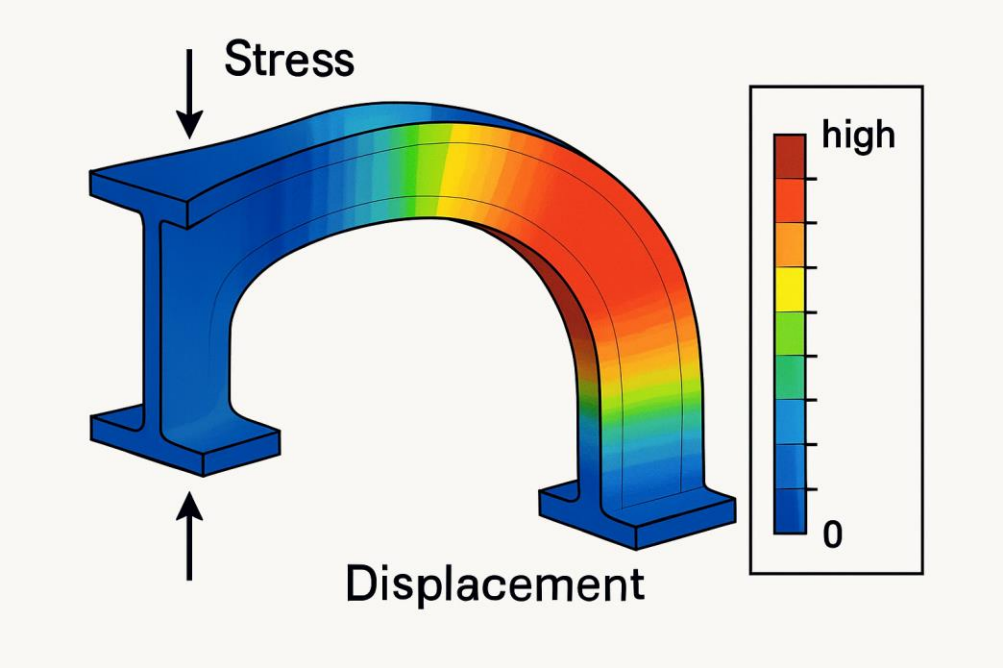
Why Not All Arcs Are Equal: Designing Bends for Constant Stress Distribution

Curves in design aren't just for aesthetic appeal. They play a crucial role in how weight and forces are distributed across a structure. When designing bent aluminum for long spans, like in roof supports, bridges, or trusses, the geometry of the arc directly impacts how stress is spread. Engineers and architects need to know that not all arcs are created equal when it comes to balancing structural loads.

The Problem with "Just Using an Arc"



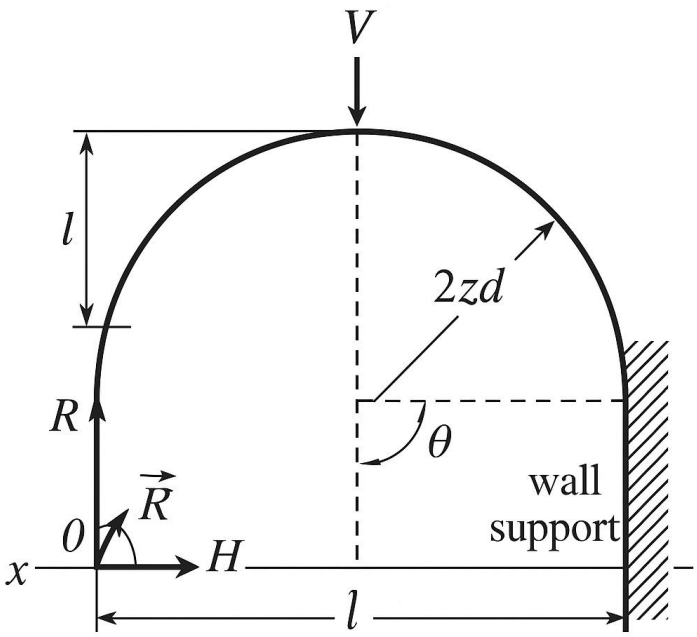
Looks Great—Until It's Under Load

Using a simple arc might seem like an easy solution, but it's not always the most effective under stress. For example, uniform-radius arcs tend to experience greater deflection at midspan, particularly under heavy loads or when unsupported. This can lead to sagging and inefficiencies. Additionally, poorly chosen geometries can create stress concentration zones, which make the material more likely to fail.

