Sucker Rod String Design – Load, Stress and Taper Selection Guide

Design Workflow, Key Methods and Practical Guidance



01 | DESIGN OVERVIEW AND ENGINEERING WORKFLOW

Guide Overview

A practical engineering reference for designing uniform and tapered sucker rod strings. This guide presents a complete, step-by-step workflow to evaluate rod configurations, loads, stresses and taper selection, and to develop a final rod tally for field implementation.

What This Guide Covers

This guide covers:

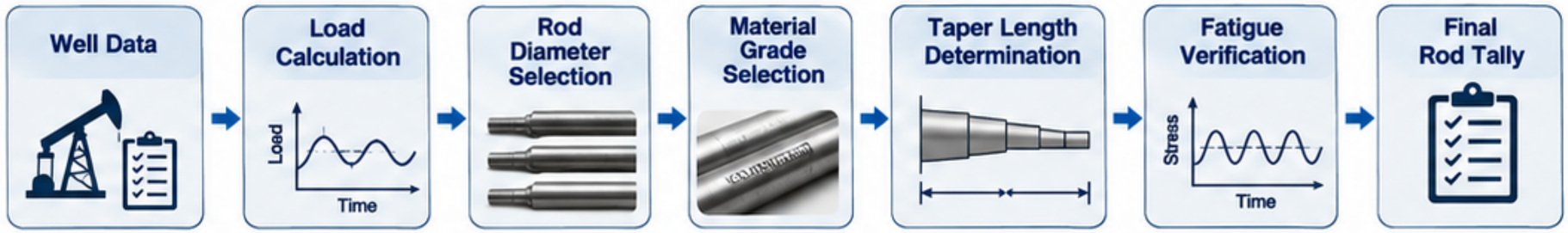
- Design inputs and required well data.
- Static and dynamic loads along the rod string.
- Axial stress evaluation in the rods.
- Rod diameter and rod grade selection.
- Taper section length determination.
- Fatigue assessment of the rod string.
- Connection verification (pin, coupling, thread).
- Final rod tally preparation and documentation.

Design Approaches

Two levels of analysis are addressed:

- **Simplified theoretical calculations** – straightforward, engineering calculations using basic models for screening and preliminary design.
- **Complete dynamic rod-string design** – a full design that accounts for the time-varying rod loads and downhole system behavior (e.g., via a rod-string dynamometer model) for final design and optimization.

Engineering Workflow – Sucker Rod String Design



Uniform Sucker Rod String (Single Diameter)



Tapered Sucker Rod String (Multiple Diameters)



Simplified Theoretical Calculations

- Engineering calculations using simplified models.
- Provides quick evaluation and preliminary sizing.
- Useful for concept selection and early design screening.

Complete Dynamic Rod-String Design

- Accounts for time-varying rod loads and system dynamics.
- Evaluates stresses and fatigue under pumping conditions.
- Used for final design, optimization and field implementation.

Engineering Note

The schematic process steps and any illustrative arrangements in this guide are for explanation only. Final string design must be verified using well-specific operating data.

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02 | WELL AND PUMPING DESIGN INPUTS

Why Well and Pumping Data Matter

Well and pumping data define the boundary conditions for sucker rod string design. They establish the downhole geometry, pumping kinematics, fluid loading and flow environment that govern rod loads, stresses and the appropriate taper configuration.

Required Design Inputs

1. Pump Setting Depth
The depth at which the downhole pump is installed; defines the active rod length and column weight.

2. Measured Depth and Vertical Depth
The actual wellbore length along the well path (measured depth) and the vertical distance from surface to the pump (vertical depth); both are required to define geometry and fluid column.

3. Well Inclination
The deviation angle of the well from vertical along the producing interval; affects axial load component, side loads and efficiency.

