue caused by uneven heating of the structure is one of the major causes of failures of structures in energy industry. Many structures loaded with uneven heating either do not have their construction correctly designed or have not taken change of strength characteristics of material into account (Fig. 1). These factors lead to their failure. By diagnostic examinations of turbo-compressor chimney structures, serious fault of walls, flanges and reinforcements of the walls were found in the form of cracks, which had a considerable length. The paper describes failures, their causes, stress analysis and proposes modifications. The exhaust tract turbo-compressor was analysed. The silencer, elbow and chimney parts were considered (Fig. 2).

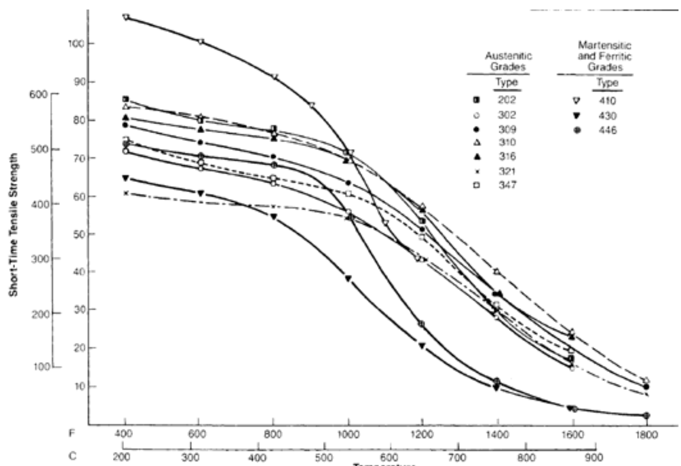

Fig. 1: Stress-strain diagram of austenitic steels at different temperatures [1]

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2 ASSESSMENT AND REFURBISHMENT OF SILENCER AND KNEE OF CHIMNEY

Exhaust tract from austenitic steel is divided in the horizontal, and the vertical part. Individual segments have length of about 5-6 m, with a rectangular or circular inner cross-section (Fig. 2). Segments are connected by compensators. Exhaust system operates at an operating temperature of about 500 ° C. The turbo-compressor undergoes many start-up and shut-down cycles per year.

By analysis with program NEXIS using FEM, the structure was divided into two separate parts - elbow and silencer with inlet pipe. Shell model was used for analysis.

Construction was loaded by four Load-cases:

LC1 - net weight of the steel construction (partial safety factor g = 1.35)
LC2 - net weight of the cladding structure (estimate 50% LC1)
LC3 - wind load (partial safety factor g = 1.5)
LC4 - uneven temperature of the walls and reinforcements 50 ° C

