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A COKE DRUM SKIRT REPLACEMENT – ANALYSIS & PRACTICAL CONSIDERATIONS

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Phillips66

AIM OF THIS PRESENTATION

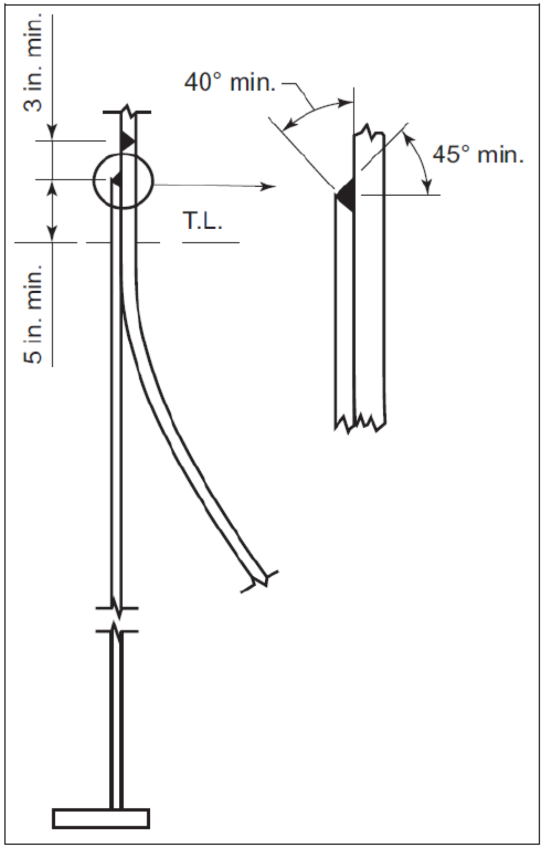


Figure 16 taken from API 934-G (2016)

- This presentation is aimed primarily at the owner operator who may be planning a skirt replacement in the future or is simply interested in seeing how others have tackled this task.

- There are numerous ways of replacing a coke drum skirt, this represents one way only, according to resource, planned duration and original drum design.

- This example describes the repair sequence for a tangential (lap) design as shown in Figure 16, API 934 G. Other skirt designs may require different repair techniques to that shown here.

INTRODUCTION

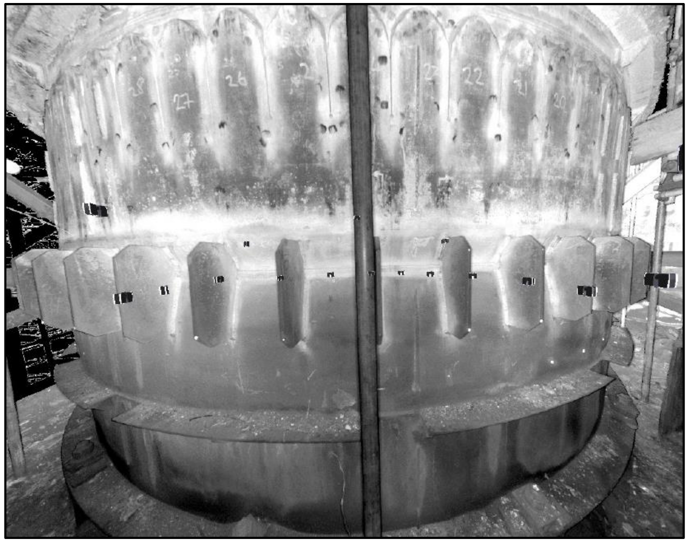
Drum specification

- Service: Premium Coke drums
- Built: 1975
- Material: ASTM A387 Gr C (1-¼ Cr), 52mm thick with internal 405 cladding
- ID: 21’-0”, T-T: 71’-5”
- Skirt design: tangential (scalloped)
- Skirt thickness: 23mm
- Mass (unfilled): 260 Tonnes

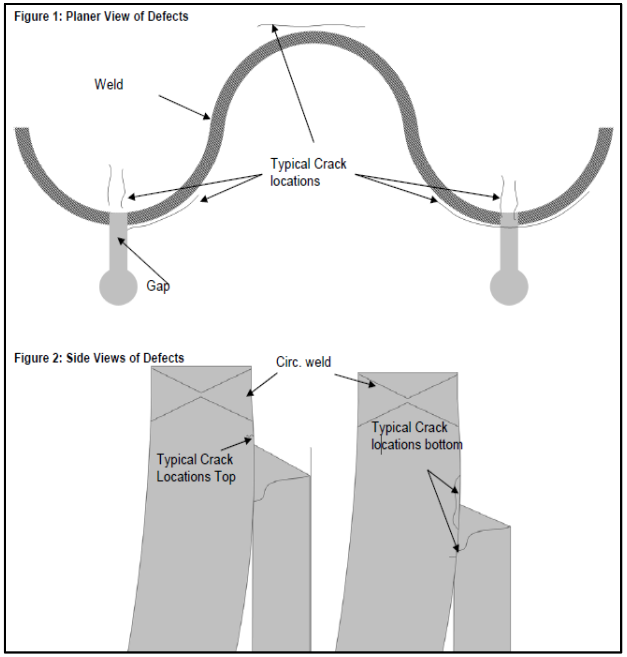
WHY REPLACE THE SKIRT?