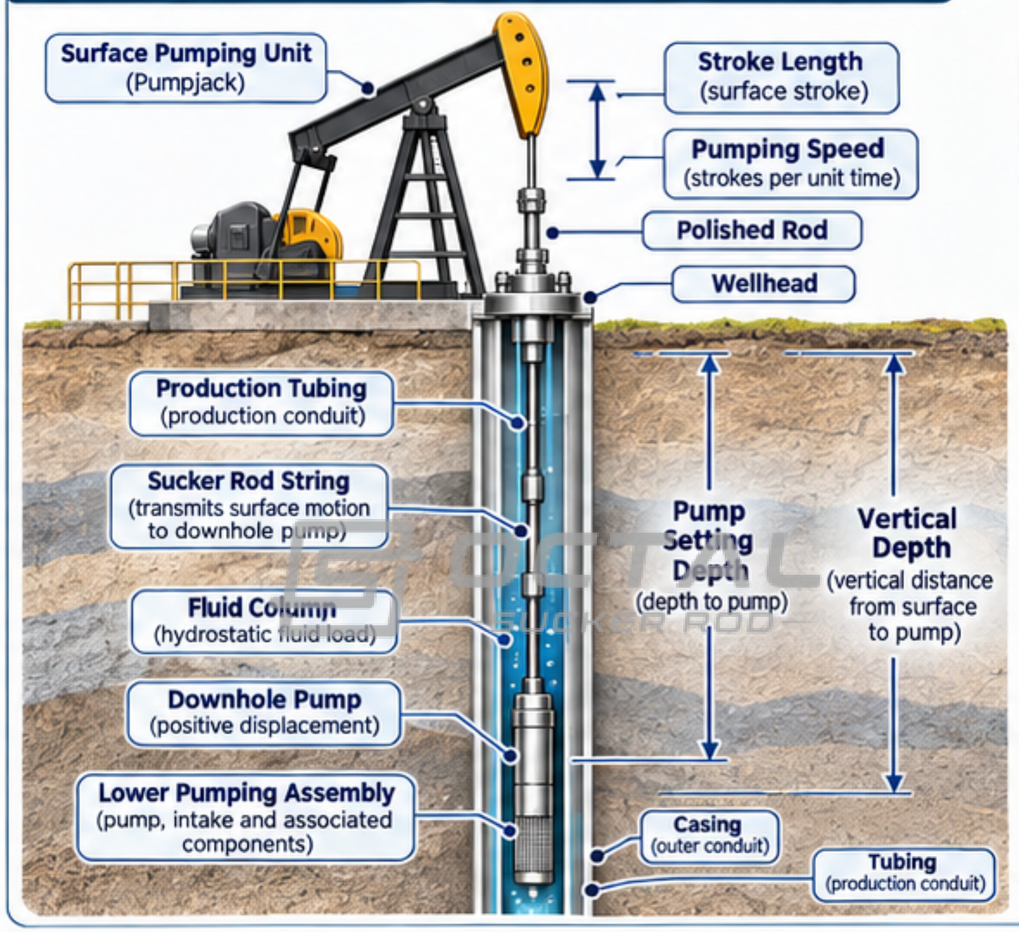
4. Stroke Length and Pumping Speed
The surface polished-rod stroke length and the pumping speed (strokes per unit time); define the rod motion and pumping cycle.

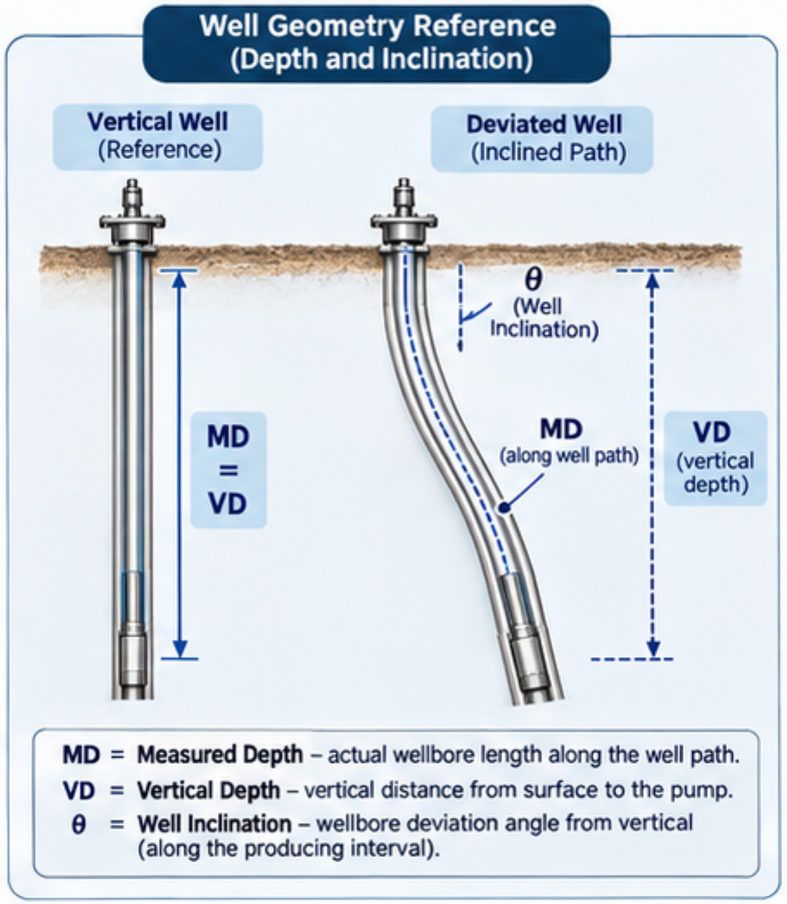
5. Fluid Loading
The hydrostatic and in-well fluid load acting on the pump and rod string; determined by fluid column height and produced fluid density.

