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.

\[
l = \frac{2\pi Rc \alpha}{360}
\]

\[
\sigma_{OD} = 218.17 D \alpha
\]

\[
\alpha_{max} = \frac{Y_f}{218.18 D}
\]

- \( l \) is arc length
- \( \alpha \) is dogleg angle
- \( R_c \) is radius of curvature
- \( \sigma_{OD} \) is pipe outer fiber stress
- \( D \) is pipe diameter
- \( \alpha \) is dogleg angle, degs./100 ft.
- \( Y_f \) is the pipe body specified minimum yield stress, SMYS
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

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, $\sigma_{\text{max}}$.
2. As the pipe rotates the point to position 2, the stress decreases to the mean tensile stress, $\sigma_{\text{m}}$. 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, $\sigma_{\text{min}}$.
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 position 2. The tensile stress decreases back to $\sigma_{\text{m}}$.
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 $\sigma_{\text{max}}$.

The alternating stress over time is cyclic stress. The difference in $\sigma_{\text{max}}$ and $\sigma_{\text{min}}$ is the stress amplitude.
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:
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 in 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](https://www.youtube.com/watch?v=1UQC9S_pP_E)