CASING DESIGN FRAMEWORK

From Classical API Basis through Triaxial Modelling, Preliminary Seat Selection and Worked Verification, to Casing While Drilling, Expandable Tubulars, GRE, Connection Limits and Combined-Load Custom Cases

« Casing Design Framework »

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Companion Tools : Casing_Design_Limit_Check (Excel) | Classic VME Design Limit Plot (Python-generated) | Design Limit Plot with illustrative Connection Strength Envelopes | Casing Design Practice Area worked questions | WE Practice Area worked example

Revision History

Revision 11G — Consolidated theoretical baseline: classical uniaxial design (API TR 5C3 / ISO TR 10400), Von Mises ellipse, Casing While Drilling / Solid Expandable Tubular / GRE loads, material selection and PREN, contingency philosophy.

Revision 12G — Added the industrial Design Limit Plot (differential pressure versus equivalent axial load), the generic software load-case catalogue, and Connection Strength Envelopes (CSE) overlaid on the VME ellipse.

Revision 13C — Added the preliminary casing-seat-selection methodology (kick tolerance, top-down and bottom-up methods), a full worked numerical example of uniaxial selection and triaxial/biaxial verification (intermediate and production casings), explicit safety-factor formulas and plastic-collapse factors, and a dedicated section on corrosion, wear and fatigue.

Revision 14C -15C – 16C - formatting

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. Revision 13C retained the entire theoretical structure of revision 12G and extended it with the preliminary casing-seat-selection methodology (top-down, bottom-up and kick-tolerance approaches), a fully worked numerical example of uniaxial pipe selection and installation verification for an intermediate and a production casing string, the cementing, thermal and ballooning force methodology, the triaxial burst and biaxial collapse verification procedure applied at a cement-top station, the explicit safety-factor formulas and plastic-collapse design factors, and a dedicated treatment of corrosion, wear and fatigue effects on load resistance. Revision 14C changed none of that technical content; it applied the formal layout template — a standalone title page, a revision-history page, standardised running headers and footers, and an Index chapter with genuine page numbers. Revision 15C likewise changed no technical content; it corrected a language-consistency defect introduced by that layout template, so that the document — including the running headers, the title page and the revision-history page — is uniform in English throughout, matching the language of the technical content, with departures from English limited to proper names, connection trade names and source URLs. Revision 16C restores a figure — the Design Limit Plot of Section 14 — that was present in the original Revision 12G source and was inadvertently dropped to caption-only text during the intervening rewrites, and expands Section 14 with additional interpretive material; no other figures existed in the source document. Throughout the document the distinction between constant Design Factors and variable applied loads is maintained. No project, field or well name appears in this framework; the numerical examples reproduced in Sections 16 through 21 are generic training exercises used solely to illustrate the calculation method.

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. An additional figure superimposes illustrative Connection Strength Envelopes for API Round, API BTC, shouldered semi-premium and premium metal-to-metal connections on the same axes.

2. Hierarchical Schema of Technical Subjects

Casing design is organised as a hierarchy. Classical uniaxial capacities form the first level: burst by the Barlow equation with the 0.875 wall tolerance; collapse in the four API regimes Yield, Plastic, Transition and Elastic; axial tension and compression; and the historical biaxial interaction of collapse with axial load. The second level is triaxial design. Principal stresses axial, hoop and radial are combined by the Von Mises criterion and mapped onto an inclined ellipse. Phase 1 is the pure yield envelope. Phase 2 is the Design Limit Plot with Design Factors applied. The third level is the set of constant Design Factors: burst 1.10 to 1.25, collapse 1.00 to 1.125, axial compression 1.30, axial tension 1.60 to 1.80, triaxial typically 1.25. Connection Design Factors in common industrial use are of the order of 1.60 in tension, 1.40 in compression and 1.25 in pressure; they never replace manufacturer Connection Strength Envelope data.

The fourth level covers technology-specific load amplification. Casing While Drilling adds continuous torque and rotation, elevated torque and drag after the Johancsik model, lateral vibration and whirling, torsional stress on connections, and combined axial, bending and torsion. Solid Expandable Tubulars add expansion force, post-expansion properties, residual stress, high-torque expandable connections and near-monobore or contingency-liner applications. GRE systems add collapse resistance during cementing, thermal-cycle limits on rate and number of cycles, density-neutron transparency of thick collars, and hybrid steel plus GRE strings. Material selection sits beside these levels: PREN, 13Cr versus 22Cr and 25Cr duplex, and corrosion-resistant alloys for high chloride plus carbon-dioxide environments. Contingency philosophy covers H2S, total losses, scaling, thermal cycling, dual-skin or protective tie-back architecture, and standardisation by well family in high-volume programmes. A fifth level is the upstream preliminary stage: casing seat selection by kick tolerance, which fixes the number of strings and setting depths before any uniaxial or triaxial capacity check is performed. Visualisation closes the hierarchy: Design Limit Plots, Connection Strength Envelope overlaid on the same axes, and the software load-case catalogue described later.

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.

Step 0 – Casing seat selection. Starting from the bottom of the well, minimum setting depths are established by kick tolerance; the points are then fine-tuned against lithological and completion considerations to produce the preliminary casing and hole-size scheme. This step, detailed in Sections 15 to 17, precedes and conditions all subsequent capacity checks.

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, illustrated numerically in Section 19.

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 and inside the factored uniaxial rectangle are accepted; those that fall outside trigger an upgrade of grade or wall thickness. Section 21 works through this check at a cement-top station.