6. Tubing Dimensions
The production tubing size, primarily the inside diameter (ID); governs annular clearance, fluid flow area and rod-tubing interactions.

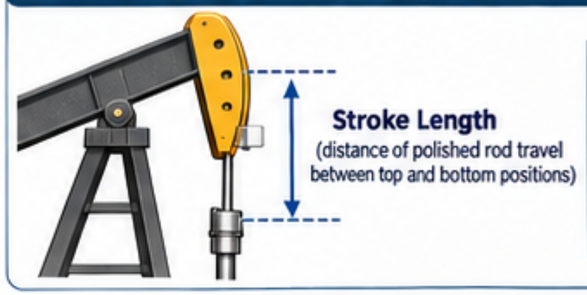
7. Produced Fluid Conditions
Key fluid properties of the produced stream (e.g., oil, water and gas characteristics); affect fluid density, foaming, compressibility and overall rod loading.

Rod-Lift System and Well Geometry – Design Inputs Overview

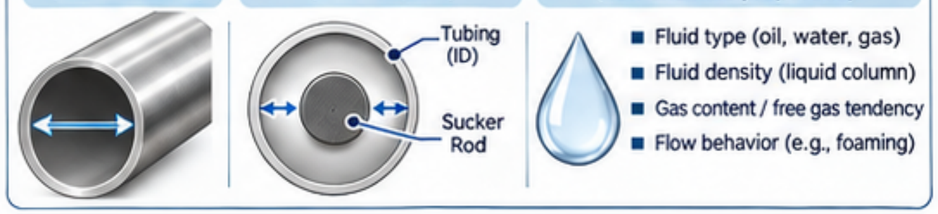




Stroke Length and Pumping Speed – Surface Relationship



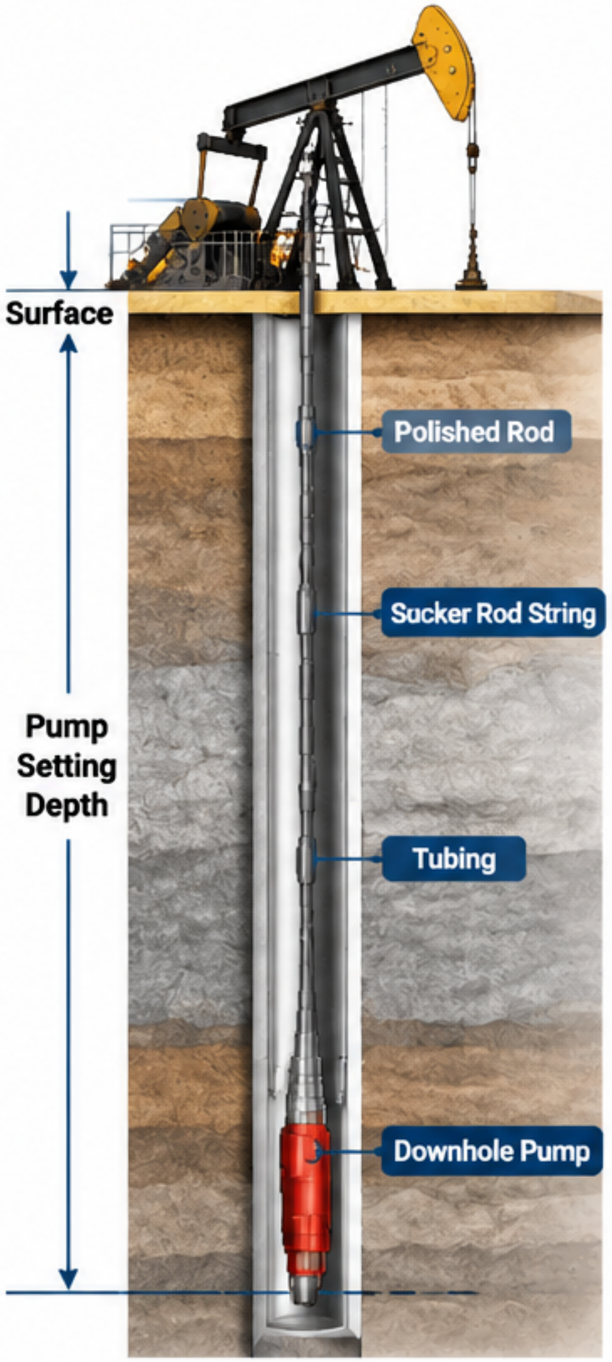
Tubing, Clearance and Produced Fluid Factors



