A NON-BOLTED RESTRAINT FOR COKE DRUMS

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ABSTRACT

The failure of coke drum anchor bolts is a demanding and recurring maintenance item for many delayed coking operators. While there are several factors that can contribute to these failures, some studies have demonstrated that significant stresses may result from thermal expansion of the drum under non-uniform thermal gradients. To address bolt failures, a restraint system that utilizes non-contacting anchor blocks has been developed and implemented for the first time on a set of operating coke drums. In this paper, the background of anchor bolt failures as well as the design and first implementation of the new restraint system are discussed.

INTRODUCTION

Coke drums are vertical refinery vessels that operate in batch cycles. The cyclic coking process generates severe, inconsistent, and unpredictable thermomechanical loads. Each cycle produces varying temperature and stress profiles in the critical regions of the shell, bottom head, and support skirt. Coke drums are typically secured to the support structure using long anchor bolts.

Typically, coke drums are designed per the ASME BPVC Code Section VIII Division1, Ref.1. Their skirts are designed for static load using AISC (American Institute of Steel Construction) design procedures, Ref.2, or similar structural design methods.

With the exception of drums that are subjected to significant seismic or wind loads, the weight of these vessels is usually sufficient to resist overturning moments. This is why, in most cases, anchor bolts are not designed for a specific load and, instead, are only intended to keep the drum in place.

The use of anchor bolts limits the ability of coke drum skirts to freely deform in response to the significant thermal transients that are generated in the drum during operations. The restraint can impose significant axial and shear forces on these bolts. In addition, vibration loads that result from process conditions and the cutting process can be significant enough to cause fatigue damage. This is why some bolts fail after few years of operation. Experience suggests that if bolts are not replaced, coke drums can move around on top of the concrete structure potentially causing piping failures and operational difficulties.

As explained above, factors not included in the design process such as cyclic loads, transient thermal gradients, residual stresses, and operational conditions play a significant role in determining the life and performance of coke drum skirts and their anchor bolts. These failures have been discussed and analyzed for decades by numerous workers in this field. Ref. 3 is an industry white paper on the subject. Ref. 4-9 are studies of skirt failures due to thermal loads. In Ref. 10-12, bolt failures are examined and analyzed.

The process of replacing coke drum anchor bolts is a demanding and disruptive endeavor. More importantly, since in-kind replacement does not address the root cause of failures, new bolts typically fail within few years of operation which makes the replacement a temporary solution.

This paper describes the first implementation of an anchoring system that is intended to minimize the underlying forces that cause bolt failures.

EQUIPMENT DESCRIPTION

Materials and wall thicknesses are shown in Table 1.

Table 1. Materials of Construction

	Material Specification.	Min.Size Thickness	Weld
Shells	SA-387 Gr.11 Cl.1 (Gr.1)	59 mm.	P4
Top of Skirt	SA-387 Gr.11 Cl.1 (Gr.1)	37 mm	P4
Bottom of Skirt	SA-516 Gr.70N (P1 Gr.2)	37 mm	P1
Anchor Bolts	SA193 B7	7/8 inch 22 mm	

The original bolts and the location of the modification are shown in Fig.1. Subject drums were operated using a fill cycle time between 18 and 12 hours. Since the new anchors were installed, they ran 12 hour cycles.
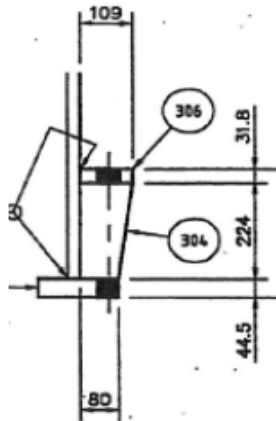
Figure 1 – Existing Base Ring, Anchor Chair and Bolting

Figure 2 – Failure of Anchor Bolts

Considerations for transient thermal loads during start-ups and shutdown, process-induced vibration loads, and impact of cyclic operation are ambiguous and left up to the discretion of the designer. Not properly accounting for these additional loading conditions can result in the failure of anchor bolts (see Figure 2), grout and shim plates (see Figure 3), or the skirt. (see Figure 4)

Figure 3 - Failure & Extrication of Shim Plates

Figure 4 – Skirt Failures

DISCUSSION

The traditional base ring and anchor chair with bolting approach to pressure vessel and tank designs appears to be satisfactory for static loading, but not for cyclic operation that includes significant transient thermal and vibration loads. Other upgrades of base rings, bolting and

anchor chairs have been implemented with largely better success than the original designs.

