Document Identifier: CASING-DESIGN-FRAMEWORK-2026

Revision: 11G

Date: 18 August 2026

Keywords: Casing Design, API TR 5C3, Von Mises Ellipse, Design Limit Plot, Design Factors, Casing While Drilling, Solid Expandable Tubulars, GRE, Connection Strength Envelope, PREN

Companion tools: Casing_Design_Limit_Check (Excel) | Classic VME Design Limit Plot (Python-generated)

CASING DESIGN FRAMEWORK

From Classical API Basis through Triaxial Modelling
to Casing While Drilling, Expandable Tubulars, GRE and Connection Limits

1. Introduction and Scope

This document consolidates the technical framework required for the design of casing strings. It starts from the classical uniaxial methods defined in API TR 5C3 / ISO TR 10400, progresses to triaxial evaluation using the Von Mises yield criterion, and then examines the additional load cases introduced by Casing While Drilling, Solid Expandable Tubulars and Glass Reinforced Epoxy systems. Connection limits are treated as a separate strength envelope on the same Design Limit Plot. Throughout the document the distinction between constant Design Factors and variable applied loads is maintained.

A companion Excel workbook supports rapid screening of pipe body and connection capacities under Standard, CwD and SET modes. A Python-generated Design Limit Plot illustrates the classic inclined Von Mises ellipse with Design Factors, uniaxial limits and discrete load points, including a deliberate CwD case that exceeds the Design Factor envelope.

2. Hierarchical Schema of Technical Subjects

CASING DESIGN

1. Classical Design Basis (API TR 5C3)
   – Burst (Barlow equation + 0.875 wall tolerance)
   – Collapse (four regimes: Yield / Plastic / Transition / Elastic)
   – Axial / Tension
   – Biaxial interaction
2. Triaxial Design – Von Mises Ellipse (VME)
   – Principal stresses: axial (σa), hoop (σt), radial (σr)
   – Yield criterion transformation → inclined ellipse
   – Phase 1: Pure yield envelope (no Design Factor)
   – Phase 2: Design Limit Plot with Design Factors applied
3. Design Factors (remain constant)
   – Burst DF: 1.10 – 1.25
   – Collapse DF: 1.00 – 1.125
   – Axial DF: 1.30 (compression) / 1.60–1.80 (tension)
   – Triaxial DF: typically 1.25
4. Casing While Drilling (CwD) – Increased Load Cases
   – Continuous torque and rotation
   – Higher torque & drag (Johancsik model)
   – Lateral vibration / whirling
   – Torsional stress on connections (often the limiting factor)
   – Combined axial + bending + torsion
   – Modelling: Design Factors stay the same; applied loads become more severe
5. Solid Expandable Tubulars (SET)
   – Expansion force and post-expansion properties
   – Residual stress after expansion
   – High-torque expandable connections
   – Near-monobore or contingency liner applications
   – Modelling: increased mechanical loads; Design Factors unchanged
6. GRE specific constraints
   – Collapse resistance during cementing (heavy-weight mud fill required)
   – Thermal cycling limits (ΔT rate, number of cycles)

– Density-neutron transparency of thick collars
– Hybrid steel + GRE strings
7. Material Selection
– PREN (Pitting Resistance Equivalent Number)
– 13Cr versus 22Cr / 25Cr Duplex
– Corrosion-resistant alloys for high Cl^- + CO_2 environments
8. Contingency and Operational Philosophy
– Contingency matrix (H_2S, total losses, scaling, thermal cycling)
– Dual-skin / protective tie-back architecture
– High-volume programmes – standardisation by well family
9. Visualisation and Implementation
– Design Limit Plots (Excel companion + Python classic plot)
– Connection Strength Envelope overlaid on the same axes

3. Sequential Progression of the Design Process

Casing design is an iterative sequence. Each new technology or operational constraint is introduced only after the previous level has been satisfied. The normal order of progression is as follows.

Step 1 – Classical uniaxial design

Burst, collapse and axial capacities are calculated according to API TR 5C3. Preliminary pipe size, weight and grade are selected. This step establishes the baseline mechanical envelope.