Skirt Bulges

- Severe buckling of skirt at Carbon steel to Chrome location.
- Arrested in 2006 after installation of support gussets.
- Bulges monitored through periodic laser scanning.
- Minor cracking at the gusset welds were observed during inspection windows and ground out each time.



CRACKING



Cone Cracking

- Original skirt design was a 'J' Prep scallop attachment.
- Extensive cracking on skirt and into cone section was monitored for many years with Advanced UT (slow growth rate).
- Maximum excavation depth during the repair was ~15mm which verified the UT results.
- Numerous on-going crack excavations to scallop area became unmanageable.
- Trigger for skirt replacement was a combination of the cracking and bulging particularly an inability to repair cracking behind scallops.

ANALYSIS (BUCKLING CHECKS)

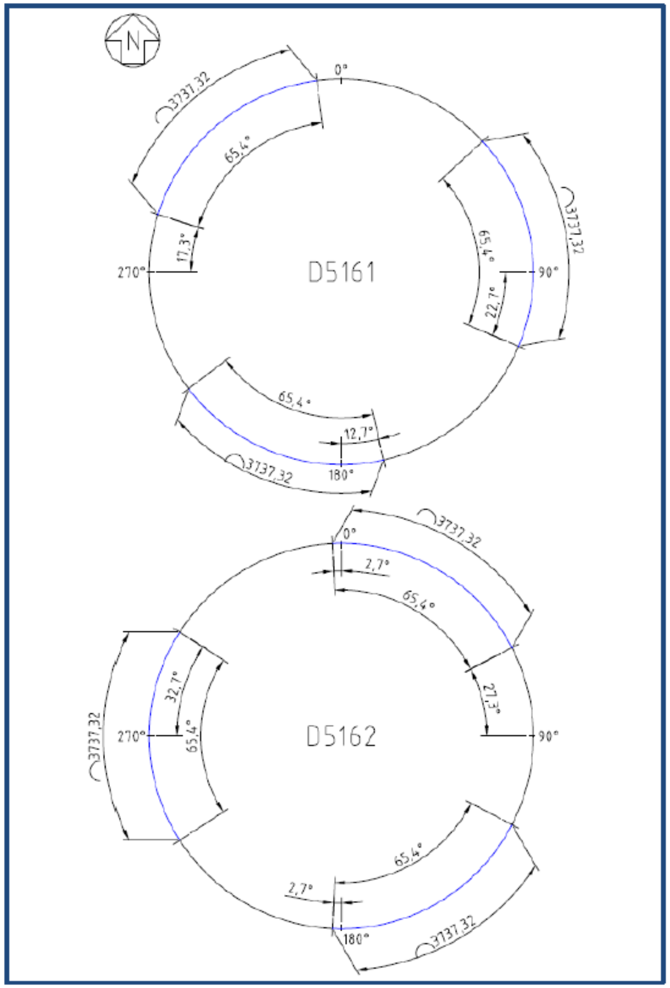


Figure 15 - Skirt Segment Removal Order (First 3 Segments in Blue)

- Due to skirt bulging, FEA was used to prove the remaining skirt would not collapse when the first 3 segments were removed (first three windows are 6" wider).
- The analysis dictated which segments should be removed first (this was optimised to avoid clashes due to drum proximity).
- New skirt sections, with reduced weld size (15mm), were analysed to prove drum stability for self weight and wind loading.

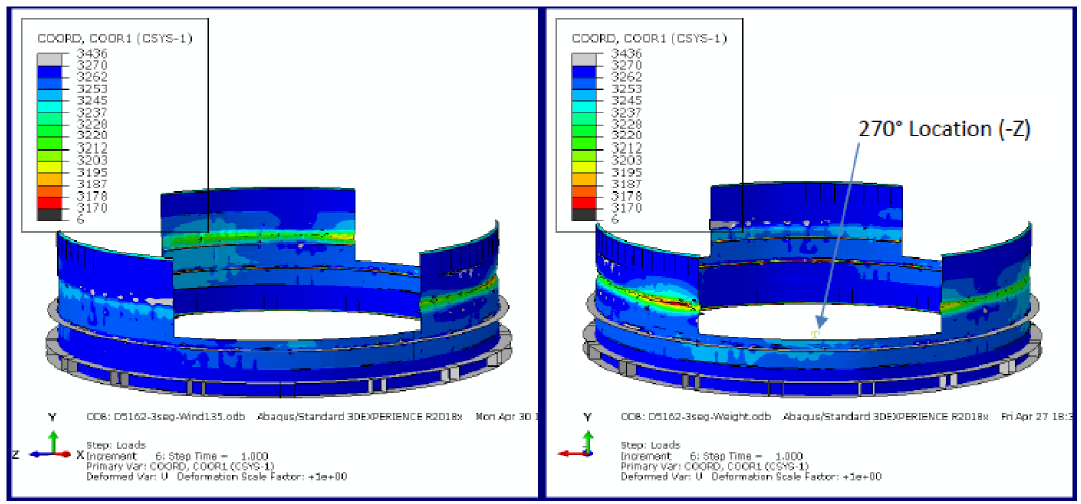
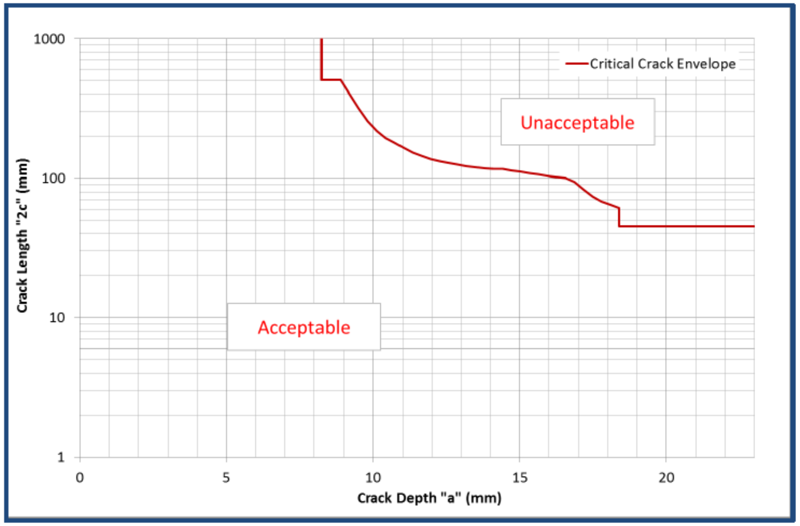