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. Custom loads that exist in the well (salt squeeze, sour service, carbon dioxide with chlorides, tectonics, thermal cycling, wear, annular pressure build-up, buckling) are entered at this step. In every case the Design Factors remain unchanged; only the applied loads increase.

Step 4 – Material, connection and contingency iteration. Fluid chemistry determines the required PREN. Thermal cycling limits restrict the use of GRE and dictate connection qualification. The Connection Strength Envelope of the connection that will actually be run is superimposed on the Design Limit Plot. A contingency matrix is prepared so that unexpected H2S, losses, scaling, salt or tectonic load 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, a different connection 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. Biaxial interaction of collapse with tension remains part of the classical step and must not be omitted before the triaxial plot is drawn.

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 ellipse (Design Factor applied), horizontal and vertical lines for the factored uniaxial ratings, and discrete markers or traces for each design load case. A load case is acceptable when it lies inside the inner ellipse and inside the factored uniaxial limits. Section 22 gives the explicit safety-factor formulas underlying this implementation.

6. Industrial Design Limit Plot: Differential Pressure versus Equivalent Axial Load

The industrial Design Limit Plot used by StressCheck and comparable packages places Equivalent Axial Load on the horizontal axis, in lbf, with compression to the left (negative) and tension to the right (positive). Differential Pressure occupies the vertical axis, in psi: burst upward when internal pressure exceeds external pressure, collapse downward in the opposite case. Equivalent Axial Load is not true axial force alone. It combines mechanical axial force with the counter-load pressure contribution so that the triaxial ellipse remains consistent with API burst and collapse ratings.

Two pipe-body envelopes are drawn. The red ellipse is the triaxial Von Mises envelope with a Design Factor typically 1.250. The black rectangle carries the factored uniaxial limits observed in industrial plots: Burst 1.100 at the top, Collapse 1.000 at the bottom, Compression 1.300 on the left, Tension 1.300 on the right. Software notes that these limits are approximate. A load case is acceptable only when it remains inside the factored VME ellipse and inside the factored uniaxial rectangle. Leaving either envelope requires an upgrade of grade, wall or connection.

Quadrant reading is part of the protocol. The upper-right quadrant is burst plus tension; the uniaxial criterion alone is often conservative there. The lower-left quadrant is collapse plus compression; this is the domain of salt squeeze, hot thermal cycles and tectonic load, and it is where the uniaxial criterion alone is insufficient. Pure tension at near-zero differential pressure is frequently governed by the connection before the pipe body. Pure compression at near-zero differential pressure immediately discriminates threads that have no positive torque shoulder.

7. Generic Software Load-Case Catalogue

Industrial casing-design software generates a standard catalogue of operational load cases. The traces commonly plotted on the Design Limit Plot are Lost Returns with Water, Pressure Test, Green Cement Pressure Test in burst, Drill Ahead in burst, Full or Partial Evacuation, Cementing, Drill Ahead in collapse, Running in Hole, Overpull Force, Pre-Cement Static Load, Post-Cement Static Load, and Green Cement Pressure Test in axial. Complementary depth plots (burst, collapse, axial and triaxial versus measured depth) locate the critical station along the string. The Design Limit Plot gathers those stations into a single decision plane. The catalogue is a starting set, not a closed list. Any physically real load missing from the catalogue is entered as a Custom Load. Sections 18 to 21 work a specific instance of this catalogue — Kick Internal Pressure, Ambient Collapse, Early Life Hot Kill and Hot Collapse — through to numerical pipe selection and triaxial verification.

8. Design Factors Remain Constant

The introduction of Casing While Drilling, expandable tubulars, GRE, salt, sour service or tectonic load does not alter the numerical values of the Design Factors. What changes is the severity of the loads that are applied to the pipe and to the connection. The same ellipse and the same safety margins are used; the engineer plots more demanding load points and, when necessary, selects a stronger tubular or a stronger connection. Typical minimum values remain: Burst 1.10–1.25, Collapse 1.00–1.125, Axial tension 1.60–1.80, Axial compression 1.30, Triaxial 1.25. Connection working values commonly used for screening are Tension 1.60, Compression 1.40 and Pressure 1.25. A flat ratio such as eighty percent of pipe-body yield is not a design.

9. 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.

A TU Delft simulation study of a geothermal CwD producer well (Nooney, 2015) evaluated the pipe body under uniaxial, biaxial and Von Mises triaxial criteria, superimposed a Johancsik torque-and-drag model, and separately computed the critical loads for sinusoidal buckling and lateral whirling as a function of wellbore inclination, weight on bit and surface rotary speed. The study found that torsional stress from continuous surface torque, rather than the bending stress produced by buckling or whirling, was generally the controlling failure mechanism, because its magnitude is comparatively higher and because conventional casing connections have relatively low torque capacity. Torque-and-drag and buckling/whirling analysis should therefore be run alongside the pipe-body triaxial check before a connection family is finalised for CwD service.

10. 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. The Connection Strength Envelope after expansion is not the pre-expansion envelope; it must be replotted on the expanded geometry.

11. 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. Exceeding those limits produces progressive matrix damage and micro-cracking. Thick fibreglass collars can be transparent to density-neutron logging tools, allowing open-hole quality logs to be recorded through the collar. Hybrid steel plus GRE strings combine the mechanical strength of steel with the corrosion resistance and logging transparency of GRE. GRE limits belong in the drilling programme and in the procurement specification, not only in the design note.