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3. Static and Dynamic Load Analysis





Load Components in a Rod-Lift System

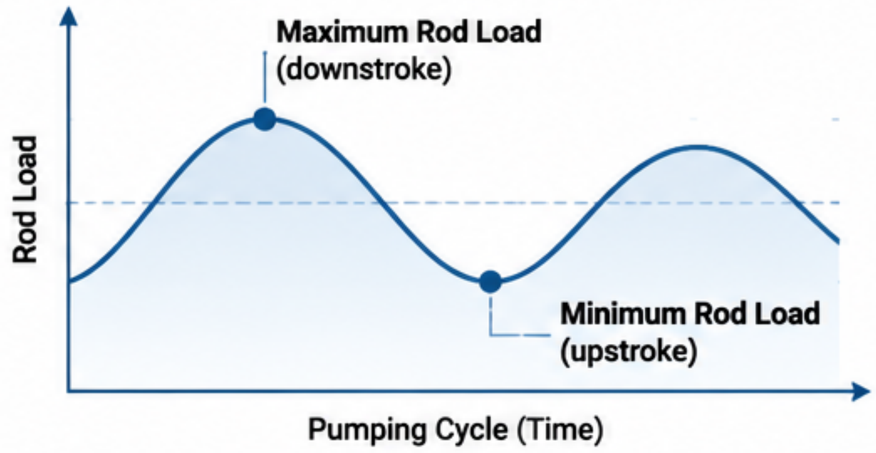
Suspended Rod Weight
The gravitational force from the weight of all rod sections below a given point.

Fluid Load
The axial force from the hydrostatic pressure of the produced fluid column.

Reciprocating Acceleration
The inertial force caused by the vertical reciprocating motion of the rod string.

Friction and Deviation Effects
Additional axial resistance from rod–tubing contact, which can increase in deviated wells.

Rod Load Variation During a Pumping Cycle



The rod load changes continoously during operation. The maximum and minimum loads are used for strength and fatigue evaluation.

Static vs. Dynamic Load

Item	Description
Static Load (Simplified)	Considers suspended rod weight and fluid load under a stationary condition, used for basic load estimation.
Dynamic Load (Actual Operation)	Includes rod weight, fluid load, reciprocating acceleration and friction, representing the real working condition during the pumping cycle.

Key Design Considerations

- ☑ Calculate the total suspended rod weight based on the string design.
- ☑ Evaluate the fluid load according to production fluid and setting depth.
- ☑ Consider dynamic effects (acceleration and deceleration) from the pumping unit.
- ☑ Assess friction and additional loads, especially in deviated wells.
- ☑ Use both maximum and minimum rod loads for rod and taper design.

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4. Axial Stress and Cross-Sectional Area



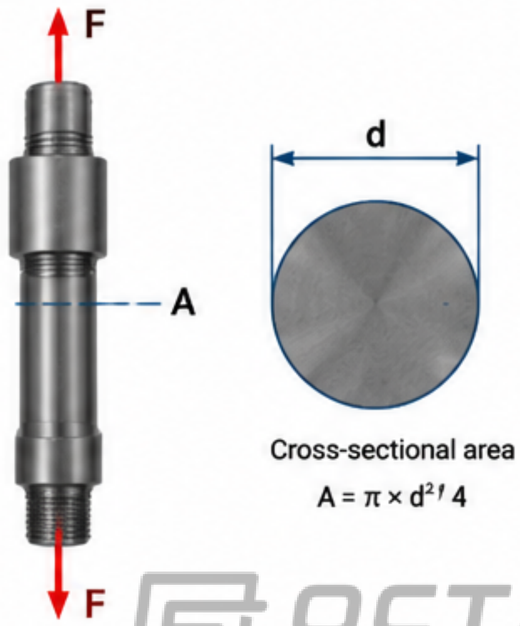
Axial Stress Formula

$$\sigma = \frac{F}{A} \quad \text{(Axial Stress)}$$

$$A = \frac{\pi \times d^2}{4} \quad \text{(Cross-Sectional Area)}$$

- σ = Axial stress in rod body (MPa or psi)
- F = Axial tensile force acting on the rod section (N or lbf)
- A = Cross-sectional area of the rod body (mm^2 or in^2)
- d = Nominal rod-body diameter (mm or in)

