Effects of Water Depth Workshop

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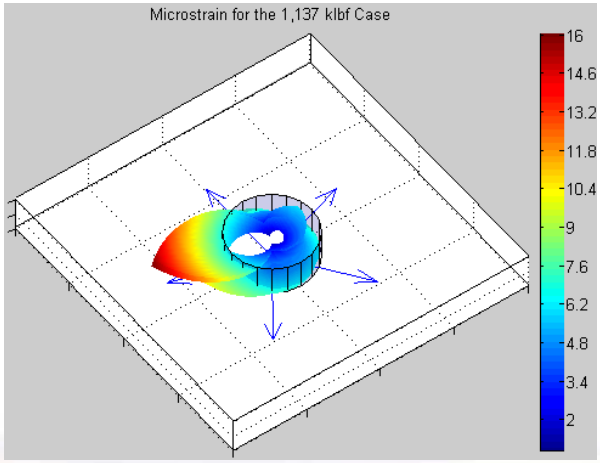
Advanced Tubular Performance Properties



Mike Payne, P.E., Ph.D.
BP

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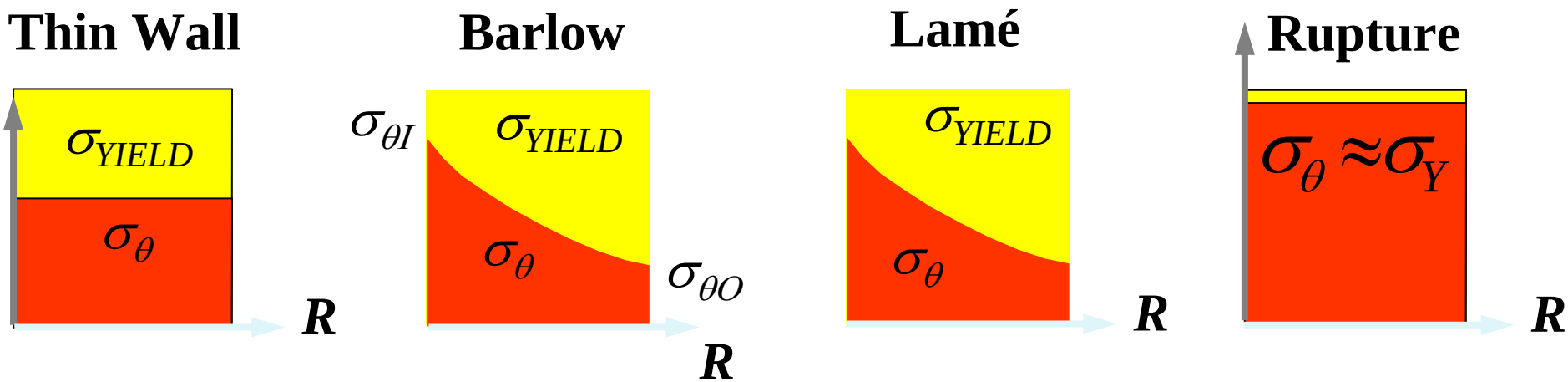
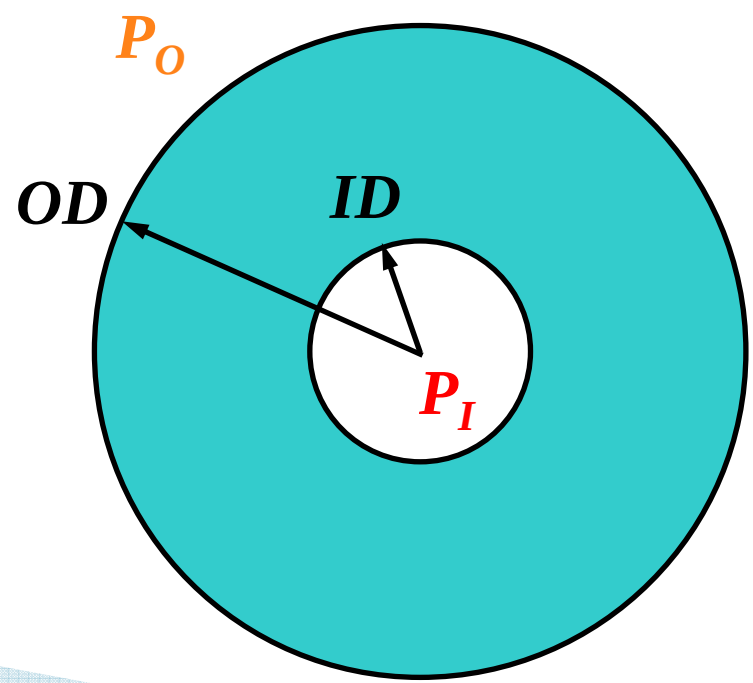
Advanced Tubular Performance Properties - Introduction

- Well Tubulars (Casings, Liners, Tubing) are normally governed by pressure based loads
- Hence, this presentation will focus on advanced treatment of internal pressure ("***Burst***") and external pressure ("*Collapse*") performance properties
- Connection Performance is also important and will be addressed by another speaker
- Other performance properties such as tension, compression, bending, torsion can be discussed but are not addressed in these slides.

Through Wall Pipe Stress Distributions

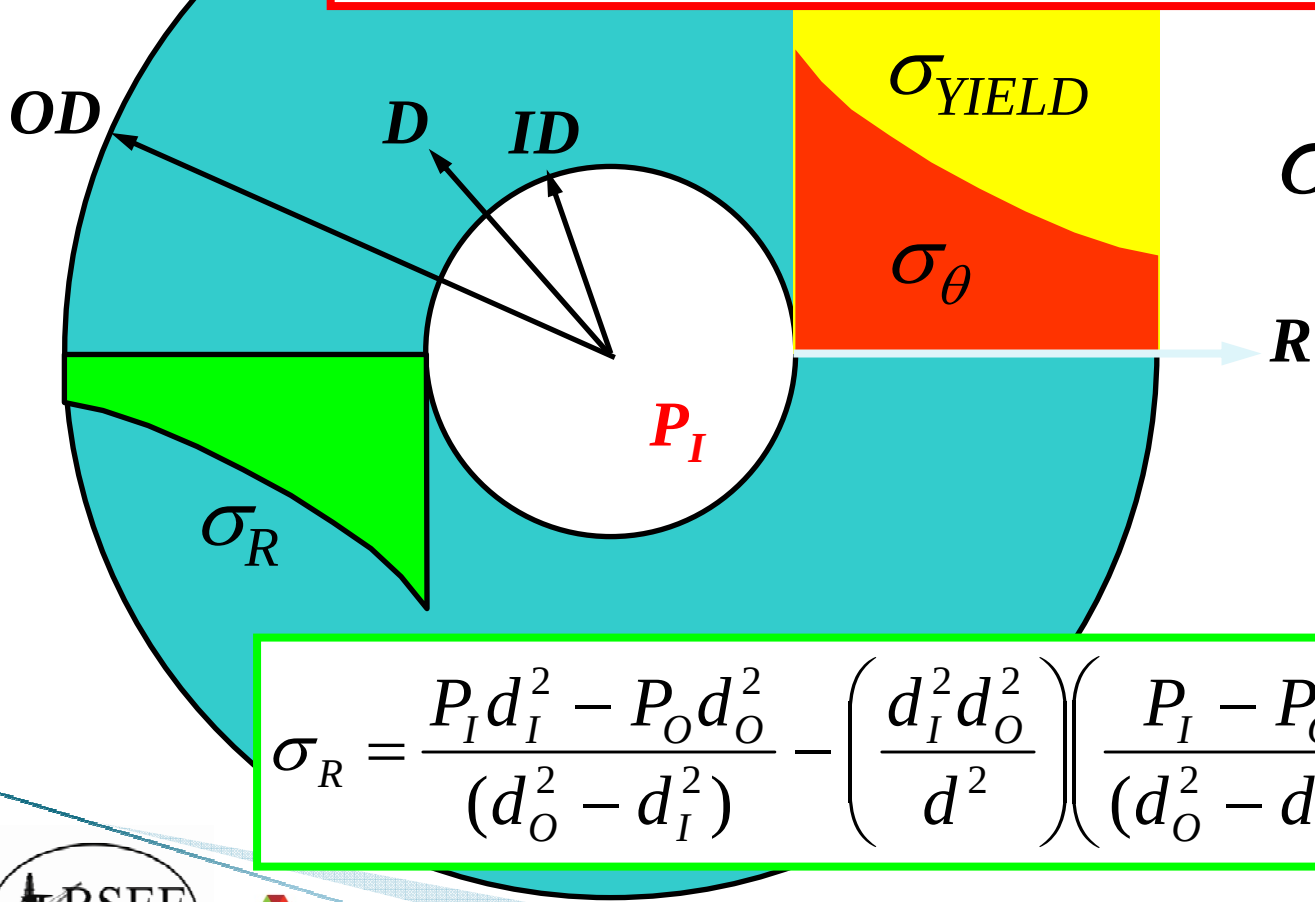


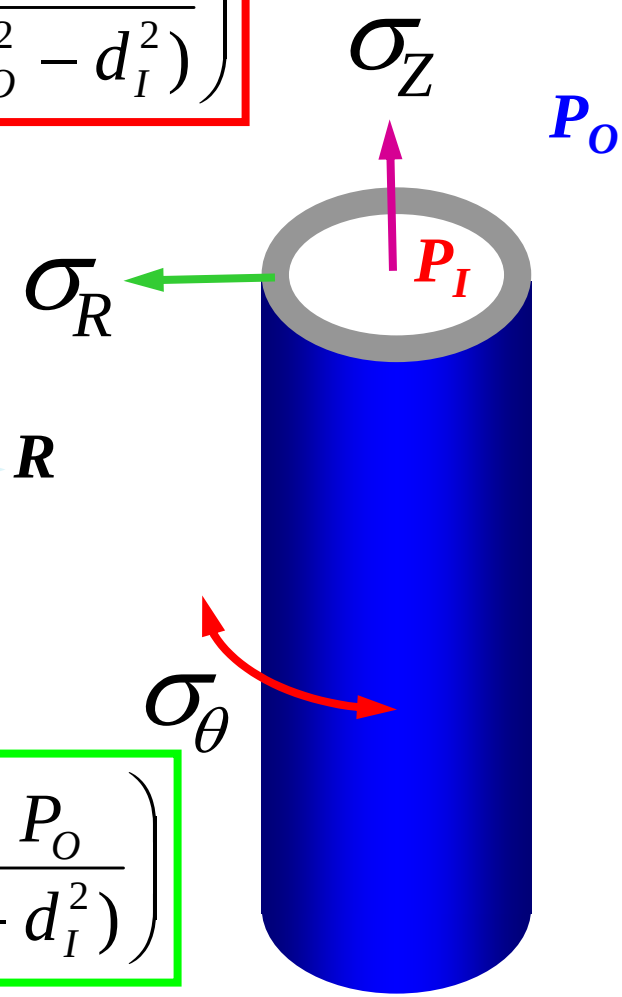
$$P_{YIELD} = \frac{2\sigma_{YIELD}(t)}{OD}$$



Thick Wall - Radial & Hoop Stress

$$\sigma_\theta = \frac{P_I d_I^2 - P_O d_O^2}{(d_O^2 - d_I^2)} + \left(\frac{d_I^2 d_O^2}{d^2}\right)\left(\frac{P_I - P_O}{(d_O^2 - d_I^2)}\right)$$





$$\sigma_R = \frac{P_I d_I^2 - P_O d_O^2}{(d_O^2 - d_I^2)} - \left(\frac{d_I^2 d_O^2}{d^2}\right)\left(\frac{P_I - P_O}{(d_O^2 - d_I^2)}\right)$$

