Bulging Assessment of Coke Drums

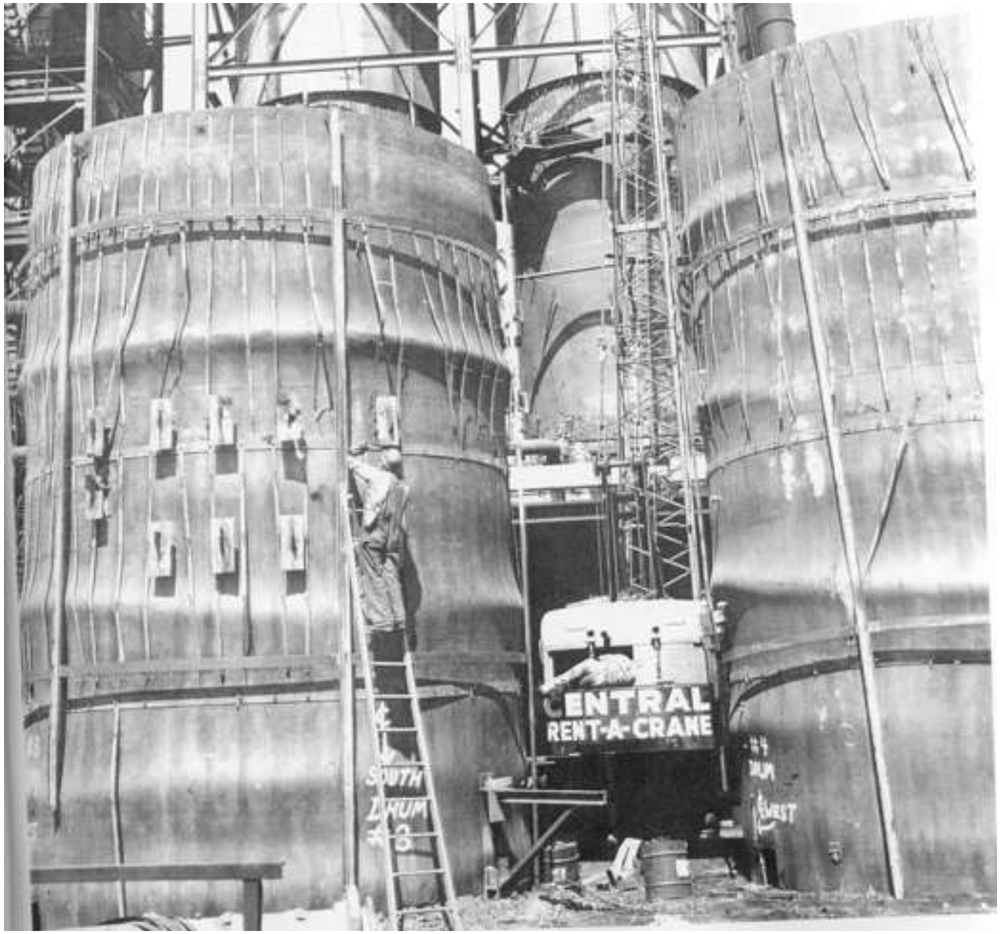
Mahmod Samman, Ph.D., P.E.
Houston Engineering Solutions
(832) 512-0109
mms@hes.us.com