Step 2 – Triaxial (Von Mises) verification

The same candidate pipes are checked against the Von Mises ellipse. Phase 1 examines pure yield. Phase 2 applies the triaxial Design Factor and overlays the uniaxial limits. Load cases that fall inside the design ellipse are accepted; those that fall outside trigger an upgrade of grade or wall thickness.

Step 3 – Technology-specific load amplification

If Casing While Drilling is planned, the torque, drag, torsional and vibrational loads are calculated and plotted on the same Design Limit Plot. If Solid Expandable Tubulars are used, the expansion forces and post-expansion residual stresses are added. If GRE sections are present, the temporary collapse load during cementing is checked. In every case the Design Factors remain unchanged; only the applied loads increase.

Step 4 – Material and contingency iteration

Fluid chemistry determines the required PREN. Thermal cycling limits restrict the use of GRE. A contingency matrix is prepared so that unexpected H_2S, losses or scaling can be handled without redesign. The process then returns to Step 2 or Step 3 until a coherent scheme is obtained.

Each iteration re-uses the same Design Limit Plot. The engineer does not change the safety factors; he adds more severe load points and, when necessary, selects a stronger pipe or a different architecture.

4. Classical Design Basis (API TR 5C3)

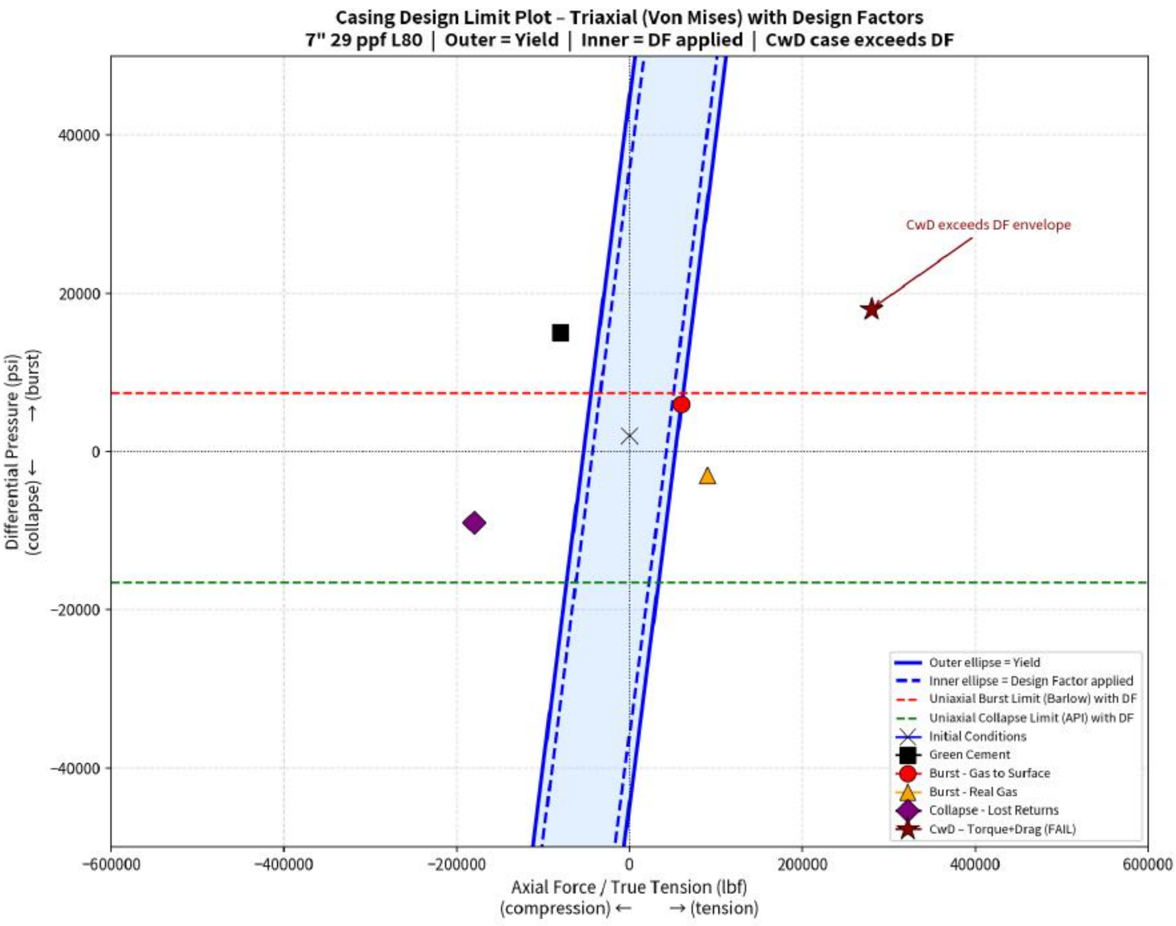
Classical design evaluates burst, collapse and axial capacity independently before any combined-load check is performed. Burst is calculated with the Barlow equation using the 0.875 wall-thickness tolerance. Collapse follows the four API regimes (yield, plastic, transition, elastic) and is reduced under axial tension. Axial capacity is governed by pipe-body yield and connection strength. These calculations define the starting envelope that later technology-specific loads must still satisfy.