The structure was assessed at two load combinations

Combi FEM 1 = LC1 x g + LC2 + LC3 x g

Combi FEM 2 = LC1 x g + LC2 + LC x g

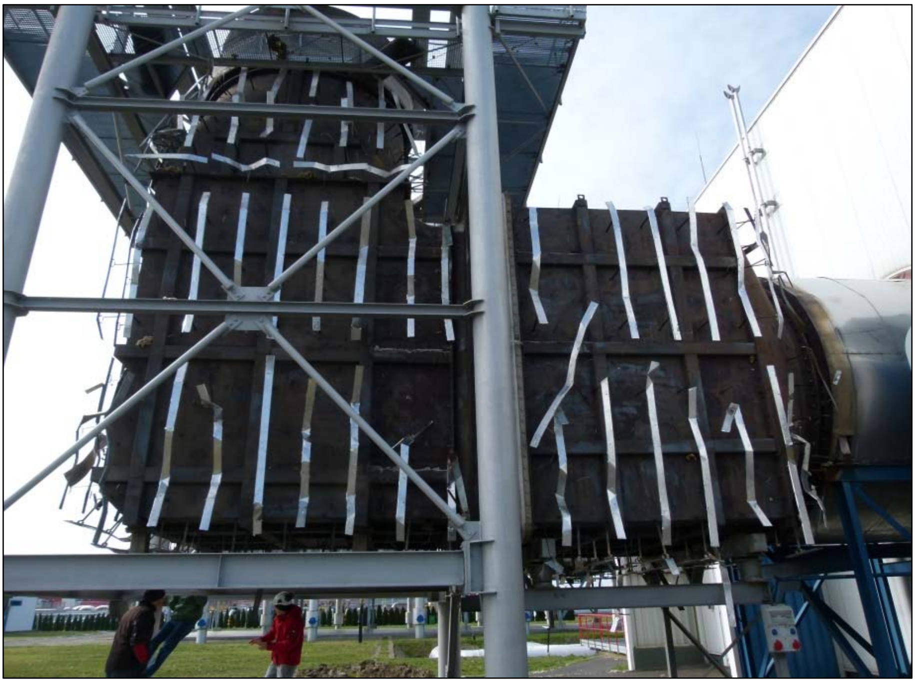


Fig. 2: Analysed structure

2.1 The Silencer

Assessed segment is a pipe of rectangular cross-section, with height of about 4000 mm, width 4500 mm approx. The wall thickness is 6 mm and the length of segment is 2900 mm. The walls are reinforced with grid of stiffeners with a U-shaped cross-section, made by bending the sheet 6 mm thick. Size 80 (70) x 160 mm. Stiffeners are welded with dashed welds (with wall creates a closed profile) to the wall. Vertical joint of stiffener in the corner of the wall segment is only a cut with an angle of 45 ° and butt-welded.

Crossing of the stiffeners is designed so that the horizontal braces are undivided (height 80 mm) and welded vertical stiffeners (height 70 mm). Segment as a whole is deposited directly over all four horizontal - stiffeners at the bottom of the two closed cross section steel beams (2xU200) located 200 mm from the ends of the segment. Saving is handled through horizontal storage plates with slotted holes to allow the thermal expansion of the lateral segment.

Cracks are concentrated in the corners and in the junctions of stiffeners with silencers and elbow. In Figure 3 we can see the crack in the corner stiffeners, and in Figure 4, in the junction of stiffeners. Most of dashed welds are cracked too.


Fig. 3: Cracks in stiffeners at the corner


Fig. 4: Cracks at the stiffeners crossing

Static analysis of model should verify that the fault corresponds to the accumulation of stress and find the cause of these disorders. The resulting stresses from a combination FEM2 (uneven temperature) are shown in Figures 5 and 6.

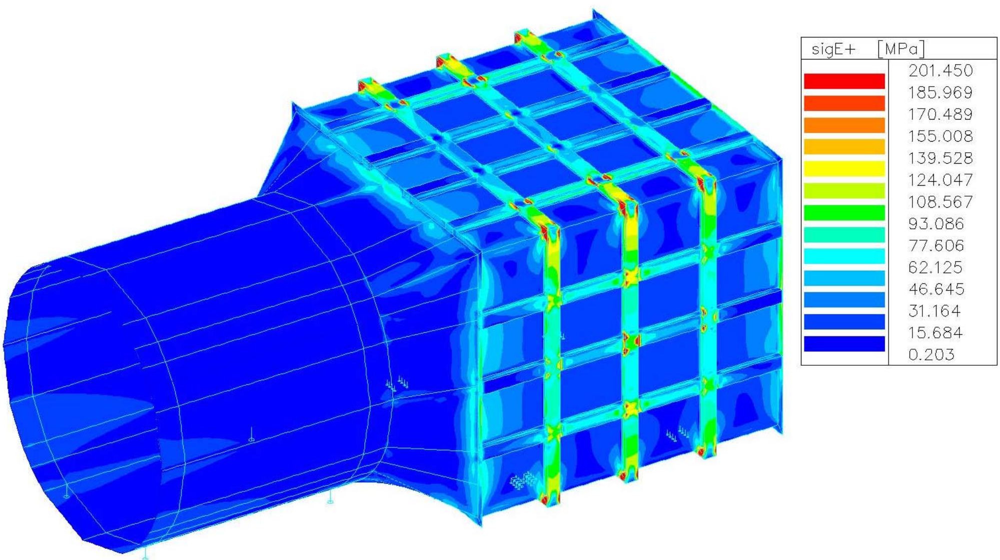


Fig. 5: Von Mises stress at the silencer [3]