Ediberto B. Tinoco
Fábio C. Marangone
Hezio R. Silva
Petrobras, Brazil

Coking.com Conference
Galveston, TX
May 2013

Introduction

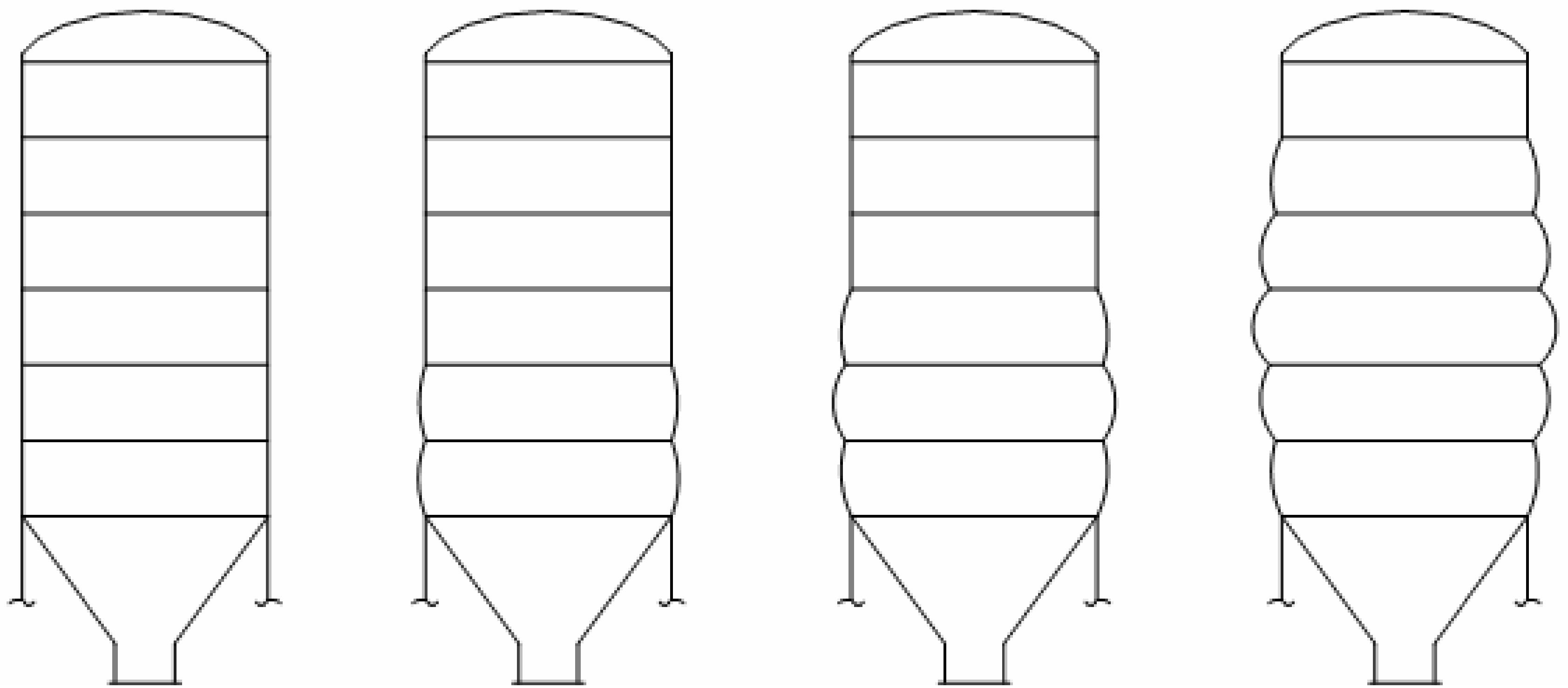
- Very common.
- Known for decades.
- Potential serious consequences.
- Premature drum replacement.
- Despite design improvements, still a problem.



Courtesy of CB&I

Historical Bulging Pattern

Weil and Rapasky paper (1958): The constrained balloon.

