Timber Rivet Connections

Design Process for a Moment Connection

Robert J. Taylor, Ph.D., P.Eng., Assoc.AIA
David M. Moses, Ph.D., P.Eng., P.E., LEED®AP

Timber rivet connections have been used successfully in many structures over the past 30 years. They are part of the U.S. and Canadian structural wood design codes, but unfortunately, there are few published design examples to aid designers. This article is targeted to the connection designer and provides a short summary of the *2005 National Design Specification® (NDS®) for Wood Construction* design process for timber rivet connections along with comments on design issues of common interest.

Moment Resisting Applications

Timber rivet connections work best when the plate of rivets is loaded in one direction as a group. The system was never intended to be used to resist a twisting moment applied in the plane of the plate. Madsen contends that a circular arrangement of rivets for such moment connections might make an interesting research problem, however, based on engineering experience, and the likely development of undesirable tension stresses perpendicular-to-grain, in-plane moment connections using timber rivets would not be recommended. Instead, designers can use other strategies to transfer moment.

Seismic Connections

Regarding seismic performance, obviously ductility can be enforced in the design of rivet connections by designing for rivet failure as the governing mode (i.e. ductile, as opposed to brittle wood failure). Dr. Marjan Popovski at FPInnovations (formerly Forintek Western Laboratory) contends that timber riveted connections are definitely one of the best connections to be used in earthquake prone areas. As proof, he has conducted exhaustive tests, including shake table tests, the results of which have been published. In earthquake prone areas, timber rivet connections should be designed to fail in rivet yielding, in order for the structure to achieve the required connection ductility. Wood failure (brittle mode governing) should be avoided at any cost.

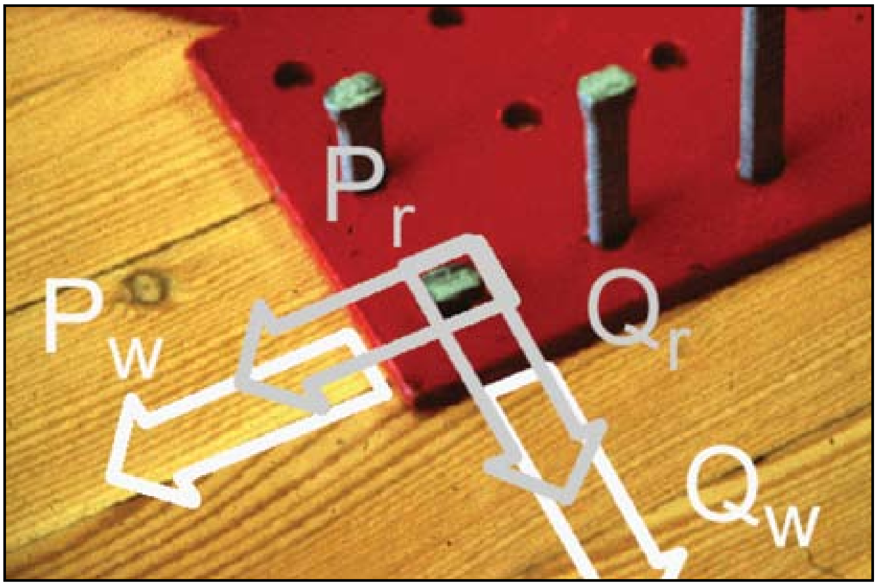

Figure 1: Four strength limit states for a typical timber rivet connection.

An improved way to enforce connection ductility is to move the ductile zone out of the rivets into the steel plates. There is far superior confidence in the ability to predict ductile behavior in structural steel, so if the steel plates are designed as the "weak link" (i.e. the fuse or energy-dissipating element of the connection) one can control and predict the ductility of the connection prior to approaching the capacity of the rivet connection in the wood. Here is an illustrative example: picture a splice between 2 pieces of wood where the steel side plates are riveted to both sides of each piece, but the steel plates are short and not continuous between wood members. Instead, use steel bolts (A325 or similar) to bolt the steel plates together with steel splice plates – essentially a steel-steel connection. Other configurations are possible too, essentially moving the weak link into the steel plates where one can more accurately predict behavior.