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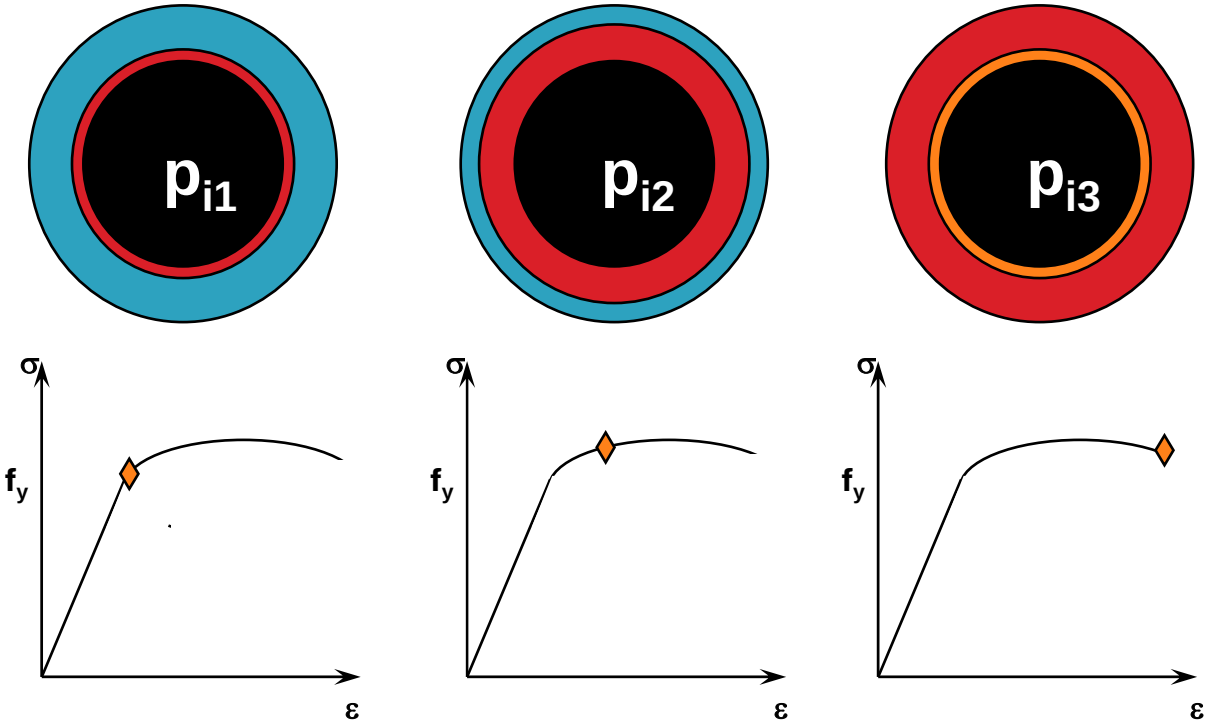
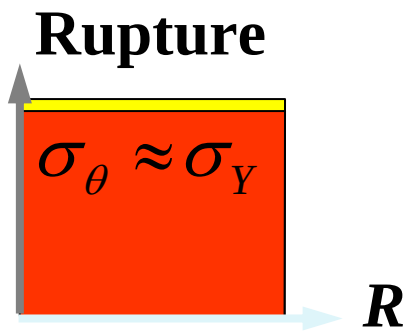
Progressive Burst (Initial yield to Ultimate Rupture)



Theoretical Rupture – Numerous Models

$$P_{Rupture} = (U_S)\ln\left(\frac{OD}{ID}\right)$$



Notes:
(1) nominal ultimate strength (U_S) (psi)
(2) nominal outer diameter (OD) (inches)
(3) nominal inner diameter (ID) (inches)
(4) estimated accuracy is ± 5%

Rupture Formulas
Shown Under Capped End Conditions

Shell - Klever-Stewart

$$P_B = \left[\left(\frac{1}{2} \right)^{1+n} + \left(\frac{1}{\sqrt{3}} \right)^{1+n} \right] UTS \frac{2\, t_{\min}}{OD - t_{\min}}$$

Shell - Paslay

$$P_B = UTS \frac{2\, t_{\min}}{OD - t_{\min}}$$

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API TR 5C3 - Pipe Rupture Test Data

Six Burst Data Sets
112 data points

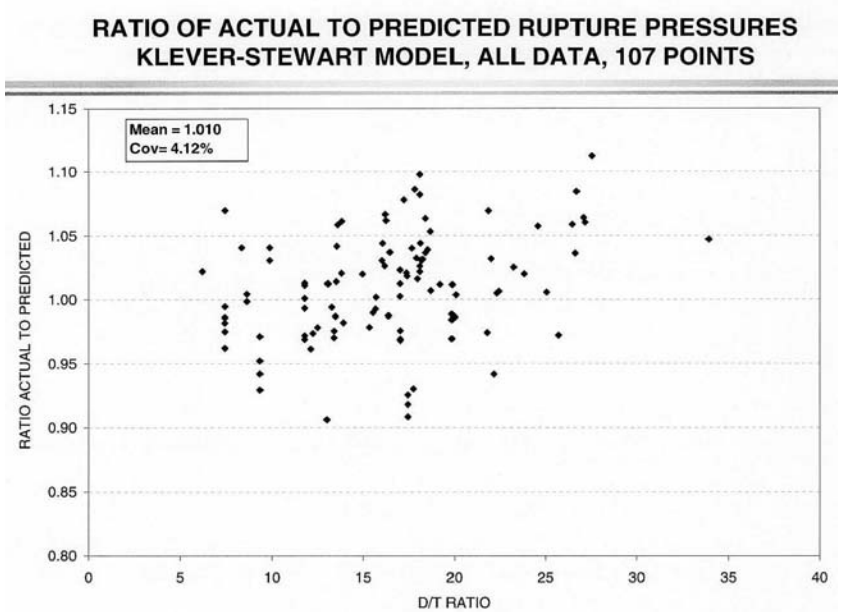
Measured Wall

- Shell Btest1
- Hydril Measured Wall
- Shell Super Duplex
- Shell Not-Worn

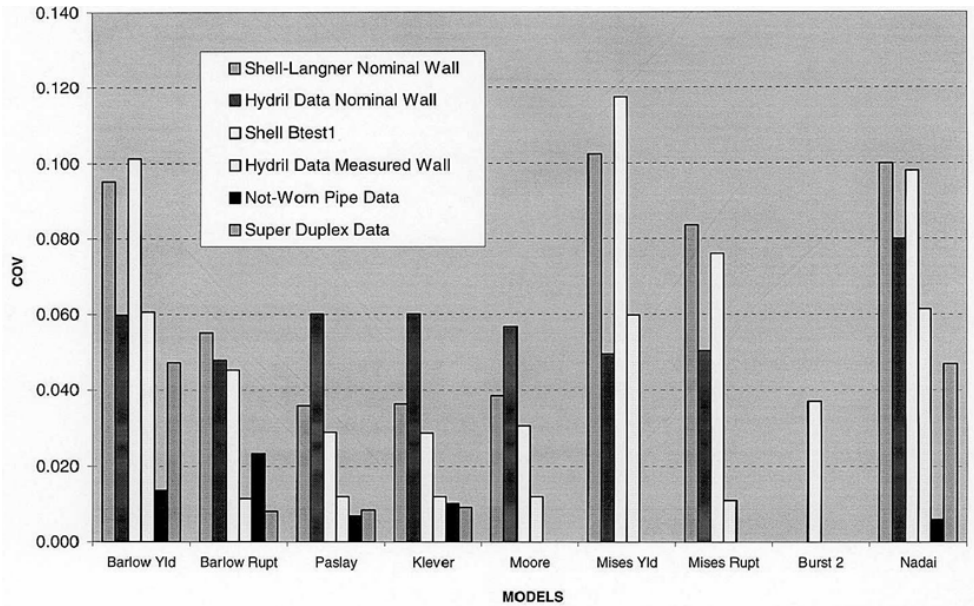
Nominal Wall

- Shell Lagner
- Hydril Nominal

Rupture Model Fits to Test Data



	Means of data sets				
	Barlow Yld	Barlow Rupt	Paslay	Klever	Nadai
	1.493	1.071	0.973	0.991	1.172
	1.223	1.092	1.010	0.997	0.978
	1.303	1.125	1.042	1.014	1.043
	1.329	1.150	1.086	1.046	1.086
	1.246	1.075	1.021	0.979	1.003
	1.270	0.990	0.940	0.982	1.044
Mean of means	**1.311**	**1.084**	**1.012**	**1.001**	**1.054**
Stdev of means	**0.097**	**0.055**	**0.051**	**0.025**	**0.069**
COV of means	**0.074**	**0.051**	**0.051**	**0.025**	**0.065**



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API MIYP Barlow Rating vs. Actual Rupture Performance

Example Project - Candidate Tubulars
Performance Properties for Internal Pressure

OD (inches)	Weight (ppf)	Wall (inches)	Grade	Burst Ratings (psi)			Δ (%)	
				API MIYP	Shell-Paslay	Stewart-Klever	Shell-Paslay	Stewart-Klever
22.000	222.28	1.000	X-60	4,770	7,140	7,150	50%	50%
18.000	93.54	0.500	L-80	3,890	5,430	5,500	40%	41%
16.000	84.00	0.495	L-80	4,330	6,070	6,140	40%	42%
13.625	88.20	0.625	SM-125TT	10,030	12,980	13,390	29%	33%
13.375	72.00	0.514	SM-125TT	8,410	10,790	11,130	28%	32%
11.750	65.00	0.534	Q-125	9,940	12,850	13,260	29%	33%
10.750	73.20	0.672	SM-125S	13,670	18,000	18,580	32%	36%
10.000	68.70	0.688	SM-125S	15,050	19,950	20,580	33%	37%
7.625	29.70	0.375	Q-125	10,760	13,970	14,410	30%	34%
5.500	29.70	0.562	SM13CrS110	19,670	28,450	29,180	45%	48%

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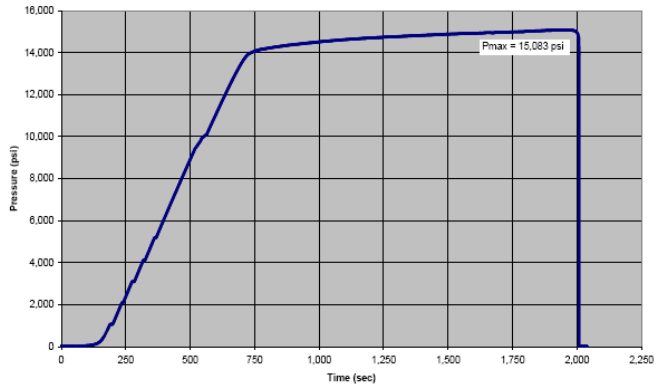
Advanced Tubular Performance Properties – Macondo Tests