Figure 7 - Radius Plot for Skirt Deformation with 3 Segments Removed (mean radius = 3264mm, max bulge in remaining shell = 94mm)

ANALYSIS (BRITTLE FRACTURE)

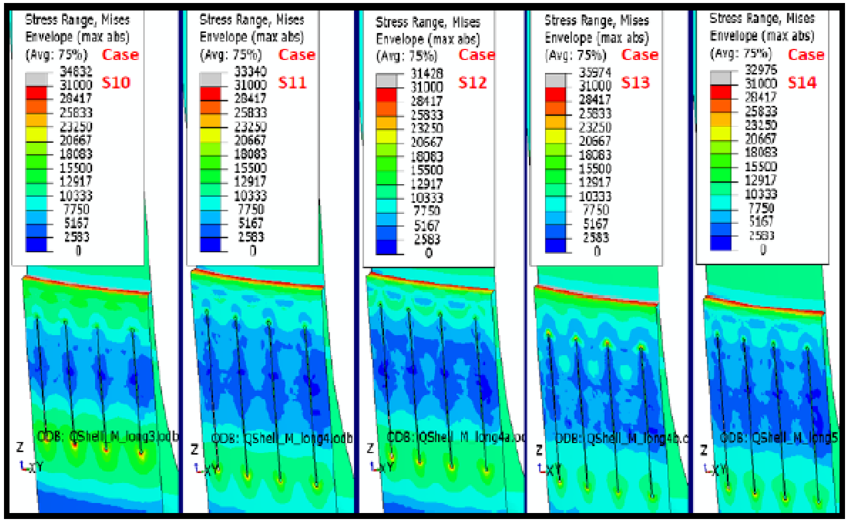


- Risk of brittle fracture due to cone cracking was considered when the first three segments are removed.
- An infinitely long crack, 8.5 mm deep could be tolerated (API 579 assessment criteria). Our cracks were known to be deeper (although shorter).
- To protect against risk of brittle fracture, all grinding, gouging and welding operations were performed at temperatures above 10°C (50°F)
- This wasn't onerous as these activities require a pre-heat as a requirement of the WPS & PQR.

Although unlikely, the risk of brittle fracture is very real. See picture (top left) which shows a brittle fracture on a coke drum top nozzle during lifting.

ANALYSIS (NEW SKIRT OPTIMISATION)

- New skirt was optimised for the longest fatigue life, scallops were removed, slots elongated and skirt thickness reduced from 23mm to 19mm.
- Attachment point was explored to try and avoid cracked areas. Final solution was constrained by circumferential weld.