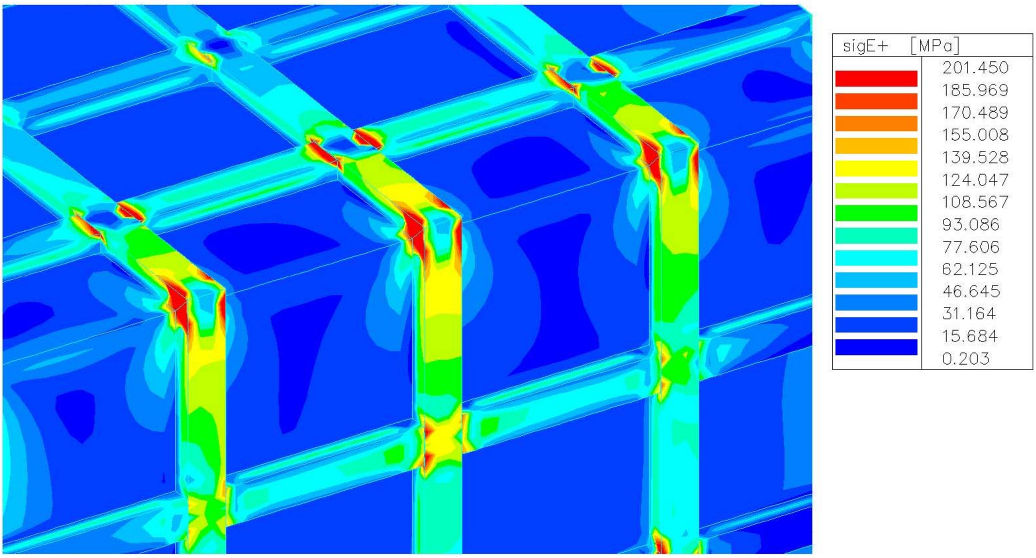


Fig. 6: Stress at the corner of stiffeners at the silencer [3]

From the resulting images of Von Mises stress *E-Sig* (outer surface structures) we can see that, by the combination FEM2 - weight and temperature, the accumulation of stress occurs in the stiffeners at corners and at junctions. The maximum value of stress is over 200MPa in several places. These points correspond with the points where the cracks appear at the structure.

2.2 The Elbow

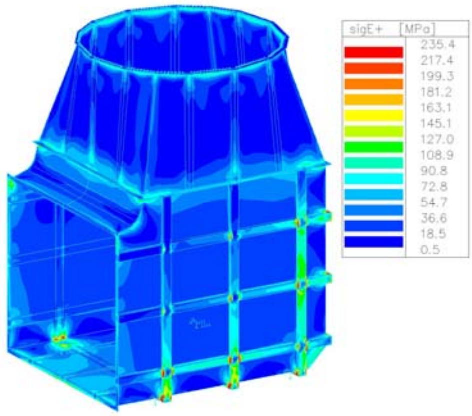
The elbow has a rectangular cross-section and is used to change direction of flow of exhaust from horizontal to vertical direction. Input (vertical) cross-section dimensions are (height x width) 3800 mm, output (horizontal) dimension 3800x3200mm and the length of the segment is 3800mm. The walls are reinforced with the same system as silencer. The wall and stiffener thickness is 4mm.

Segment is standing on four short rectangular section columns, which can slide in direction about 45 ° to the axis of the segment. This establishment allows free thermal expansion of the whole segment.

The second part of the elbow is a vertical transition piece from rectangular cross-section to the circular cross section with diameter 3200 mm. It is perched on the first segment through the screw flange connection. It is connected to the compensator at the opposite end.

The results of analysis are on the fig 7 and 8.