Sucker Rod Cross-Section and Axial Load

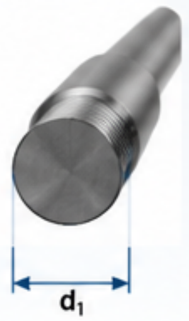


Cross-sectional area

$A = \pi \times d^2 / 4$

Effect of Rod Diameter on Cross-Sectional Area and Stress

Smaller Diameter

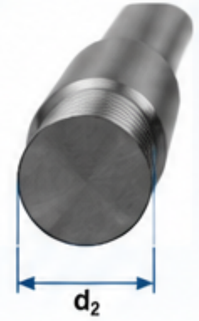




A_1

Smaller cross-sectional area
Higher nominal stress
(for the same axial force)

Intermediate Diameter

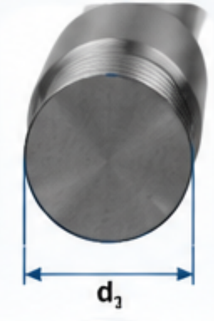




A_2

Larger cross-sectional area
Lower nominal stress
(for the same axial force)

Larger Diameter

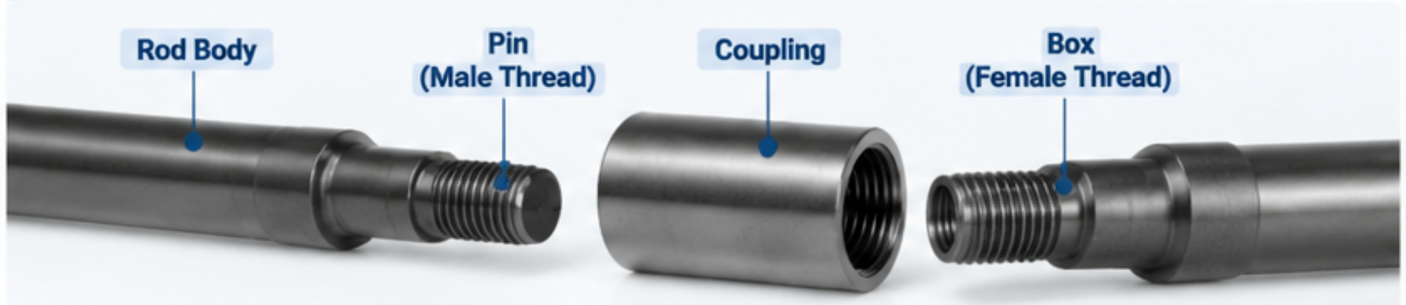




A_3

Larger cross-sectional area
Lower nominal stress
(for the same axial force)

Typical Sucker Rod Components



Comparison of Rod Diameter and Cross-Sectional Area

Item	Nominal Rod Diameter (d)	Cross-Sectional Area (A)	Axial Stress at the Same Force (F)
Smaller diameter	d_1	A_1	Higher
Intermediate diameter	d_2	A_2	Lower
Larger diameter	d_3	A_3	Lower

Key Points

- Axial stress in the rod body depends on the axial tensile force and the cross-sectional area.
- A larger rod diameter provides a larger cross-sectional area under the same axial force, which can reduce the nominal axial stress.
- Actual rod string design must also consider material grade, dynamic loading, stress concentration at threaded connections and operating conditions.

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05 | ROD DIAMETER AND MATERIAL GRADE SELECTION

Why Diameter and Grade Must Be Selected Together

Rod diameter affects the cross-sectional area of the rod body and, for a given load, determines the nominal rod-body stress.

Material grade affects the mechanical strength of the rod, including the yield strength and the allowable operating stress under field loading and environment.

Therefore, rod diameter and material grade must be checked together to ensure that the calculated stress is within the allowable level for the selected grade under the expected operating conditions.

Key Concepts

Rod Diameter
Determines the cross-sectional area and nominal rod-body stress under the design load.

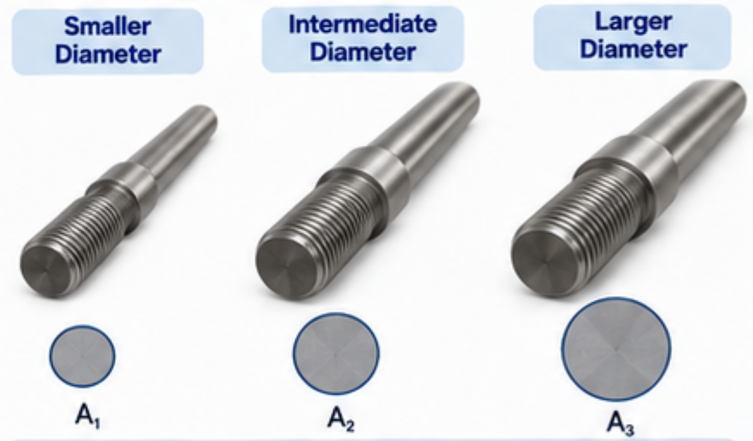
Yield Strength
The stress level at which permanent deformation begins; a key indicator of load-carrying capacity.