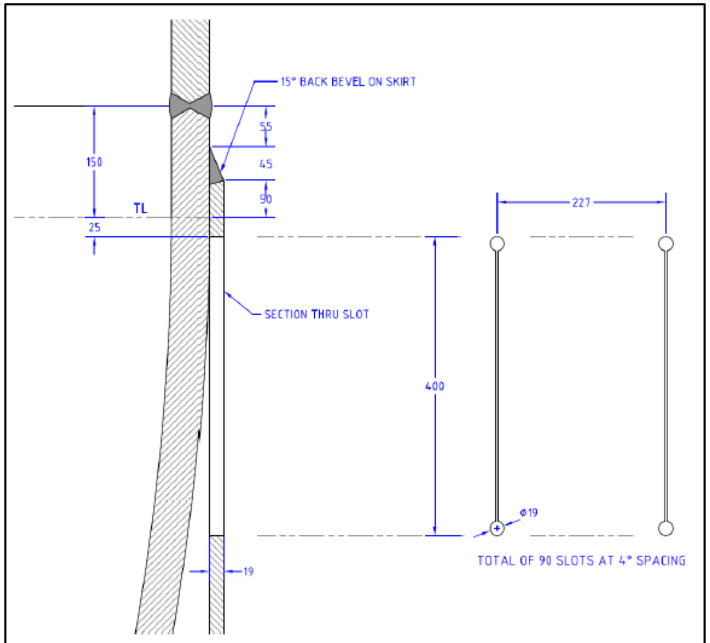
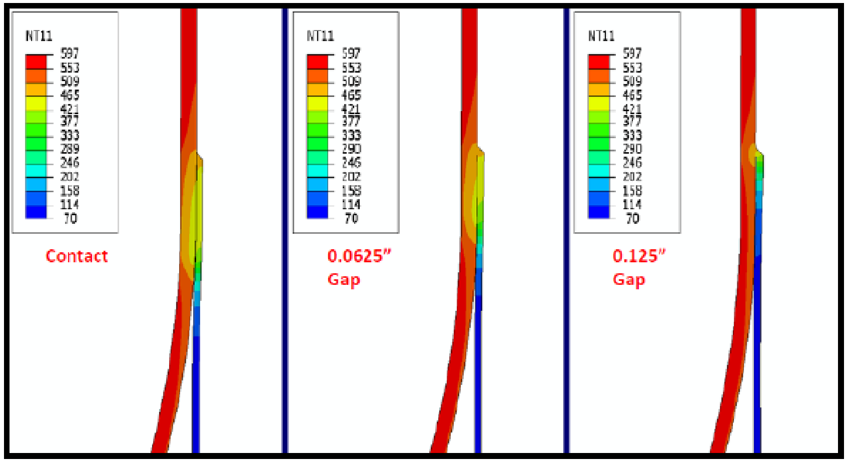
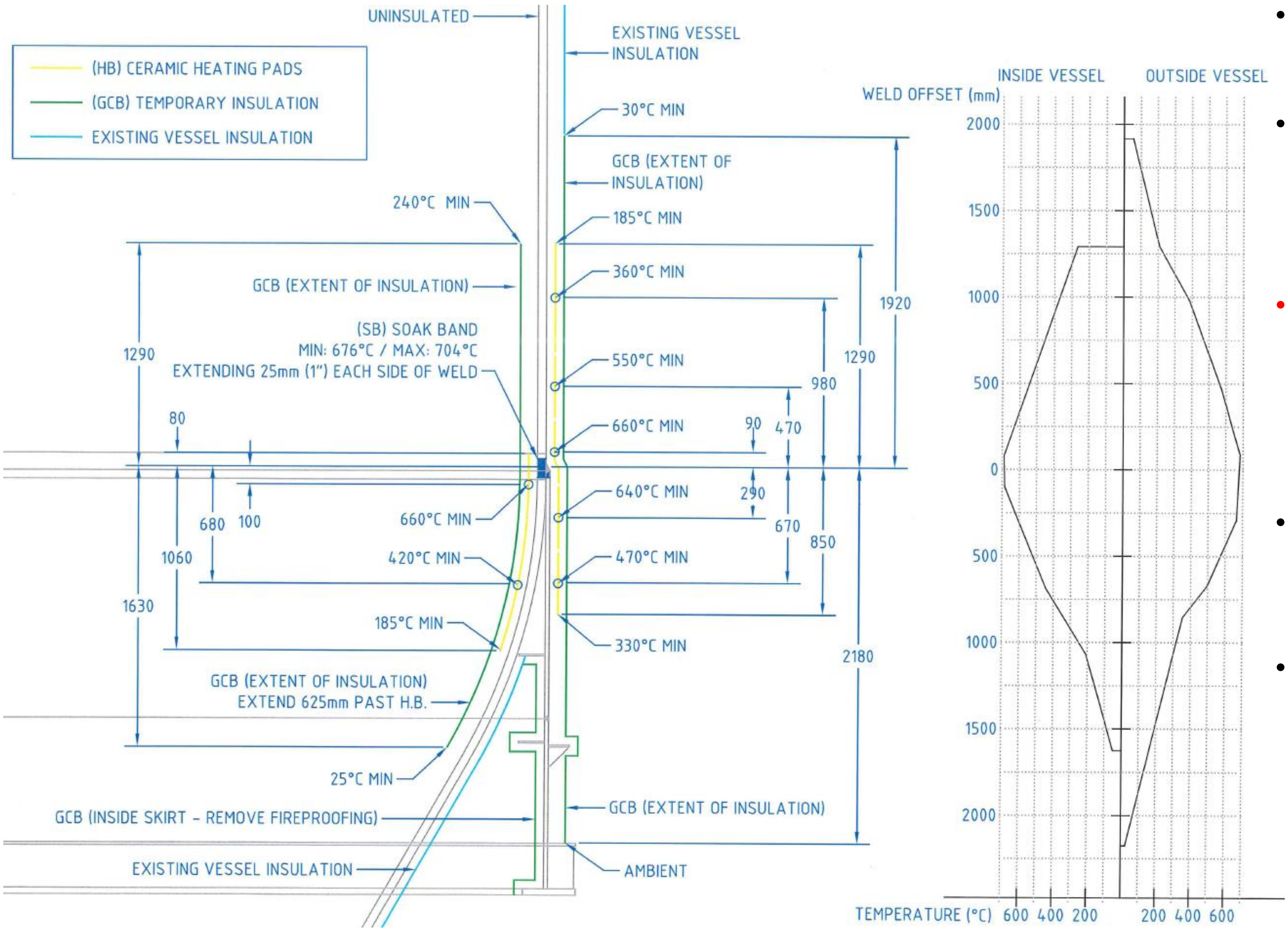