Design Process

Essentially, there are four strength limit states to a timber rivet connection (*Figure 1*); two parallel-to-grain (P-direction), and two perpendicular-to-grain (Q-direction). For each grain direction either the rivet yields and controls, or the wood fiber controls. If the load is applied only in the P-direction, or only in the Q-direction, then the number of strength limit-states to check reduces to two: rivet yielding and wood fiber control. The lower strength will govern the design. The perforated plate is stiff and, although rarely an issue, should also be checked using appropriate steel code provisions. Although, as mentioned previously, this potential limit state in the plate's tensile capacity could be added to the above states should one wish to assure connection ductility.

The design process is simple, regardless whether ASD or LRFD is used, and is best implemented using a spreadsheet, or other calculation software because of its recursive nature:

- Determine total loads that must be resisted (demand).
- Assume a trial design based on connection configuration geometry that will accommodate a grid of rivets, considering tabulated minimum edge and end distances. The main variables here are: plate thickness, rivet length, rivet spacing parallel-to-grain, number of rows of rivets, and number of rivets in each row.
- Check rivet capacity – an equation is given for this based on the capacity of a single rivet through a single plate. There are two equations: one each for the P and Q directions respectively (*NDS* 13.2-1 and 13.2-2).

- Check wood capacity parallel-to-grain (P-direction) – from a table based on rivets installed on faces of the connection. The tables are organized by rivet length and by plate thickness for typical rivet grid spacings. Footnotes to the table offer explanations of member width. The tables simplify the design process tremendously and allow the designer to avoid using complex equations for predicting wood capacity in shear or tension. The equations were originally developed and verified by tests. For details on these equations, see the *2005 NDS Commentary*.

NDS Tables 13.2.1A – 13.2.1F are for connections with steel side plates on opposite sides of the wood member. The reference design value in the table is for the capacity of one ¼-inch side plate with associated rivets (*NDS* C13.2.1). Thus for a connection with plates on opposing faces, the designer would *double the table value* to determine the reference capacity of the connection. For connections with a single plate of rivets on one side of the wood member, the designer enters the table with *twice* the thickness of the wood member to get the correct reference capacity for a single-sided connection.