From the resulting images of VonMises stress *E-Sig* (outer surface structures) we can see that, by the combination FEM2 - weight and temperature, the accumulation of stress occurs in the stiffeners at corners and at junctions. The maximum value of stress is over 200 MPa in several places by temperature difference of 50 degree Celsius. At real structure was measured the temperature difference of 294 degree Celsius. It is assumed that, by measured temperature has material reached the Yield stress 360 MPa at many places. These points correspond with the points where the cracks appear at the structure.



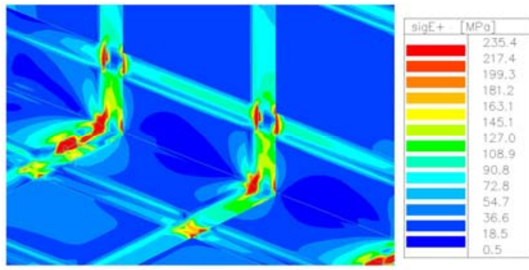


Fig. 7: Elbow model [3]   Fig. 8: Detail in the corner of the stiffeners [3]

2.3 The proposed changes

Based on visual inspection and static analysis were designed following modification of the structure of the two segments - the shock and knees (Figure 9, Figure 10.):

a) Welding, all welds connecting stiffeners to the walls from dashed to continuous with a minimum height of 3 mm.
b) Strengthening the stiffeners in the corners by welding reinforcing plate with thickness 10 mm. The weld must be designed as blunt. Weld reinforcing plate will be using fillet welds height 4 mm. (Fig. 8)
c) Strengthening the crossing of stiffeners. Before the treatment are necessary deflected plates to deal. In the first phase, the difference in height of upper edge of the vertical and horizontal stiffeners offset by welding plates with thickness 5 – 8 mm. Welds will be solved as fillet with a height of 3.5 mm and a head butt weld will, then it is necessary to resurface the plane. The second phase will be welded fillet welds amplifying 3.5 mm plate thickness 6 mm in the shape of a cross, which will increase the stiffness of the joint. (Fig. 9)
d) Enlargement motion of sliding support on the basis of the measured.

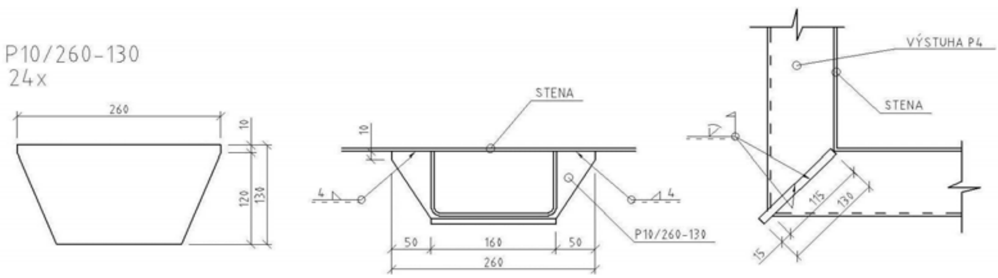


Fig. 9: Detail1-Strengthening stiffeners in the corners of elbow and silencer [3]

