CLOSURE

Designing Compact Gussets with the Uniform Force Method

Paper by Larry S. Muir
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I would like to begin by thanking Mr. Arias for his interest in and comments regarding my paper. I believe that an open and vigorous discourse is the best way to advance our understanding and practice of engineering.

Mr. Arias addresses three separate issues, which I will try to restate:

1. I have found only one of a number of possible solutions to the problem.

2. I have applied arbitrary geometric constraints to the analysis, and my analysis does not reflect the behavior of the connection.

3. I present an alternative that uses ΔV_b to arbitrarily manipulate the distribution of vertical forces in the connection.

I agree with all three of Mr. Arias' points enumerated here. However, I disagree with the conclusions developed from these points. It is my understanding that Mr. Arias's main problem with the approach presented in my paper is that it is arbitrary and does not accurately reflect the true behavior of the connection. From this he concludes that the procedure may result in inadequate designs and that the traditional UFM more accurately reflects the behavior of the connection and therefore results in safer designs.

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I contend that no one—not Mr. Arias, not myself, not Dr. Thornton, the originator of the UFM—can accurately predict the behavior of any connection. That is why all connection design—and, in all likelihood, virtually all structural steel design—is accomplished based, either implicitly or explicitly, on the Lower Bound Theorem. The Lower Bound Theorem states that the applied external forces in equilibrium with the internal force field are less than or, at most, equal to the applied external force that would cause failure, provided that all the limit states are satisfied and sufficient ductility exists to allow redistribution of the forces. In other words, as long as sufficient ductility is present and all applicable limit states are satisfied, design can safely proceed based on any arbitrary distribution of forces, as long as the distribution satisfies equilibrium. If this was not true, designs would quickly grind to a halt as we constructed and calibrated, through physical testing, highly complex finite element models for every detail and possible load case for our designs.

Mr. Arias brings up many arguments that are certainly true. There will undoubtedly be some moment present in the physical connection at the beam-to-column interface. However, this moment will be limited to some value less that the ultimate strength of the beam-to-column connection. As the loads imposed on the connection approach the connection strength, the elements will begin to yield and therefore shed load to stiffer elements. As it turns out, neglecting the rotational stiffness of this connection and the resulting imposed moments in the analysis actually adds to, and not subtracts from, the safety of the connection. Any additional restraint will serve to strengthen, not weaken, the structure.

As Mr. Arias states, increasing the β dimension of the connection will tend it make it more rigid at the gusset-to-column interface. This will, as Mr. Arias asserts, draw moment from the gusset-to-beam interface. The prediction that no moment exists at the gusset-to-column interface is most certainly incorrect, as are all the other forces predicted by the proposed procedure. Some of the predicted forces are too high, some are too low, but still the resulting design is safe and will carry the loads, or else the Lower Bound Theorem is wrong and so too are countless structures in service.

This same logic justifies the use of ΔV_b to manipulate the distribution of the forces in the connection. The use of ΔV_b predates my paper and has been present in the AISC *Manual* for many years. It is used primarily where the beam end connection is subjected to a high shear load due to gravity loads, so that it cannot resist the additional load imposed by the bracing with a typical connection. In some instances, the additional shear induced by the bracing may be such that the beam web itself is overstressed when subjected to the forces predicted by the UFM. If the beam and its connections maintained their stiffness throughout loading and then suddenly snapped like glass, it would be inappropriate to apply ΔV_b—but this is not how steel behaves.

Finally, Mr. Arias suggests that the traditional UFM is inherently superior to the procedure presented in the paper. Based on his previous arguments regarding the generalized UFM presented in the paper, this implies he feels the traditional UFM is less arbitrary than the generalized method. In fact, it could be argued that the traditional UFM is actually more arbitrary in the constraints it chooses to impose on the force distribution. When he derived the traditional UFM, Dr. William Thornton arbitrarily chose to pass the forces V_c and H_c through a point at the intersection of the top of steel and the face of the column. This ensured that no moment would exist in a section cut through the column at the top of steel. This choice was based in part on figures shown in Blodgett's *Design of Welded Structures*. It resulted in more elegant-appearing equations for the interface forces than my proposed generalized method, but actually contained one additional arbitrary geometric constraint than the generalized procedure.

In conclusion, the procedure presented in my paper was never intended to accurately predict the forces present in the connection. It was intended instead as an improvement to an existing tool by which an admissible force distribution can be obtained that has been proven through use to produce safe and economical designs.