

Test-based Available Strengths for Aluminum Structures

Part 2

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This is Part 2 of a two-part series. Part 1 (STRUCTURE, September 2021) summarized two methods, including equations for finding available strengths for aluminum based on tests. It also includes plots of calculated safety factors for various conditions. Part 2 compares results from these methods. Please note that Figure numbering continues from Part 1.

This second part continues the exploration of Methods 1 and 2 in the 2020 edition of the *Specification for Aluminum Structures* (Appendix 1; section 1.3) for determining available strengths based on testing.

Comparison of Method 1 and 2 Results

Refer to Figures 6 through 9 for plots of the ratio of allowable strengths (ASD) from Method 1 to corresponding values from Method 2 for the sets of variables considered. The same legend (Figure 9) for coefficients of variation applies to each plot. Quantities include:

- R_{TM} : average (mean) test load
- $R_{I\Omega}$: Method 1 allowable load
- K : statistical coefficient
- C_V : coefficient of variation
- Ω : Method 1 safety factor, from the *Specification*
- R_{2SF} : Method 2 allowable load
- $m_1 = R_{I\Omega} / R_{TM} = (1 - KC_V) / \Omega$: for Method 1 (see Equation 2 in Part 1), as used for plots.
- $m_2^* = R_{2SF} / R_{TM} = 1 / S_{F2}^*$: for Method 2 (refer to Equation 7 in Part 1). Here the asterisk indicates that the larger of the calculated safety factor (S_{F2}) and the minimum safety factor (the applicable Ω in the *Specification*) is used.

Each plotted point corresponds to the ratio m_1 / m_2^* . Each plotted line (“curve”) represents a value of C_V , which ranges from 4% to 20%.

Table of bounding values of m_1 / m_2^* for LRFD.

Case	Minimum m_1 / m_2^*	Maximum m_1 / m_2^*
Beam Rupture	9%	89%
Tension-Member Rupture	10%	89%
Tapping-Screw Connections	8%	89%
Welded Connection	13%	113%

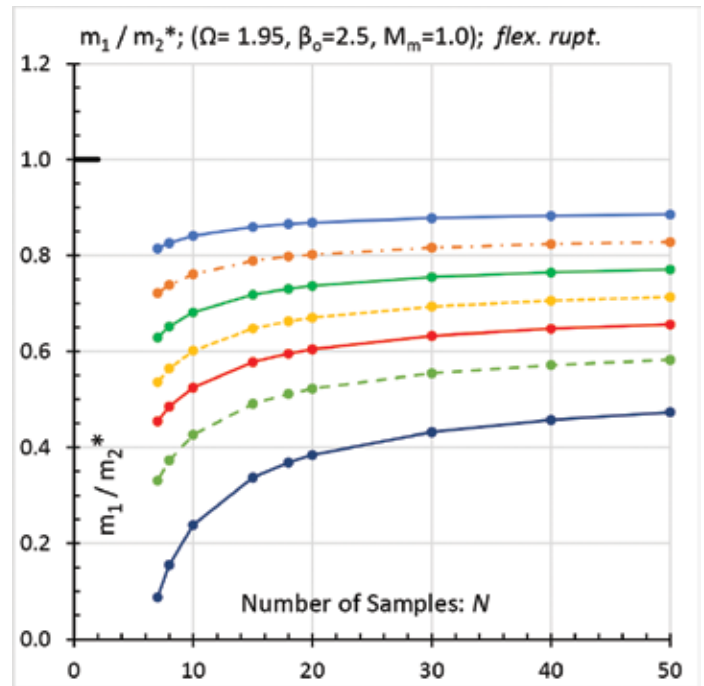


Figure 6. Ratios of allowable strengths: beam rupture.

The smallest C_V is the top line in each figure. The number of samples (N) extends from 7 to 50.

The target reliability indices, β_o (equal to 2.5, 3.0, and 3.5) used in Method 2, correspond to failure probabilities for a 50-year load recurrence of 0.621%, 0.135%, and 0.023%, respectively. Values of β_o are given at the top of each figure. For those cases where the Method 1 available load is less than that of Method 2, the failure probability is also less.

As an example (Figure 6: beam rupture), for a set of test specimens with $C_V = 12\%$, $N = 18$, and $K = 3.370$, the non-dimensional ratios m_1 and m_2^* are equal to 0.305 and 0.513, respectively. Thus, the allowable strength for Method 1 is 30.5% of the test average, and for Method 2, it is 51.3% of the test average. Therefore, $m_1 / m_2^* = 0.596$, which indicates that $R_{I\Omega}$ (the Method 1 allowable strength) is 59.6% of R_{2SF} (the Method 2 allowable strength).