Figure 56 - Skirt Connection Detail



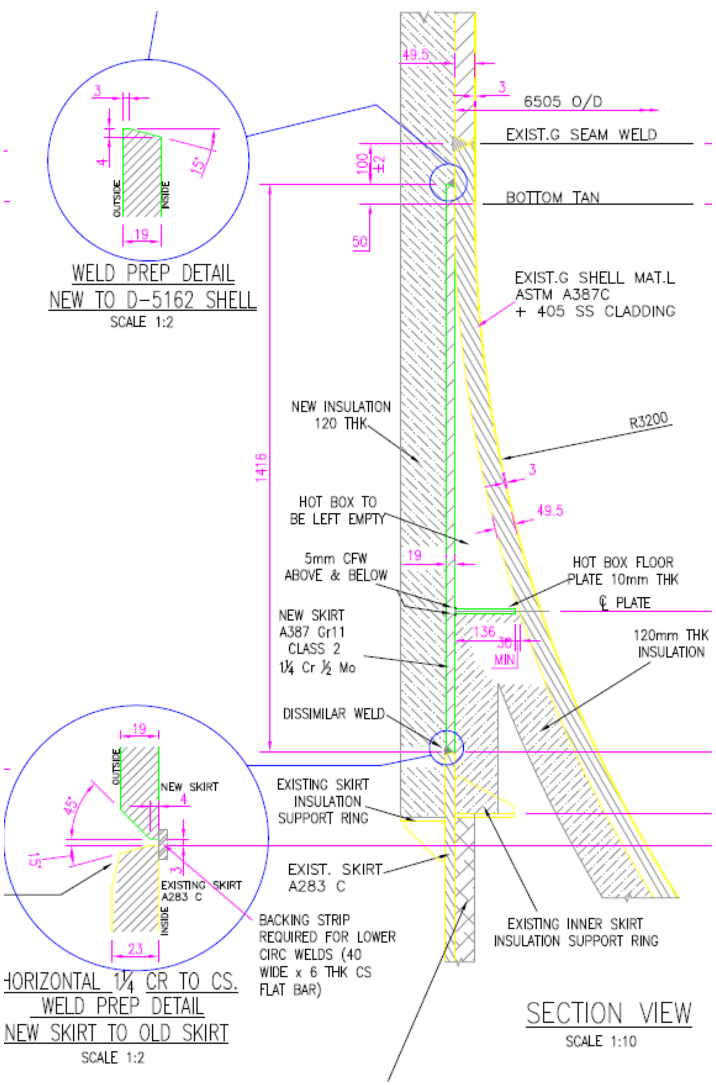
For an in-depth look at a tangential skirt design, see PVP2019-93135 "A review of optimising the design of a new coke drum skirt"

ANALYSIS (PWHT OPTIMISATION)



- Based on WRC 452 principals.
- FEA used to size heating band and gradient control band.
- Anchor bolts were <u>not</u> removed, preventing the skirt from expanding at its base.
- Thermal gradients were controlled to limit stresses.
- Key temperature locations we used to monitor progress.

WELDING PROCESSES



PWHT

1. Cone repair – TIG (manual GTAW)
2. Skirt-to-shell attachment weld – TIG + automated MIG (GMAW-P)
3. "Tees" – TIG (GTAW) with backing strip

Temper Bead

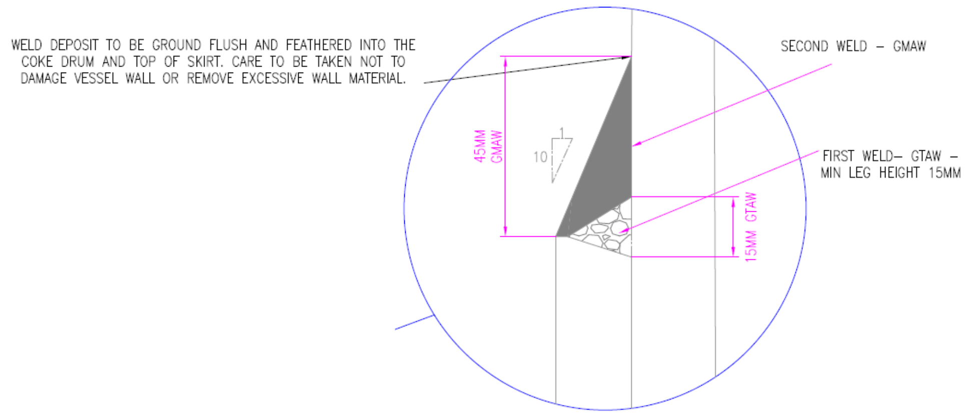
4. Vertical skirt welds – MIG (GMAW-P) with backing strip
5. Skirt-to-skirt weld - MIG (GMAW-P) with backing strip

- TIG (GTAW) chosen for superior weld quality.
- MIG (GMAW-P) chosen for automation (speed).
- Full PWHT chosen for attachment weld to give predicable reduction in stress and hardness (critical weld)*
- Temper-bead chosen for less critical welds that were not subject to full PWHT.

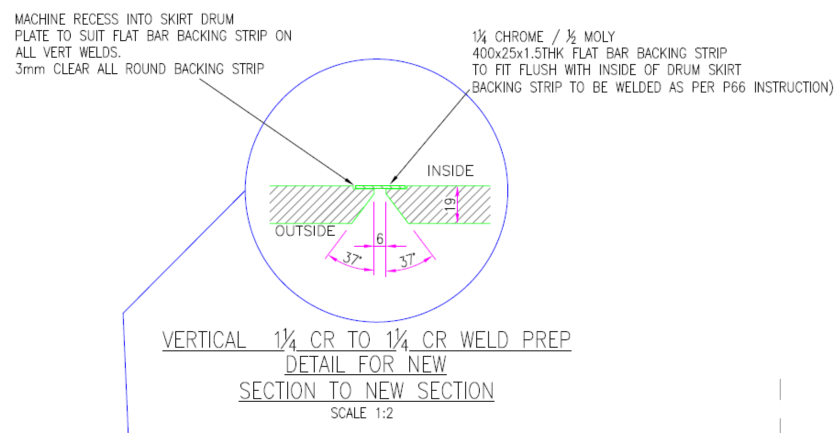
*It would have been perfectly possible to temper-bead the attachment weld providing welding process and parameters were controlled accurately as per the WPS.

