Technical Note

DESIGN OF GLUED-IN RODS OR BARS

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NZS 3603 and its soon to be released replacement NZS AS 1720.1 do not contain provisions for the design of glued-in rods or bars. Currently, reference is normally made to Chapter 29 of the Timber Design Guide (Buchanan et al. 2007), which outlines design provisions based on testing of a limited number of locally available glues and epoxies.

The technical literature and European Technical Assessment (ETA) of several timber specific glues produced in Europe require the design of glued-in rods or bars to be carried out in accordance with the German National Annex to Eurocode 5 (DIN, 2013).

The following technical note follows the current methods contained in the German National Annex to Eurocode 5 (DIN, 2013). These provisions can be considered as an alternative to Chapter 29 of the Timber Design Guide. Formatting has been made to be consistent with DZ NZS AS 1720.1/V6.0 (here cited as NZS AS 1720.1 for clarity). Commentary boxes are provided to explain the background of the provisions and to provide further guidance.

1 DESIGN CAPACITIES OF GLUED-IN RODS OR BARS

This section applies to joints in timber members with glued-in or epoxied threaded rods or deformed bars with diameters between 6 mm and 32 mm.

All glues or epoxies used for glued-in rods or bars shall be specifically approved for the use for joints in timber members.

Glued-in rods or bars shall not be used in members which are likely to have an in-service moisture content of more than 20%.

Adequate corrosion protection of the threaded rods or deformed bars outside the timber member shall be provided as per Technical Specification SNZ TS 3404 Durability requirement for steel structures and components (SNZ, 2018).

C1

Glued-in rods or bars should be installed when the moisture content of the timber is as near as possible to the in-service equilibrium moisture content of the timber member. Moisture content variations of more than 5% of the timber member between the time of installation and in service conditions can lead to the loss of adhesion of the glue or epoxy due to the moisture deformation of the wood.

The adhesion of the rod or bar with the timber cannot be guaranteed for timber members with a moisture content of more than 20%, as likely moisture variations of the timber will lead to increased shear stresses in the glued interface and will also lead to the splitting of the joint area. Typically, all members which are not protected by the weather have an average moisture content of more than 20%.

Gluing of rods or bars must be done in controlled, factory conditions with adequate quality control and skilled personnel. Manufacturer's instructions regarding mixing, opening time, ambient temperature and pot life should be strictly adhered to. On-site gluing is not recommended because the effectiveness of the grouting operation cannot be assured (Buchanan, 2007).

The diameter of the hole in the timber should be at least 2 mm larger than the nominal diameter of the rod or bar and should allow for the minimum thickness of adhesive as specified by the supplier. The hole in the timber should be clean cut and cleaned from saw dust and wood chips. It should be ensured that the rods or bars are centred in the hole during the application of the adhesive. The instructions of the adhesive supplier should be followed when applying the glue or epoxy or follow the guidance in the Timber Design Guide (Buchanan, 2007).

1.1 Type 1 joints (shear)

1.1.1 Design capacities for Type 1 joints

The design capacity ($V_{d,j}$) for a type 1 joint containing *n* glued-in rods or bars in shear to resist lateral loads shall satisfy the following:

$$V_{d,j} \geq V^* \quad (1)$$

where

$$V_{d,j} = n \, n_{a,y} \quad (2)$$

and

V^* = the design action effect in shear

n = number of glued-in rods or bars resisting the design action effect in shear

$n_{a,y}$ = minimum applicable fastener design ultimate yielding strength from Table 4.31 in section 4A.7.3.2.1 of NZS AS 1720.1

The glued-in rod modification factor k_{70} shall be applied when determining the timber embedment strength $f_{i,a}$, as per section 4A.7.3.2.2.1. k_{70} shall be taken as:

k_{70} = 1.25 for glued-in rods or bars installed perpendicular to the wood fibres

= 0.125 for glued-in rods or bars installed parallel to the wood fibres

The embedment length l_{ef} shall satisfy the following minimum length

$$l_{ef} \geq max\{0.5 \, D^2; \, 10 \, D\} \quad (3)$$

For glued-in rods or bars which are installed at an angle between 0° and 90° to the wood fibres, the design embedment strength shall be determined through linear interpolation.