5. Triaxial Design – Von Mises Ellipse

The Von Mises criterion combines axial, hoop and radial stresses into a single equivalent stress. Mapped onto the differential-pressure versus axial-force plane, the yield surface becomes an inclined ellipse. Phase 1 shows the pure yield envelope. Phase 2 scales the ellipse by the triaxial Design Factor and adds the uniaxial burst and collapse lines. All subsequent operational load cases are plotted on this same diagram.

The classic appearance of the Design Limit Plot consists of an outer solid ellipse (yield), an inner dashed ellipse (Design Factor applied), horizontal dashed lines for the factored uniaxial burst and collapse ratings, and discrete markers for each design load case. A load case is acceptable when it lies inside the inner ellipse and inside the factored uniaxial limits.

Figure – Classic VME Design Limit Plot with Design Factors and load points



Outer ellipse = Yield | Inner ellipse = Design Factor applied | Excel / Python model based on principal stress transformation. CwD point deliberately placed outside DF envelope for demonstration.

6. Design Factors Remain Constant

The introduction of Casing While Drilling or expandable tubulars does not alter the numerical values of the Design Factors. What changes is the severity of the loads that are applied to the pipe. The same ellipse and the same safety margins are used; the engineer simply plots more demanding load points and, when necessary, selects a stronger tubular. Typical minimum values are: Burst 1.10–1.25, Collapse 1.00–1.125, Axial tension 1.60–1.80, Axial compression 1.30, Triaxial 1.25.

7. Casing While Drilling – Increased Load Cases

When the casing itself is rotated and used to drill, continuous torque, elevated drag, torsional stress and lateral vibration appear. Connections often become the limiting component. These additional loads are quantified by torque-and-drag models and vibration analysis, then plotted on the existing Design Limit Plot. The Design Factors stay unchanged; only the applied loads increase. A deliberate CwD load point placed outside the inner (DF) ellipse demonstrates a failed check and the need for a higher-capacity pipe or connection.

8. Solid Expandable Tubulars

Expansion produces high internal pressure, plastic deformation, wall-thickness reduction and residual stress. After expansion the pipe is re-evaluated with the new geometry and residual-stress state, still using the original Design Factors and the same Von Mises ellipse. High-torque expandable connections allow rotation when required. Near-monobore architectures and contingency liners are typical applications.

9. GRE Specific Constraints

An empty GRE section has limited collapse resistance. Before or during cementing the section must be filled with heavy-weight mud so that internal pressure supports the wall against the external cement hydrostatic head. GRE materials also carry manufacturer limits on temperature rate and cumulative thermal cycles. Thick fibreglass collars can be transparent to density-neutron logging tools, allowing open-hole quality logs to be recorded through the collar. Hybrid steel + GRE strings combine the mechanical strength of steel with the corrosion resistance and logging transparency of GRE.

10. Material Selection and PREN

In high-chloride, CO_2-containing brines the Pitting Resistance Equivalent Number guides alloy selection. Conventional 13Cr grades are frequently outside the safe envelope, while 22Cr and 25Cr duplex stainless steels remain inside. Unexpected H_2S forces an immediate upgrade. The Vallourec Material Selection Guide lists expandable grades (VM ET / 13ET) and GRE-liner options under special applications and corrosion mitigation.