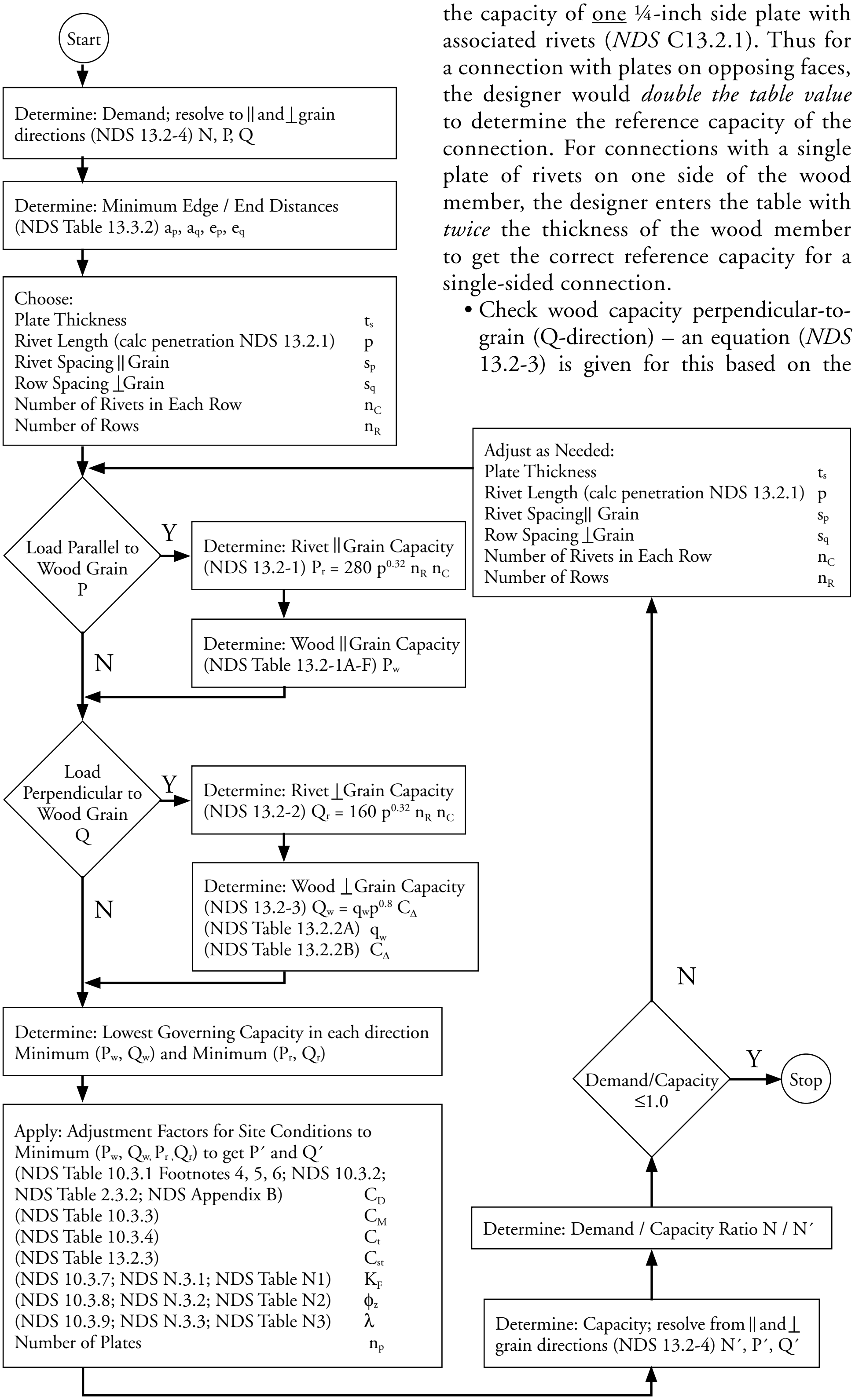

Figure 2: Timber rivet design process flowchart from the 2005 NDS.

- Check wood capacity perpendicular-to-grain (Q-direction) – an equation (*NDS* 13.2-3) is given for this based on the capacity of a single rivet through a single plate. The equation references two tables: one for the reference value (*NDS* Table 13.2.2A) based on one plate with rivets installed in one side of the connection, and another for the geometry factor, C_Δ, (*NDS* Table 13.2.2B). Again, the reference design value obtained from the equation is *doubled* for connections having *two* side plates.
- The lowest capacity of the four checks will govern the capacity of the connection. If rivet yield governs, then ductility of the connection is assured. If wood capacity controls, the connection is likely to be less ductile.
- Adjust the determined capacity for site environmental conditions using adjustment factors.
- Calculate the demand:capacity ratio – a value less than 1.0 is safe. If the ratio is greater than 1.0, try adding more rivets and repeat the trial design. Off the table for number of rivets? Try increasing the rivet spacing parallel-to-grain and move to another table. No good? Try increasing the plate thickness. Still not enough? Try increasing the rivet length in increments to the maximum penetration permitted by the connection geometry, and repeat the trial.

A flowchart in *Figure 2* illustrates the design process as referenced in the *2005 NDS*.

Design Example – Moment Splice

An example of a moment splice connection is shown in *Figure 3 (page 44)*. Calculations for the splice were based on the *2005 NDS* timber rivet provisions found in Chapter 13.