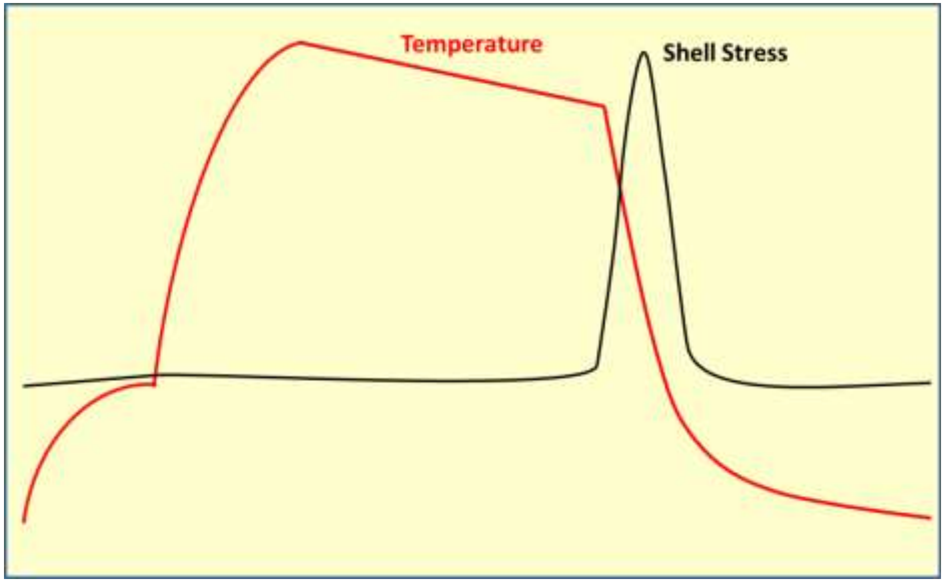


Consequences of Bulging

- PRIMARY: Excessive strain
- SECONDARY: Increase in nominal stress
- Leaks and fires

Possible Causes of Bulging

- Progressive non-uniform radial growth.
- Radial growth:
  - Quench stress.
  - Strength of base metal.
  - Type of feed.
- Non-uniform:
  - Mismatch.
  - Imperfections.
  - Side inlet.
  - Random channeling.
  - Local post weld heat treatment (PWHT)
- Progressive (ratcheting)



Shell Cracks

- Bulging-induced cracks
- Weld cracks
- Combination

Bulging-Induced Cracks

Bulging Assessment per API-579 / ASME-FFS

- Level 1: N/A to coke drums
  - Fabrication tolerance.
  - Not for cyclic service.
- Level 2: N/A to coke drums
  - **Stress analysis criterion removed** after 2001 Edition. **No replacement yet**.
- Level 3: Infeasible and costly process
  - Lack of proper load definition.
  - Costly to obtain data.
  - Prohibitive to simulate bulging.
  - Research work.

Industry Practice

- Stress analysis
- Geometric analysis
- Strain analysis

Stress Analysis

- High stress concentration correlates with severity.
- Linear elastic finite element analysis.
- Drum is built with bulges (no plastic strain).
- Apply design / unit loads.
- Advantages
  - Simple
- Disadvantages
  - Unrealistic model.
  - Susceptible to several error sources (e.g. ovality, bulge shape, ..)
  - Excludes primary cause of bulging failure.