Tensile Properties
Overall tensile performance (e.g., yield and ultimate strength, elongation) used for material selection and quality control.

Heat Treatment
Controlled thermal process to achieve the desired mechanical properties and performance consistency.

Corrosion Exposure
CO_2, H_2S, produced water and general corrosive service can affect material selection and service reliability.

Rod Diameter Comparison



Larger diameter provides greater cross-sectional area ($A_3 > A_2 > A_1$).

Material Grade and Mechanical Properties

Rod Grade (Example)	Yield Strength (Genetel)	Tensile Properties (General)	Heat Treatment (Typical)	Typical Service Consideration
Grade A (General Purpose)	Standard level for conventional service	Balanced tensile performance for general use	Normalized / Quenched and Tempered	Suitable for conventional operating conditions
Grade B (Higher Strength)	Higher level than Grade A	Higher tensile capacity and toughness	Quenched and Tempered	For higher-load or more demanding service
Grade C (High Strength)	Higher level than Grade B	High tensile performance with good toughness	Quenched and Tempered (controlled)	For severe service (e.g., higher loads, longer strings, or challenging environments)

Material Evaluation and Testing

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Tensile Testing



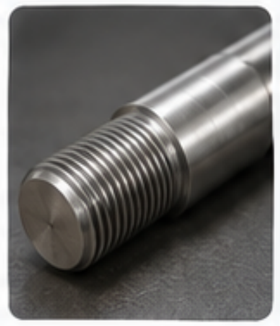
Heat Treatment Control



Material Verification



Surface / Condition Review



Corrosion Exposure Considerations



- **CO_2 (carbon dioxide)** — can contribute to corrosive service.
- **H_2S (hydrogen sulfide)** — can increase the severity of corrosion and material demand.
- **Produced water** — contains dissolved salts and corrosive species.
- **General corrosive service** — the combined environment can affect material selection, coatings and overall reliability.

Selection Principles

- **Check load and stress first:** determine the rod loads and nominal rod-body stress from the design model.
- **Select diameter and grade together:** choose a diameter that provides adequate area, and a material grade with suitable mechanical strength for the calculated stress and operating conditions.
- **Review heat-treatment condition:** ensure the rod is supplied with the required heat treatment and consistent properties.
- **Consider corrosion exposure:** evaluate the presence of CO_2, H_2S, produced water and other corrosive factors in the well.
- **Verify connection compatibility:** confirm that the selected diameter and grade are compatible with the connection type and system design.

Caution

Higher material strength must not be treated as equivalent to longer fatigue life. Fatigue performance is influenced by multiple factors, including load variations, dynamic conditions, stress concentration and surface condition.

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6. Taper Length and Section Configuration

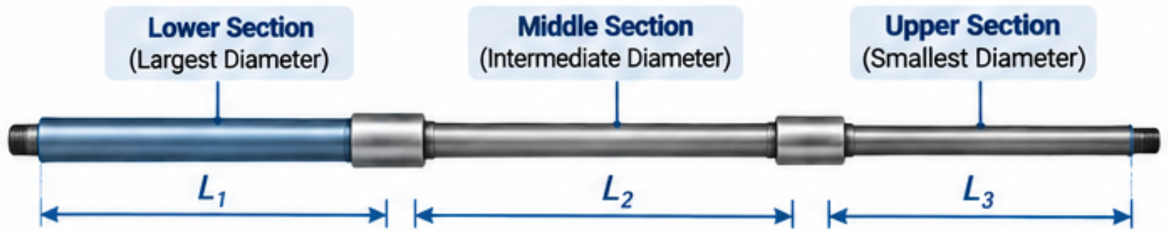


Tapered Rod String Configuration

A tapered rod string uses two or more rod diameters to gradually reduce the rod load toward the surface, improving load distribution and operational stability.