To overcome the repeated failures of anchor bolts a sliding restraint plate system was developed. The first variation implemented was a plate system free to slide with only guiding plates. The anchor bolts were removed. This system has performed satisfactorily for four years.

Figure 5 shows an early version of the sliding restraint.

**Figure 5 - Early Version of Sliding Restraint**

Examination and study of the full operational loading revealed higher than anticipated loads would occur under increased operational conditions.

It was therefore determined an upgraded restraint system would be required. This prompted the application of the more comprehensive non-bolted restraint system. The modifications were as follows;

- The existing bolts are no longer used to restrain the drum.
- Anchor blocks that do not contact the drum are added and designed to fit the existing bolts and their support structure.
- There is no change to the existing skirt base plates, gussets, existing bolt holes, which are left as is.
- Low friction slide plates are employed at 16 locations to reduce the friction and hence the shear loads.
- 32 anchors blocks and 64 additional bolts are required.
- A new block is installed to contain the sliding plate accounting for:

 –circumferential clearance,
 –axial clearance, and
 –radial clearance.

The modified system was initially built and assembled as shown in Figure 6 below
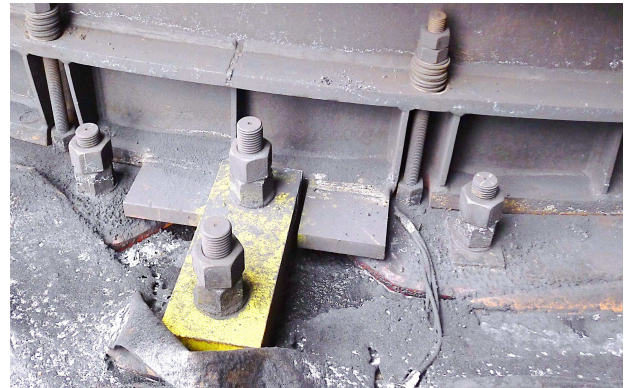
Figure 6 - First Modified Assembly

The restraint assembly before and after final grout is shown in Figs. 7-8. This system has satisfactorily performed for two years.

Figure 7 – Assembly before Final Grout

Figure 8 - Final Assembly

It is important to recognize and mitigate operational and environmental challenges that may negatively impact the effectiveness of these anchors, such as the icing of restraints shown in Figure 9 which was mitigated with steam lancing and ice removal.
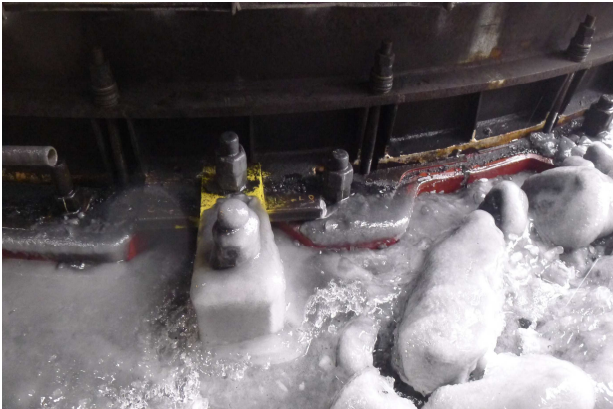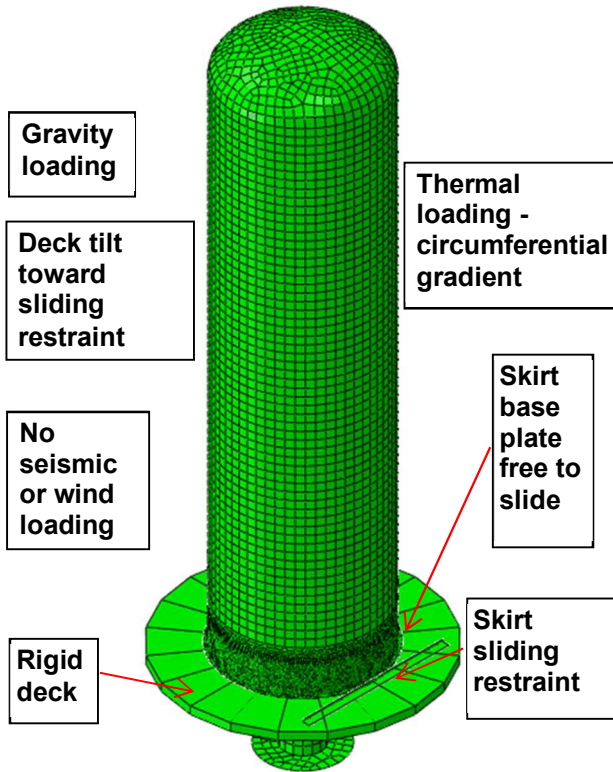