Strain Analysis

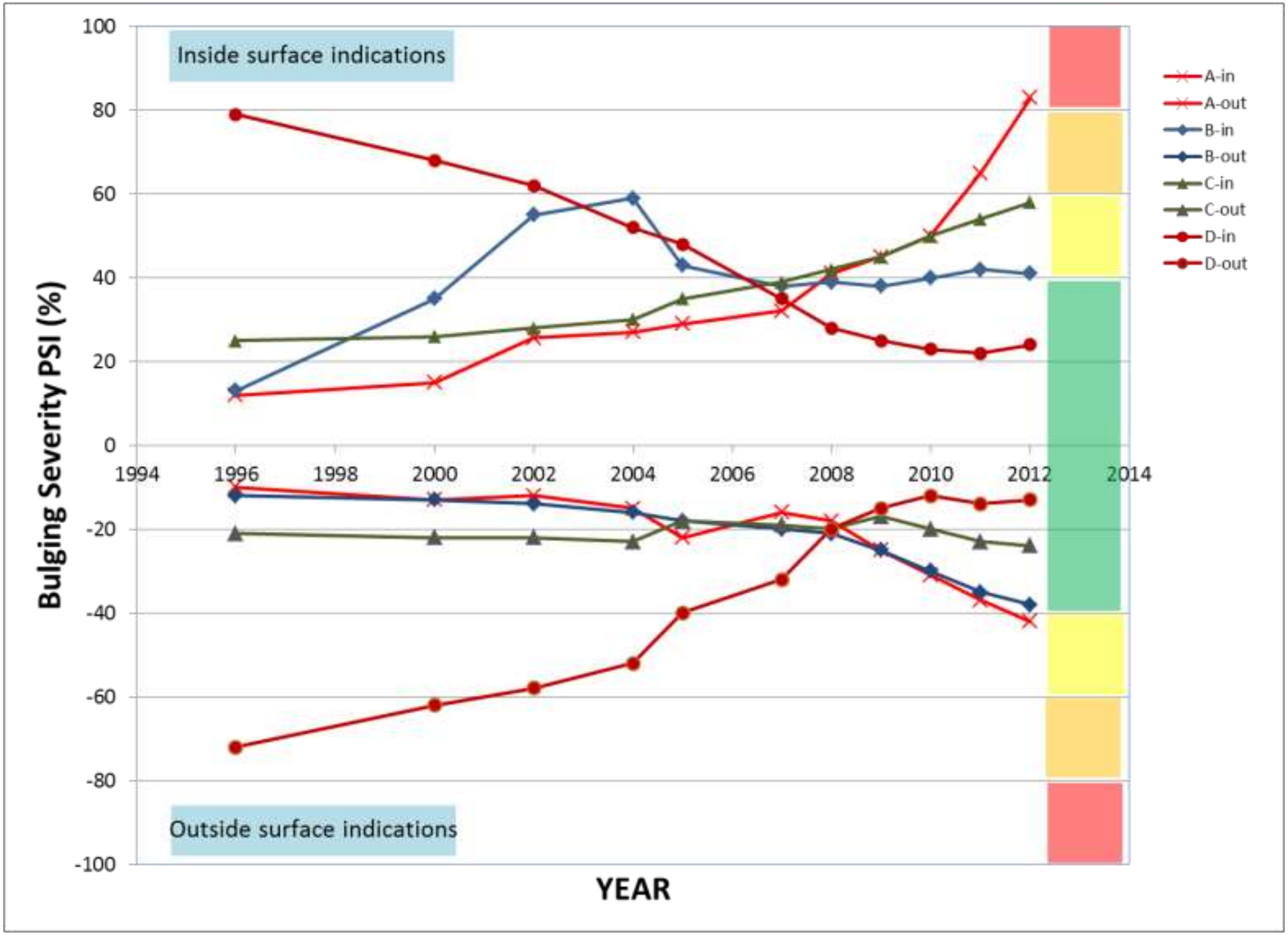
- High strain correlates with severity.
- Plastic Strain Index (PSI)™ uses failure limit of API 579/ ASME FFS
- Advantages:
  – Focuses on primary mode of failure.
  – Excellent correlation with bulging cracks.
  – Uses failure limits of industry standard.
- Disadvantages:
  – Relatively new.

PSI Analysis

- Four-tier severity system: Design, Concern, Danger, and Failure.
- Used to determine likelihood of bulging-induced cracking and frequency of laser scanning.
- Can be used for other pressure vessels with bulges of similar failure modes.

PSI magnitude	Severity Grade	Likelihood of Bulging-Induced Cracks	Recommended Frequency of Laser Scanning
80% to 100%	Failure	Likely	6 months to 1 year
60% to 80%	Danger	Probable	1 year
40% to 60%	Concern	Possible	1 to 2 years
0 to 40%	Design	Unlikely	2 to 3 years