WELD DESIGN

- Flat top tangential design with 15° reverse weld prep. This was chosen to ensure the best root possible based on welder access.
- Two-part weld chosen as a compromise between quality, welding speed and cost.
- Final weld size influenced by existing design and proximity to cone circumferential weld.
- Backing strips used to prevent fusion to the cone at the top of the vertical welds and to accommodate the varying root gap during skirt installation. This ensured high quality roots with MIG (GMAW-P) process.
- A “mock-up” was used to validate the WPS, PQR and to prove the chosen geometry.
- A second mock-up was made of the existing scalloped skirt attachment weld which was demolished using the air-arc gouging process. This allowed accurate demolition durations to be feedback into the overall repair schedule.



SHELL TO SKIRT WELD DETAIL

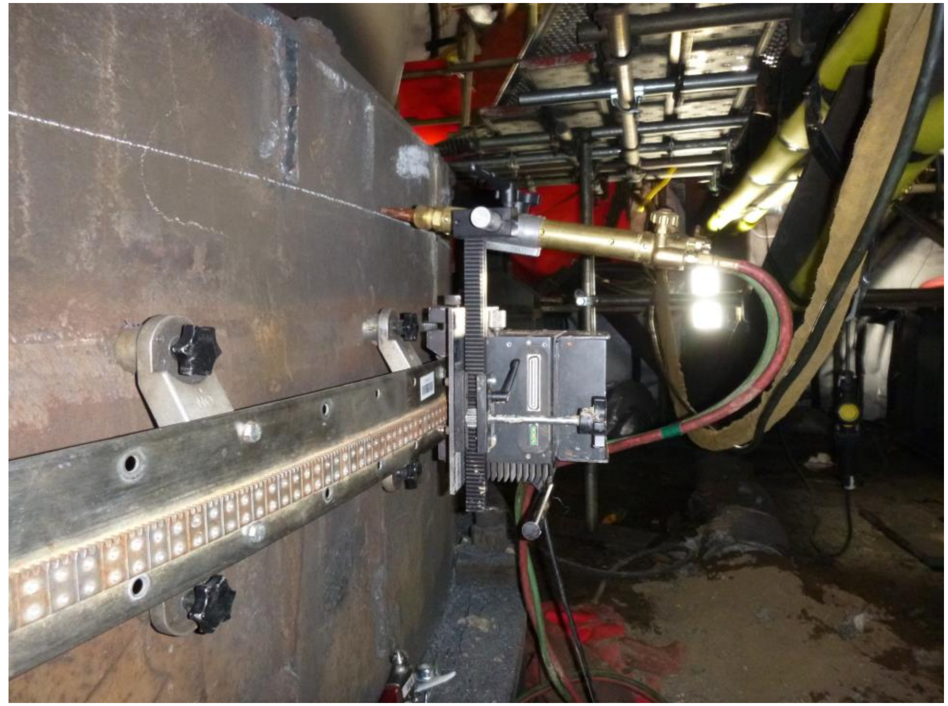


VERTICAL 1¼ CR TO 1¼ CR WELD PREP DETAIL FOR NEW SECTION TO NEW SECTION
SCALE 1:2

REPAIR SEQUENCE - CONE REPAIRS

1. 12(off) new skirt sections fabricated off-site.
2. Resistance heat pads installed on the inside of the drum.
3. Air-arc gouge existing skirt “window” sections (3 per drum). Pre-heat: 50 ° C (120 ° F).
4. Grind / gouge existing cone cracks verified with MPI. Pre-heat reduced to 40 ° C (100 ° F).
5. TIG (GTAW) weld repair excavations. Pre-heat to 150 ° C (300 ° F).

REPAIR SEQUENCE - SKIRT PREP



6. Grind flush and repeat MPI.
7. Mark up bottom skirt cut line (Note: this will set the location of the skirt-to-cone attachment weld*). Cut line is referenced from the concrete octagon.
8. Automated Oxy-Acetylene used to cut bottom skirt at 15° prep angle.

* Due to the skirt buckling the cone circumferential weld was out (vertically) by 1” over the diameter on one of the drums.

REPAIR SEQUENCE - SKIRT FIT UP

9. Install replacement skirt sections with backing strip, tack welding and "dogging" in the skirt as needed to achieve acceptable fit-up; 3 mm (1/8") or less. Due to the skirt only being 19 mm (3/4") thick, this was achievable in conjunction with the cone being reasonably round resulting in an average gap of 1.6 mm (1/16").