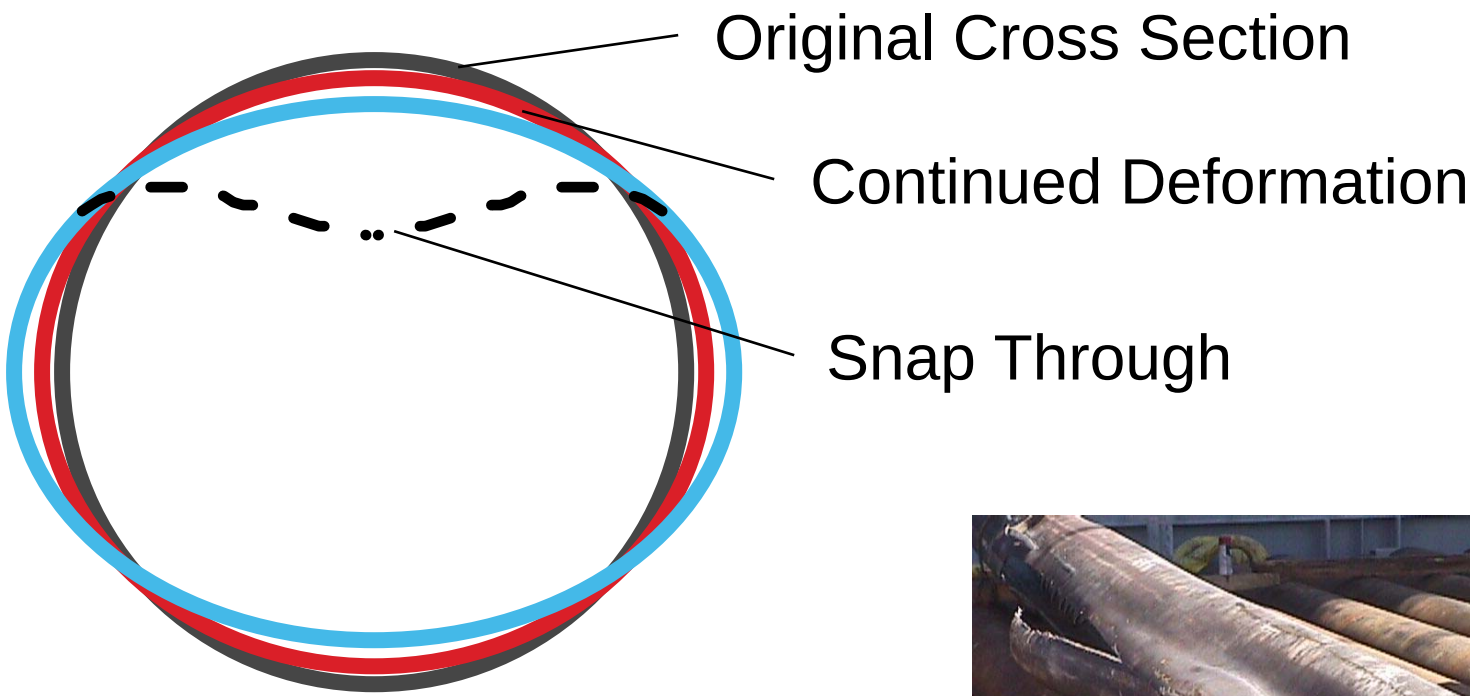
TEST REPORT
IR 379: 13-5/8" 88.2# Q-125HC
Rupture Testing on BP Macondo Relief Well
Revision 00
5/26/2010



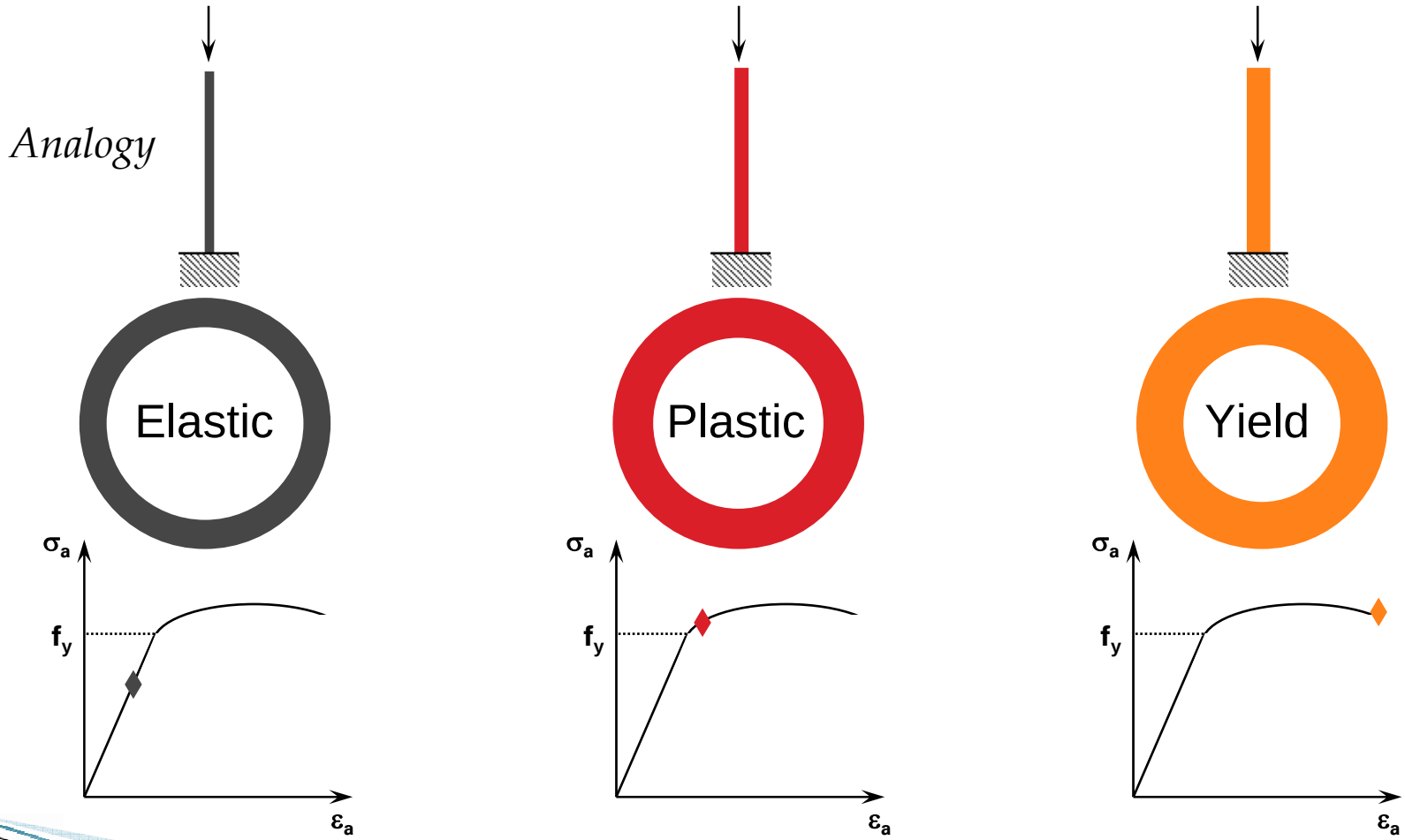
Specimen Number	Rupture Pressure (psi)	Approximate Yield Pressure (psi)
Sample 1 – VAM SLIJ-II	14,861	13,850
Sample 2 – Pipe Body	15,083	14,000
Sample 3 – Pipe Body	15,124	14,150
Sample 4 – Pipe Body	15,313	14,325
Sample 5 – Pipe Body	15,251	14,300
Sample 6 – Pipe Body	15,130	14,200
Sample 7 – Pipe Body	15,313	14,450
Sample 8 – Pipe Body	15,291	14,250
Sample 9 – Pipe Body	15,207	14,100
Sample 10 – Pipe Body	15,171	14,050

