Engineering Bulletin		**Document #:** BLTN-042
		Revision: A
Drill Pipe Bending Capacity		**Created By:** Jim Brock
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Background

WSI is often asked "What is the bending capacity of my drill pipe?" API and drill pipe OEM's do not provide a "bending" rating for their products as bending is a direct tradeoff with fatigue life.

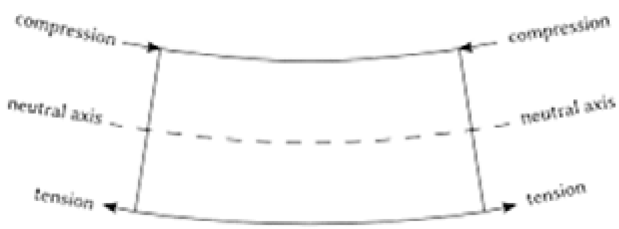
Details

Drill stem tool joints and connection bending

API does not provide bending ratings or maximum bending capacity for API tool joints/connections. Drill pipe OEM's do not provide bending ratings or maximum bending capacity for their proprietary tool joint/connections. Typically the tool joint is much stiffer, larger outside diameter and greater wall thickness, than the pipe body. The pipe body is typically the limiting factor in bending.

Pipe body bending

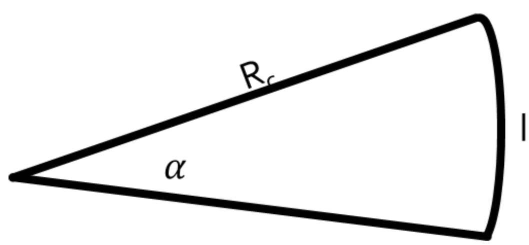
When subjected to bending, the side of the pipe on the inside of the curve is shortened or put in compression. The opposite side of the drill pipe, on the outside of the curve, is stretched or put in tension.



Source: Physics forum

Drill pipe bending occurs when the pipe passes through a curved hole build section or through a dogleg. Drill pipe bending also occurs when the drill pipe is buckled.

Increasing the bending severity, increasing the dogleg angle or decreasing the radius of curvature, increases the pipe body outer fiber stress. For a given hole curvature, the outer fiber stress will be greater for a larger diameter pipe than for a smaller diameter pipe.



$l = 2\pi\, Rc\, \alpha/360$

$\sigma_{OD} = 218.17\ D\ \alpha$

$\alpha_{max} = Y_p / 218.18\ D$

- l is arc length
- α is dogleg angle
- Rc is radius of curvature
- σ_{OD} is pipe outer fiber stress
- D is pipe diameter
- α is dogleg angle, degs./100 ft.
- Y_p is the pipe body specified minimum yield stress,SMYS

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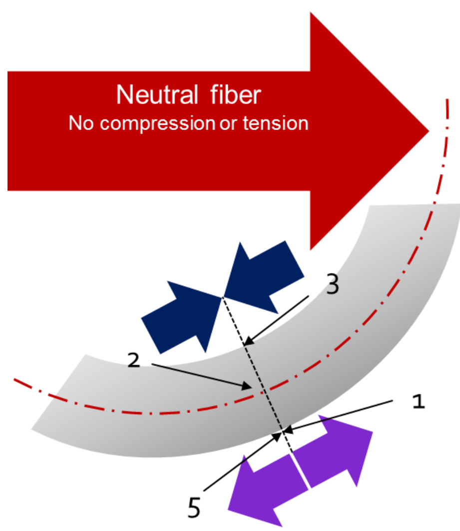
According to the equation above, 5” diameter S135 drill pipe will yield when subjected to a bend of 124 degrees per 100 feet. *However, this bend severity is much, much higher that practical due to increased side loads and casing wear and decreased fatigue life.*

Fatigue

When the drill pipe is subjected to bending and rotation, the stress for a given point on the outside surface of the pipe repeatedly cycles from tension to compression:

- Tensile stress when the point rotates to the outside of the bend.
- No stress when the point rotates to the centerline of the pipe
- Compressive stress when the point rotates to the inside of the bend



Source: NOV Grant Prideco

The axial stress created from bending, either tension or compression, is additive to the other axial forces such as string weight. This is illustrated in the charts above and below for a given point of the pipe body outside diameter. Follow the point as it changes position as the pipe rotates:

1. At position 1, the point is on the outside of the bend. The tensile stress is at the maximum level, σ_{max}.
2. As the pipe rotates the point to position 2, the stress decreases to the mean tensile stress, σ_m. This is the steady stress imposed by the string weight. Stress from bending is zero at the centerline of the pipe.
3. As the pipe rotates further, the point moves from the pipe centerline to the inside of the bend. The tensile stress decreases to the minimum stress, σ_{min}.
4. As the pipe rotates further, the point moves from the inside of the bend back to the pipe centerline on the opposite side of the pipe from positon 2. The tensile stress decreases back to, σ_m.
5. As the pipe rotates completing one rotation, or one cycle; the point moves from the pipe centerline back to the outside of the bend. The tensile stress increases back to σ_{max}.

The alternating stress over time is cyclic stress. The difference in σ_{max} and σ_{min} is the stress amplitude.