Figure 9 – Icing of Restraints

Figure 10 – Boundary Conditions

ANALYSIS

A three-dimensional nonlinear finite element analysis was performed using the shell element mesh and boundary conditions of Fig. 10. Since the purpose of the analysis is to determine bolt loads needed to resist thermal cycling, loads did not include seismic or wind loads.

The following load steps were applied in the same order:

1. Weight: maximum weight of drum and contents
2. Tilt: simulates the effect of an imperfect deck slope
3. Thermal cycle-1
   a) Apply a steady state circumferential thermal gradient of 93 °C - 427 °C (200°F - 800°F).
   b) Back to uniform ambient temperature of 70°F
4. Repeat thermal cycle -2
5. Repeat thermal cycle -3
6. Repeat thermal cycle -4
7. Repeat thermal cycle -5

Gravity load: weight of vessel Nominal factored to reach 4.6 million pounds to account for contents and non-structural components applied in negative Y direction.

Tilt: To simulate a deck slope of 1:100, 1% of weight is applied in positive X direction

Thermal Loading: The entire coke drum including top and bottom heads are assigned a circumferential thermal gradient that linearly varies from 93 °C on one side to 427 °C midway to 93 °C on the opposite side   (200°F - 800°F to 200°F).
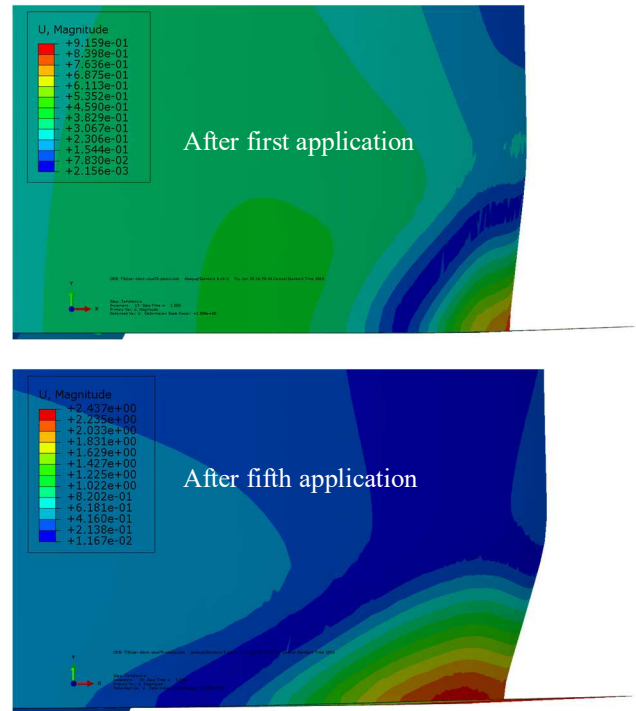

Figure 11 - Baseplate Displacement Magnitude (inch) at Ambient Temperature after Load Application (no magnification).

Sliding Skirt Base Plate: The base plate is free to slide on the deck surface. The analysis modeled sliding behavior using friction coefficients of 0.5 and 0.25 which model expected sliding behavior in a manner. These lower-bound values were intended to provide a conservative high-end estimate of the reaction load

experienced by the restraint. The effect of friction coefficient on restraint reaction is examined in [12].