Table 1: Summary of Rupture Testing Maximum Pressure

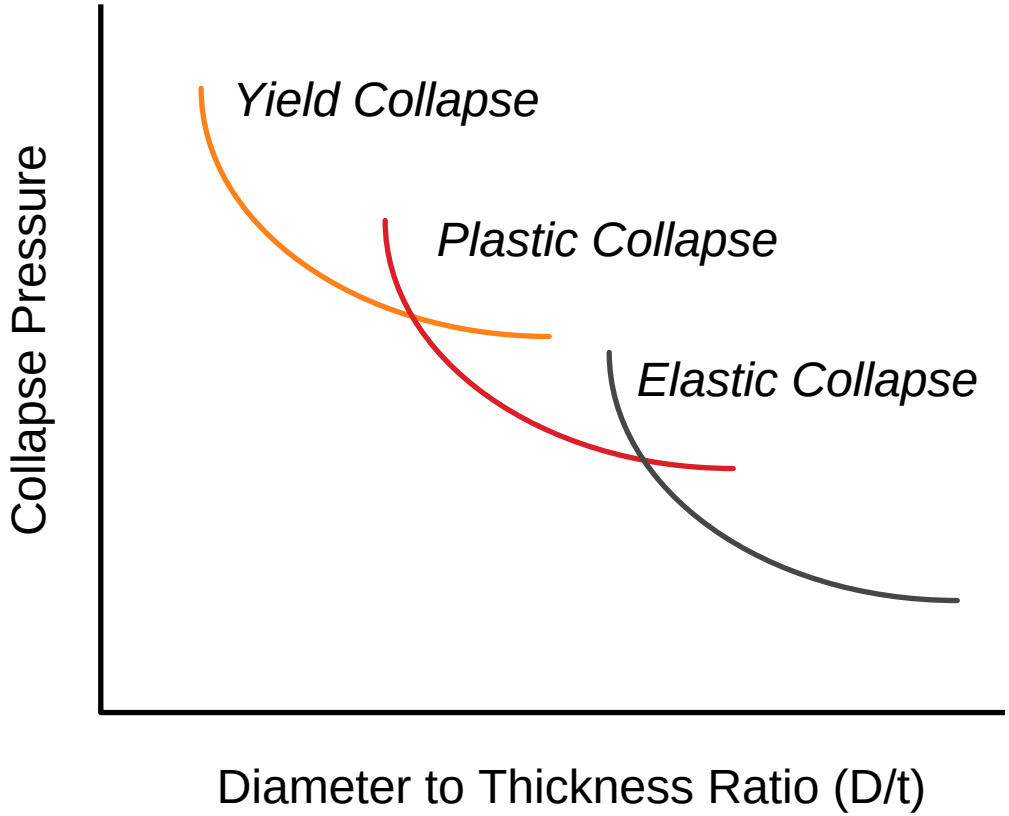
Collapse


Original Cross Section
Continued Deformation
Snap Through

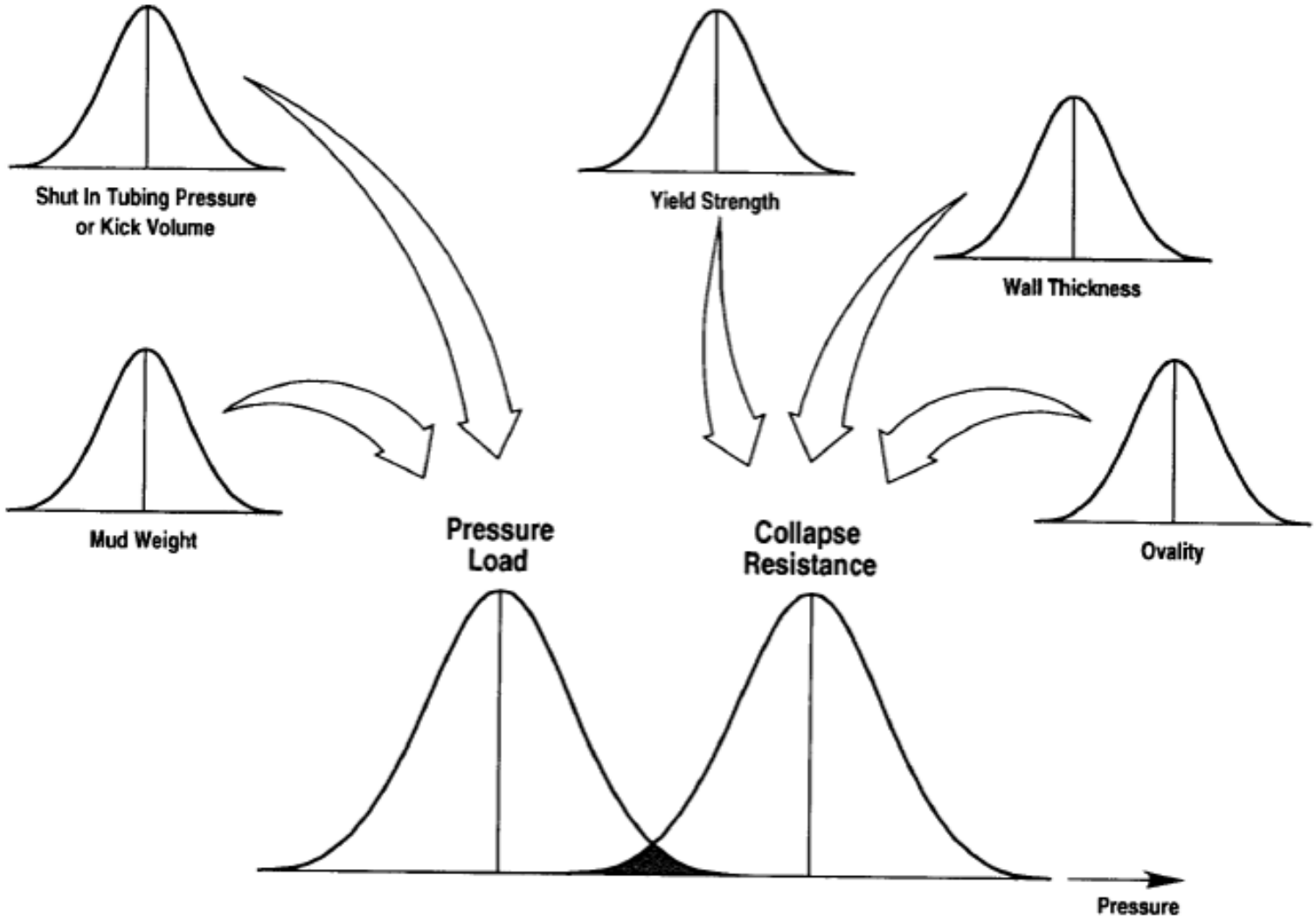
Collapse modes



Lowest collapse pressure governs



Real World is Stochastic not Deterministic



Key Collapse Factors

Influencing factors

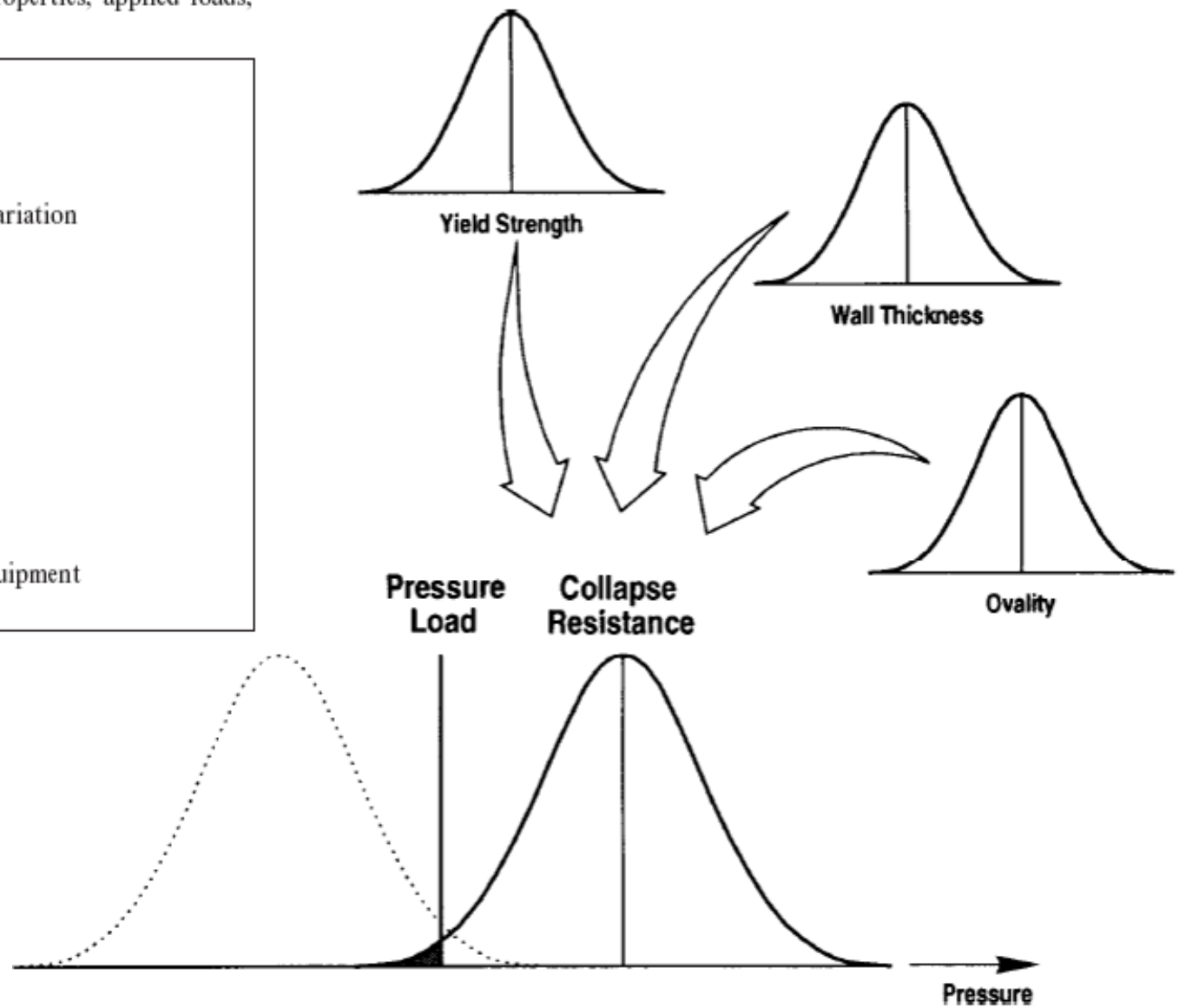
Collapse resistance is influenced by a complex combination of geometrical characteristics, material properties, applied loads, and load conditions:

Geometry
- o Outer Diameter (D)
- o Wall thickness (t)
- o Ovality
- o Eccentricity or wall thickness variation

Mechanical properties
- o Yield strength
- o Young's modulus
- o Stress - Strain curve
- o Residual stress

Applied loads
- o Tension - Compression
- o Bending, Torsion,…

Testing parameters
- o Length / D of tested sample
- o Parasite loads due to testing equipment
- o Pressure gradient



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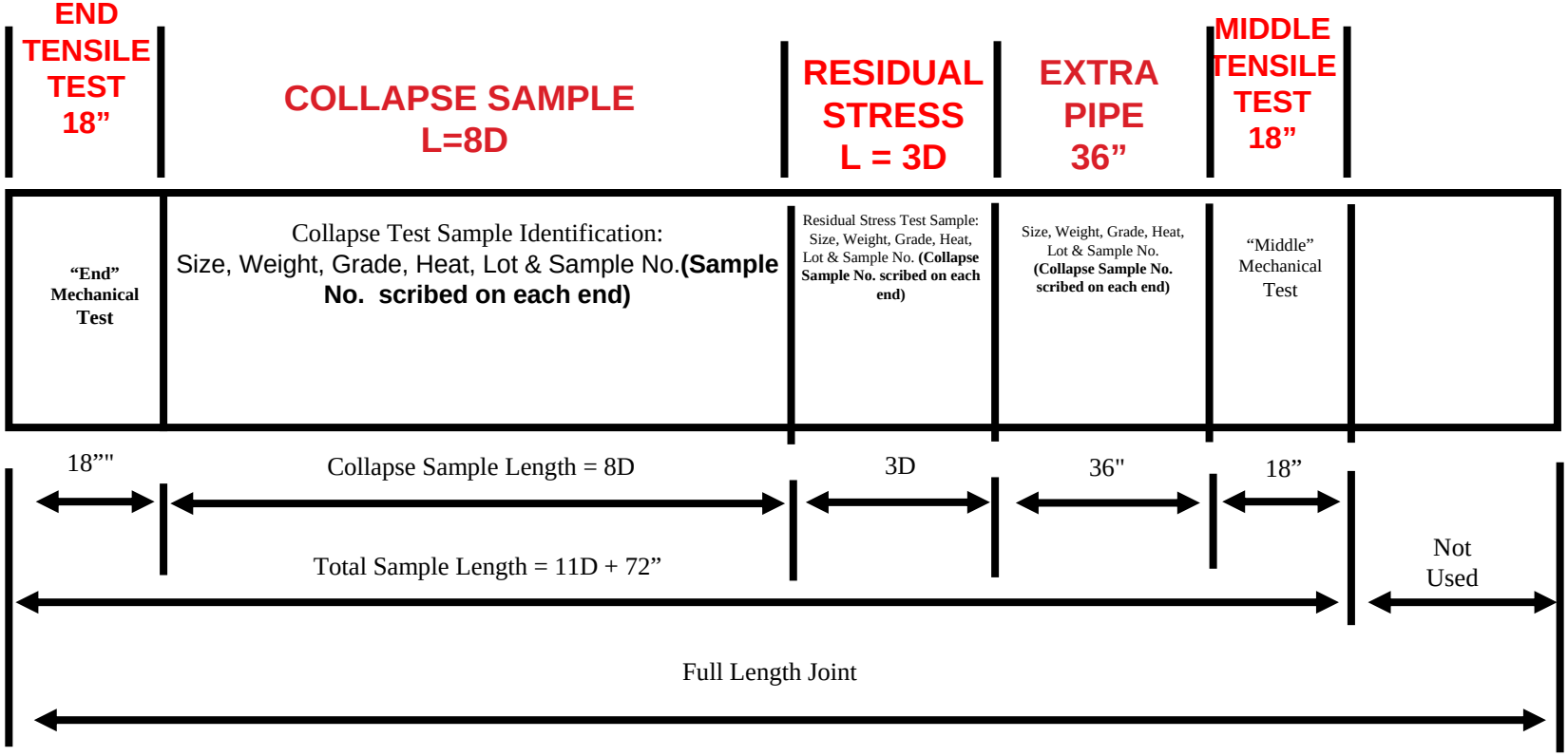
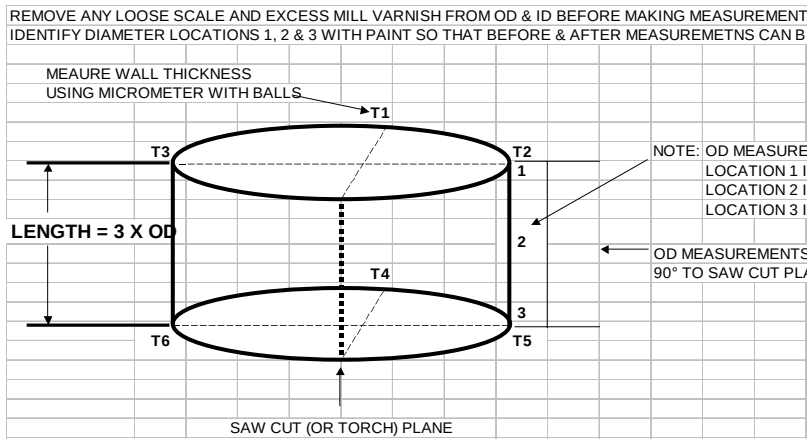
DEA-130
Modernization of Tubular Collapse Performance Properties
June 2002