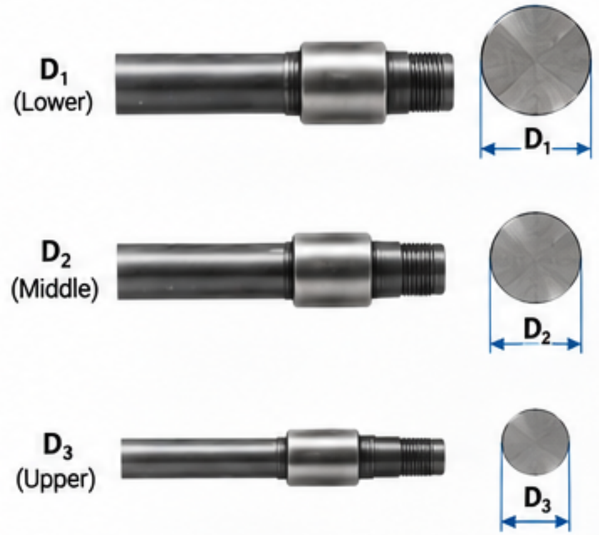
Typical Three-Section Tapered String



Key Terms

Section Diameter	The rod body diameter of each section (e.g., D_1, D_2, D_3).
Section Length	The length of each diameter section (e.g., L_1, L_2, L_3), determined by rod-load design calculations.
Transition Position	The depth at which the rod diameter changes from a larger to a smaller size.
Load Matching	The arrangement of diameters and lengths to keep rod loads within an acceptable range along the string.
Rod Tally	A detailed list of each section, including diameter, length, quantity and total length.

Section Configuration Example (Illustrative Only)



Taper Section Design Considerations

Section Diameter	Select diameters based on the calculated rod load and allowable stress.
Section Length	Determine each section length through design calculation and load distribution.
Transition Position	Define the depth of diameter changes considering the actual well profile.
Load Matching	Ensure a balanced load profile and avoid excessive stress concentration.
Rod Tally	Prepare a complete rod tally showing diameter, length, quantity and total length.

Rod Tally Example (Format)

Section	Rod Diameter D (in)	Section Length L (ft)	Quantity (pcs)	Remarks
Lower Section	D_1	L_1	—	Largest diameter (highest load)
Middle Section	D_2	L_2	—	Intermediate diameter
Upper Section	D_3	L_3	—	Smallest diameter (lower load)
Total	$L_1 + L_2 + L_3$			Total string length

Important Notes

1. The number of sections, diameters and section lengths should be determined by design calculations, not by a fixed or universal ratio.
2. The section arrangement should match the well conditions, pump setting and expected load profile.
3. The transition position should consider load change, well deviation and operational experience.
4. The rod tally must be clearly documented for manufacturing, inspection and field installation.

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07 | Fatigue and Connection Verification

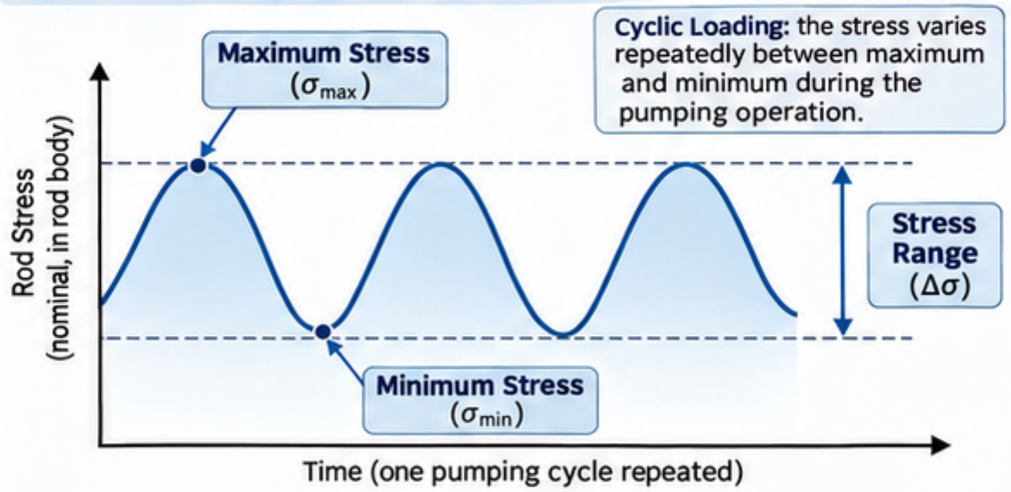


Fatigue Loading in a Sucker Rod String

The sucker rod string is subjected to cyclic loading during the pumping operation. Rod stress varies between a maximum stress (at peak load, e.g., upstroke) and a minimum stress (at lowest load, e.g., downstroke) in each pumping cycle. The repeated stress variation can cause fatigue damage over time, which should be considered in design and verification.



