Modern Wood Fasteners

The Key to Mass Timber Construction
Part 3: Design Guidelines for Glued-in Rods

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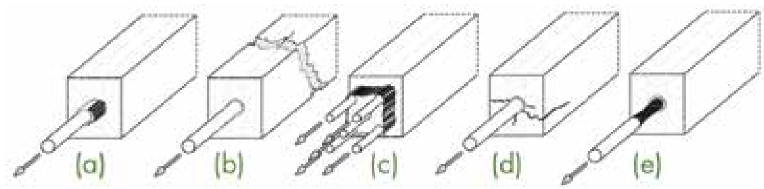

Figure 1. Potential failure modes: a) pull-out due to bondline or wood shear; b) net-tension; c) group tear-out; d) splitting; e) rod tensile failure. From Tlustochowicz et al. (2011)

This is the third part of the series of articles on modern wood fasteners. Part 1 (STRUCTURE, August 2020) focused on self-tapping screws (STS). Part 2 (STRUCTURE, February 2021) introduced the reader to glued-in rods (GIR) and the components making up these joints. This concluding part summarizes design guidelines for the GIR connections. Despite the interest among designers of mass timber construction, there is no official recognition in U.S. and Canadian design codes for GIR connections. This article sheds light on the state of the art of this emerging technology. We caution the reader that this an area of development without code approvals in the U.S. and Canada – the content is provided as informational and is not to be used for design.

Design Considerations

Connection Configuration

When designing GIR connections, the load path and failure modes of adjoining members should be carefully considered. Apart from the tensile failure of the rods or pull-out due to bondline failure, wood failure modes in the vicinity of the rods due to shear, splitting, net-tension, or group tear-out are possible (*Figure 1*). Rods may also experience buckling if loaded in compression, although it has rarely been observed. Sizing a GIR joint is a compromise between efficiency (equal strength and stiffness with the adjoining members) and undesirable wood failures. Assuming the ratio of Young's modulus of steel to timber along the grain equals 20, it can be shown that spacing the rods at four times the diameter of the rod would provide equal axial stiffness of the rods and the timber member. But smaller spacing between rods and closer edge distances to the face of the timber member increases the probability of brittle shear, splitting, or tensile failures.

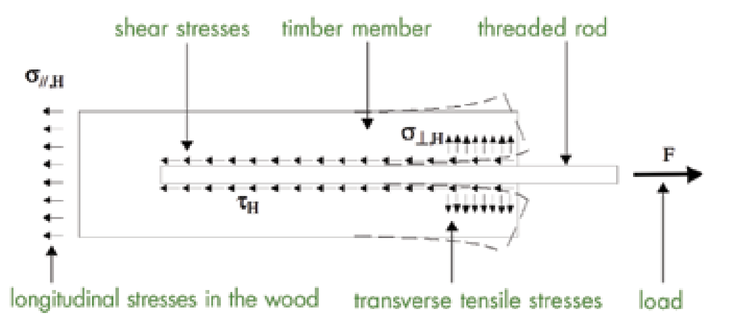

Figure 2. Stresses in timber around the glued-in rod loaded in withdrawal. From Fabris (2001)

The following design particulars can be found in European literature. To calculate the tensile strength of timber in the joint, it is assumed that each rod of diameter d glued parallel to grain can activate a maximum cross-section of $6d \times 6d = 36d^2$ of surrounding wood (note this has not been adopted and is still being researched). Also, sufficient shear area and volume of the surrounding wood are needed to resist the longitudinal shear and transverse tensile stresses around the rod (*Figure 2*); hence, joints with closely spaced rods would be prone to splitting and shear failures. The spacing and edge distance allowing an area of $5d \times 5d = 25d^2$ around each rod inserted parallel to grain has been most often cited in the literature, again, still being researched and not adopted. The volume of timber around the glued-in rod may be increased by countersinking the bonded portion and leaving an unbonded length of approximately $5d$ at the end of the member to reduce the risk of splitting (*Figure 3*). Such countersinking proved to be effective and allowed further reductions of rod spacing to $3.5d$. Also, the ductility and displacement capacity of the joint is enhanced when the countersinking is employed.

Transverse reinforcement near the ends of timber members has proved to be effective in protecting the timber members from splitting, and it is mandatory in the Russian design standard. In New Zealand, it is recommended to place not more than three closely spaced rods in one row and to offset the ends of the rods by at least 3 inches (75 mm) to avoid stress concentrations and minimize the risk of rupture at the ends of the rods. It is important that the rods are evenly spaced to achieve the optimum force flow in high-capacity joints.

Group Effects

Suppose the yielding capacity of rods is higher than their pull-out capacity. In that case, premature failure of an individual rod may occur due to irregular force distribution in a joint with multiple rods. The stiffer the joint, the less stress redistribution is possible. To account for the uneven force distribution in a joint, a 10% reduction is applied to the resistance of GIR joints with two rods and a 25% reduction for all other configurations, in accordance with the Russian design standard on glulam timber structures with glued-in rods (SP 382.1325800.2017). In New Zealand, no reduction is applied on groups of two rods, 10% reduction on 3 and 4 rods, and 20% reduction is applied for groups of 5 and 6 rods – larger groups are not recommended. In tests, the force distribution between rods in a joint depends on the joint configuration, the orientation of rods relative to wood grain, and load direction.