11 OPERATORS
3 INDUSTRY/GOV'T AGENCIES
11 MANUFACTURERS

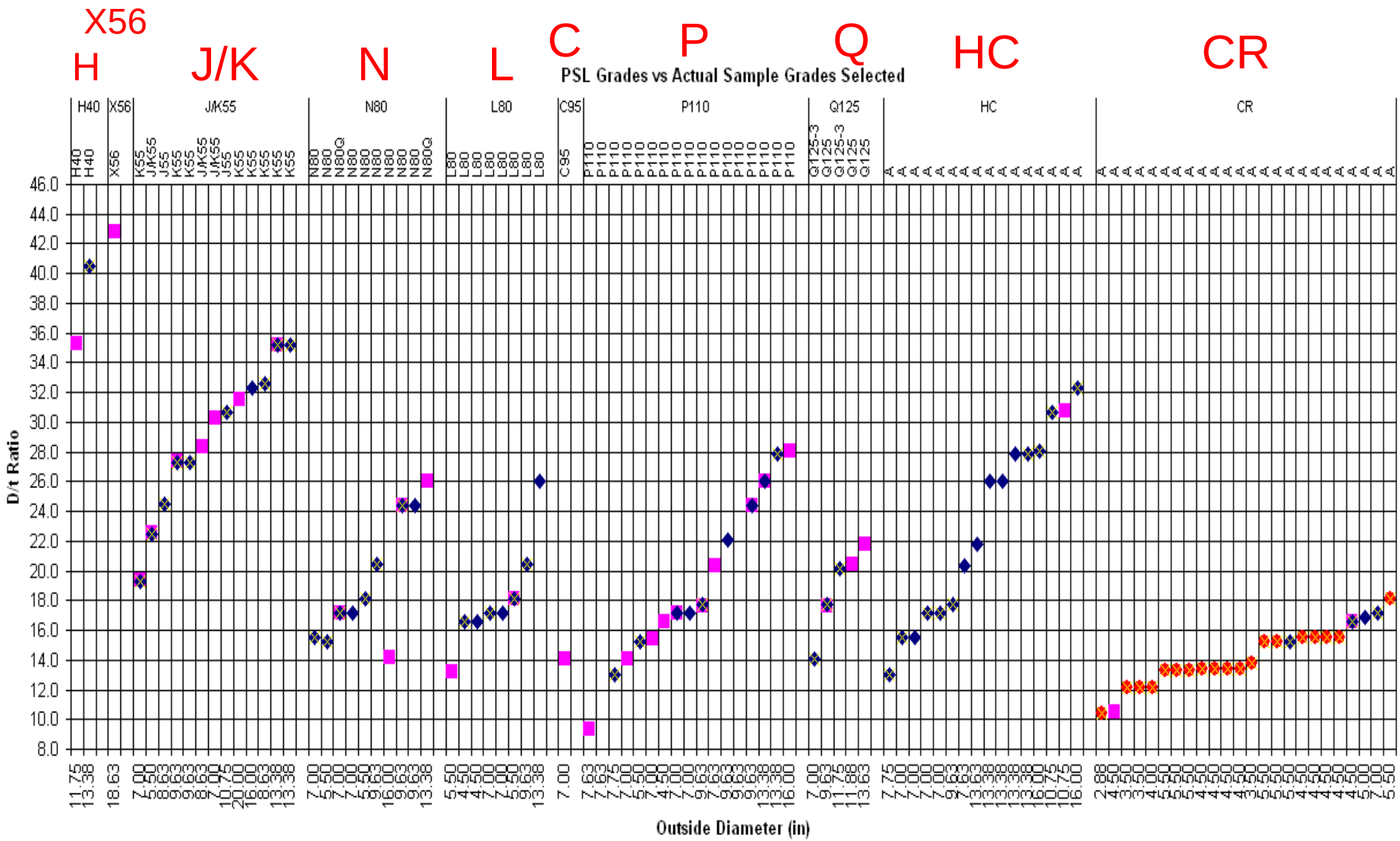
199	Samples Selected from Stock
11	Different Manufacturers Participated
17	Samples Doanted by Shell
216	Total Samples
151	Samples Tested

Layout of DEA-130 Pipe Samples





DEA-130 Preferred Samples vs. Actual Samples



Example DEA-130 Collapse Test Data

				SOUTHWEST RESEARCH INSTITUTE							
				DEA-130 PIPE COLLAPSE DATA SHEET							
	Filename :	shell18.xls									
	Pipe Sample:	NK15Cr110				Sample Collapse Pressure :			14,641	Psig	
	Grade:	110				Failure Location (small axis)			0/315-135/180		
	Nom.Weight(lb/ft.)	20.00	Sample Weight:	74.8	lbs.	Test Date :			10/1/2001		
	Pipe O.D.	5 1/2	Pipe Length:	44	inch						
	Actual Weight(lb/ft.)	20.40									
Longitude		End "A"	1 x O.D.	2 x O.D.	3 x O.D.	4 x O.D.	5 x O.D.	6 x O.D.	7 x O.D.	End "B"	AVERAGE
Radial Axis						Wall Thickness	(inches)				
Degrees	0	0.384	0.376	0.374	0.367	0.366	0.370	0.374	0.379	0.364	0.373
	45	0.376	0.379	0.371	0.366	0.367	0.364	0.368	0.372	0.366	0.370
	90	0.376	0.373	0.370	0.364	0.360	0.359	0.367	0.369	0.367	0.367
	135	0.373	0.375	0.373	0.367	0.362	0.362	0.363	0.363	0.365	0.367
	180	0.374	0.376	0.376	0.377	0.372	0.370	0.370	0.374	0.365	0.373
	225	0.385	0.379	0.380	0.383	0.377	0.380	0.375	0.378	0.367	0.378
	270	0.374	0.372	0.374	0.378	0.383	0.384	0.384	0.385	0.375	0.379
	315	0.378	0.373	0.374	0.378	0.379	0.380	0.377	0.374	0.376	0.377
Avg.Thickness		0.378	0.375	0.374	0.373	0.371	0.371	0.372	0.374	0.368	0.373
Avg O.D. (PI-Tape)		5.531	5.530	5.531	5.531	5.529	5.530	5.530	5.531	5.530	5.530
Actual O.D. @ 0/180		5.528	5.527	5.527	5.528	5.526	5.529	5.528	5.528	5.530	5.528
Ovality Gauge Max (+)		.017/255	.015/255	.014/255	.012/255	.020/255	.014/255	.012/255	.016/255	.016/255	
Ovality Gauge Min (-)		.007/155	.007/155	.007/155	.008/155	.000/0	.003/155	.003/155	.002/155	.001/155	
Ovality Max & Min indicated in inches. 2nd number represents location in degrees.											
Ovality, (Max-Min)/Avg		0.43%	0.40%	0.38%	0.36%	0.36%	0.31%	0.27%	0.33%	0.31%	0.35%
Eccentricity,	0-180	2.65%	0.00%	0.53%	2.68%	1.62%	0.00%	1.07%	1.34%	0.27%	1.13%
(tmax-tmin)/tav	45-225	2.38%	0.00%	2.41%	4.56%	2.70%	4.31%	1.88%	1.60%	0.27%	2.24%
	90-270	0.53%	0.27%	1.07%	3.76%	6.20%	6.74%	4.57%	4.28%	2.17%	3.29%
	135-315	1.32%	0.53%	0.27%	2.95%	4.59%	4.85%	3.76%	2.94%	2.99%	2.69%
Actual Avg D/T		14.65	14.73	14.79	14.85	14.91	14.90	14.86	14.78	15.02	14.83
T-Max	0.385										
T-Min	0.359										
T-Avg.	0.373										
STDEV.	0.006487										
Pipe Sample Failure Details:		SAMPLE FLATTENED AT 0/315 - 135/180 DEG FROM END A TO END B									
			0/315 DEG		135/180DEG						

SUMMARY OF COLLAPSE TEST DATA

	PER SAMPLE	TOTAL
OD	9	1,359
WALL	72	10,872
OVALITY	9	1,359
ECCENTRICITY	36	5,436
RESIDUAL STRESS	1	151
COLLAPSE PRESSURE	1	151
YIELD STRENGTH	2	302

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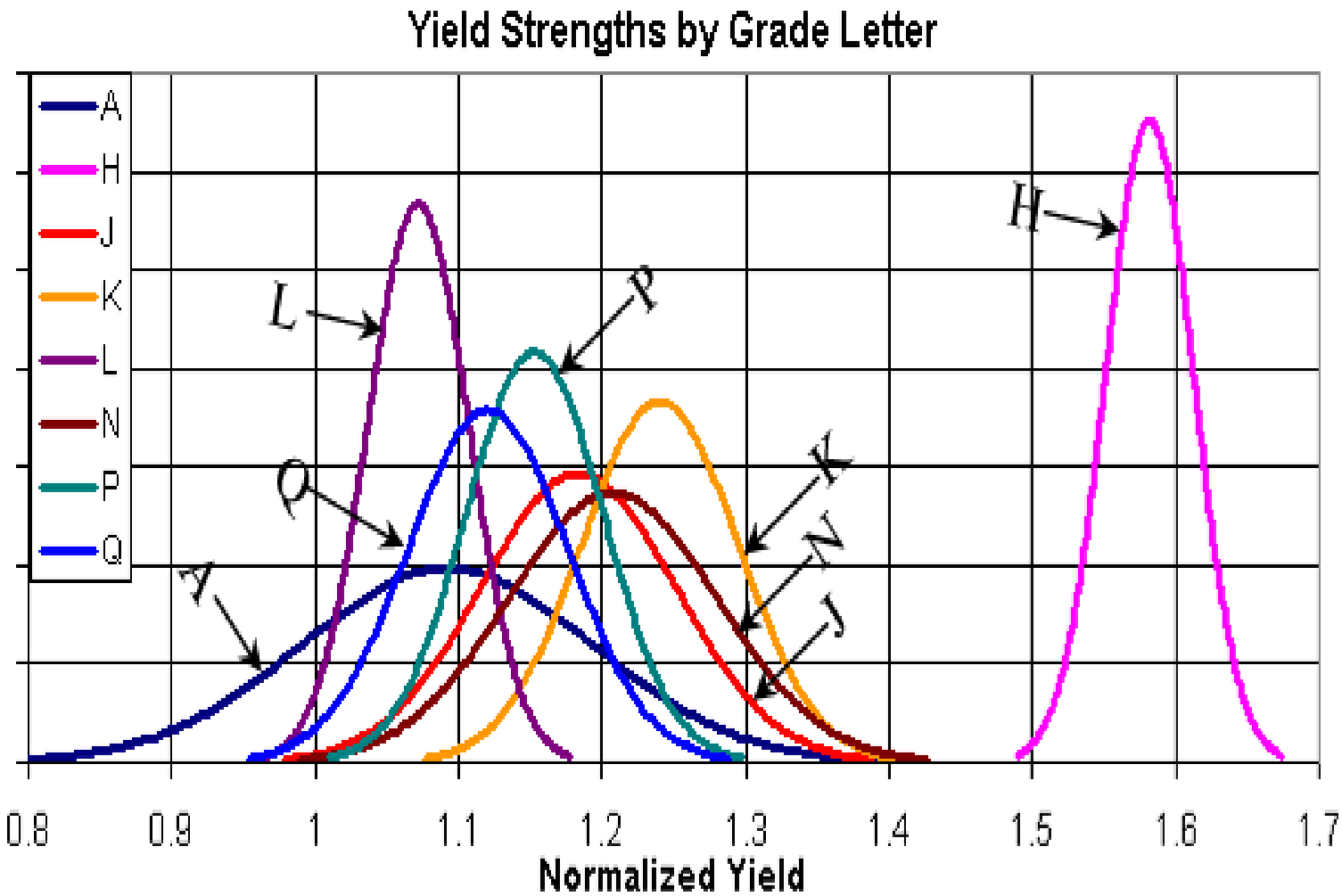
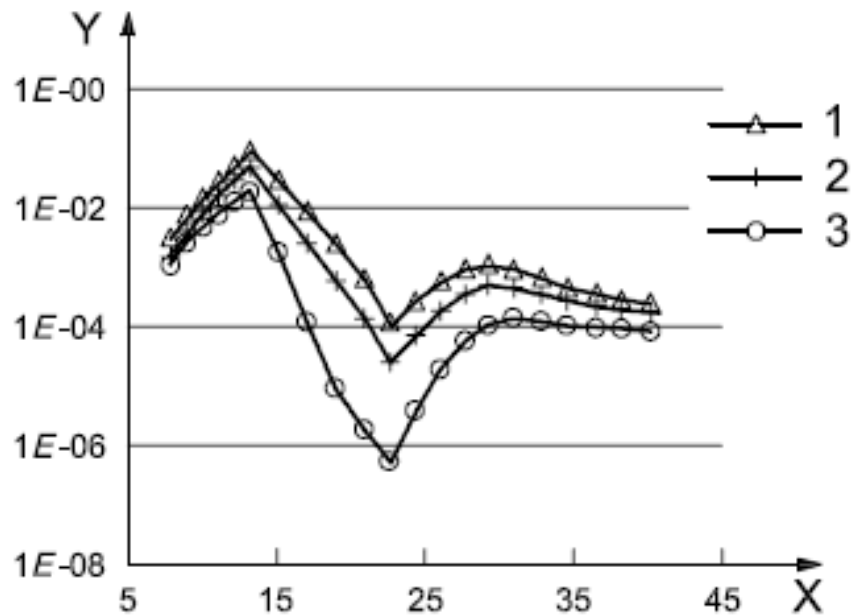
Normalized Yield Strength by Grade