12. 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. Sour service is defined by NACE MR0175 / ISO 15156. Typical maximum grade under sour conditions is L80, with Rockwell hardness not exceeding 23. Aggravating factors for sulphide-stress cracking are falling temperature, rising H_2S partial pressure, hardness, applied stress, falling pH and the presence of oxygen or carbon dioxide. Wall loss from corrosion and wear must be applied to the ratings before the Design Limit Plot is drawn; Section 23 details how each uniaxial rating is affected. Manufacturer material-selection guides list expandable grades and GRE-liner options under special applications and corrosion mitigation.

13. Custom Loads That Must Be Superimposed When They Exist

Automatic software load cases do not exhaust the physical inventory. As soon as a constraint is geologically or chemically plausible it is entered as a Custom Load on the same Design Limit Plot. Design Factors stay constant; only point severity increases.

Salt squeeze. External pressure is no longer hydrostatic alone. Flowing salt applies an additional confinement, historically often taken at an order of magnitude of at least one psi per foot over the squeezing interval. The case plots as collapse plus compression. High-collapse pipe or a dedicated salt-interval architecture may be required. Section 18 recalls, from first principles, why salt is capable of generating such point loads and how they are combated.

H2S. Sour service restricts the admissible material rather than reshaping the ellipse. The NACE / ISO 15156 envelope applies. A grade acceptable in sweet service may be prohibited in sour service.

Carbon dioxide with chlorides. General corrosion and pitting set the PREN. Thirteen-chrome is often insufficient at high chloride. Duplex 22Cr or 25Cr is evaluated when the PREN requires it. Metal-to-metal seals are also exposed to pitting.

Tectonics. Fault shear, reservoir compaction, formation slip and foundation loads produce non-hydrostatic axial force and bending. They are entered as custom axial force plus moment and shift traces toward compression or out of the ellipse.

Thermal cycles. Expansion locked by cement on heat-up, tension on cool-down. Critical for geothermal service, cold injection, steam and carbon-dioxide injection. Cyclic traces must appear on the plot. Connections then require ISO 13679 / API RP 5C5 qualification and a thermal protocol of the TWCCEP type. Section 20 gives the explicit thermal- and ballooning-force formulas used to generate these traces.

Remaining relevant loads. Adhesive, abrasive or three-body wear, commonly taken as a ten-percent wall reduction for surface-string burst, and detailed further in Section 23. Annular pressure build-up after cementing. Buckling on incomplete top of cement or a poorly landed hanger. Overpull, shock and drag during installation. Full or partial evacuation. Green cement when slurry density exceeds the internal fluid.

14. 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. 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. Real designs must use manufacturer CSE data obtained under ISO 13679 / API RP 5C5, preferably CAL IV, and under a thermal protocol such as TWCCEP when cycles are present.

API Round (STC / LTC). V-thread. Seal by thread compound only. Tension efficiency often sixty to eighty percent of pipe-body yield. Jump-out is common. The CSE is narrow in tension plus burst and very small in compression. Use is limited to vertical wells, liquid service and modest pressure.

API BTC. Trapezoidal profile. Tension capacity often close to one hundred percent of pipe-body yield. No metal-to-metal seal. Seal by threads plus compound. Compression is well below pipe-body capacity because there is no positive torque shoulder. Jump-out remains possible under tension plus internal pressure: the positive load flank of about three degrees flares the box. Under thermal cycles or gas the compound degrades and the helical leak path opens, shrinking the CSE further.

Shouldered semi-premium. A torque shoulder is added to a buttress-type thread. Compression capacity and make-up control improve. Seal still depends largely on compound. The CSE sits between BTC and a gas-tight premium.

Premium metal-to-metal (VAM TOP, TenarisHydril Blue and equivalents). Radial metal-to-metal seal, torque shoulder, often a hooked thread with negative load flank. Gas tightness does not rely on compound. The CSE is wider in burst, in tension and especially in compression. Thermal-cycle and bending performance improve. Make-up must be performed with a tubular-running or jam unit, power tongs and live torque-turn. Typical acceptance windows are shoulder torque between five and seventy percent of final make-up torque and delta-turns between 0.01 and 0.10 turn. Manufacturer accept and reject graphs belong in the field procedure. Make-up records and the CSE are archived for the well life, commonly twenty-five to thirty years, in a storage system that meets the applicable national integrity and provenance rules.

High-torque and expandable connections. The CSE is specific before and after expansion. Post-expansion geometry and residual stress change the envelope; the pre-expansion CSE is not reused.

Protocol. Draw the pipe-body ellipse and the uniaxial rectangle. Overlay the CSE of each candidate family. Plot every load case, including custom loads. Accept only the pipe-plus-connection pair whose traces remain inside both envelopes. Design Factors are not changed when a point leaves the CSE while still inside the pipe-body ellipse; the thread is changed.