Skirt movement is restrained by a rigid analytical vertical surface.

Deck Base Boundary Condition: The "table top" or deck is modeled as an analytical rigid surface fixed in all directions.

• Initial drum movement is mainly resisted by one anchor block at the onset of movement. After local plastic deformation occurs, other blocks participate more effectively in restraining the drum. Because of that, distortion in the baseplate is overestimated and calculated shear forces are conservative.

• As a result of the excessive local plastic deformation in the baseplate during the first application of the thermal gradient, subsequent applications did not result in contact with the anchor block and, instead, caused more local distortions in the baseplate. A comparison of the deformation magnitude (with no magnification) at ambient temperature after the first and fifth applications is shown in Fig. 11. The Von Mises stress on the inside and outside surfaces under the fifth load application is shown in Fig. 12. Residual Von Mises Stress at ambient temperature after 5th load application is shown in Fig. 13.

At a friction coefficient of 0.5, the maximum calculated reaction force is 189.3 kips (842 kN). At a friction coefficient of 0.25, the force dropped to 121.7 kips (541 kN)
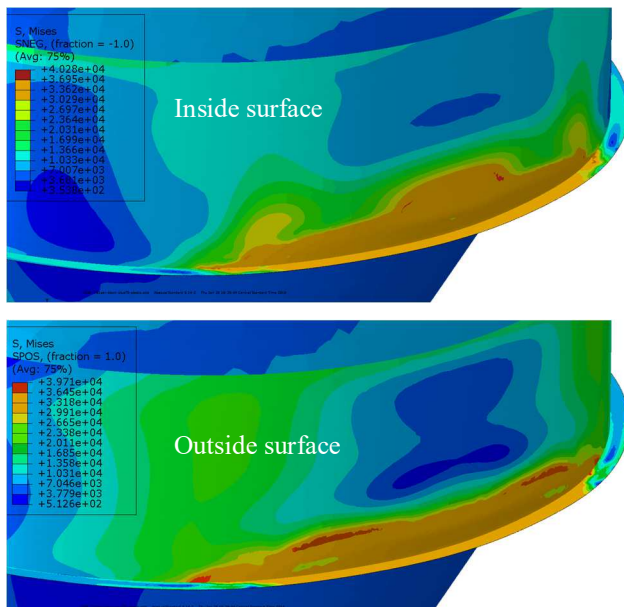
Figure 12 Von Mises Stress (psi) under 5th Load Application (no magnification)
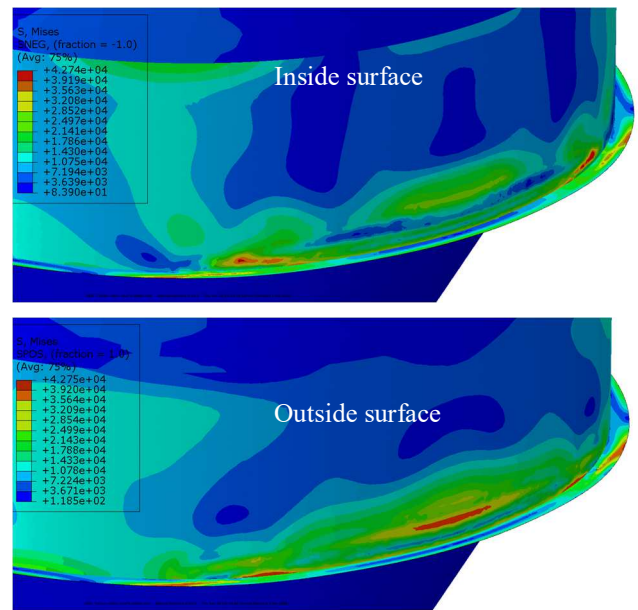
Figure 13 Residual Von Mises Stress (psi) at Ambient Temperature after 5th Load Application (no magnification)

CONCLUSIONS

The new coke drum anchoring system documented herein is aimed at mitigating recurring anchor bolt failures that are widely observed in industry. The new system allows the bottom of the skirt to react to transient thermal gradients in the drum with minimal restraint. So far, the first application of this non-bolted anchoring system has worked successfully.

ACKNOWLEDGEMENTS

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