PSI Trending

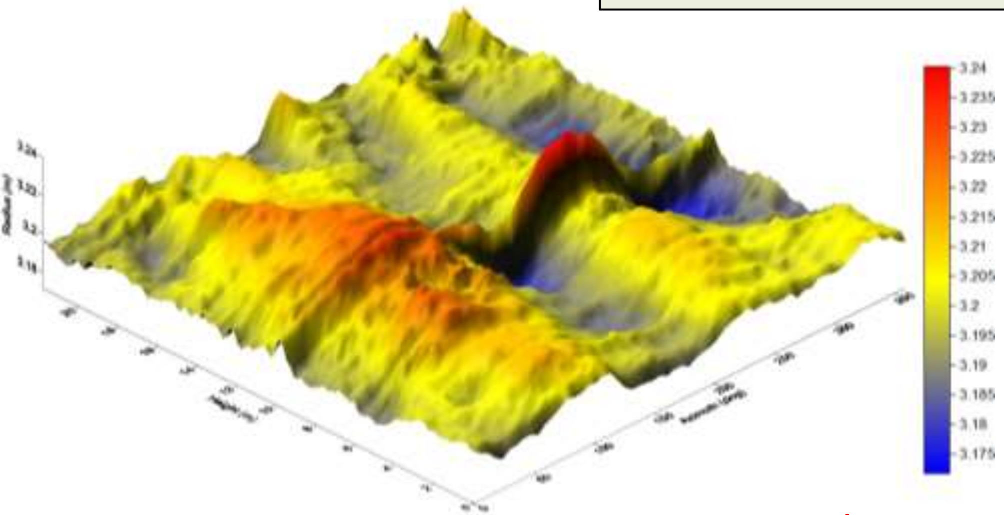


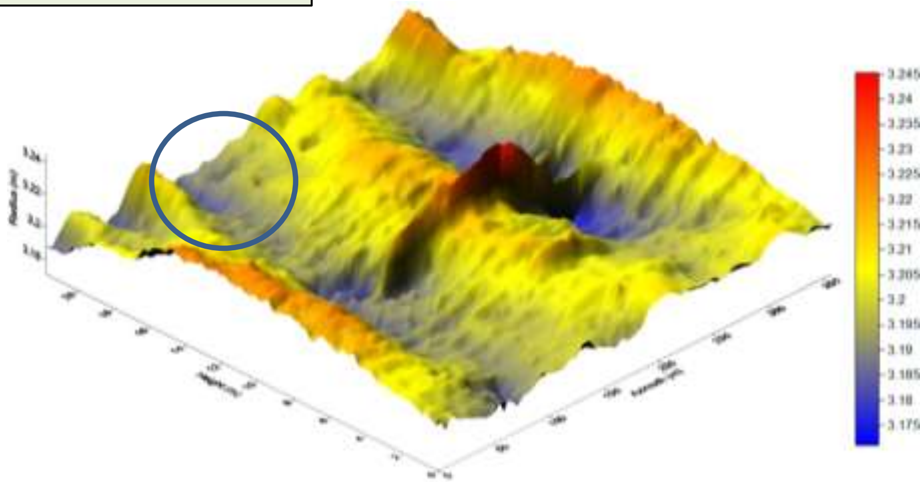
Case Study

- Four sister drums commissioned in 1994.
- Inside diameter: 6.400 meters (21 ft).
- Tangent-to-tangent length: 22.6 meters (74 ft)
- Material: 1Cr - 1/2Mo with stainless steel clad (SA-240 TP405).
- Variable wall thickness: 12.5 to 25 mm (0.492 to 0.984 inch) with 3 mm clad.
- Nominal 48 hour full cycles (24 hour fill).
- Compare stress and strain analysis techniques.