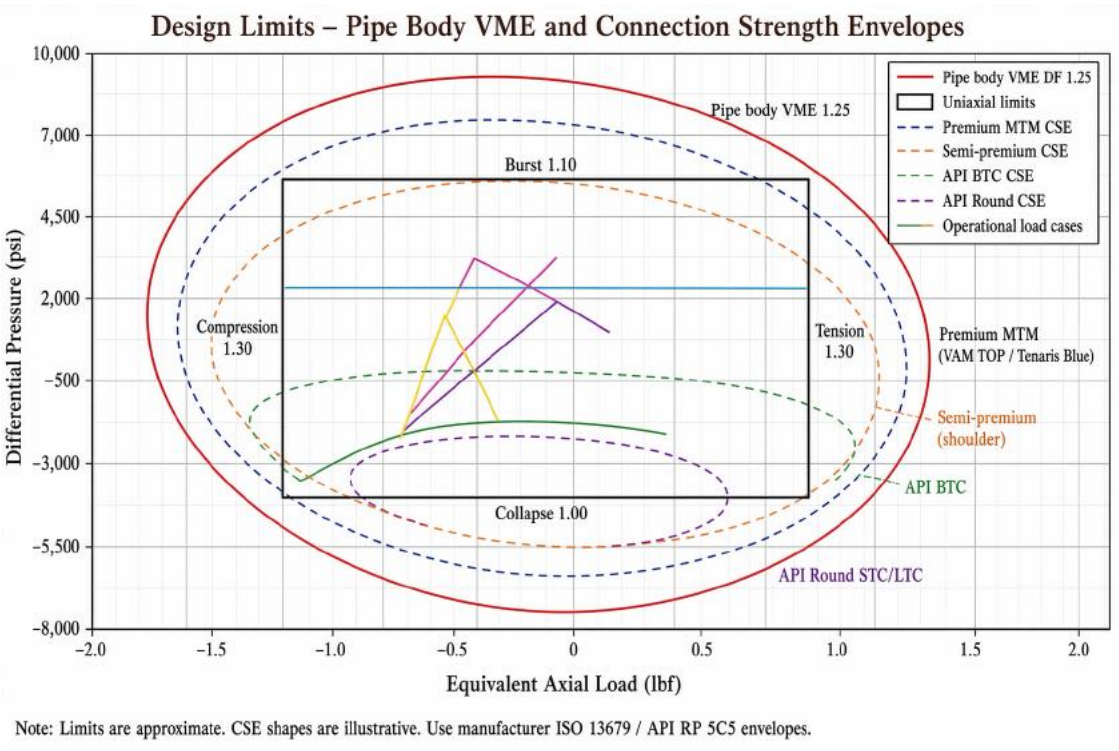

Figure. Illustrative Design Limit Plot: pipe-body VME ellipse at Design Factor 1.25, uniaxial rectangle Burst 1.10 / Collapse 1.00 / Tension 1.30 / Compression 1.30, and nested Connection Strength Envelopes for premium metal-to-metal, shouldered semi-premium, API BTC and API Round. Envelope shapes are pedagogical. Manufacturer ISO 13679 / API RP 5C5 data replace them in a live design.

Reading the figure. The outer red curve is the pipe-body Von Mises envelope already scaled by the triaxial Design Factor of 1.25; nothing plotted outside it is admissible regardless of connection. The black rectangle is the factored uniaxial box from Section 6 (Burst 1.10 at the top, Collapse 1.00 at the bottom, Compression 1.30 on the left, Tension 1.30 on the right) and must independently contain every load point — a trace can sit inside the VME ellipse and still fail the uniaxial box, and vice versa near the corners. The four dashed curves are the nested Connection Strength Envelopes: the premium metal-to-metal envelope (dark blue) is visibly the widest in every quadrant, in particular in compression, which is exactly why it is favoured for Casing While Drilling and thermal-cycling service (Sections 9 and 13); the shouldered semi-premium envelope (orange) sits between it and API BTC, gaining compression capacity from its torque shoulder while still relying on compound for the seal; the API BTC envelope (green) is markedly narrower in compression, consistent with the absence of a positive torque shoulder described earlier in this section; and the API Round STC/LTC envelope (purple) is the narrowest of all four, particularly on the tension side, illustrating why its use is confined to vertical wells and modest pressure. The solid green trace inside all four envelopes is an illustrative set of operational load cases from the catalogue of Section 7 — cementing, drilling and production points strung together — and it is this trace, not the pipe-body ellipse alone, that must be checked against the innermost of the connection envelopes actually being run; a scheme built on API Round would already leave this particular trace outside its CSE in the lower-left, collapse-plus-compression quadrant, which is the practical reading a design engineer takes from the plot before ever opening StressCheck or the companion workbook.

15. Preliminary Casing Design – Casing Seat Selection Methodology

Casing design proceeds in two stages. The preliminary stage delivers the casing and hole sizes and the casing setting depths. The detailed stage, addressed in Sections 4 through 14 and again numerically in Sections 18 to 21, delivers casing weight, grade, coupling selection, wellhead interface and sealing-liner system. A drilling liner provides zonal isolation or additional shoe strength where the previous casing is already strong enough to withstand the pressure loads generated by drilling to the next total depth. A production liner is set across the reservoir section where the production casing above is strong enough to withstand service loads for the life of the well. In both cases the liner reduces the time and cost of running a full string back to the wellhead. The final hole size is governed primarily by completion size, logging requirements, coring requirements and well-testing requirements; the final casing or liner size follows from the hole size above it, the completion outside diameter, production-logging access, perforating-gun clearance, zonal-isolation requirements and local pipe availability.

Two methods are most appropriate for initial casing-seat selection: the top-down method and the unlimited-kick-volume method. The limited-kick-volume method is more appropriate once the design is being finalised, because it additionally requires the planned hole size and bottom-hole-assembly geometry, and a realistic estimate of kick volume — either a standard organisational value or a value modelled with a well-control simulator — which in turn demands a level of local operational knowledge that is not always available at the preliminary stage.

The order of priority for fixing casing shoe depths follows a bottom-up logic even though the seat-selection plot itself may be read top-down. Design starts from the bottom of the well and is based initially on kick tolerance, so as to determine the minimum setting depth needed to reach each subsequent casing point. Once these depths are fixed for every string on which a BOP or diverter will be installed, they are fine-tuned against lithological considerations — unstable formations, shallow hydrocarbons, lost-circulation zones, freshwater horizons and the risk of borehole failure from prolonged chemical exposure to the drilling fluid — to obtain the final casing shoe depth and, in combination with logging, testing, production and contingency requirements, the minimum casing size.