11. Connection Limits on the Design Limit Plot

Connections are not modelled by reducing the pipe-body Design Factor. They are modelled with a separate Connection Strength Envelope (CSE). On the Design Limit Plot two envelopes appear: the pipe-body VME ellipse (factored) and the connection CSE (factored). A load case is acceptable only when it lies inside both envelopes. In many cases the connection becomes the limiting factor in pure tension or under combined tension plus internal pressure. Illustrative capacities for BTC, premium metal-to-metal and expandable connections are provided in the companion Excel tool; real designs must use manufacturer CSE data.

12. Contingency and Operational Philosophy

A contingency matrix lists the actions required if H_2S, total losses, severe scaling or excessive thermal cycling occur. Long-lead items are identified early. In high-volume campaigns the first wells are fully characterised; later wells of the same family use a frozen scheme while the contingency options remain available. Dual-skin or protective tie-back architectures provide an additional barrier when aquifer protection or gas-zone isolation is critical.

13. Visualisation and the Supporting Excel Tool

The companion Excel workbook allows the user to select an example casing, choose Standard / CwD / SET mode, enter or select connection data, and verify safety factors against minimum Design Factors for both pipe body and connection. The classic inclined Design Limit Plot (outer yield ellipse, inner DF ellipse, uniaxial limits and discrete load points) is generated by a Python script that implements the principal-stress transformation. A deliberate CwD load point is placed outside the DF envelope to demonstrate a failed check.

Recommended companion files:

- • Excel: Casing_Design_Limit_Check series (inputs, connection library, results, parametric data)
- • Plot: VME_Classic_Design_Limit_Plot (PNG / PDF) showing the reference inclined shape with load points

14. List of References

1. API Technical Report 5C3, 7th edition, June 2018. Calculating Performance Properties of Pipe Used as Casing or Tubing.

2. ISO TR 10400. Petroleum and natural gas industries – Equations and calculations for the properties of casing, tubing, drill pipe and line pipe used as casing or tubing.

3. Shell. Casing and Tubing Design Manual, WS 38.80.31.31-Gen, Revision 0.1, 2013.

4. Oliasoft. Axial, Burst, Collapse and Triaxial Safety Factor Calculations and VME Plot (technical note).

5. Vallourec / Nippon Steel. VAM Book, December 2023.

6. Vallourec. Material Selection Guide (standard applications and severe environments).

7. TU Delft. Casing While Drilling Thesis (KCN), 2015.

8. Byrom, T.G. Casing and Liners for Drilling and Completion.

9. ZC Steel Pipe. Casing Design Basics: Collapse, Burst and Tension.

15. Definition of Acronyms

API – American Petroleum Institute

CSE – Connection Strength Envelope

CwD – Casing While Drilling

DF – Design Factor

GRE – Glass Reinforced Epoxy

PREN – Pitting Resistance Equivalent Number

SET – Solid Expandable Tubular

VME – Von Mises Ellipse

INDEX

CASING DESIGN LIMIT CHECK – based on v6 (Quadratic VME) + revisions + CwD/SET overload cases

Revision 6H | 18 Aug 2026 | Builds on v6 quadratic method, flexible Inputs, casing reminders

METHOD (from v6)

Ellipse generated by solving the von Mises quadratic: $\sigma a^2 + \sigma h^2 - \sigma a \cdot \sigma h = Yp^2$
For each Axial Force, the two ΔP branches (upper & lower) are calculated → classic inclined shape.
Connection shown as rectangular cut-offs (factored tension / compression / Pi / Pe) on the same axes.
CwD and SET modes amplify the applied loads; Design Factors stay constant. Overload cases are provided that exceed weaker casing/thread envelopes.

HOW TO USE

1. Sheet 1_Inputs – select casing (or Custom), set Mode (Standard / CwD / SET), enter base loads and DFs
2. Sheet 2_Connection – select connection or Custom
3. Sheet 3_Results – review SF and PASS/FAIL for pipe and connection
4. Sheet 4_VME_Plot – quadratic points + connection rectangle + overload markers (CwD / SET)

Casing under study is recalled at the top of each calculation sheet.