API Collapse Reliability Levels vs. D/t



Key

X specified outside diameter/specified wall thickness

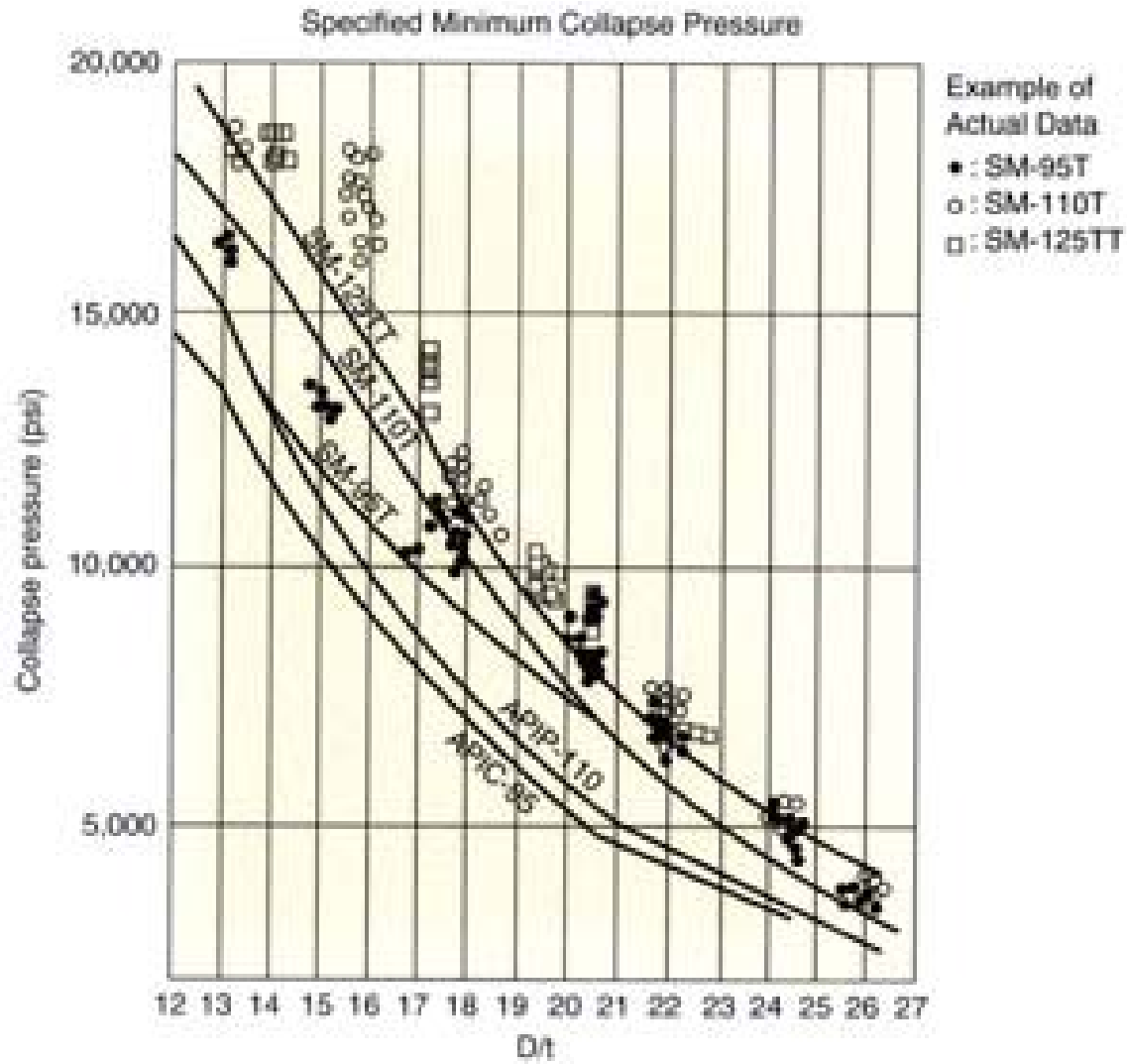
Y predicted failure probability

1 cold rotary straightened

2 hot rotary straightened

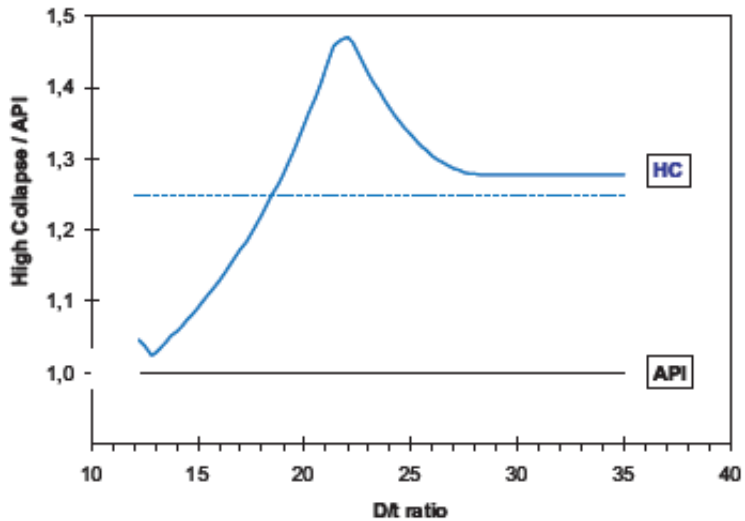
3 not straightened

Example of High Collapse Ratings



Example of High Collapse Ratings/Impacts

On average, V&M TUBES provides guaranteed High Collapse performance values that exceed API by +25% to +40%.



Thus alternate solutions are made available by V&M TUBES High Collapse grades:

Consider 13 3/8" 72# VM110HC w/ 3900 psi Collapse instead of 13 3/8"72# P110 w/ 2880 psi Collapse for your exploration campaign, with +35% safety margin

Consider 9 5/8" 53.50# VM110HC w/ 10550 psi Collapse instead of 9 7/8"62.80# P110 w/ 10280 psi Collapse for OD clearance and 17% weight reduction, still preserving your drift at 8.5"

Consider 7" 26# VM110HC w/ 8620 psi Collapse instead of 7" 32# N80 w/ 8600 psi Collapse for your tubing application, with +6% production flow

Consider 9 5/8"47# VM95HC w/ 7420 psi Collapse instead of 9 5/8" 53.50# C95 w/ 7340 psi Collapse for your riser system, with 11% weight gain

Consider 10 3/4"65.70# VM110HCSS w/ 8530 psi Collapse instead of 10 3/4" 71.10# T95 w/ 8480 psi Collapse for your HP-HT & Sour Service well

Consider 10 3/4" 109# VM110HCSS w/ 21040 psi Collapse along with 9 7/8"62.80# T95 w/ 8480 psi Collapse to go through a salt dome or clay section of your drilling program, still preserving your drift 8.5"

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Pipe Not Really Round or Simple

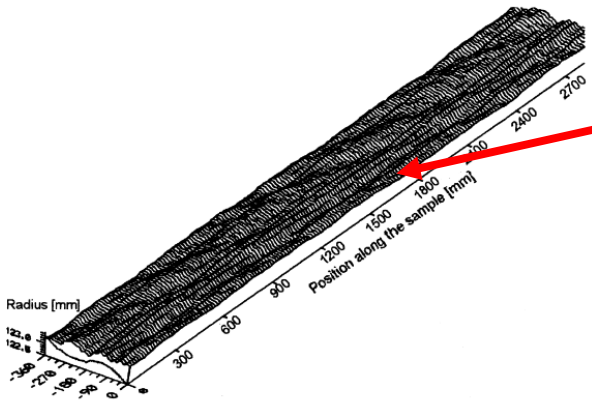

Fig. 3—Mapping of the external surface

Helical Wall and OD

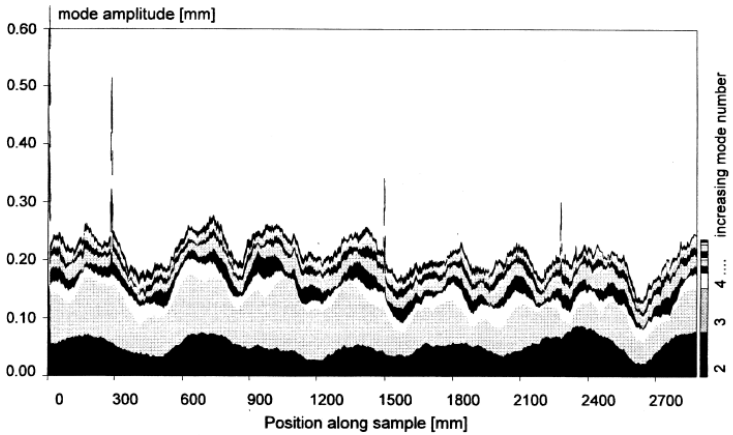

Fig. 4—Modal analysis. Mode amplitude distribution along a sample

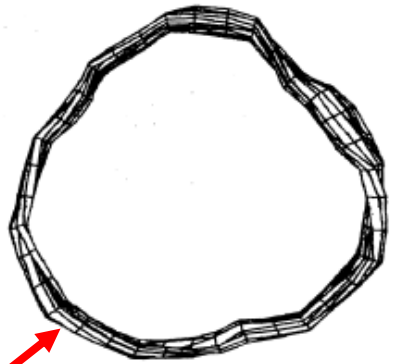

Fig. 8—Three dimensional finite element model (imperfections amplified 50 x)