Two categories of input are required. Top-down and unlimited-kick-volume calculations need the local pore-pressure and formation-strength regimes together with the margins that will be held above pore pressure and below fracture pressure. Limited-kick-volume calculations additionally need the planned hole sizes and BHA geometry, with the probable kick volume estimated either from a standard organisational value or from well-control modelling software. Formation strength is normally sourced from leak-off or limit tests in offset or nearby wells; the principal limitation is that such data is only strictly valid at similar inclination and azimuth, and does not describe true formation strength — particularly when limit-test rather than leak-off data is used — so the strength is often under-estimated and the resulting casing setting depths run deeper than strictly required.

Kick tolerance describes the capacity of the well's pressure envelope — BOP, wellhead, casing and open-hole formations — to withstand the pressures generated when the well is shut in following a kick, whether due to swabbing or to drilling into an over-pressured zone, and during the subsequent well-control operation, whether by bullheading or by circulating the influx to surface. At any point in the well the drilling-fluid density must simultaneously exceed the pore pressure, to prevent an influx, and remain below the formation strength, to prevent losses or fracture; safety margins are conventionally applied to both limits, commonly of the order of plus or minus 200 psi (or a fractional ppg equivalent) above pore pressure and 100 to 200 psi below formation strength.

16. Worked Method: Top-Down, Bottom-Up and Gas-Kick-Tolerance Seat Selection

The top-down method converts the pore-pressure and fracture-pressure profile to equivalent mud-weight gradients, adds a trip margin above the minimum mud weight and subtracts a fracture margin from the maximum mud weight, then plots both curves against depth. Starting from surface, a vertical line is dropped from the running maximum-mud-weight point until it meets the minimum-mud-weight line; that intersection fixes the next casing setting depth, and the process repeats from the new maximum-mud-weight value. In a representative training data set covering roughly 1,000 to 13,000 ft TVD, applying a 0.5 ppg margin above pore pressure and a 0.75 ppg margin below fracture pressure yields setting depths at approximately 2,000, 5,400, 8,100 and 11,800 ft TVD, with an additional string possibly required at total depth depending on the final over-pressured interval.

The bottom-up, kick-tolerance method instead works in constant pressure rather than constant gradient. Starting from total depth, a vertical line is drawn upward from the minimum acceptable pressure (pore pressure plus a fixed psi margin, representing an uncontrolled influx with no gradient), and its intersection with the maximum acceptable pressure line (fracture pressure minus a fixed psi margin) fixes the next casing point upward; the process repeats until the required separation between the two lines can no longer be generated. Because the margins are expressed as constant pressures rather than constant gradients, and are typically larger in absolute terms near the shallow section, this method generally produces a materially higher number of casing strings than the top-down, constant-gradient approach applied to the same pressure data.

A third, physics-based check applies specifically to the kick-tolerance depth immediately above a target reservoir. Assuming a swabbed influx of known volume that behaves as an ideal gas (pV = constant) and is displaced up the annulus by the Driller's Method at constant bottom-hole pressure, the height and density of the influx are recalculated at successive positions as it migrates toward surface: as the confining pressure falls the influx volume increases and its density falls proportionally, so both the height of the gas column and the pressure at its top change at each step. Plotting the resulting pressure at the top of the migrating influx against depth, together with the formation-strength profile, identifies the depth at which the influx pressure would exceed formation strength; the minimum casing shoe depth must be at or below that intersection. In a representative metric worked case (8-1/2 in hole to 3,600 m TVD, a 4.75 m3 kick on bottom, a 2.25 kPa/m initial influx gradient), the intersection — and hence the minimum required shoe depth — occurs at approximately 2,550 m TVD.

17. Casing Shoe Depth: Reasons Other Than Kick Tolerance

Kick tolerance is rarely the only driver of a casing setting depth. Independent reasons to set a shoe include isolating overlying unstable formations, isolating overlying shallow hydrocarbon zones, isolating overlying lost-circulation intervals, isolating overlying freshwater horizons, and preventing borehole failure caused by timedependent chemical instability from prolonged exposure to the drilling fluid. Exploration wells that must reach a coring or logging target through a small final hole size are typically designed with two candidate schemes at the seat-selection stage: a conventional scheme that reaches total depth one hole size larger than strictly required, preserving one full level of contingency, and a less conventional scheme using a tighter combination of hole and casing sizes, which trades away contingency for reduced total footprint and commonly requires special clearance couplings or low-weight, special-drift casing. Solid Expandable Tubulars (see Section 10) offer, in principle, an alternative path to a near-monobore scheme by expanding a scab or drilling liner close to the original casing internal diameter, reducing the number of hole-size steps that would otherwise be required.

18. Detailed Casing Design – Load Case Determination Principles

Design loads can be expected to act on a casing string during installation of the string, during subsequent drilling in open hole below the shoe, and during later operation of the well — testing, production or injection. Three further factors affect the ability of a string to withstand a load over the life of the well: corrosion, fatigue and casing wear, each treated in Section 23. Triaxial stress analysis is the only realistic assessment of load-carrying capacity because it compares the combined effect of radial, tangential and axial stresses in the casing wall with the material yield strength, rather than checking burst, collapse and axial capacity independently as the classical uniaxial method does.