FULL REVISION LOG

Rev	Date	Change attempted	Result / note
FINAL	18 Aug	Screening Excel + classic Python VME plot	Companion tools
7–10	17–18 Aug	Toggle / both-ellipses experiments	Abandoned for production; v6 quadratic kept as reference
6H	18 Aug	THIS FILE – v6 base + revision log + CwD/SET overload cases that exceed weaker envelopes	Current
6	17 Aug	Quadratic VME solution + flexible Inputs	Best mathematical basis; user extended with VLOOKUP-style selection
5	17 Aug	Normalized parametric + Units toggle	Tilt still weak / toggle fragile
4	17 Aug	Parametric inclined ellipse + connection envelope	Ellipse collapsed to line in real units
3	17 Aug	Casing example selector + VME chart	OK
2	17 Aug	Connection tab + typical connections	OK
1	17 Aug	First Design Limit Check (pipe body only)	Baseline

TUBULAR DATA & LOAD CASE

EXAMPLE CASING

Select example	7in 29ppf L80	Changing this updates OD / t / Yp below

Database

Casing	OD (in)	t (in)	Yp (psi)
7in 29ppf L80	7.000	0.408	80,000
7in 32ppf P110	7.000	0.453	110,000
9-5/8in 47ppf L80	9.625	0.472	80,000
9-5/8in 53.5ppf P110	9.625	0.545	110,000
13-3/8in 68ppf K55	13.375	0.480	55,000
CUSTOM	7.000	0.408	80,000

MODE

Application Mode	Standard	
Amplification	1.00	CwD 1.35 | SET 1.25 (screening hypothesis)

ACTIVE TUBULAR (auto from selector or Custon

	7in 29ppf L80
OD (in)	7.000
t (in)	0.408
ID (in)	6.184
Yp (psi)	80,000
Area (in²)	8.449
Fa_yield (lbf)	675,954
pb Barlow (psi)	8,160.0

CUSTOM (when Casing = Custom)

Custom OD (in)	7.000
Custom t (in)	0.408
Custom Yp (psi)	80,000

BASE LOAD CASE +

Axial Force (lbf) [+ = tension]	150,000
Pi (psi)	5,000
Pe (psi)	2,000
ΔP (psi)	3,000
Amplified Axial (lbf)	150,000
Amplified ΔP (psi)	3,000

PIPE DF

DF Burst	1.10
DF Collapse	1.00
DF Axial T	1.60
DF Axial C	1.30
DF Triaxial	1.25

OVERLOAD CASES (for visualisation – exceed weaker casing/thread)

Case	Fa (lbf)	ΔP (psi)	Amplified Fa	Amplified ΔP
Service – normal	120,000	4,000	120,000	4,000
CwD – elevated torque/drag	320,000	9,000	320,000	9,000
CwD – severe (exceeds L80/BTC)	480,000	12,000	480,000	12,000
SET – post-expansion residual	200,000	7,000	200,000	7,000
SET – expansion peak (severe)	420,000	11,000	420,000	11,000

Note: CwD severe and SET expansion peak are sized to fall outside typical L80 + BTC envelopes while remaining inside high-capacity P110 + premium en

CONNECTION SELECTION

Casing under study: 7in 29ppf L80

	7in 29ppf L80
Connection choice	BTC (standard)

TYPICAL DATABASE (illustrative)

Type	Tension (lbf)	Compression (lbf)	Pi (psi)	Pe (psi)
BTC (standard)	450,000	380,000	5,500	4,500
Premium Metal-to-Metal	580,000	520,000	7,500	6,000
High-Torque Expandable	400,000	360,000	5,000	4,000
Custom connection	500,000	450,000	6,500	5,000

ACTIVE VALUES	
Tension (lbf)	450,000
Compression (lbf)	380,000
Pi (psi)	5,500
Pe (psi)	4,500

CUSTOM	
Custom Tension	500,000
Custom Compression	450,000
Custom Pi	6,500
Custom Pe	5,000

CONNECTION DF	
DF Tension	1.60
DF Compression	1.40
DF Pressure	1.25

RESULTS – PIPE + CONNECTION

Casing under study: 7in 29ppf L80 | Mode: Standard | Connection: BTC (standard)

	7in 29ppf L80
Pipe Burst (psi)	8,160.0
Pipe Axial Yield (lbf)	675,954
Amplified Axial	150,000
Amplified ΔP	3,000

PIPE SF			
Burst SF	2.72	1.1	PASS
Axial SF	4.51	1.6	PASS

CONNECTION SF	BTC (standard)		
Conn Tension SF	3.00	1.6	PASS
Conn Pressure SF	1.83	1.25	PASS