For Method 1 (Equation 2), note that if $KC_V > 1.0$, $R_{I\Omega}$ would be negative and thus not a physically usable value. For such a KC_V value, no $R_{I\Omega}$ meets the criteria of 99% exceedance with 95% confidence. As an illustration, consider $C_V = 0.20$, $N = 6$ and $K = 5.062$, for which $KC_V = 1.012$. This is a limitation on Method 1's range of applicability. Method 2 does not have this limitation, but it requires a minimum N of 4 versus Method 1's minimum of 3. Also, Method 2 calls for

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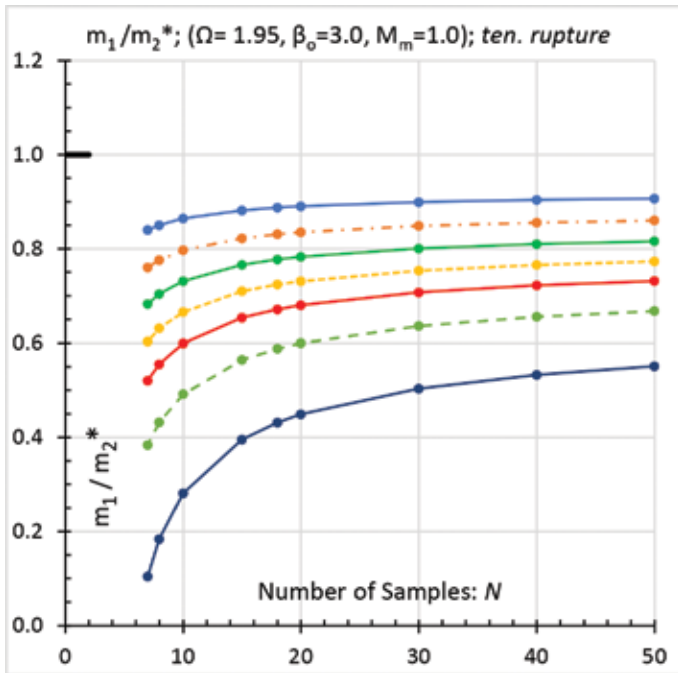


Figure 7. Ratios of allowable strengths: tension-member rupture.

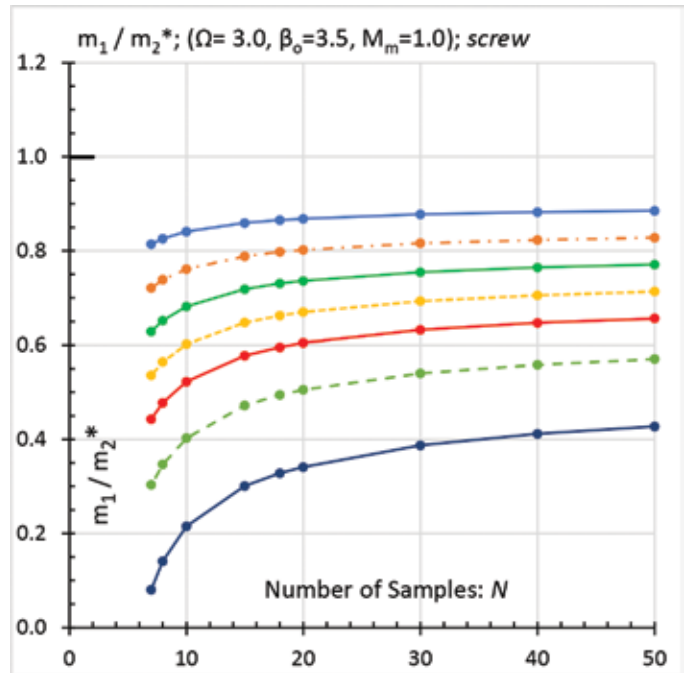


Figure 8. Ratios of allowable strengths: tapping-screw connections.

three additional tests if any test value deviates from the average by more than 10%.

Ranges of Ratio m_1 / m_2^*

For ASD (Figures 6 through 9), the ranges of the ratio (m_1 / m_2^*) of Method 1 allowable strengths to the corresponding Method 2 values are, to the nearest percentage point:

- Figure 6 (flexural rupture): from 9% to 89%.

- Figure 7 (tensile rupture): from 10% to 91%.
- Figure 8 (tapping screw connections): from 8% to 89%.
- Figure 9 (welded connections): from 14% to 117%, which is the largest range.

For LRFD (not plotted), the ranges of the ratio m_1 / m_2^* to the nearest percentage point are given in the Table. All individual LRFD ratios are less than or equal to and within a few percentage points of the corresponding ASD ratios. (The largest difference is 3.9%, for welded connections at $N = 50$ and $C_V = 4\%$.)