Inclined Rods

According to the Russian standard, rods glued at angles between 20° and 90° to the grain are considered inclined. Often, inclined rods are used for reinforcement of notched supports (*Figure 4*). The length and positioning of rods should prevent transverse splitting

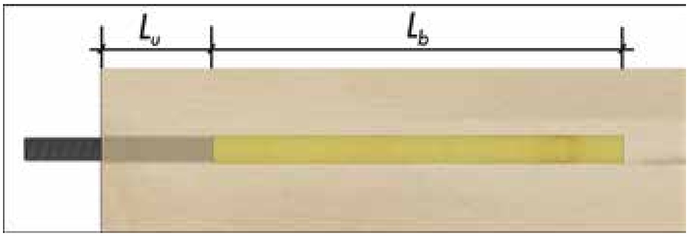

Figure 3. Countersinking of glued-in rod. Notation: L_b = bonded length, L_u = unbonded length.

of timber at the embedded end. The minimum spacing along the grain depends on the angle of inclination and varies between 7.5*d* (for α > 60°) and 14*d* (for α < 30°), otherwise, 10*d*.

Service Conditions and Corrosion

GIR connections are suitable for structures designed for dry service conditions. A noticeable reduction of pull-out strength at high moisture content has been reported in the literature. Furthermore, wood shrinkage and swelling are not compatible with the linear expansion of steel and may lead to excessive splitting of timber or bond failure. For similar reasons, joints should be fabricated in conditions as near as possible to the in-service environment. Although the adhesive and surrounding wood protects the bonded part of the rods, the rods usually are exposed at their ends. In severely corrosive environments, it is recommended to use stainless or zinc-coated steel rods. In accordance with the Russian standard, the structures with GIR joints are permitted in environments with sustained elevated temperatures above 95°F (35°C) but not higher than 122°F (50°C) and the relative humidity not less than 50%. In Europe, wood adhesives are rated for use up to 140°F (60°C) via stringent tests.

Fire and High-Temperature Applications

Guidelines for fire resistance need to be developed. In principle, the timber surrounding the steel has an insulating effect on the rods. The wood will char and provide protection to the steel rods, as is now required in certain applications noted in timber design standards in the U.S. and Canada. Since steel is known to have low heat resistance, all steel parts of the GIR joints should be protected against fire. Research on the heat resistance of adhesives and GIR joints is underway.

Other Current Considerations

Hardwood (beech) glulam and LVL are being studied right now in Europe and have great potential due to their high density leading to high bondline strength and efficient GIR connections. Currently, a new draft of design rules for joints with bonded-in rods, considering all findings accumulated over the last fifty years, has been circulated in Europe, and similar efforts are being undertaken in Canada and at the ISO level. Time will tell if consensus can be reached on the general rules that will lead to new U.S. and Canadian standards.

Application

That lack of recognition in North American building codes, as well as lack of consensus among other nations that have recognized GIR in their codes, may raise a legitimate question for the reader: "Is this even a realistic option for my project?" It is, although it will take more work than more common connections because prescriptive building code provisions lag behind new technologies. Building codes like the *International Building Code* (IBC) in the U.S. or the *National Building Code* (NBC) of Canada allow for innovation through provisions for the approval of alternative, non-codified means and methods. In the U.S., this is addressed in IBC section 104.11, the American Society of Civil Engineers' ASCE 7-16, *Minimum Design Loads for Buildings and Other Structures* (section 1.3.1.3), and the *National Design Specification* (NDS®) *for Wood Construction* (sections 1.1.1.5 and 11.1.1.3). In Canada, see the CSA Group's standard CSA O86, *Engineering Design in Wood* (section 4.3.2). These provisions involve demonstrating that something not addressed by the code nevertheless meets the code's intent by performing equivalently to code-recognized products or procedures.

Much like the International Code Council's ICC-ES reports that many U.S. engineers are already familiar with, other nations have product evaluation reports, such as the European Technical Assessment (ETA) or the National Technical Assessment (NTA) reports that may be used to demonstrate equivalence. The potential use must be within the range of applicability and restrictions

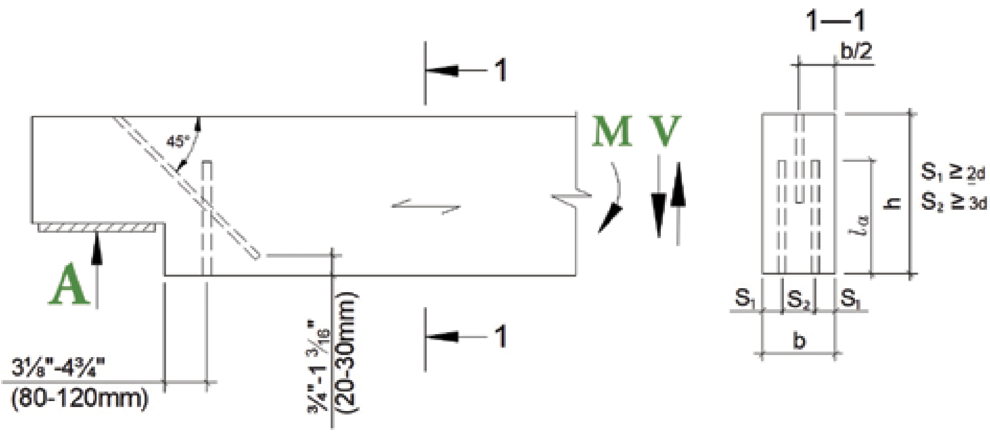

Figure 4. Reinforcement of notched beams at support. Reproduced from SP 382.1325800.2017.

defined in those documents for them to be valid support. The engineer should understand the basis of published strengths and any differences in design factors from foreign reports and translate those as needed to values compatible with the project jurisdiction's design methods. The Authority Having Jurisdiction (AHJ) may require testing if the supporting documents are not accepted, so the engineer should be prepared to make a thorough, well-reasoned case to the building official initially, explaining foreign terminology and derivations of values. An independent peer review may also be necessary. However, with good planning, glued-in rods can open up new avenues to safe, strong, concealed wood connections in North America as they have elsewhere.▪

References are included in the PDF version of the article at **STRUCTUREmag.org**.

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