If the distance of the rod or bar furthest away from the loaded edge is less than 0.7d, then the tension perpendicular to grain stresses from the force component perpendicular to grain shall be verified with the provisions in section 4A.7.3.3 Table 4.34 of NZS AS 1720.1. Alternatively, the provisions provided in sections C4.1 or C5.1 of the *NZ Wood Guide - Reinforcement of Timber members* (NZ Wood, 2020) shall be followed. It is good practice to reinforce joints with glued-in rods or bars in shear.

Note: When determining $n_{a,y}$ the effective diameter *D* of the threaded rod or deformed bar shall be used. The effective diameter for threaded rods is defined as the average between the core diameter and the outer thread diameter. The effective diameter for deformed bars is the net diameter.

C1.1.1

The design capacity of glued-in rods or bars resisting lateral shear can be calculated using the Johansen equations (also known as the European Yield Model) as per the detailed method for joints. The rope effect as allowed for bolted connections can be taken into consideration.

Due to the adhesion between the rod or bar and the timber, the embedment area is increased and a very high friction between the steel and the timber can be achieved. This results in increased stiffness and higher capacities of the connection, leading to the 25% increase in embedment strength. For glued-in rods or bars installed parallel to the wood grain, low embedment strengths can be achieved, reducing the embedment strength to only 10% of the value for rods or bars installed perpendicular to grain (Blaß and Sandhaas, 2017). The large reduction in capacity for rods or bars installed parallel to grain is because the glued in rods or bars are pushing the tubular fibres of the wood apart as shown in Figure C1, creating tension perpendicular to grain stresses around an already disturbed area providing little resistance.

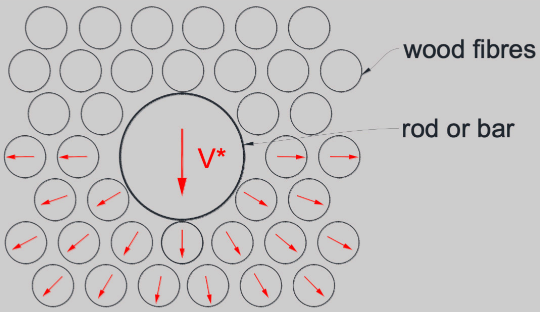
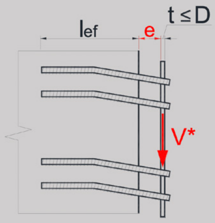
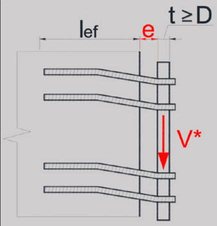


Figure C1: Displacement of wood fibres for rods or bars installed parallel to grain loaded in shear

If the load application is at a distance *e* from the timber member or bond line of the rod or bar (i.e. there is a gap between the timber member or bond line and the point of load application), the minimum applicable fastener design ultimate yielding strength $n_{a,y}$ can be determined with the equations shown in Table 1.

Table 1: Load application at a distance e from the bond line for rods or bars loaded in shear

	$n_{\alpha,y} = f_{1,\alpha}\, D \left(\sqrt{e^2 + \frac{2\, M_y}{D\, f_{1,\alpha}}} - e \right)$	(C1)
	$n_{\alpha,y} = f_{1,\alpha}\, D \left(\sqrt{e^2 + \frac{4\, M_y}{D\, f_{1,\alpha}}} - e \right)$	(C2)

where

- D = the nominal diameter of the rod or bar
- M_y = the ultimate fastener design yield strength determined from clause 4A.7.3.2.2.2 of NZS AS 1720.1
- e = the eccentricity as per figures Table 1 if applicable due to the geometry of the connection
- $f_{1,a}$ = the design embedment strength
- t = the thickness of the member at the load application

For member thicknesses t between $D/2$ and D, the design ultimate yielding strength can be determined by linear interpolation.