Radius Map

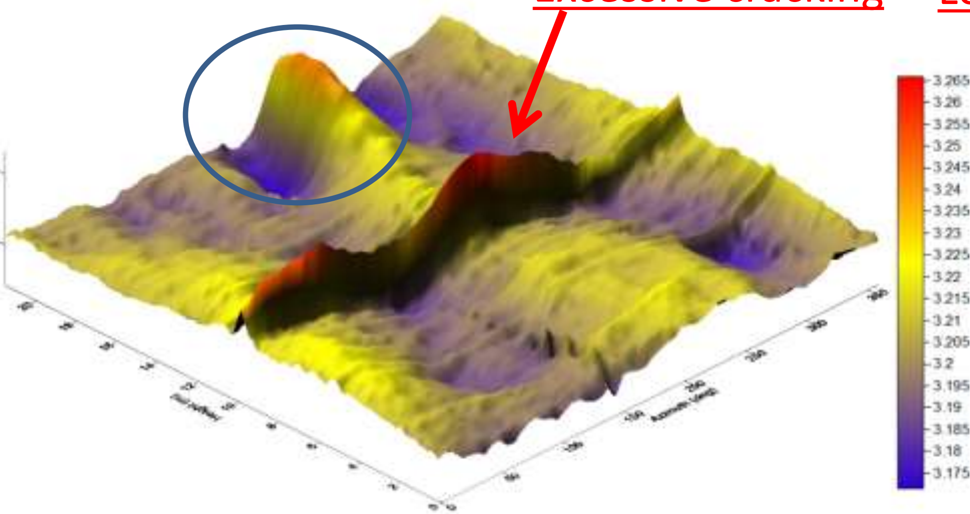
Various degrees of ovality circled

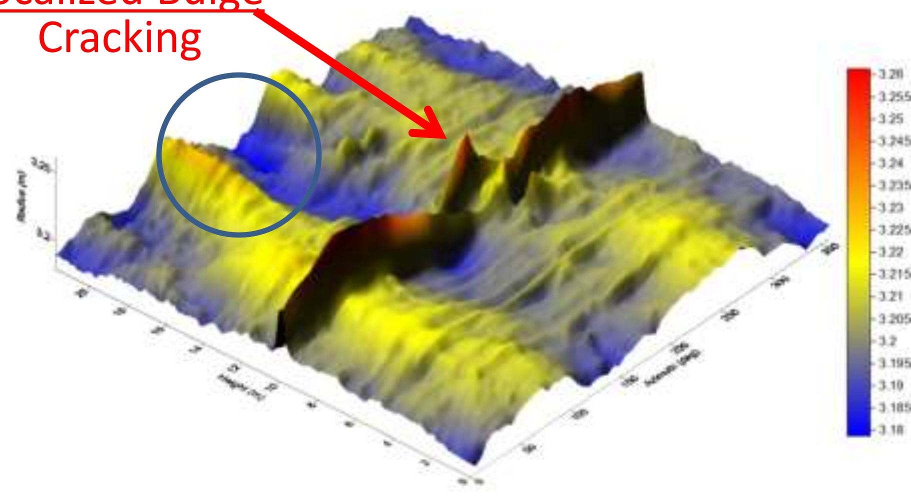




Excessive cracking

Localized Bulge
Cracking