Annulus-fluid density is degraded back to its base fluid — water for water-based systems, base oil for oil-based systems — when evaluating longer-term production burst loads, on the assumption that solids and weighting material will eventually settle out; the same degradation is not assumed for collapse loads, which are evaluated with the original, undegraded fluid density. Salt can plastically deform around the pipe and generate very high external point loads, in extreme diapiric cases approaching the overburden gradient; the load acts laterally and does not itself alter the hydrostatic pressure profile above or below the salt. The majority of pressure loads on casing originate from changes in the internal pressure profile: an increase produces burst loading, a reduction produces collapse loading.

Drilling temporarily perturbs the local geothermal gradient, warming shallow formations and cooling deeper ones for as long as circulation continues; once circulation stops the formations gradually return to the undisturbed gradient. Production of oil and gas circulates hot reservoir fluid up the tubing, progressively heating the tubing, the annular fluids and, over a longer period, the surrounding formation, with a slow return to the undisturbed gradient once production stops. Water injection has the opposite effect, cooling the annular fluids, casing and near-wellbore formation for the duration of injection. These same temperature excursions are the physical basis of the thermal-force calculation given in Section 20.

19. Worked Example: Uniaxial Burst and Collapse Pipe Selection

The following training example illustrates, with representative figures, how the preceding sections combine into a pipe-selection decision for a deviated offshore development well (RKB elevation 80 ft, water depth 410 ft, total depth 19,200 ft MD). The well path is vertical to 2,750 ft MD, builds to 45° inclination by 5,000 ft MD at a dogleg severity of 2°/100 ft, and holds tangent to total depth. The illustrative casing scheme is summarised below.

OD (in)	Name	Hole size (in)	Shoe MD (ft)	Shoe TVD (ft)	Mud at shoe (ppg)
30	Conductor	36	690	690	8.6
18-5/8	Surface casing	24	1,280	1,280	8.75
13-3/8	Intermediate casing	16	9,200	7,745.6	10.3
9-5/8	Production casing	12-1/4	16,200	12,695.3	10.8

OD (in)	Name	Hole size (in)	Shoe MD (ft)	Shoe TVD (ft)	Mud at shoe (ppg)
7	Production liner	8-1/2	19,200	14,816.6	11.8

For the 13-3/8 in intermediate casing the governing burst load is a Kick Internal Pressure Design: a gas kick is assumed at the next section total depth, using the maximum pore-pressure equivalent mud weight at that depth plus a 0.5 ppg margin, with the gas column pressure profile capped, where it would otherwise exceed it, by the formation-strength value at the 13-3/8 in shoe (an assumed 0.1 psi/ft gas gradient is used in the absence of measured gas properties). The governing collapse load is an Ambient Collapse case, in which the mud inside the casing is lost to the open-hole formation at whichever depth produces the largest drop in mud level, evaluated across the full pore-pressure profile below the shoe. In the illustrative data set this combination produces a maximum burst load of 4,099 psi at the wellhead and a maximum collapse load of 539 psi at the resulting mud level; against a Minimum Acceptable Design Safety Factor of 1.25 in burst and 1.0 in collapse, a 72 ppf L-80 pipe (5,380 psi burst rating, 2,669 psi collapse rating) satisfies both loads, giving minimum safety factors of 1.31 in burst and 4.96 in collapse. The same pipe is then checked, unfactored for wear, against the running/installation axial load obtained by superimposing dry weight, buoyant force and bending force through the build section; a Minimum Acceptable Design Safety Factor of 1.4 in tension and 1.1 in compression is applied to the pipe-body axial rating for this check.

For the 9-5/8 in production casing the governing burst load is an Early Life Hot Kill: the shut-in tubing pressure is derived from the formation pressure at the perforation depth minus the static reservoir-fluid hydrostatic gradient, a bullheading margin (500 psi in this development-well example) is added, and the resulting pressure is applied above a completion-fluid column with the packer location conservatively ignored. The governing collapse load is a Hot Collapse case assuming full evacuation of the casing to atmospheric pressure. In the illustrative data set this combination produces a maximum burst load of 7,545 psi at the cement top and a maximum collapse load of 7,394 psi at the shoe; a 53.5 ppf P-110 pipe (10,900 psi burst rating, 7,950 psi collapse rating) satisfies both loads at the same Minimum Acceptable Design Safety Factors, giving minimum safety factors of 1.44 in burst and 1.08 in collapse — the latter close enough to unity that it is carried forward into the biaxial collapse check of Section 21.

20. Cementing Axial Load, Thermal and Ballooning Force Methodology

The axial load at initial conditions, immediately after cementing, is obtained by superimposing three components along the string: the dry weight of the casing hanging below each point of interest; the buoyant force generated by the pressure exerted, at the assumed float-collar location, by the mud column inside the casing against the mud-plus-slurry column outside it; and the bending force generated wherever the string passes through a build section, calculated from an augmented dogleg (the planned value plus an allowance, typically of the order of 2°/100 ft, for tortuosity). Where a tail slurry occupies part of an inclined section, its true-vertical-depth length — rather than its measured-depth length — is used in the external-pressure calculation.

Subsequent thermal and ballooning forces are calculated only over the free, uncemented length of the string and are added to the initial-conditions axial load to obtain the axial force at the end of the load case being analysed. The thermal force is $\Delta F(\text{thermal}) = -\alpha \times E \times As \times \Delta T$, where α is the coefficient of thermal expansion of steel (approximately 6.9×10^{-6} °F^{-1}), E is Young's modulus for steel (approximately 3.0×10^{7} psi), As is the cross-sectional steel area of the pipe, and ΔT is the change in the average temperature over the free length between the undisturbed geothermal profile assumed at cementing and the operating — production or injection — temperature profile; the undisturbed gradient is conservatively used as the initial condition even though the well was warmer while circulating. The ballooning force is $\Delta F(\text{ballooning}) = 2 \times \nu \times (\Delta IP \times A(ID) - \Delta EP \times A(OD)) + \nu \times L \times (\Delta\rho(i) \times A(ID) - \Delta\rho(o) \times A(OD))$, where ν is Poisson's ratio for steel (0.3), ΔIP and ΔEP are the changes in surface internal and external pressure between cementing and the load case, Δρ(i) and Δρ(o) are the corresponding changes in internal and external fluid gradient, and L is the free length. For a full-evacuation collapse load, where no thermal excursion is assumed, only the ballooning term is carried forward; for a hot burst or hot collapse load evaluated at production temperature, both the thermal and the ballooning terms apply.