Triangular Cross Section

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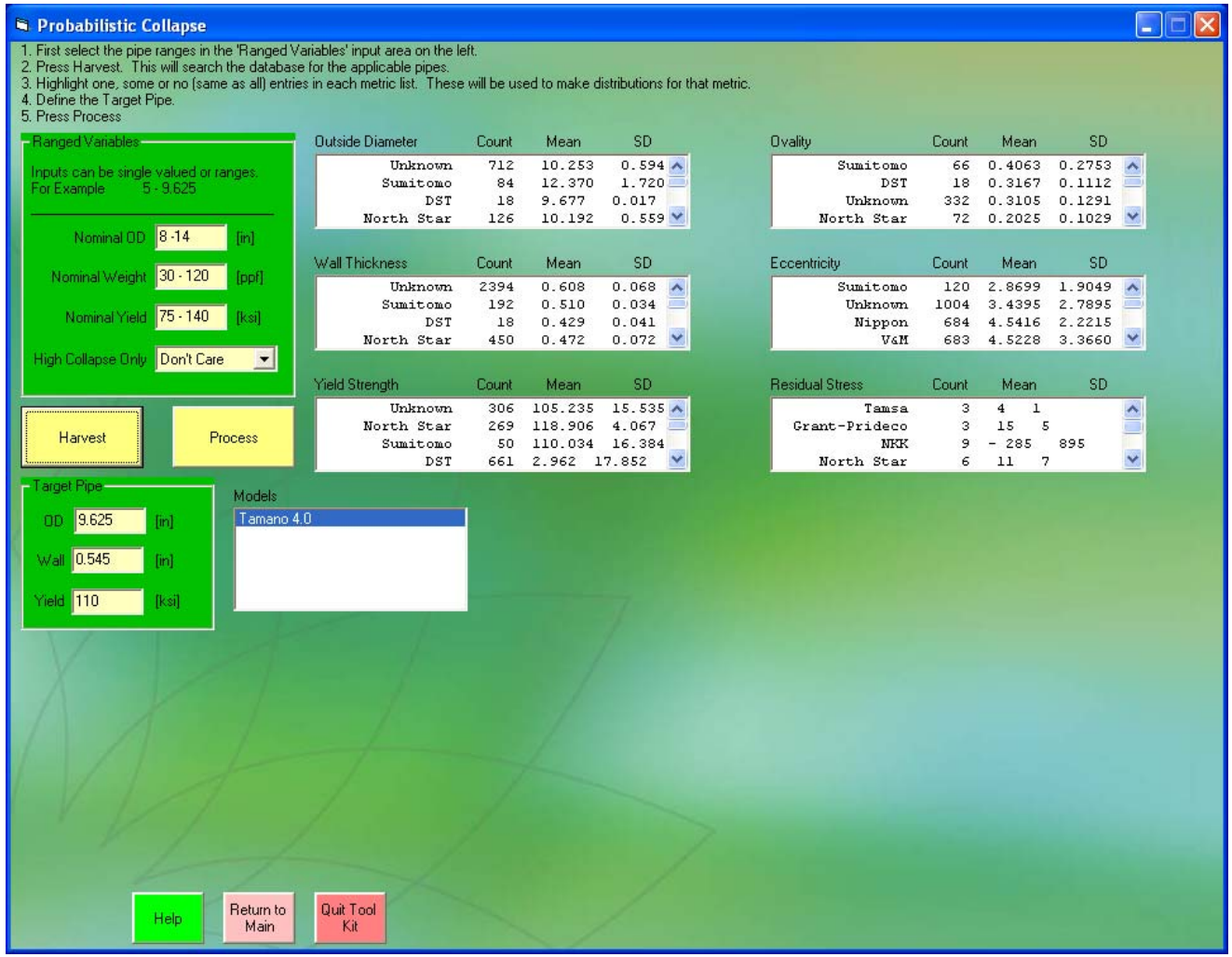
BP Database and Tools for Advanced Casing Analysis



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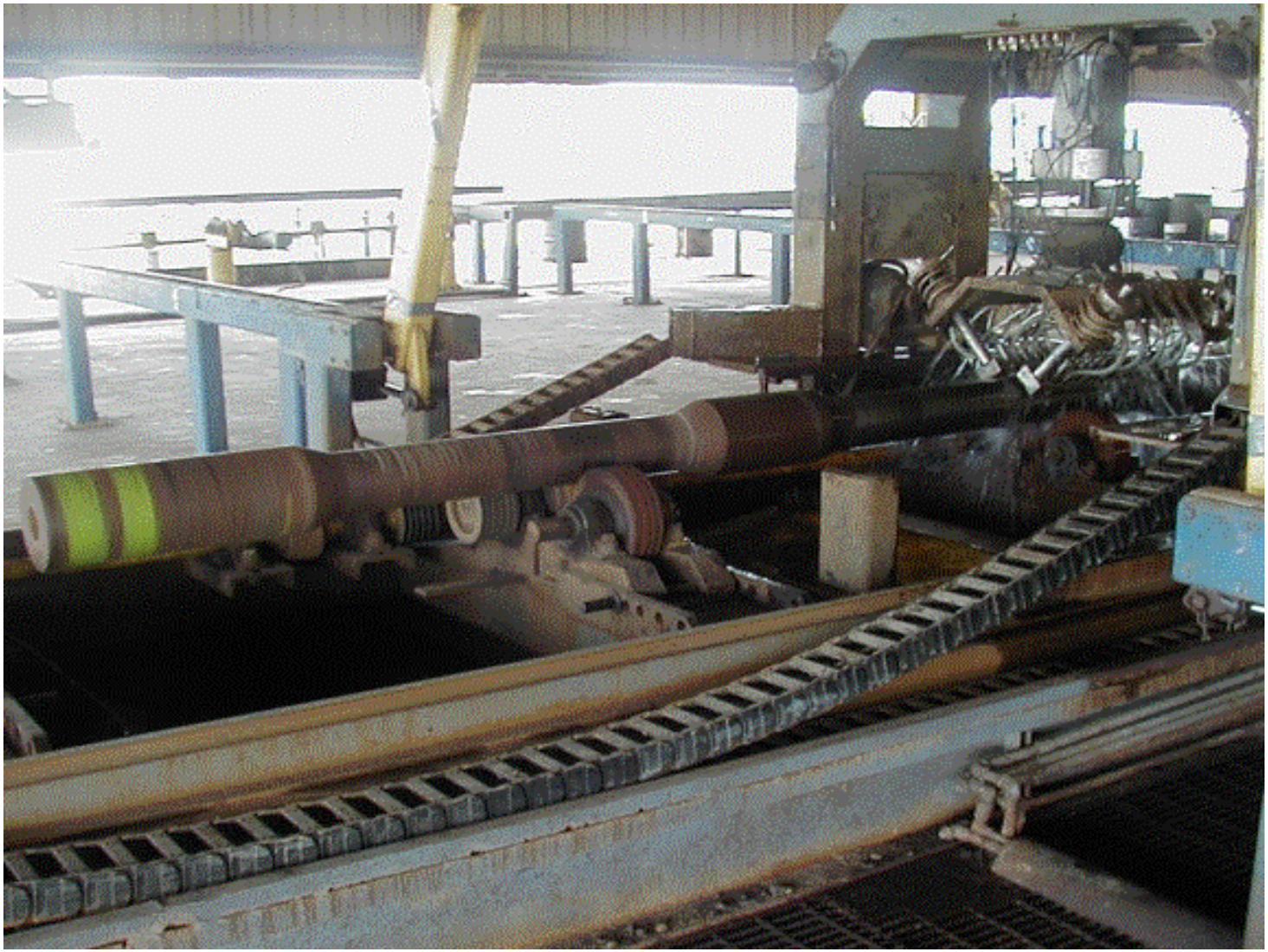
Ability for Full and Detailed Casing Inspections



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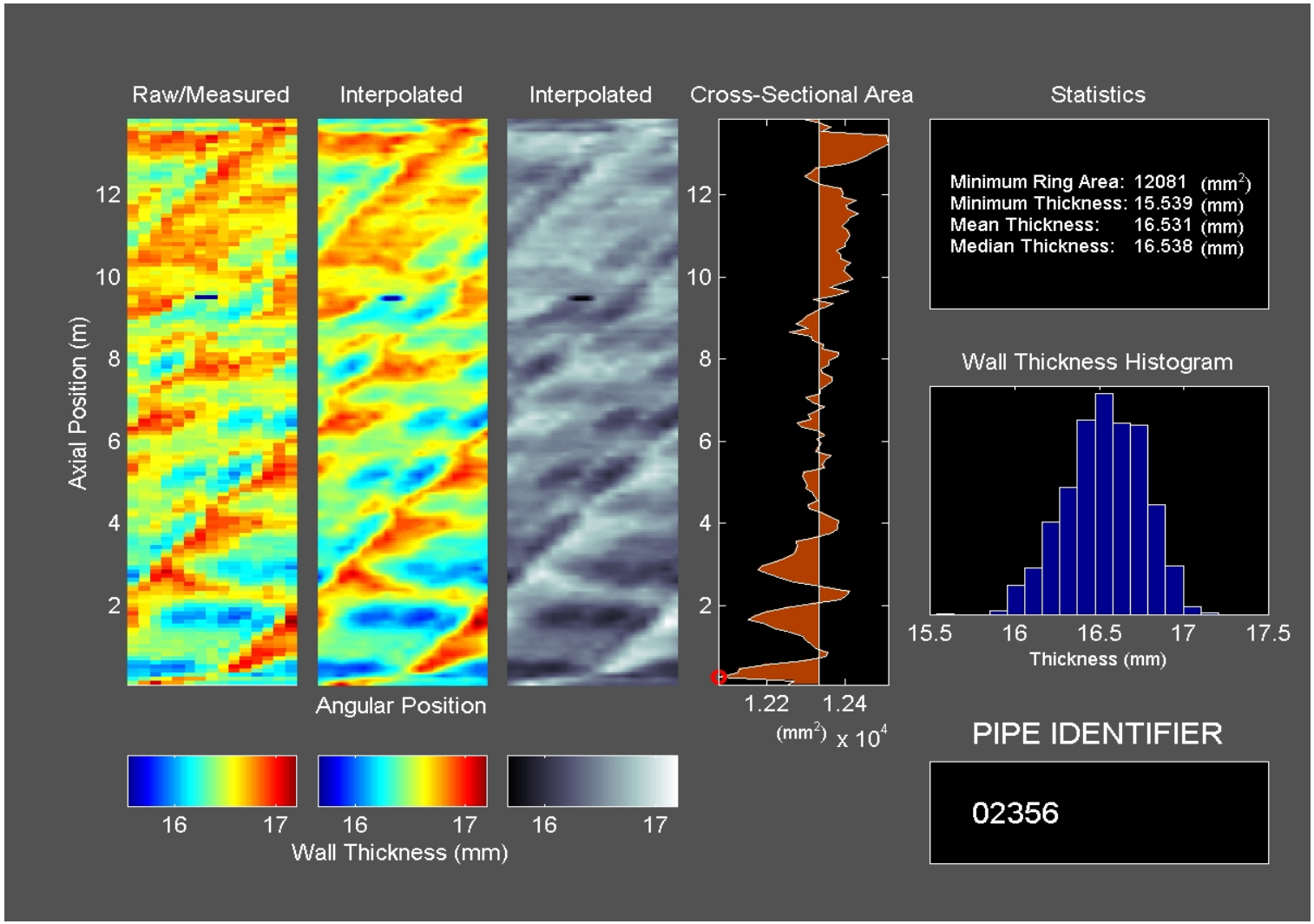
Full 3D Wall Mapping for Performance Assurance



