The Uniform Force Method: Questions and Answers

People ask a lot of questions about the Uniform Force Method used to design beam-column-brace connections that are part of the vertical bracing system in steel structures. I will present and answer a number of the questions here.

This is an update to some material that was provided on my website a number of years back. Since that time AISC Design Guide 29 (written by Bill Thornton and me) was published. In my opinion the most important part of the Design Guide is the single-page first chapter, which briefly explains the basic design philosophy which underlies not just the design of vertical brace connections but some extent all structural steel design. I encourage engineers to reread this section each time they employ the Design Guide.

I have added a couple of very common questions to the beginning of the list. They address the need or ability to use the Uniform Force method. In my experience there is still a surprising amount of confusion surrounding the use and intent of the Uniform Force Method.

I have also removed all references to the Uniform Force Method as "UFM". Over the last several years I have developed an aversion to acronyms and abbreviations. They are used too often in our industry and often in ways that obfuscate when the intent is to enlighten. Pixels and bits are cheap.

Q: Must the Uniform Force Method always be used to design vertical brace connections?

A: No. As is described below and consistent with the single-page first chapter of AISC Design Guide 29, the Uniform Force Method is simply a standardized means of determining a statically admissible force distribution. While the Uniform Force Method is believed to generally produce the most efficient force distribution, there are certainly conditions for which other distributions might be beneficial.

Q: can the Uniform Force Method be applied to this or that specific condition?

A: The answer is almost always "Yes". The Uniform Force Method is simply a standardized means of determining a statically admissible force distribution. If your goal is to satisfy statics, which it always should be, then you can apply the Uniform Force Method. A number of special cases of the Uniform Force Method have been developed to address such conditions as connections only to one of the member, nonconcentric work points, and non-orthogonal members.

That said it often does not make sense to apply the Uniform Force Method to very simple or very complex conditions.

An example of a very simple condition, which is often asked about, is a common configuration of horizontal bracing where the gussets attach the webs of orthogonal beams. The Uniform Force Method can certainly be applied to this condition. However, the result will be that one brace component will be delivered to one of the beams while the other component will be delivered to the other beam – an obvious result.

While one can modify the Uniform Force Method to address a very wide range of conditions, checking the proposed solution will inevitably involve drawing free-body diagrams. Therefore unless one is tackling a great number of very complex and similar conditions, it is often not worth the time and effort required to develop closed form solutions.

Q: What is the Uniform Force Method?

A: The Uniform Force Method is a universally applicable method that can be used to determine the interface forces for beam-column-brace connections. The resulting forces will satisfy equilibrium and will be consistent with the boundary conditions of the plates (there will be no transverse force applied to a column web). It is also believed that the Uniform Force Method will produce the most economical connections in most cases, since no moments will be applied at the interface connections.

Q: Do the forces resulting from the Uniform Force Method represent the actual forces that will exist in the connection during service?

A: The forces resulting from the Uniform Force Method represent one of an infinite set of force distributions that satisfy equilibrium. It is unlikely that the forces resulting from the Uniform Force Method accurately predict the forces that will exist in service. However, as long as the limit states are satisfied and sufficient ductility exists, a design based on the forces resulting from the Uniform Force Method will be safe.

Q: Satisfying the geometrical restraints of the Uniform Force Method can sometimes result in large gusset plates. Is there any way around this problem?

A: Larry Muir has developed a generalization of the Uniform Force Method. The details can be found in "Designing Compact Gussets with the Uniform Force Method" AISC Engineering Journal. 1st Quarter 2008, which can be downloaded from the Publications & Presentations section of the LarryMuir.com website.

Q: Who first developed the Uniform Force Method and what was the basis?

A: William A. Thornton, Chief Engineer of Cives Steel Company, first developed the Uniform Force Method. The original inspiration for the unique convergence of the three forces came from finite element models produces by Ralph Richard, which showed that the gusset interface forces and the brace force tended to converge at a single point.

Q: Are there any published derivations of the Uniform Force Method?

A: Yes. A derivation of a generalized Uniform Force Method is available in "Designing Compact Gussets with the Uniform Force Method" AISC Engineering Journal. 1st Quarter 2008, which can be downloaded from the Publications & Presentations section of the LarryMuir.com website. Appendix A of Design Guide 29 also provide a derivation.

The original Uniform Force Method can be derived by placing the column control point at the intersection of the center of the column and the top flange of the beam.

Q: Are there any empirical (physical) data supporting the use of the Uniform Force Method?