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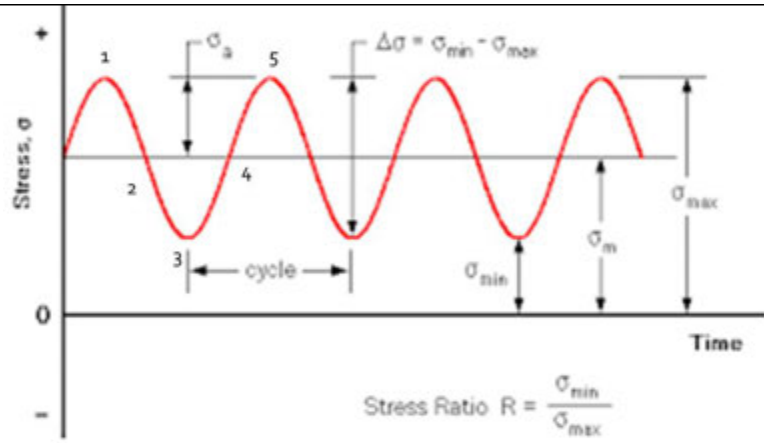

Source: fea-optimization.com

Fatigue is the weakening of a material caused by repeatedly applied loads. It is the progressive and localized structural damage that occurs when a material is subjected to cyclic loading. The nominal maximum stress values that cause such damage may be much less than the yield strength of the material. *For a specific pipe and a specific amount of pipe rotation, increasing the bend radius will increase the stress amplitude and reduce the fatigue life of the pipe*. The estimated fatigue life for different drill pipe grades and stress levels are shown in Figure 77 from API RP7G. See below:

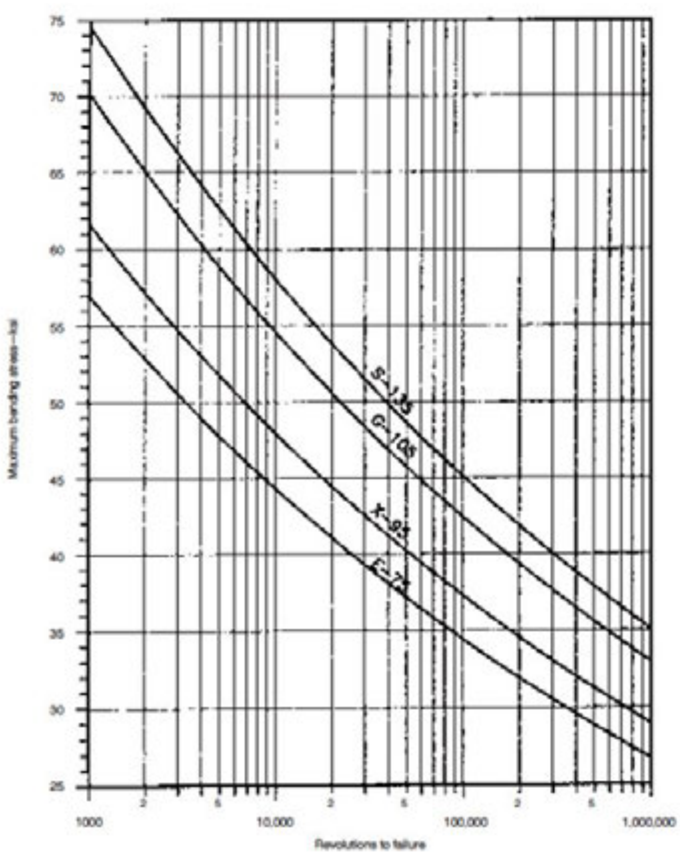

Figure 77—Minimum Failure Limits for API Drillpipe Noncorrosive Service

Source: API RP 7G Figure 44

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$M = y/I_x\ \sigma$ - the bending moment about the neutral axis

σ - the bending stress

y - the perpendicular distance to the neutral axis

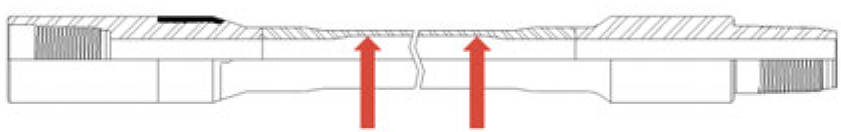
Ix - $I_x = \pi (D4 - d4) / 64$ - the second moment of area about the neutral axis x.

D - cylinder outside diameter

d - cylinder inside diameter

The attached graph from API RG7G displays the minimum fatigue limits for drill pipe under bending for a non-corrosive environment. It is a just place to start. It considers only the pipe body, rotation (cycles) and stress (bending). Of course, corrosion, slip-cuts and other stress risers would reduce fatigue life and must be determined from experience for the specific application.

Fatigue failure of drill pipe typically initiates at the intersection of the internal upset with the pipe inside diameter. The change in cross section from the relatively large tool joint to the relatively small pipe body, creates a stress riser is this area. See figure below.



Side load

Bending is usually accompanied by side loads on the drill pipe. A rule of thumb is to limit side loads to 60 lb per foot or less to mitigate casing and tool joint wear.

Summary

- Drill pipe bending ratings are not provided by API of OEM's
- Increasing bending with rotation, increases cyclical stress amplitude, increases fatigue, and decreases drill pipe life.

Example

A common example of fatigue failure from bending: https://www.youtube.com/watch?v=1UQC9S_pP_E

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