REPAIR SEQUENCE - TIG WELD

10. TIG (GTAW) attachment weld to a height of 15mm (check with gauge). MPI and PAUT (external) after reducing pre-heat.

REPAIR SEQUENCE – DISSIMILAR WELD

11. Temper-bead MIG (GMAW) skirt-to-skirt dissimilar weld. Pre-heat to 150 ° C (300 ° F).

12. Air-arc gouge remaining skirt window sections. *Note: Drum is now sitting on a 15mm weld over half its circumference!*

13. Install remaining new skirt sections in the same way as the first sections.

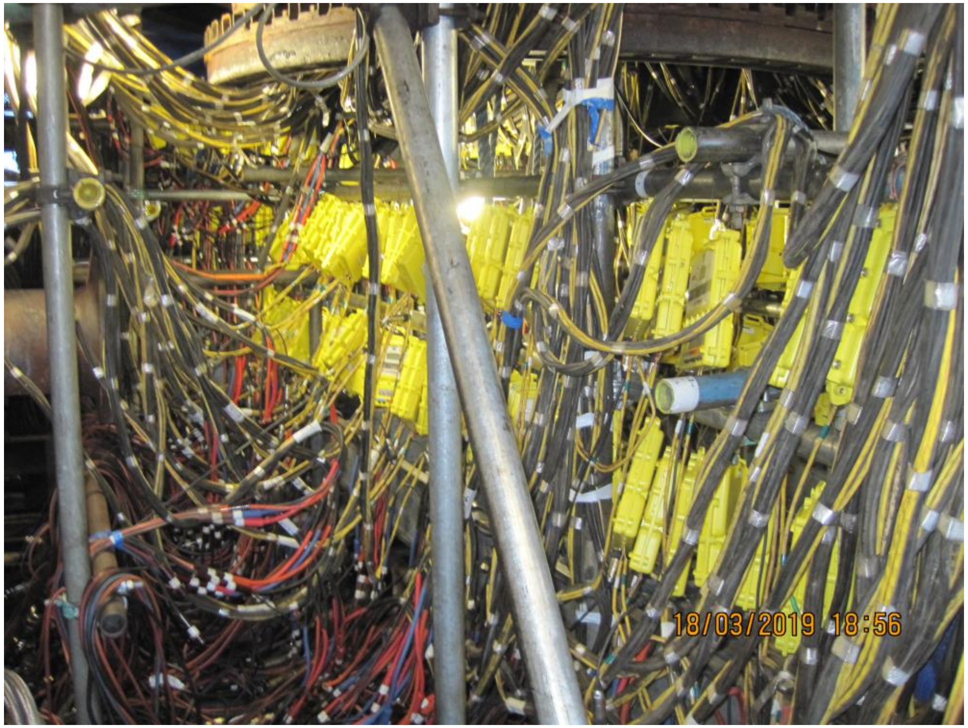
REPAIR SEQUENCE – AUTOMATED MIG WELD

14. TIG (GTAW) weld “tee sections” to approx. 6” down the vertical weld area.
15. Fill and cap attachment weld using automated MIG (GMAW-P).

REPAIR SEQUENCE – VERT'S & PROFILING

16. Temper-bead MIG (GMAW) weld skirt-vertical welds.
17. Grind and polish attachment weld.

REPAIR SEQUENCE - PWHT

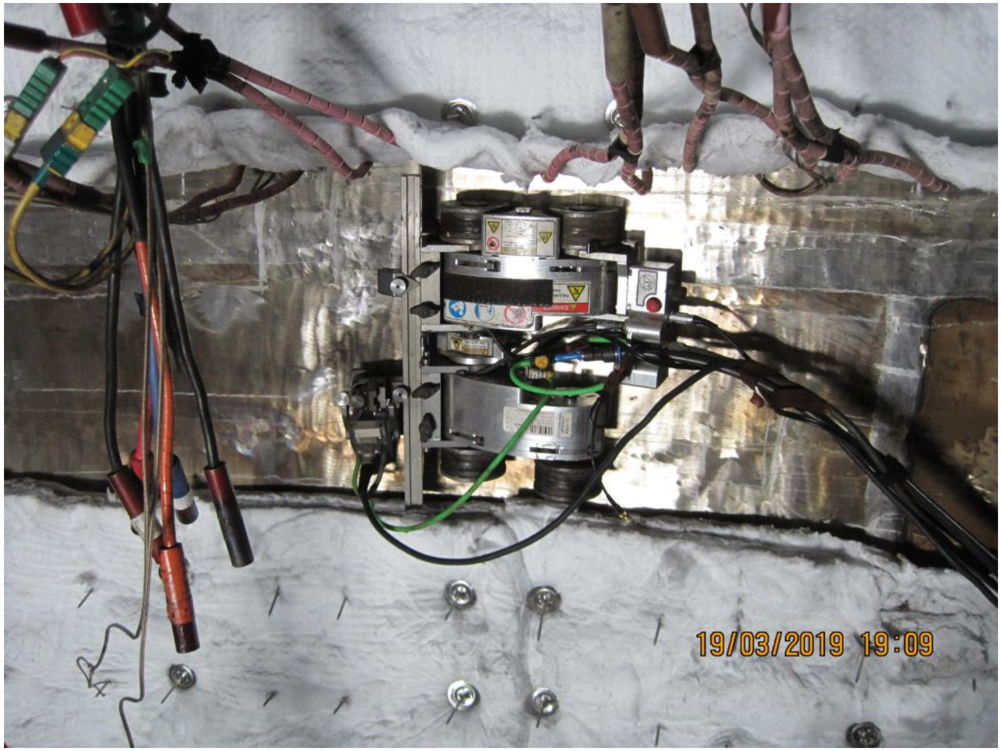


18. MPI all welds.
19. PWHT attachment weld at 690°C (1275°F) for two hours.
20. MPI all welds & PAUT (automated) attachment weld from the inside of drum.
21. PMI all welds
22. Complete QA/QC documentation.