21. Triaxial Burst and Biaxial Collapse Verification – Worked Method

At the depth of interest — typically the cement top, where the free length above changes to a cemented, axially restrained section below — the triaxial check requires the three principal stresses at the end of the load condition. The axial stress without bending is the uniform axial force at that depth (the cementing axial load from Section 20, plus the thermal and ballooning increments for the load case under review) divided by the steel cross-sectional area, itself reduced for an assumed wear allowance (commonly of the order of 8 percent of nominal wall) to remain conservative. The bending stress is $\sigma(b) = \pm 218 \times D \times \phi$, evaluated separately at the pipe outer wall using the nominal outside diameter and at the pipe inner wall using an inside diameter increased for both minimum-wall manufacturing tolerance (87.5 percent of nominal wall per API) and wear allowance; the dogleg ϕ used is the planned value plus an allowance for drilling tortuosity and, for a production load evaluated after cementing, a further allowance for buckling-induced curvature of the uncemented section (of the order of 1 to 1.5°/100 ft). The uniform and bending components are summed algebraically at each of the four wall/bend-side combinations (outer wall concave side, inner wall concave side, inner wall convex side, outer wall convex side) to give four axial-stress values.

Radial stress follows directly from the Lamé thick-wall relations: at the pipe inner wall σ(r) equals minus the internal pressure, and at the pipe outer wall σ(r) equals minus the external pressure, both taken at the end of the load case. Tangential stress at the inner and outer wall follows the corresponding Lamé equations combining internal pressure, external pressure and the inner and outer cross-sectional areas (the inner area itself adjusted for wall tolerance and wear where the bending-stress calculation used the adjusted inside diameter). The Von Mises equivalent stress is then evaluated at each wall/bend combination as the square root of one half of the sum of the squared differences between each pair of the three principal stresses (tangential, radial, axial); the governing value is the maximum across the four combinations, which typically occurs at the inner wall on the concave, negative-bending side of the dogleg.

The yield strength used for comparison is de-rated for temperature. In the absence of a manufacturer-specific de-rating schedule, a value of 0.03 percent loss of yield per degree Fahrenheit above 70°F is an accepted default: $Yp(derated) = Yp \times (1 - 0.03\% \times \Delta T)$, with ΔT taken from 70°F to the operating temperature at the depth of interest. The triaxial safety factor is then the derated yield divided by the governing Von Mises stress; a value at or above the Minimum Acceptable Design Safety Factor, typically 1.25, verifies the pipe for the load case at that depth.

Biaxial collapse verification follows a related but distinct path. The axial force at the depth of interest for the specific collapse load under review (for example an ambient, full-evacuation collapse with no thermal excursion) is obtained from the initial cementing axial load plus the applicable ballooning increment, and the corresponding axial stress Sa is obtained by dividing by the steel cross-sectional area. This axial stress reduces the effective collapse yield through $Ypa = [\sqrt{1 - 0.75 \times (Sa/Yp)^2} - 0.5 \times (Sa/Yp)] \times Yp$, using the temperature-derated Yp appropriate to the (generally cooler, undisturbed) collapse load condition. Where the pipe's outside-diameter-to-wall-thickness ratio places it in the API plastic-collapse regime, the biaxially downrated collapse capacity is $Pp = Ypa \times [A/(OD/t) - B] - C$, with the empirical factors A, B and C taken from the plastic-collapse-factor table in Section 22 for the grade concerned, or for the nearest de-rated equivalent when the actual derated yield falls between listed grades. The resulting collapse capacity is compared with the maximum collapse differential pressure at the same depth to obtain the biaxial collapse safety factor.

22. Safety Factor Formulas and Plastic Collapse Design Factors

The Barlow burst equation, with the API 0.875 minimum-wall-tolerance factor, is P(burst) = 0.875 × (2 × Yp × t / Do), where Yp is pipe-body yield strength, t is nominal wall thickness and Do is nominal outside diameter. Following the safety-factor convention set out in API TR 5C3 (7th edition) and reproduced in common industrial screening notes, the four governing safety factors are SF(axial) = Y(cor) / σ(a), the corrected yield strength divided by axial stress; SF(burst) = pb / Δp, burst rating divided by differential pressure; SF(collapse) = pc / Δp, collapse rating divided by differential pressure; and SF(triax) = Yp / VME(cor), temperature-corrected yield divided by the corrected Von Mises equivalent stress. These four ratios are the quantities compared, load case by load case and station by station, against the Minimum Acceptable Design Safety Factors listed in Sections 6 and 8.

The empirical A, B and C factors used in the plastic-collapse formula of Section 21 are grade-dependent and are reproduced below for the common casing grades.