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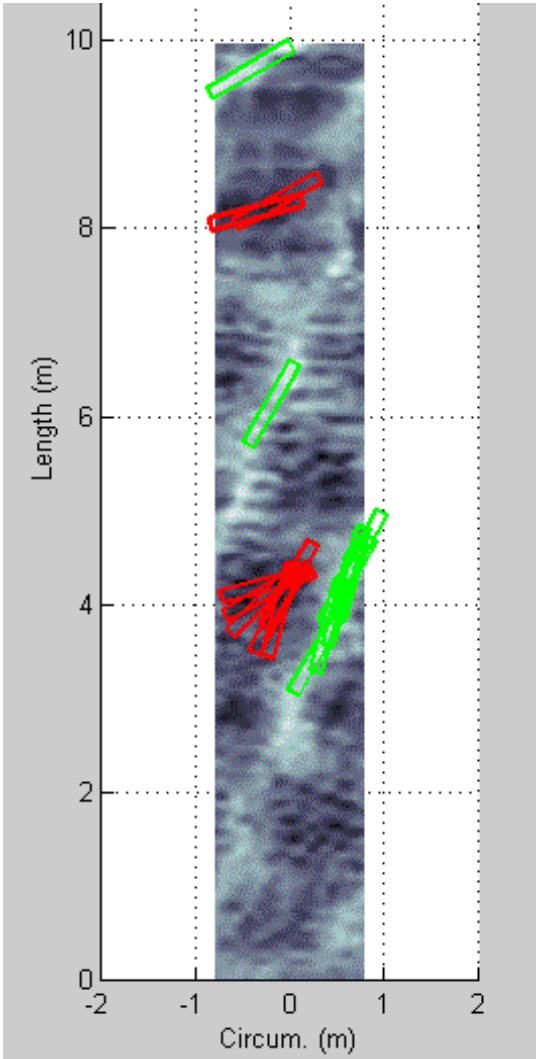
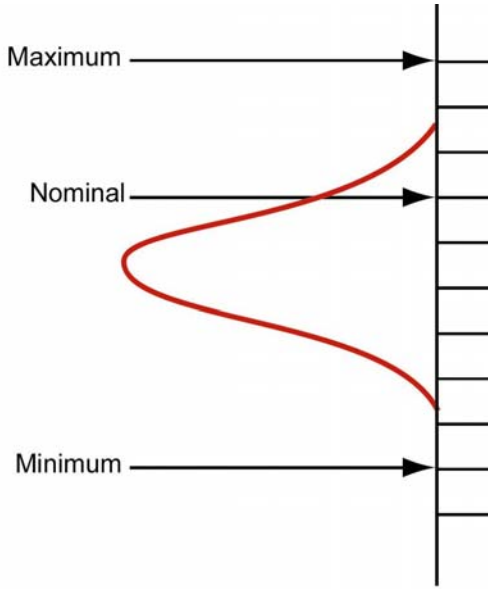
Specific Analysis of Wall Map for Internal Pressure



$$\left\{ \begin{array}{c} OD \\ WT \\ \sigma_{yp} \\ \sigma_{ul} \\ \sigma_{res} \end{array} \right\}$$



Load Types Vary and Hence Design Methods Should Also

4.3 LOADING CONDITIONS

Riser structural analysis should consider, as a minimum, design cases comprising combinations of conditions for checking:

a. Maximum stress.
b. Maximum deflection or curvature.
c. Lifetime fatigue or service life.
d. Hydrostatic collapse.
e. Maximum loading on specific components.

The objective is to find the appropriate structural response for comparison to the limits and allowables given in Section 5.

4.3.1 Maximum Operating Conditions

The operator's plan of operation affects many of the design and operating limits for the risers. Environmental limits should be set for each mode of operation, including normal operation, in-place pressure testing, connected operation, inspection, maintenance and repair. Riser functions, stress levels, angles, clearances and equipment handling methods should be evaluated when setting design and operating limits.

4.3.2 Extreme Conditions

Extreme events are those events that produce riser responses having a low probability of being exceeded in the lifetime of the riser, e.g. an event with a return period of 100 years. There may be different events that give the worst response for different parts of the structure. To find the maximum or minimum responses, different combinations of wave heights and periods, current profiles, internal pressure, minimum and maximum vessel offset, etc., should be considered. When waves and vessel motions in waves contribute to the loads, the expected maximum response in a suitable duration should be estimated.[1,2] See Section 6.

4.3.5 Accidental

4.3.5.1 Design cases associated with partial loss of riser tension (or buoyancy) should be checked.

4.3.5.2 Design cases associated with partial loss of station-keeping ability should be checked:

a. Loss of one mooring line or tendon.
b. Dynamic positioning (dp) failure (drive-off or drift-off).

4.3.5.3 Production risers that serve as production casing should be designed for pressures caused by a tubing leak near the surface in combination with associated environmental conditions. The probability and consequences of fire, explosion, and collision should be evaluated and mitigating strategies appropriate to the level of risk considered.

4.3.6 Survival

To test the robustness of the design, the designer should evaluate response to survival conditions that exceed the extreme design events. For example, the response to events with a longer return period could be checked to determine

quency (LF) offsets should be consistent with the wave and current conditions with which they are associated.

4.4.1.4 Maximum operating conditions, when less than extreme conditions, should be established by the operator at a level consistent with the probability of occurrence of the riser operating state or event being analyzed and should cover all expected operating conditions. For example, if the riser system is designed to be disconnected before reaching the extreme condition, then the maximum connected case would be analyzed for some lesser environmental condition.[3]

4.4.1.5 Several tensioner failure conditions should generally be examined, including one where there is reduced capacity and one where there is total collapse of the tensioning system. In addition, the riser system should be analyzed for the situation where one mooring line is broken, potentially resulting in a larger offset of the vessel.

4.4.1.6 Installation and transportation environmental conditions should be established by the operator but should generally ensure that the required operations can be conducted without undue interruptions or delays. A 1-year seasonal storm level can be considered as a starting point. Different conditions may be selected for various stages in the opera-

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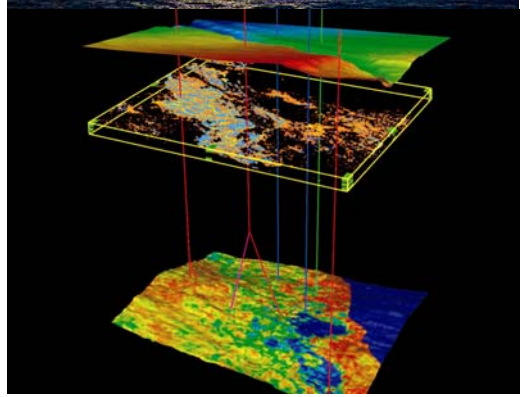
Load Types Vary and Hence Design Methods Should Also

Table 2—Design Matrix for Rigid Risers

Design Case	Load Category	Environmental Condition (from Table 1)	Pressure	Reduced Tensioner Capacity or One Mooring Line Broken	C_f[a,b]
1	Operating	Maximum operating	Design	No	1.0
2	Extreme	Extreme	Design	No	1.2
3	Extreme	Maximum operating	Extreme	No	1.2
4	Extreme	Maximum operating	Design	Yes	1.2
5	Temporary	Temporary	Associated	No	1.2
6	Test[d]	Maximum operating	Test[d]	No	1.35
7	Survival	Survival	Associated	No	1.5
8	Survival	Extreme	Associated	Yes	1.5
9	Fatigue	Fatigue	Operating	No	Note[c]

Notes:
Anisotropic materials may require special consideration.
[a]Use of C_f is described in Section 5: strength issues are discussed in 5.2, deflections in 5.3, collapse issues in 5.4 and 5.5, fatigue in 5.6.
[b]Pipeline codes may require lower C_f for risers that are part of a pipeline.
[c]Not applicable.
[d]Plant testing for rigid risers should be agreed between user and manufacturer.

Questions and Discussions



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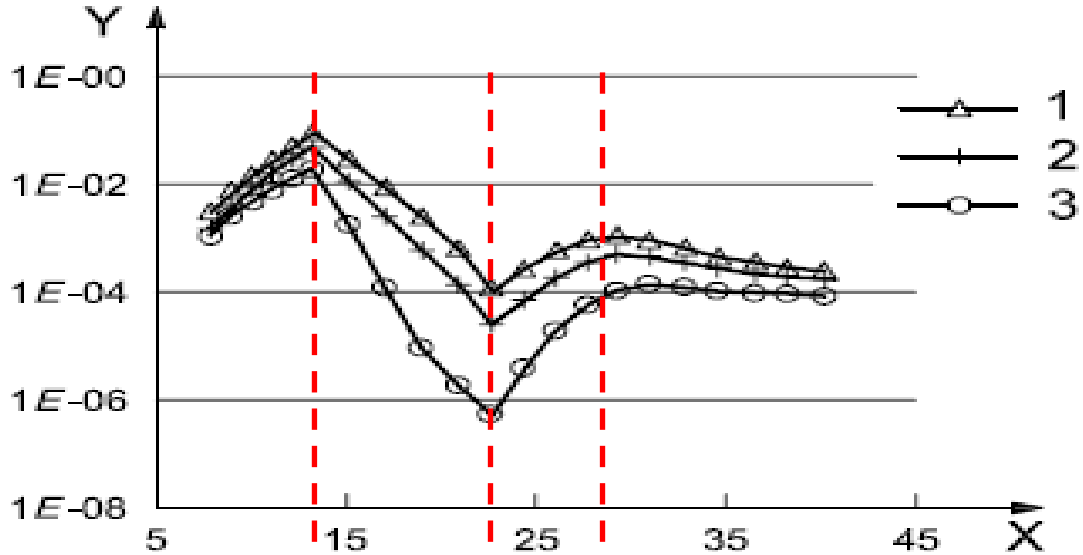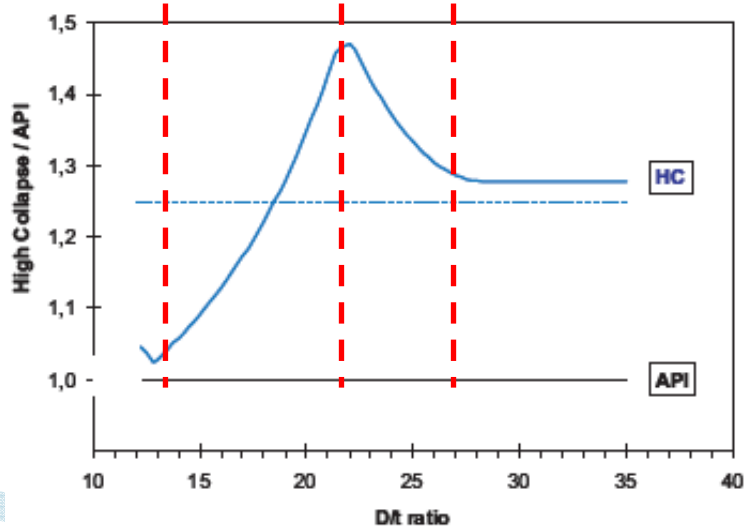
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