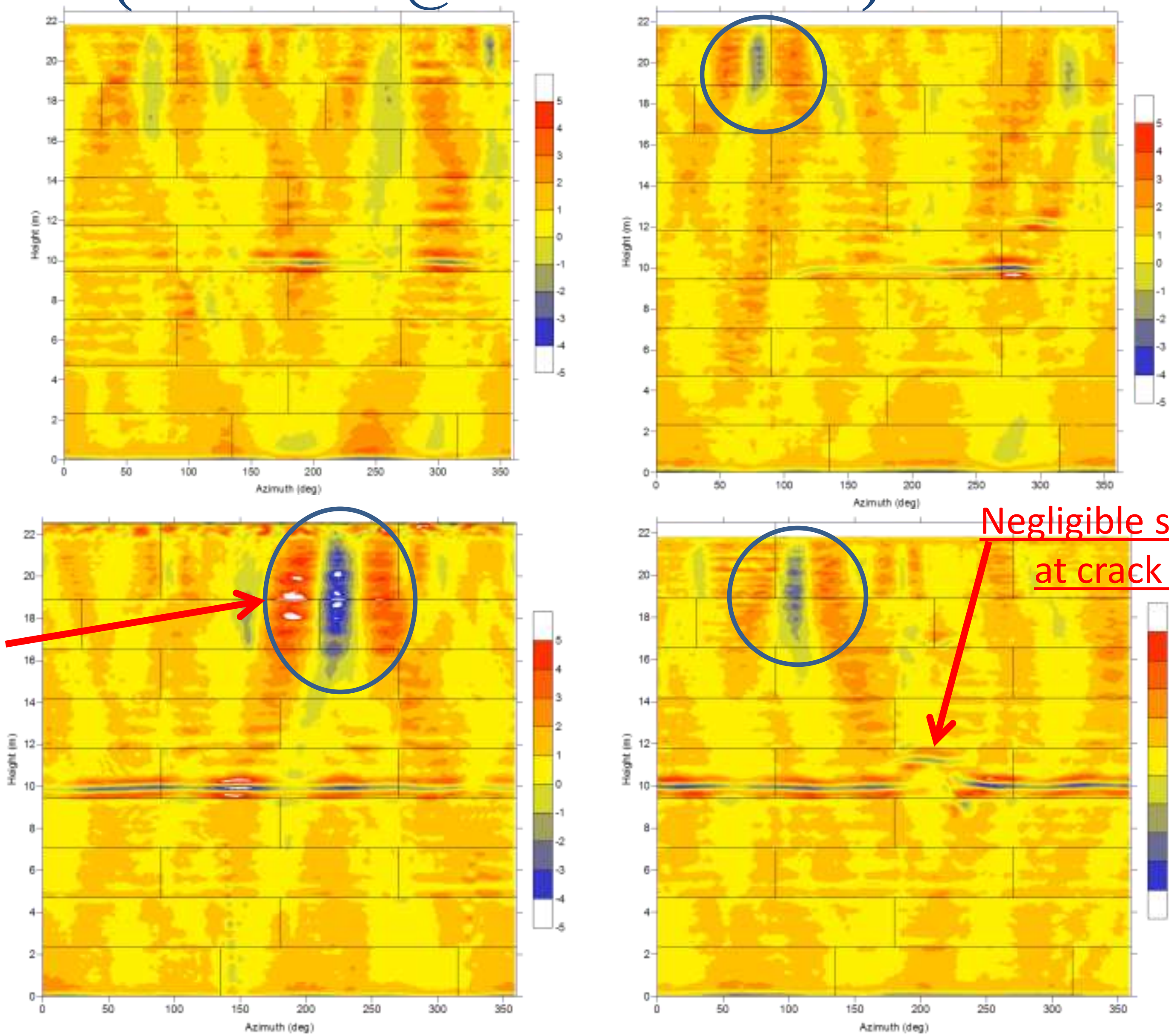




Stress Concentration Factor

(axial SCF @ outside surface)

Ovality-based High stress concentrations highlighted



Stress Concentration Factor
(Summary)

