Making Simple Connections in Engineering

BY THOMAS W. HARTMANN, P.E.

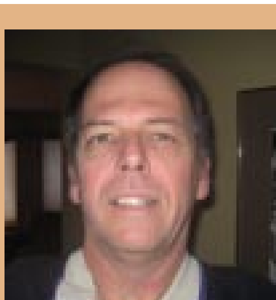
Part of good engineering is good, old-fashioned intuition.

IT IS EASY TO RECOGNIZE that the world of codes and analysis is getting more complex. New codes, with increasingly intricate provisions, often require more and more computer analysis. It is perhaps ironic that the computer has served a pivotal role in making this possible; without computing power, the simple rules of yesterday would still be required. While a computer also can be used to simplify analysis, most "old-time" engineers can create an appropriate scheme "on the back of a napkin," as they say; the rest is detail.

While no modern engineer really wants to go back to the "good old days" before computers, it seems increasingly difficult to teach engineering interns that "statics" still live somewhere in that big pile of computer output. My engineering professors at the University of Illinois wouldn't grade a problem if it didn't have an accompanying sketch, and usually expected a second sketch summarizing the results. Sketching reveals a thought process and frames a problem graphically.

Change is not just happening in engineering either. As a dad, my daughter and I are challenged by "new math." New math is "old math" in a new wrapper of more conceptual thinking. My daughter, Kelsey, and I can sketch out our new math of how many cow feet and how many chicken feet there are in her barnyard problem from math class, and we sometimes solve the problem just in our discussion of the picture.

So it still remains that structural engineering relies on a combination of test results, design rules, experience, intuition, and common sense to foster the creation of simple solutions from complex problems. The practice of engineering is a combination of both "art" and science; experienced engineers know solutions "by feel." Calculations and analysis often prove that intuitive feeling is correct.



Thomas W. Hartmann is lead structural engineer of the Power Group with CH2M Hill in Englewood, Colo.

A while ago, when working on a master's degree at Colorado State University, I used my thesis research to develop a simple formula that can be used to efficiently determine the coefficients *C* for eccentrically loaded bolted connections. My advisor (another Illinois alumni, Dr. Daniel Vanderbilt) challenged me to get creative. He suggested that, from an engineer's view towards simplicity, a useful, practical connection design approach can be much like the classic stress interaction formula:

$P/A + M/S < 1$?

Or for bolts, something simple like:

$P/N + (Pe)/Z < 1$?

Taking the creative part a step further, consider the use of geometric parameters γN and δZ as follows:

$P/\gamma N + (Pe)/\delta Z < 1$

This is my "napkin sketch" of design for a bolt group that reflects the interaction between the direct axial force (parameter γN) and moment due to eccentricity (parameter δZ). As I will now illustrate, this geometric formula can work for *any* bolt configuration, including arbitrary layouts as well as mixed connector sizes.

The factor "γN" takes into account the non-linear distribution of force to each bolt in a long connection. Correlating it to long-lap testing with A307 bolts by Bendigo in 1963:

$\gamma = (1\text{-}0.0062{*}h)$ – Equation 1

The variable "h" is the greatest dimension (normally a diagonal between corner bolts) of the connection. For a connection with h = 36-in., γ = 0.88, which is generally consistent with the AISC reduction for long lap connections tested.

The variable "δ" represents the effect of load-deformation distribution of shear, based upon the distance of the connection with respect to the load center. The load-deformation factor $\delta = (1\text{-}e^{-10\Delta})^{0.55}$ (AISC *Steel Construction Manual*, Figure 7-3), is applied to each bolt within the connection group. Here is the ugly formula, but fortunately you only need to do it once per geometry, and it is "scalable":

$\delta Z = \Sigma\delta_n A_n d_n$ – Equation 2

where A_n is the bolt area and d_n is the distance from the centroid of the bolt group to the center of the nth bolt. The torsional capacity of the connection, without consideration of the bolt load-deformation reduction, is really easy:

$Z = \Sigma A_n d_n$ – Equation 3

If you want an even more simple approach, I'd suggest that you forget the "δ" and the "γ" and just use the "Z" and the "N." The formula for the coefficient is based upon the combined interaction of the axial and eccentric shear loads on each bolt.

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The final, simple interaction formulas were developed in a 1996 paper published in the ASCE *Practice Periodical on Structural Design and Construction*. The formulas to solve for coefficient "C" follow:

$C=1/[(1/\gamma N)^2+(1/\delta Z)^2]$ – Equation 4a

or the yet simpler:

$C=1/[(1/N)^2+(1/Z)^2]$ – Equation 4b

When considering high eccentricity connections, this can be further simplified as:

$C=Z/e$ – Equation 5, where e is the eccentricity.

The interesting conclusion is that bolted connection capacity can be directly solved without iteration. As an example, a single column of connectors can be tabulated as:

N # of bolts	γN	Z	δZ	h inches
2	1.96	3.00	3.00	3.0
3	2.89	6.00	6.00	6.0
4	3.77	12.00	11.94	9.0
Etc.				

This easy formula allows intuitive simplification of bolt connection analysis, and Equation 5 allows a quick preliminary rule-of-thumb check. Even capacity improvement to existing connections can be obtained by merely drilling larger holes and installing larger bolts.

One of those old Illinois professors I mentioned above said that engineers should "be lazy" and do the least amount of good work. I'd update that saying to "be efficient"; it's more politically correct today to focus on productivity rather than sloth. Plus, I like to think that formulas like the one above don't encourage laziness, but rather efficiency.

I've posted a spreadsheet that solves this formula at **www.steelutilitiesonline.com** (search for "Bolted Connection Design), an awesome tool that AISC created as an open (but unmanaged—check anything you get before you use it) location for engineers and others to share their spreadsheets and programs. The forum also allows for inquiries and discussions between engineers. It's a good resource that helps users wade through the difficulties of structural design, and helps them verify that the software—and their understanding of what it does and how it works—is correct. MSC