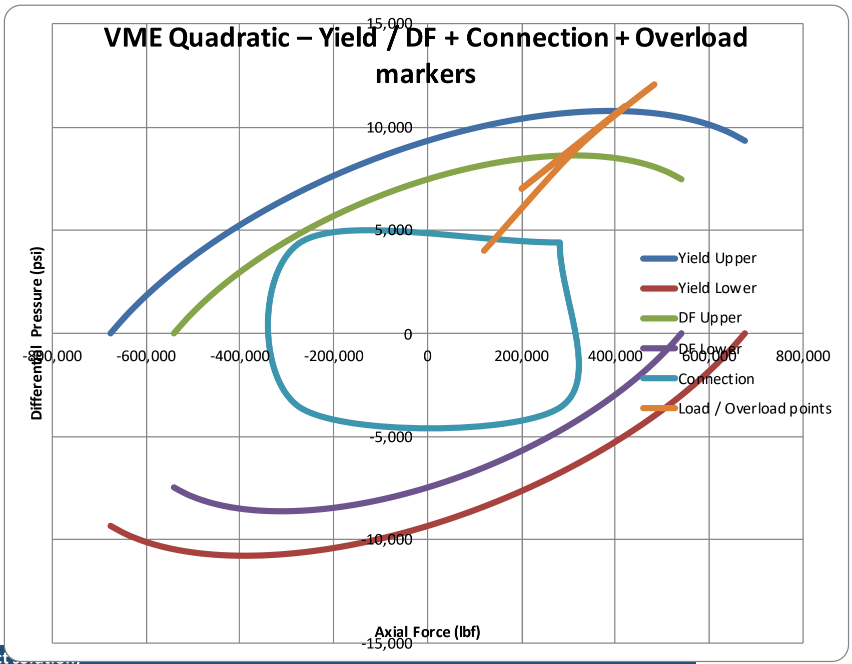
FINAL	**ACCEPTABLE**

VME DESIGN LIMIT PLOT – Quadratic solution + CwD/SET overload markers

Casing: 7in 29ppf L80 | Mode: Standard | Connection: BTC (standard)

Pipe parameters	7in 29ppf L80
Yp (psi)	80,000
Area (in²)	8.449
Fa_yield (lbf)	675,954
pb (psi)	8,160.0
DF triaxial	1.25
OD (in)	7.000
t (in)	0.408

Connection cut-offs (factored)	BTC (standard)
Conn T (lbf)	281,250
Conn C (lbf)	-271,429
Conn Pi (psi)	4,400.0
Conn Pe (psi)	-3,600.0



QUADRATIC VME POINTS (exact solution)