Arcs focused purely on aesthetics may lead to over-design or unexpected deflection because the arc isn't tailored to handle the forces in play. While arcs can be beautiful,

designers need to go beyond the curve to ensure the structure can carry the load effectively.

What Does "Constant Stress Distribution" Actually Mean?



Design That Balances Forces Naturally

An ideal arc aims to distribute internal stress evenly across the entire curve. However, the success of this balance depends on factors such as material, load, and support. Even stress distribution prevents localized deformation and torsional twisting, which can weaken the structure. Evenly distributed stress also reduces the likelihood of material fatigue, especially in dynamic or outdoor environments.

Achieving constant stress distribution requires more than just a simple curve; it depends on geometry, material selection, and support methods to maintain proper balance.

When to Use Parabolic vs. Circular Arcs

Curves That Work With Gravity, Not Against It

Each type of arc serves a different purpose, depending on the application.

- Circular arcs are easy to fabricate but tend to concentrate stress at the center, particularly when unsupported. This concentration can lead to higher stresses at midspan. Circular arcs work well when loads are minimal or distributed, such as in aesthetic paneling, but are less ideal for long spans.
- Parabolic and catenary arcs are better suited for handling loads under gravity. A parabolic arc is ideal when the load is evenly distributed, such as in suspension frames or open shelters. Catenary arcs are commonly used in tensioned canopies to manage loads with minimal deflection.

Real-world examples:

- Parabolic archways in transport terminals balance gravity-induced loads by distributing stress evenly along the curve.
- Catenary curves in tensioned canopies effectively manage forces in structures like modern shelters.
- Circular ribs in aesthetic paneling, where loads are minimal, focus on design rather than structural performance.

How Profile Shape and Wall Thickness Play a Role

The Arc Alone Isn’t Enough

Choosing the right arc geometry is crucial, but profile shape and wall thickness also significantly affect the strength of the structure. For example:

- Deeper or reinforced profiles resist buckling and bending, making them ideal for long-span applications.
- Oval or asymmetrical profiles may deform if the load isn’t centered, which leads to uneven stress distribution.
- Thicker wall sections or deeper profiles at the peak of the arc help resist flexing, but their effectiveness depends on the span, material, and overall arc geometry.

The moment of inertia principle helps determine the optimal cross-section shape to ensure the profile can withstand the stresses it will face.

Design Tips for Long-Span Curves in Aluminum

Keep It Light, Strong, and Smart

When designing long-span aluminum structures, balancing weight, strength, and efficiency is key. Here are some tips to get it right:

- Use simulation software to test real-world load conditions and verify that your design performs as expected under actual stress.
- Avoid placing holes or notches near high-stress zones, such as the peaks of arcs, because they can weaken the material. Consider the entire load path when designing.
- Consider pre-curved reinforcement ribs or multi-axis bends for additional support without adding unnecessary weight.
- Define support placement early where and how you place supports significantly affect stress distribution. Incorrect placement can cause weak points and uneven stress distribution.

Lessons from the Field: Case Studies

When a Better Arc Made All the Difference

In real-world applications, selecting the right arc geometry can greatly enhance structural performance. Here are a few examples:

- A pedestrian footbridge sagged after one year due to inadequate support for the circular arc, underscoring the need for proper reinforcement and support with the right arc geometry.
- A stadium canopy switched to variable-radius bending, reducing weight by 18%. This change improved stress distribution and made the structure both lighter and more efficient.
- An open-air bus terminal was designed with parabolic ribs, eliminating the need for post-tensioning. This case highlights how optimized arc shapes can save material and reduce costs.

Conclusion

If You're Going to Bend It—Balance It

Not all arcs are structurally equal. The geometry you choose plays a critical role in how the structure handles stress. Different arc shapes have their own advantages depending on the load type, span, and material properties. Whether you use a circular, parabolic, or catenary arc, each has distinct benefits that should align with the structural demands.

By understanding how arcs behave under stress, designers can make informed decisions that result in stronger, more efficient designs. Whether focusing on aesthetic beauty or structural efficiency, understanding the nuances of different arcs can lead to long-span aluminum structures that are both strong and visually appealing.

[CTA: At Inductaflex, we specialize in precision CNC bending, helping you create aluminum structures that balance strength and design. Let us help you bring your projects to life with precision and efficiency.]