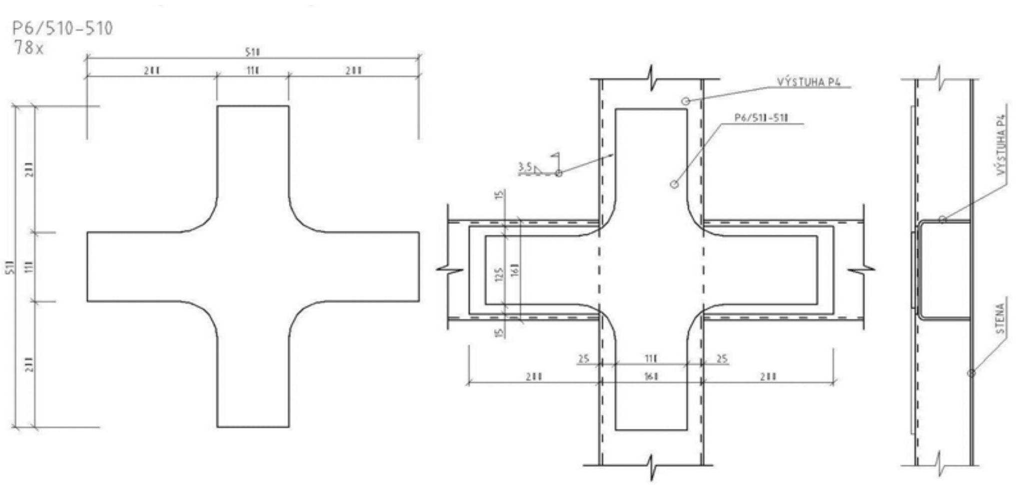


Fig. 10: Detail 2 – Strengthening the stiffeners crossing 2 phase [3]

3 ANALYSIS OF VERTICAL CIRCLE SECTION

This chapter analyses the last part of the exhaust tract, the circular chimney located above the elbow (Fig. 11). The height of the chimney is about 16.9 m, with the chimney consisting of three segments with a diameter of 3200 mm, the wall thickness being 4 mm. At the joint of segments there is a mounting flange plate with the thickness of 16 mm and the width of 100 mm. The flanges are connected with 36 screws M20 to move away from each other 10 °. The middle segment is in the middle intermediate horizontal reinforcement with the same size as the mounting flange. Last upper segment cone extends and is finished with a roof with baffles of flowing gas.

The maximum temperature of the chimney flue has a value of 475 °C.

Disorders occur especially in the lower mounting flanges of all segments (fig. 12) and place of the intermediate stiffeners.

Cracks arose during last three years (since the last diagnostic examinations) with the increased frequency of starts. These start-ups heat the constructions unevenly, causing uneven thermal expansion. This phenomenon gives rise to significant voltage spikes and low-cycle fatigue.

3.1 Analysis of mounting flange

Chimney is welded from 4 mm thick plates. Flange is 100 mm wide and 16 mm thick. At figures 14 and 15 are resulting Von Mises stresses.

Structural details were analysed in FEM software Ansys. Structure was loaded with temperature of 400 ° C, which acted only on the chimney wall, not at the flange.

The design was modelled with the real dimensions of the shell-element SHELL 93. Stainless steel was specified using a working diagram and normative characteristics of this material. Intended yield strength was fy = 230 MPa, modulus of elasticity E = 200 GPa and thermal expansion α = 1.7 e-fifth. Size of finite elements was chosen 35 mm.

Stress level at the chimney segment and the mounting flange in existing condition is on Figure 13.