Grade	A	B	C
K-55	2.991	0.0541	1,206
L-80	3.071	0.0667	1,955
C-90 / X-95	3.124	0.0743	2,404
G-105	3.162	0.0794	2,702
P-110	3.181	0.0819	2,852
Q-125	3.239	0.0895	3,301
S-135	3.278	0.0946	3,601

Where the temperature-derated yield strength of the pipe falls between two listed grades, it is acceptable screening practice to use the A, B and C triplet of the nearest lower listed grade rather than interpolating, consistent with the treatment shown in Section 21.

23. Corrosion, Wear and Fatigue – Effects on Load Resistance

Corrosion reduces load resistance in two distinct ways: by removing metal volume and so reducing the effective wall thickness used in every uniaxial and triaxial rating, and by weakening the casing material itself, lowering its resistance ratings; in the presence of an unsuitable grade for the service, cracking failure of the pipe body can occur at stresses well below yield through environmentally assisted mechanisms. The principal mitigations are the use of corrosion-resistant alloys, corrosion inhibitors (realistic mainly in production tubing), plastic-coated pipe (realistic mainly for internal tubing corrosion) and cathodic protection; the appropriate combination is location- and fluid-chemistry-specific and should be confirmed against local or regional corrosion data (see also Section 12 on PREN and sour-service grade limits). Of the three uniaxial ratings, burst resistance is normally the most severely affected by corrosion, degraded by both general wall-thickness reduction and localised pitting; collapse resistance is comparatively little affected except where local pitting produces a significant local wall-thickness reduction; axial strength is affected only by very severe wall loss, sufficient to meaningfully reduce the cross-sectional steel area.

Casing wear results mainly from the rotation of drill-string tool joints against the internal wall of the casing, and requires the combination of a significant contact force, an abrasive contact surface and extended rotation concentrated at one point — conditions most often met in deviated or extended-reach wells with prolonged rotary drilling below a given casing shoe. Wear is detected, combated or compensated locally through wear modelling ahead of the well, the use of smooth hardfacing on drill-string components, non-rotating drill-pipe protectors, optimised directional-drilling design to minimise contact-force concentrations, reduced string rotation through the use of mud motors across the affected tangent sections, deliberately increased wall thickness of casing run across identified high-wear intervals, and monitoring by metal-recovery analysis or dedicated casing-wear logs. As with corrosion, burst resistance is normally the most severely affected uniaxial rating, degraded by both general wall-thickness reduction and localised, typically high-side, wear; collapse resistance is little affected except where there is a general overall reduction in wall thickness; axial strength is affected only by very severe wall loss.

Fatigue is introduced, in the hierarchy of Section 2, alongside corrosion and wear as one of the three factors governing a string's ability to withstand load over the life of the well. In casing service it arises principally from cyclic bending in a dogleg during rotation (relevant to Casing While Drilling, Section 9), from repeated thermal cycling of a producing or injecting well (Sections 13 and 20), and from cyclic pressure testing or well-control events; it is managed by limiting cyclic stress amplitude relative to the applicable material S-N behaviour, by the thermal-cycle qualification protocols referenced in Section 13, and, for CwD strings, by keeping rotating time and rotary speed consistent with the torsional and bending-stress limits identified in Section 9.

24. Contingency and Operational Philosophy

A contingency matrix lists the actions required if H2S, total losses, severe scaling, excessive thermal cycling, unanticipated salt squeeze, tectonic shear or connection leak occur. Mitigation routes are defined in advance: grade upgrade, dual-skin or protective tie-back, change of connection family, high-collapse interval, or remedial cement. 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. Provenance of pipe and connections is retained so that barrier integrity can be reconstructed over the well life.

25. Visualisation and Supporting Tools

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 described in Section 5 and applies the formulas of Section 22. A deliberate CwD load point is placed outside the DF envelope to demonstrate a failed check. Industrial software such as StressCheck produces the same plane in equivalent-axial-load versus differential-pressure coordinates and plots the software load-case catalogue of Section 7 as coloured traces. Recommended companion files are the Casing_Design_Limit_Check series, the VME classic plot, the illustrative pipe-body-plus-CSE figure, and the Section 15-21 worked calculation set, all issued with this revision.

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CASING-DESIGN-FRAMEWORK-2026 Revision 15C, 4 September 2026 (technical content retained in full; document-wide language consistency corrected).

CASING-DESIGN-FRAMEWORK-2026 Revision 14C, 4 September 2026 (technical content retained in full; formal layout template applied).

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CASING-DESIGN-FRAMEWORK-2026 Revision 11G, 18 August 2026 (superseded theoretical baseline retained in full by every subsequent revision).

27. Definition of Acronyms

APB – Annular Pressure Build-up

API – American Petroleum Institute

BHA – Bottom Hole Assembly

BTC – Buttress Thread and Coupling

CAL – Connection Application Level (ISO 13679 / API RP 5C5)

CITHP – Closed-In Tubing Head Pressure

CSE – Connection Strength Envelope

CwD – Casing While Drilling

DF – Design Factor

DLS – Dogleg Severity

EMW – Equivalent Mud Weight

GRE – Glass Reinforced Epoxy

LTC – Long Thread and Coupling (API Round)

MADSF – Minimum Acceptable Design Safety Factor

MD – Measured Depth

OBM – Oil-Based Mud

PREN – Pitting Resistance Equivalent Number

SET – Solid Expandable Tubular

STC – Short Thread and Coupling (API Round)

StressCheck – Landmark / Halliburton casing-design software producing the industrial Design Limit Plot

TOC – Top Of Cement

TRS – Tubular Running Services

TVD – True Vertical Depth

TWCCEP – Thermal Well Casing Connection Evaluation Protocol

VME – Von Mises Ellipse / Von Mises Equivalent

WOB – Weight On Bit

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