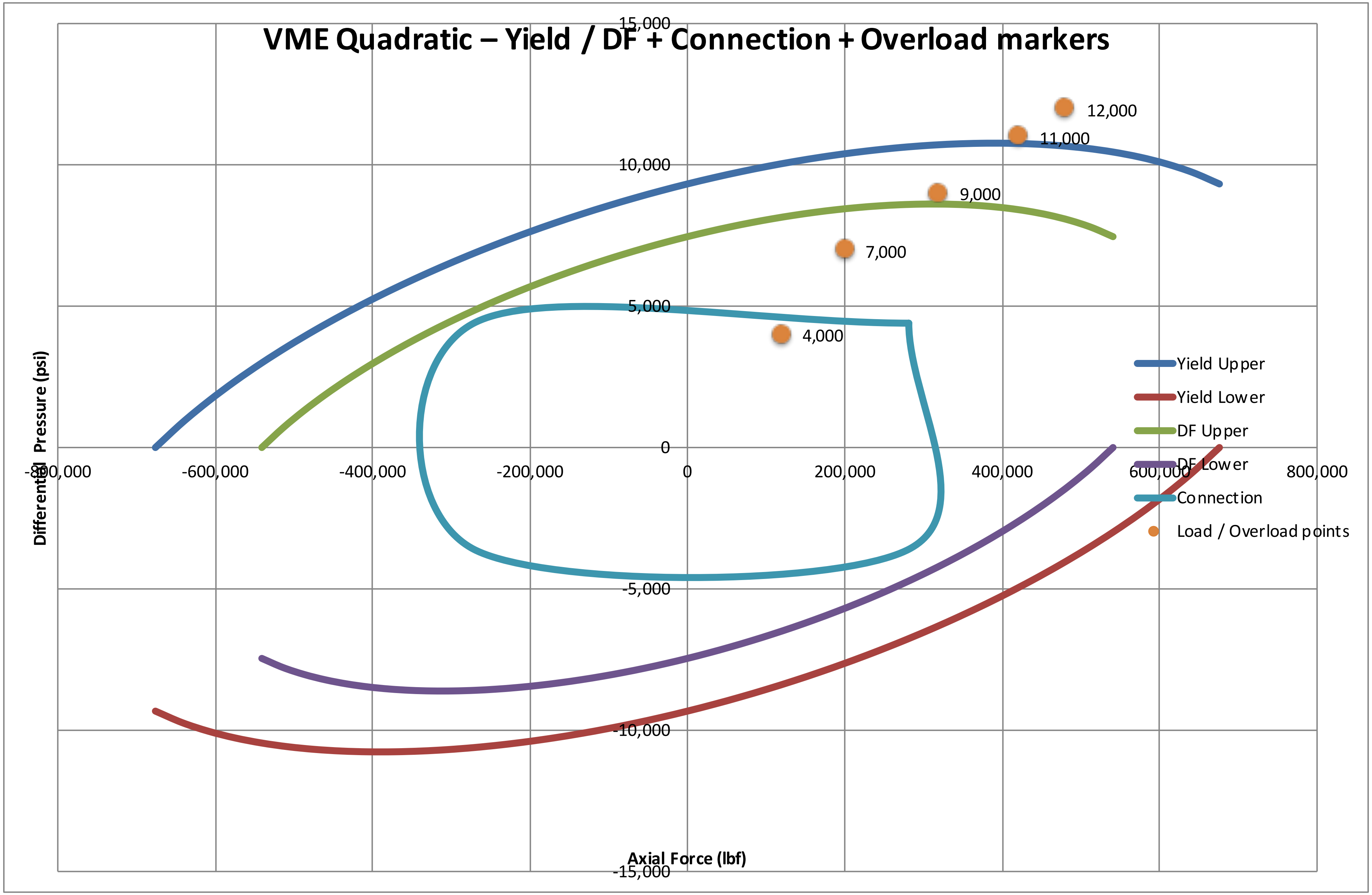
i	Fa_lbf	sigma_a	Disc	DP_upper	DP_lower	Fa_DF	DP_up_DF	DP_lo_DF
0.0	-675954.1	-80000.0	6400000000.0	0.0	-9325.7	-540763.3	0.0	-7460.6
1.0	-642156.4	-76000.0	8272000000.0	871.4	-9730.8	-513725.1	697.1	-7784.7
2.0	-608358.7	-72000.0	10048000000.0	1646.0	-10039.1	-486687.0	1316.8	-8031.3
3.0	-574561.0	-68000.0	11728000000.0	2348.7	-10275.5	-459648.8	1878.9	-8220.4
4.0	-540763.3	-64000.0	13312000000.0	2994.6	-10455.2	-432610.6	2395.7	-8364.1
5.0	-506965.6	-60000.0	14800000000.0	3593.6	-10587.9	-405572.5	2874.9	-8470.3
6.0	-473167.9	-56000.0	16192000000.0	4152.7	-10680.7	-378534.3	3322.2	-8544.6
7.0	-439370.2	-52000.0	17488000000.0	4677.0	-10738.7	-351496.1	3741.6	-8591.0
8.0	-405572.5	-48000.0	18688000000.0	5170.2	-10765.6	-324458.0	4136.1	-8612.5
9.0	-371774.8	-44000.0	19792000000.0	5635.3	-10764.4	-297419.8	4508.2	-8611.6
10.0	-337977.1	-40000.0	20800000000.0	6074.7	-10737.5	-270381.6	4859.7	-8590.0
11.0	-304179.4	-36000.0	21712000000.0	6490.1	-10686.7	-243343.5	5192.1	-8549.3
12.0	-270381.6	-32000.0	22528000000.0	6883.2	-10613.4	-216305.3	5506.5	-8490.8
13.0	-236583.9	-28000.0	23248000000.0	7255.0	-10519.0	-189267.2	5804.0	-8415.2
14.0	-202786.2	-24000.0	23872000000.0	7606.6	-10404.3	-162229.0	6085.3	-8323.5
15.0	-168988.5	-20000.0	24400000000.0	7938.8	-10270.2	-135190.8	6351.0	-8216.2
16.0	-135190.8	-16000.0	24832000000.0	8252.2	-10117.3	-108152.7	6601.8	-8093.9
17.0	-101393.1	-12000.0	25168000000.0	8547.3	-9946.1	-81114.5	6837.8	-7956.9
18.0	-67595.4	-8000.0	25408000000.0	8824.4	-9757.0	-54076.3	7059.5	-7805.6
19.0	-33797.7	-4000.0	25552000000.0	9083.8	-9550.1	-27038.2	7267.1	-7640.1
20.0	0.0	0.0	25600000000.0	9325.7	-9325.7	0.0	7460.6	-7460.6
21.0	33797.7	4000.0	25552000000.0	9550.1	-9083.8	27038.2	7640.1	-7267.1
22.0	67595.4	8000.0	25408000000.0	9757.0	-8824.4	54076.3	7805.6	-7059.5
23.0	101393.1	12000.0	25168000000.0	9946.1	-8547.3	81114.5	7956.9	-6837.8