A: Yes. Designs resulting from the Uniform Force Method have been compared to full-scale tests of vertical bracing connections, and there is good correlation between the two.

Q: Is it appropriate to design based on other force distributions that are not consistent with the Uniform Force Method?

A: Yes. A safe design can be obtained using any force distribution that satisfies equilibrium, as long as no limit states are exceeded and sufficient ductility exists. However, not all force distributions will result in economical connections.

Q: If any force distribution that satisfies equilibrium (within reason) can be used in design, why is the Uniform Force Method the only approach included in the AISC Steel Manual?

A: Prior to issuing the 9th Edition Steel Manual AISC sought out design methods for vertical bracing connections. Various methods were submitted and essentially competed for a place in the Manual. Bill Thornton's Uniform Force Method, which was ultimately the only method adopted by the Manual Committee, was the only method that was:

1. Universally applicable
2. Consistent with the boundary conditions of the gusset
3. Satisfied equilibrium
4. Consistently produced economical designs

Q: Can the Uniform Force Method be applied to truss connections as well as vertical brace connections?

A: Yes. It is common practice to use the Uniform Force Method when designing truss connections that are configured similar to typical vertical brace connections.

Q: Can the Uniform Force Method be applied to connections involving not orthogonal beam and column members?

A: Yes. Bill Thornton has developed modifications to account for non-orthogonal framing. This condition is presented in Design Guide 29.

Q: Can the Uniform Force Method be used when the work-points are nonconcentric?

A: Yes. Bill Thornton has developed modifications to account for nonconcentric work-points. This condition is presented in Design Guide 29.

Q: What is ΔV_b and when would it be used?

A: ΔV_b allows the designer to move a portion of the vertical brace load that would otherwise be delivered to the beam-to-column connection back to the gusset-to-column connection. This is sometimes necessary due to a large beam end reaction already present in the beam. The ΔV_b lowers the vertical force transferred between the gusset and the beam and the beam and the column and also increases the force transferred between the column and the gusset. This results in a moment at the beam-to-gusset interface. An imbalance is created in both the gusset and the beam simultaneously. This imbalance is commonly resolved by the additional moment at the gusset-to-beam interface.

Q: When $\bar{\alpha}$ does not equal α or ΔV_b is used, where should the resulting moment be applied?

A: It is common to apply the resulting moment at the gusset-to-beam interface. This is done for several reasons:

1. The gusset-to-beam connection is typically welded, while the gusset-to-column connection is typically bolted. The welded gusset-to-beam connection will therefore often be the stiffer connection and will tend to attract more of the moment.
2. It is usually simpler and more economical to design a welded connection to resist moment than it is to design a bolted connection to resist moment.

It should be noted that neither the beam nor the column would see any moments beyond the limits of the connections. Even with a ΔV_b or α not equal to $\bar{\alpha}$, the beam and column remain only axially loaded.

Q: When using the Uniform Force Method must the beam-to-column connection be centered on the depth of the beam?

A: The Uniform Force Method assumes the connection is centered on the depth of the beam. It is good practice to try to maintain this geometry, though slight variations should not be a problem. It is typical practice to either use a full-depth connection or a centered partial-depth connection.

Q: Why is ΔH_c not usually included in discussions of the Uniform Force Method?

A: Theoretically it is possible to use an H_c to change the distribution of the horizontal force between the beam-to-column and the gusset-to-column connections. However, doing so would involve adding a moment to one or both of these interfaces. Accommodating the additional moment in these connections would in most instances prove to be uneconomical, so it is not usually considered to be a viable option.

Q: Is it more economical to move the work-point to the corner of the gusset and consider eccentricities in the beam and column than to use a concentric work-point and the Uniform Force Method?

A: Most structures are designed with the vertical bracing connection work-points at the member centerlines. This is probably done out of habit, because most people don't think about the alternatives, and because it saves the engineer time. Moving the WP to the face of the column and/or the face of the beam is usually considered to be the more economical solution. It may reduce the dimensions of the gusset, which will prevent fouling with mechanical systems. Additionally it reduces the forces at the gusset interfaces, which may result in smaller welds, fewer bolts, etc. This arrangement will add a moment to the columns and beams, which will have to be considered in the design. Though the additional moment may increase the size of the main members somewhat, the cost savings in the gusset design will often more than offset the additional column weight. It has been estimated that 50% of the cost of structural steel "in the air" (after being fabricated and erected) is due to the configuration of the connections. Making improvements in the connection design can reap huge benefits in terms of schedule, safety and economy.