Fig. 11: Segment of the vertical chimney

Fig. 12. Detached mount flange

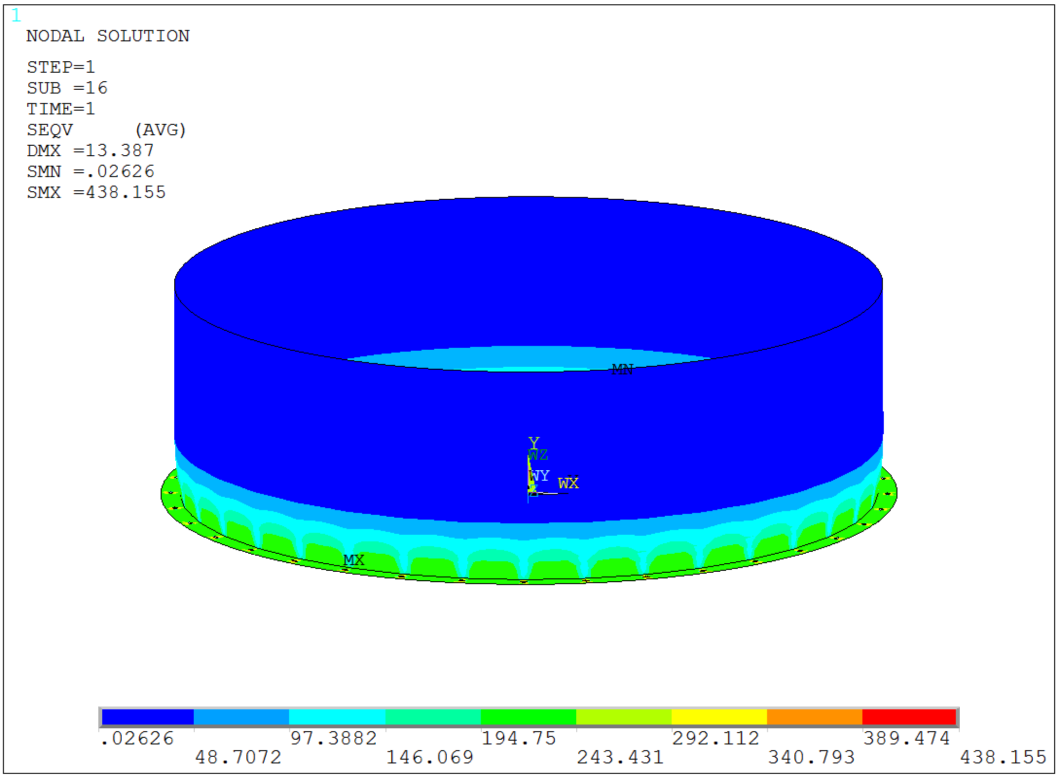


Fig. 13: Stress on the chimney segment near mount flange before structure modifications [3]

Strengthening using welded stiffeners and pads from sheet 4 mm thick and 150 mm wide

Strengthening of the mount flange is realized by welding 36 pieces of plate stiffeners with thickness of 12 mm. Pipe was reinforced by a pad with the thickness of 4 mm in the place of welding to the stiffeners. The width of the pad is 150 mm, its height being 400 mm. (Fig. 14). At figures 15 and 16, are the resulting stress.

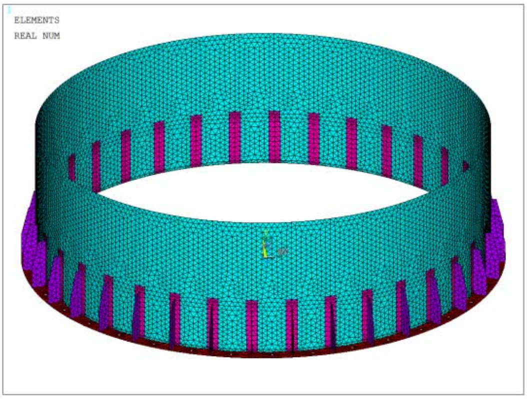


Fig. 14: Model of the modified chimney segment [3]

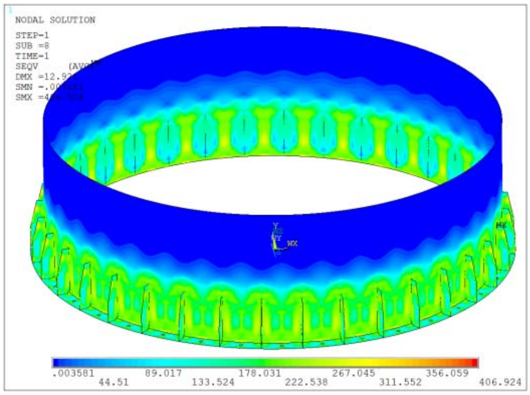


Fig. 15:Von Mises Stresses at the modified chimney segment [3]