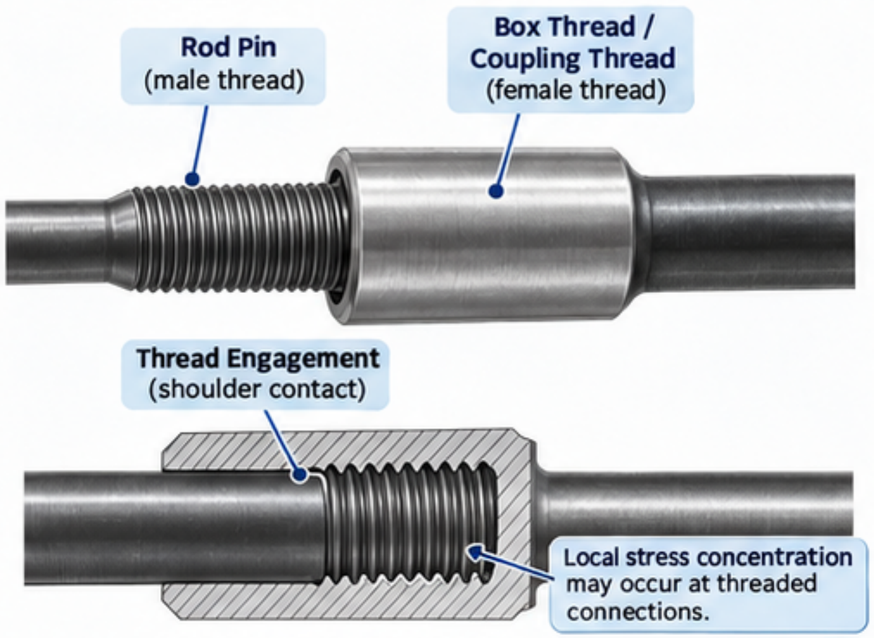
Cyclic Loading and Rod Stress



Key Stress Concepts

Maximum Stress	The highest rod-body stress in a pumping cycle.
Minimum Stress	The lowest rod-body stress in a pumping cycle.
Stress Range	The difference between maximum and minimum stress ($\Delta\sigma = \sigma_{max} - \sigma_{min}$), which governs fatigue severity.
Cyclic Loading	Repeated stress variation between maximum and minimum stress during the pumping operation.

Threaded Connection

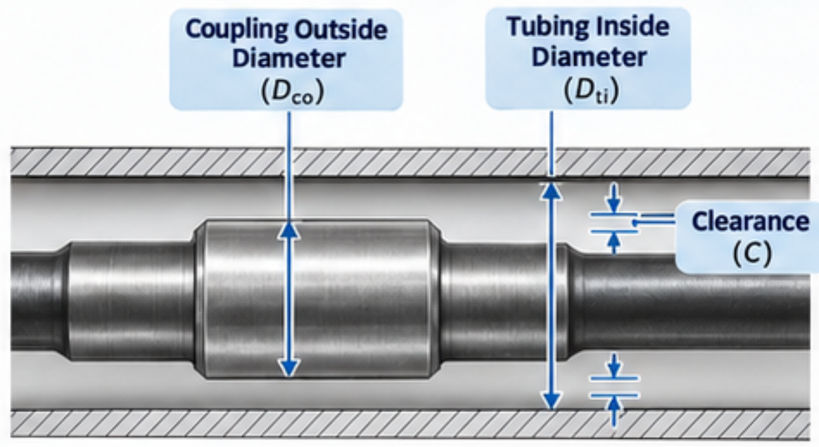


Coupling Strength / Connection Verification

The connection and coupling should be verified to ensure reliable load transfer and structural integrity under cyclic loading.

Connection Engagement	Confirm proper thread engagement (e.g., make-up and shoulder contact) to ensure a stable connection.
Load Transfer	Ensure the rod load can be effectively and continuously transferred through the threaded connection and coupling.
Connection Compatibility	Verify that rod, pin and coupling threads are compatible in type, size and configuration.
Structural Integrity	Confirm that the connection and coupling maintain structural integrity under repeated (cyclic) loading throughout the design life.

Tubing Clearance



Insufficient clearance can increase the risk of rod-tubing contact (rubbing), which may lead to higher wear, additional stress and reduced service life, especially in deviated wells.

Design Verification Checklist / Notes

- ☑ Evaluate maximum and minimum rod stress (nominal rod-body stress) for the designed operating condition.
- ☑ Confirm the stress range ($\Delta\sigma$) under cyclic loading and consider its impact on fatigue life.
- ☑ Review the threaded connection condition (e.g., thread engagement and shoulder contact).
- ☑ Verify coupling suitability (e.g., engagement, load transfer, compatibility and structural integrity).
- ☑ Check tubing clearance (rod/coupling OD vs. tubing ID), especially for deviated wells where contact risk is higher.