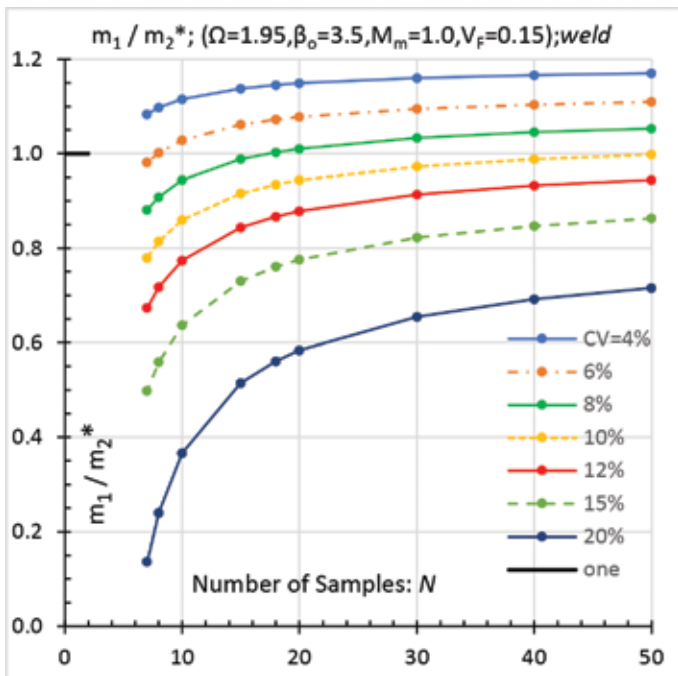


Figure 9. Ratios of allowable strengths: welded connection.

Overall Trends

Figures 6 to 8 pertain, respectively, to the limit states of flexural rupture, tensile rupture, and the various failure modes (e.g., fastener tension, pull-out, pull-over, shear, etc.) for connections utilizing tapping screws.

- For these three figures, Method 1 allowable strengths more closely approach the corresponding Method 2 strengths when there is a combination of relatively low C_V and large N .
- As the number of samples (N) increases while C_V is held constant, Method 1 allowable strengths tend toward those of Method 2.
- For a given N and a decrease in C_V , Method 1 allowable strengths also tend toward the corresponding Method 2 strengths.

Figure 9 (welded connections) is an exception. Here, for $4\% \leq C_V \leq 8\%$, all of the 4% curve and most of the 6% and 8% curves exceed 1.0; i.e., the Method 1 allowable values exceed the corresponding ones from Method 2. This is partly due to the combination of a small and medium C_V with a relatively large value of V_F (0.15 vs. 0.05) in Method 2. Also, for these three curves at $m_1 / m_2^* > 1.0$, both a decreasing C_V and an increasing N cause the Method 1 allowable strengths to be increasingly larger, on a percentage basis, than the corresponding ones of Method 2.

Small N and Large C_V

For test sets consisting of a relatively small number of specimens (e.g., 7 to about 12) and which have a large coefficient of variation (e.g., 15% and 20%) for the test strengths, it is evident that the use of Method 1 entails a substantial “penalty” as compared to Method 2. Recall that Method 1 utilizes a progressively larger factor (K ; see Figure 1 in Part 1) to address the inherent uncertainty associated with small N . If C_V is also large, then the combined effect on the allowable strength is quite substantial.

Consider a hypothetical case (tension member rupture; Figure 7) where initial testing includes four specimens. At least one specimen is found to have a strength that differs from the average by more than 10%. Thus, per Method 2, three more samples are tested for a total $N = 7$. The C_V for $N = 7$ is determined to be 15%. For Method 2, the allowable strength $R_{2SF} = 0.406 R_{TM}$. For Method 1, the allowable strength ($R_{1\Omega}$) is $0.156 R_{TM}$. Therefore, the ratio $m_1 / m_2^* = 0.384$; the Method 1 allowable strength is 38% of the Method 2 allowable strength. If additional specimens are tested, the test average and coefficient of variation could be similar to the values for seven specimens. If so, then the allowable strengths would increase. Try eight more specimens for a total $N = 15$. Here, $R_{2SF} = 0.429 R_{TM}$ and $R_{1\Omega} = 0.242 R_{TM}$. These results reflect a 5.6% increase in Method 2’s allowable strength and a 55% increase for Method 1. Also, Method 1 allowable strength would rise to 56% of that for Method 2 (i.e., $m_1 / m_2^* = 0.565$).

Conclusion

As these comparisons have demonstrated for the cases considered, Method 1 available strengths are generally smaller (more conservative) than the corresponding ones of Method 2. However, Method 1 involves fewer input parameters and is easier to use than Method 2. The available strength differences can be large, especially for a combination of a small number of specimens (N) and a large coefficient of variation (C_V). An exception occurs for welded connections, for most or all N at C_V of 4% to 8%, for which Method 1 available strengths are larger than those of Method 2. This is due to a large V_F (fabrication-variation parameter) for welded connections. ■



References are included in Part 1’s online version of this series at STRUCTUREmag.org.

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