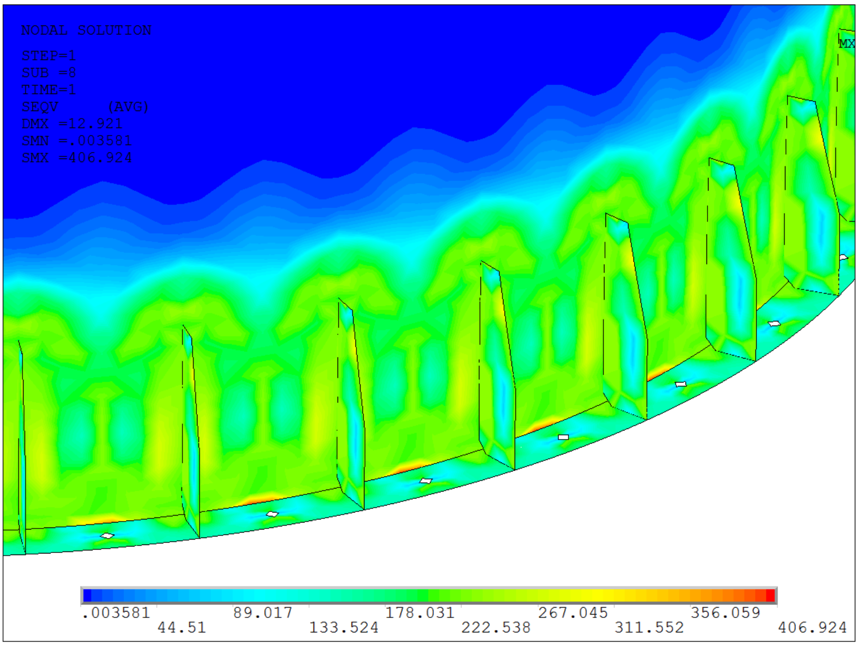


Fig. 16: Stresses at the modified chimney segment - detail[3]

From the resulting images of Von Mises stress of strengthen structure we can see that, the stresses are quite equal at the whole perimeter without peaks. Average value is 220 MPa.

Strengthening the mounting flanges:

Detached mounting flanges were welded the original location using butt, respectively fillet welds. It was necessary to shape them to their original circular shape so to allow the segments to re-connect with each other. After the flange was welded to the pipe, the pads from sheet of thickness 4 mm and size 150/400 were welded to. Pads have shift away from each other and 10° total there were all around 36 pc. After that to the flange and pad was welded reinforcement from sheet thickness of 12 mm and size of 96/350 mm.

3.2 Analysis of intermediate flange

The chimney was modelled in its existing state. The pipe is welded from sheet 4 mm thick and intermediate stiffener has width of 100 mm and thickness 16 mm. Figure 17 shows stresses in the structure in its current state.

Strengthening of the intermediate flange is realized by welding a plate with the thickness of 4 mm from the inner side of pipe. From the outer side, 36 pieces plate stiffeners with thickness of 12 mm were welded (Fig. 18). The resulting stresses after this modification can be seen at figure 19.