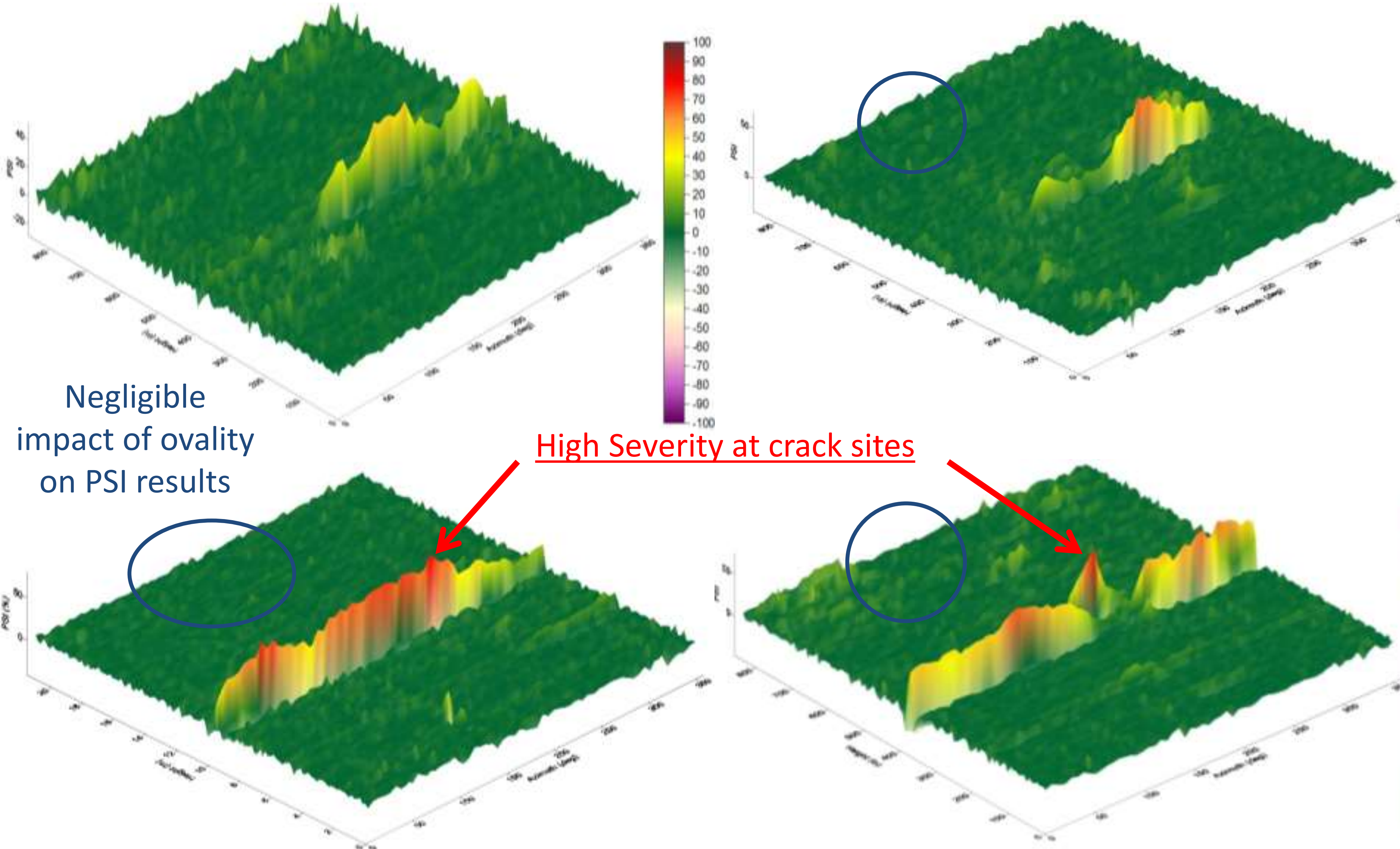
Axial Stress - Inside Surface		
Drum	Max Positive	Max Negative
A	5.7	-2.4
B	6.7	-3.6
C	7.8	-3.5
D	6.4	-3.8

Hoop Stress - Inside Surface		
Drum	Max Positive	Max Negative
A	4.2	-1.0
B	3.1	-0.6
C	4.0	-2.1
D	3.9	-0.7

Axial Stress - Outside Surface		
Drum	Max Positive	Max Negative
A	5.0	-3.2
B	5.6	-3.8
C	8.8	-5.2
D	5.4	-3.9

Hoop Stress - Outside Surface		
Drum	Max Positive	Max Negative
A	3.0	-2.2
B	3.0	-1.0
C	4.1	-2.1
D	2.7	-1.8

Plastic Strain Index (PSI)



Plastic Strain Index (PSI)
(Summary)

Drum	A	B	C	D
Maximum PSI (inside surface)	+51.5%	+67.0%	+80.8%	+76.1%
Minimum PSI (outside surface)	-28.0%	-33.2%	-41.0%	-47.3%
Surface of highest severity	inside	inside	inside	inside
Severity level	Concern	Danger	Failure	Danger

Conclusions from Case Study

- Stress and strain analysis techniques produce significantly different results.
- Stress analysis appeared to be susceptible to several error sources such as drum ovality and bulge shape.
- PSI has correlated well with bulging-induced cracks.

Summary

- Bulging is a common and recurring problem in coke drums that is linked to their design, fabrication, and operation.
- Stress analysis of bulging is based on the assumption that stress concentration is an indication of severity. The method uses unit or design loads to calculate stress concentrations.
- The Plastic Strain Index (PSI) is a strain assessment method based on failure limits of API 579/ ASME FFS.
- An example assessment of four coke drums revealed that:
  - Stress and strain analysis techniques produce significantly different results.
  - Stress analysis appeared to be susceptible to several error sources such as drum ovality and bulge shape.
  - PSI has correlated well with bulging-induced cracks.