24.0	135190.8	16000.0	24832000000.0	10117.3	-8252.2	108152.7	8093.9	-6601.8
25.0	168988.5	20000.0	24400000000.0	10270.2	-7938.8	135190.8	8216.2	-6351.0
26.0	202786.2	24000.0	23872000000.0	10404.3	-7606.6	162229.0	8323.5	-6085.3
27.0	236583.9	28000.0	23248000000.0	10519.0	-7255.0	189267.2	8415.2	-5804.0
28.0	270381.6	32000.0	22528000000.0	10613.4	-6883.2	216305.3	8490.8	-5506.5
29.0	304179.4	36000.0	21712000000.0	10686.7	-6490.1	243343.5	8549.3	-5192.1
30.0	337977.1	40000.0	20800000000.0	10737.5	-6074.7	270381.6	8590.0	-4859.7
31.0	371774.8	44000.0	19792000000.0	10764.4	-5635.3	297419.8	8611.6	-4508.2
32.0	405572.5	48000.0	18688000000.0	10765.6	-5170.2	324458.0	8612.5	-4136.1
33.0	439370.2	52000.0	17488000000.0	10738.7	-4677.0	351496.1	8591.0	-3741.6
34.0	473167.9	56000.0	16192000000.0	10680.7	-4152.7	378534.3	8544.6	-3322.2
35.0	506965.6	60000.0	14800000000.0	10587.9	-3593.6	405572.5	8470.3	-2874.9
36.0	540763.3	64000.0	13312000000.0	10455.2	-2994.6	432610.6	8364.1	-2395.7
37.0	574561.0	68000.0	11728000000.0	10275.5	-2348.7	459648.8	8220.4	-1878.9
38.0	608358.7	72000.0	10048000000.0	10039.1	-1646.0	486687.0	8031.3	-1316.8
39.0	642156.4	76000.0	8272000000.0	9730.8	-871.4	513725.1	7784.7	-697.1
40.0	675954.1	80000.0	6400000000.0	9325.7	0.0	540763.3	7460.6	0.0

OVERLOAD / SERVICE MARKERS (amplified Fa, Δ

Case	Fa_amp	ΔP_amp
Service – norma	120,000	4,000
CwD – elevated	320,000	9,000
CwD – severe (e	480,000	12,000
SET – post-expa	200,000	7,000
SET – expansion	420,000	11,000

CONNECTION R

Axial	ΔP
281,250.0	4,400.0
281,250.0	-3,600.0
-271,428.6	-3,600.0
-271,428.6	4,400.0
281,250.0	4,400.0



VME Quadratic – Yield / DF + Connection + Overload markers
15,000
10,000
5,000
0
-5,000
-10,000
-15,000
-800,000
-600,000
-400,000
-200,000
0
200,000
400,000
600,000
800,000
Differential Pressure (psi)
Axial Force (lbf)
12,000
11,000
9,000
7,000
4,000
Yield Upper
Yield Lower
DF Upper
DF Lower
Connection
Load / Overload points