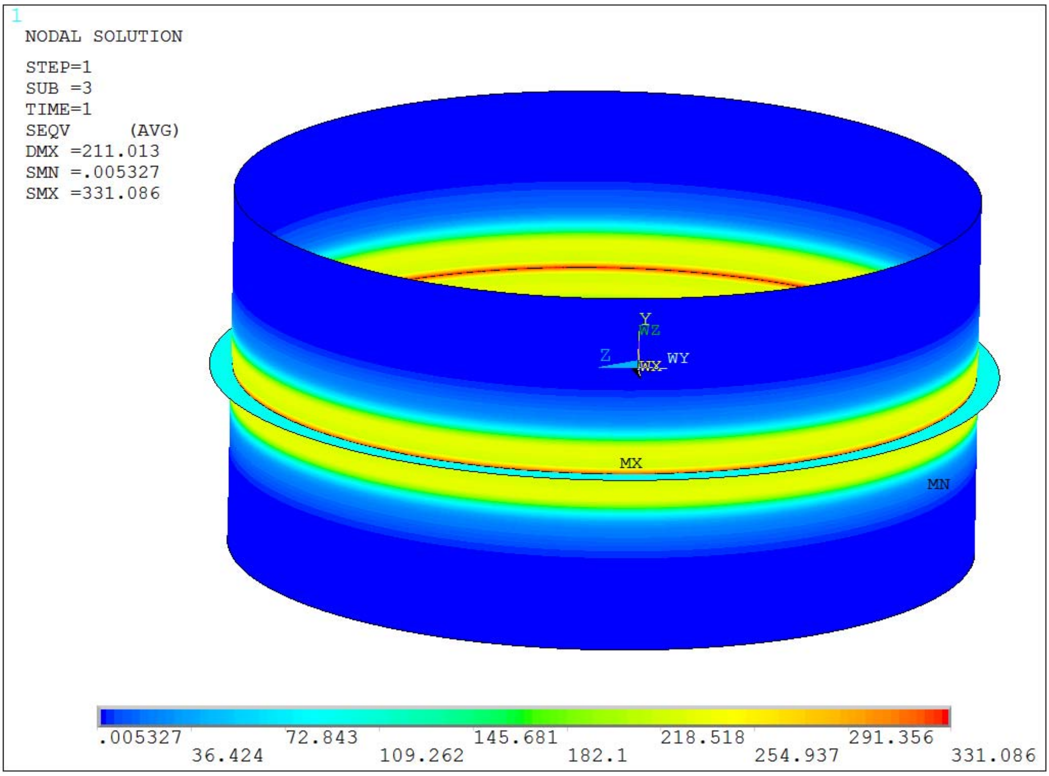


Fig. 17: Von Mises stresses of segment with inner flange before strengthening [3]

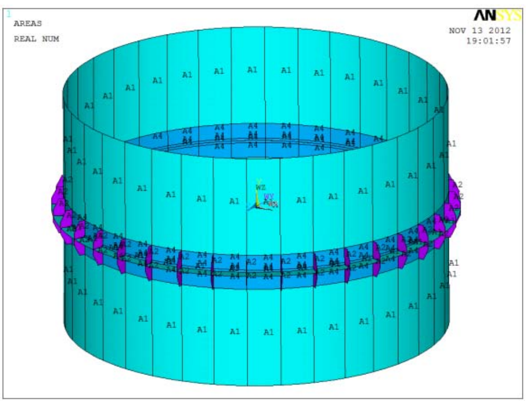


Fig. 18: Model of segment with inner flange [3]

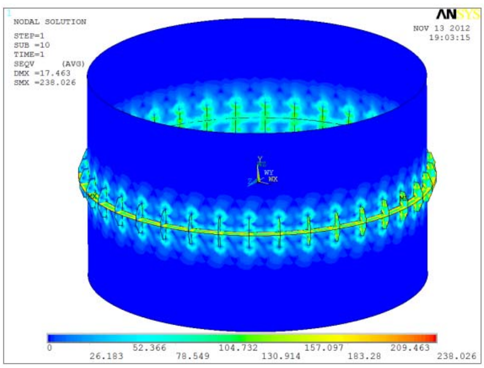


Fig. 19: Stresses at the modified chimney segment [3]

From the resulting images of Von Mises stress we can see that, at the connection flange to pipe are stresses lower – half then before.

Based on the provided analysis, the various types of critical details of were designed with the following construction modifications. The same material as in the existing chimney was used – austenitic steel.

Cracks around the intermediate stiffeners are welded by butt weld. From the inside of the chimney, a reinforcing strip of 4 mm sheet was welded around the perimeter. Belt width is 400 mm (200 mm above and 200 mm below), composed of segments with length 1000 mm, which is welded with 3 mm high fillet welds on the top and bottom welded.

From the outside 150 mm high and 90 mm wide stiffeners were welded using two-sided fillet. Diversion of reinforcements will be 10° apart and their amount will be 36 pc.

After realization of repairs and reinforcements, it was possible to proceed with assembly of chimney construction. Individual segments were joined with each other in the place of mounting flanges with screws M20 from material A2. Pads were put under the bolt head and the nut.

It is recommended not to insulate the chimney, so that future diagnostic examinations can be performed.

4 CONCLUSION

The article presented, being based on diagnostic inspections of practice, highlights the importance of design of steel structures to the effects of uneven heating of the structure. It shows the failures, analyses their causes and proposes measures.

ACKNOWLEDGMENT

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