The moment splice is part of a three-pinned 12.25-inch x 70-inch 24F-V8 Douglas-fir glulam arch spanning 300 feet. Each half of the arch was spliced at its midpoint for shipping, and the moment splice was designed to resist a 400 k-ft moment due to wind (300 k-ft) and dead (100 k-ft) loading. The splice connection used a single rivet plate at the top and bottom of the member and opposing plates on the sides of the member to develop the tension force across the splice due to the moment. This strategy kept tension-perpendicular stresses to a minimum.

The design was done in two steps:

Step 1: Design of the top rivet plate to take most of the moment.

Step 2: Design of side rivet plates to take the remaining moment.

Additional steps to complete the design included design of split rings or shear keys to resist shear, as well as checking of plate

Figure 3: A timber rivet moment splice is part of a three-pinned 12.25-inch x 70-inch 24F-V8 Douglas-fir glulam arch spanning 300 feet.

thicknesses, net section, and addition of plate stiffeners as required. Checking rivet group block pull-out failure of the wood member, or other known local stress effects due to the rivets, was not needed since these failure modes were included in the generation of the *2005 NDS* timber rivet table values (see *2005 NDS* Appendix section E.1.1 for more information).

The final solution is shown in *Figure 4*. Detailed calculations are available in a more complete online version of the article at **www.awc.org/pdf/TimberRivetConnections.pdf**.

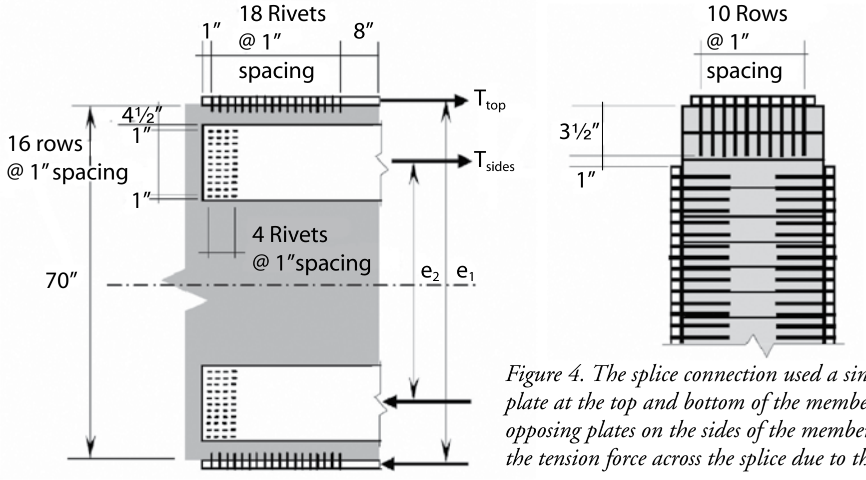

Figure 4. The splice connection used a single rivet plate at the top and bottom of the member and opposing plates on the sides of the member to develop the tension force across the splice due to the moment.

Summary

Timber rivets are a versatile means of making large scale timber connections functionally and aesthetically possible. The design process for timber rivet connections using current code references is presented. An example of a moment splice is also provided to illustrate the process.▪

Dr. Robert J. Taylor, P.Eng., Assoc. AIA, serves as AWC's Director, Technology Transfer. He has accumulated over 30 years of experience in Canada and the U.S. in academia, industry, and government. Robert is an award-winning speaker, educator and presenter of wood design education topics to varied audiences.

Dr. David M. Moses, P.Eng., P.E., LEED®AP (Equilibrium Consulting Inc.) is a structural engineer specializing in timber engineering in Toronto, Canada. Much of his work is in the area of sustainable design where timber plays a key role. For further information, contact David at ***dmoses@eqcanada.com****.*

Disclaimer

It is intended that this article be used in conjunction with competent engineering design. The authors, AF&PA, and Equilibrium Consulting, Inc. assume no responsibility for errors and/or omissions in this article, or for any engineering designs, plans, or construction prepared from it.

References for this article are available online. Please visit **www.awc.org**.

Reprinted with permission from Wood Design Focus, Winter 2007.