INSPECTION

NDT

- MPI (Mag Particle Inspection) used to detect surface indications.
- PAUT (Phased Array Ultrasonic Testing - manual and automated) used to inspect volumetrically.
- PMI (Positive Material Identification) used to confirm materials through chemical analysis
- Inspection criteria – ASME VIII Div 1
- Controlled through quality plan & P66 supplied inspection resources
- 24 hour delayed cracking inspection (automated PAUT)



Automated PAUT from inside the drum post PWHT

REPAIRS

Weld location	Schedule	NDT method	Findings	Remediation
Skirt-to-shell attachment weld	Prior to welding	MPI	2 indications, max 3mm deep.	Ground out.
Skirt-to-shell attachment weld	After TIG welding 1st weld.	MPI	2 indications, 1mm deep (HAZ region).	Ground out.
Skirt-to-shell attachment weld	After TIG welding 1st weld.	Manual PAUT (external) Note: it was extremally difficult to see the root.	i. Intermittent lack of fusion at weld toe (800mm long). ii. 80mm lack of fusion 2mm below weld cap.	i. Ground out and will be re-welded with fill and cap welds. ii. Ground out, re-welded and re-examined.
Skirt-to-skirt weld	Before PWHT	MPI	Linear indications. Max depth 8mm.	Ground out, re-welded and re-examined.
Vertical welds	Before PWHT	MPI	i. Indications < 2mm deep. ii. Indications >2mm deep (Max 15mm deep). iii. One vertical weld was rejected.	i. Ground out. ii. Ground out, re-welded and re-examined. iii. Fully excavated, re-welded and re-examined.
Skirt-to-shell attachment weld	Before PWHT	MPI	Linear indications. Max depth 1.5mm.	Ground out.
All welds	After PWHT	MPI	Attachment weld and tee sections clear of all indications. All other indications assessed as lack of fusion (no evidence of cracking). All indications to be monitored.	
Skirt-to-shell attachment weld	After PWHT	Automated PAUT (internal)	No cracking into cone. Linear indications (lack of fusion) were noted in the TIG/MIG interface (both drums) and a single lack of fusion indication at the TIG root. All indications will be monitored.	

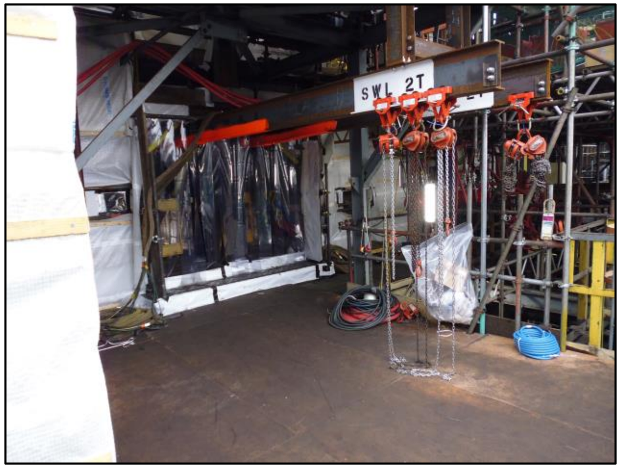
SKIRT REPLACEMENT FACTS & FIGURES

- No injuries, on time, on budget.
- Total duration: 21 days from fist cut through to final inspection.
- PWHT used 5.5 Mega Watts of electrical energy.
- Number of repairs (requiring re-welding): 5
- Number of men (welding contractor): 45
- Total man hours (welding contractor): 9950

CRITICAL STEPS

- FEA analysis
    1. Demonstrate buckled skirt is stable after first 50% of skirt is removed.
    2. Brittle fracture check on existing skirt segments due to cone cracking.
    3. New skirt optimisation.
    4. Design of PWHT as skirt is not being unbolted.
- Sound weld design including prep' angles and prove with a mock-up.
- No air-arc gouging without pre-heat.
- Mark up bottom horizontal cut line accounting for skirt bulging and drum lean (cone weld may no longer be co-planer to the support plinth – a laser level helps!)
- Repair of existing cone cracking with high quality welds.
- Skirt life is highly dependant upon fit up. Aim for the smallest gap possible.
- Skirt attachment weld to be made to the highest quality (there are many ways of achieving this!)
- Make good use of accurate volumetric UT methods, especially if you don't plan to make repairs after PWHT!

HELP YOUR CONTRACTOR



- Provide clean, enclosed workspace with active ventilation and safe access/egress.
- New skirts were floated in on bespoke “run-way” beams which allowed for precise alignment.
- Temporary “tent” constructed to keep PPE, permits and welding consumables dry.
- Viewing windows installed to monitor progress without having to enter the space where grinding & welding were taking place.
- Scaffold platforms constructed to store PWHT equipment and route cables & air hoses.
- Entire area treated as a “confined space” with 24 hour hole/fire watchers.
- All personnel fitted with 4-way gas monitors.
- Welding contractor used air-fed hoods during grinding, air-arcing and welding activities.