For more information refer to Blaß et al. (2004).

1.1.2 Spacing, edge and end distances for Type 1 joints (shear)

For glued-in rods or bars installed perpendicular to the wood fibres the distances as per section 4.4.4 of NZS AS 1720.1 apply, as long as the conditions in table 4.1 of NZS AS 1720.1 are satisfied. Alternatively, the distances as per section 4A.5.5.4 apply, if in addition the brittle failure modes as per 4A.7.3.3 of NZS AS 1720.1 are verified.

For glued-in rods or bars installed parallel to the wood fibres the minimum distances shown in Figure 1 apply.

1.2 Type 2 joints (axial)

1.2.1 Design capacities for Type 2 joints

The design capacity ($N_{d,j}$) for a type 2 joint in which glued-in rods or bars are loaded in direct tension shall satisfy

$$N_{d,j} \geq N^* \tag{4}$$

where $N_{d,j}$ is the lesser of

$$N_{d,j} = n\, N_{d,tr} \tag{5}$$

$$N_{d,j} = \phi_a\, k_1 k_{15}\, n_{ef}\, \pi\, D\, l_{ef}\, f_a \tag{6}$$

and

- N^* = the design action effect in direct tension
- n = number of glued-in rods or bars in the joint
- n_{ef} = $n^{0.9}$
  = effective number of glued-in rods or bars in the joint
- k_1 = duration of load factor for fasteners
- k_{15} = factor for effect of seasoning of timber
- $N_{d,tr}$ = design capacity of rod or bar in tension
- $Ø_a$ = 0.7 for the capacity factor for adhesives
- D = is the nominal diameter of the rod or bar
- l_{ef} = the embedment length of the glued-in rod or bar
- f_a = the bond line strength of the adhesive for glued-in rods or bars

The embedment length l_{ef} shall satisfy the following minimum length

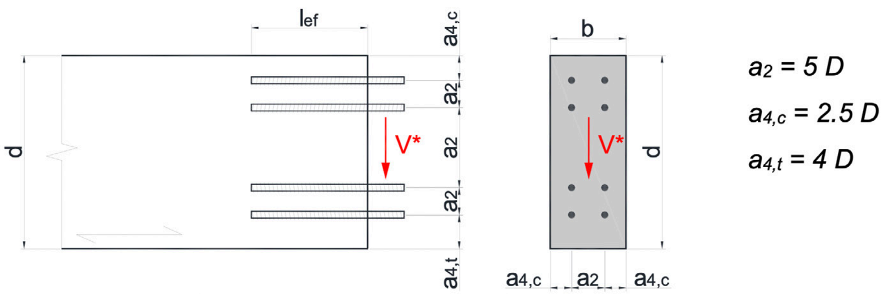


Figure 1: Distances for glued-in rods or bars installed parallel to the wood fibres and loaded in shear

$$l_{ef} \geq max\{0.5\,D^2;\ 10\,D\} \tag{7}$$

In equation (6) l_{ef} shall not be taken as larger than *1000 mm* or *40 D*.

Unless determined by testing or specified by the glue or epoxy supplier, the bond line strength f_a in MPa shall be determined as

$$f_a = \begin{cases} 4.0 & for\ l_{ef} \leq 250\ mm \\ 5.25 - 0.005\ l_{ef} & for\ 250\ mm < l_{ef} \leq 500\ mm \\ 3.5 - 0.0015\ l_{ef} & for\ 500\ mm < l_{ef} \leq 1000\ mm \end{cases} \tag{8}$$

In addition to the requirement in Equation (4), the design capacity in tension parallel to grain $N_{d,t}$ of the timber cross section at the head of the rods or bars shall satisfy the following

$$N_{d,t} \geq N^* \tag{9}$$

where

$$N_{d,t} = \phi\ k_1 k_4 k_6\ A_{ef}\ f_t' \tag{10}$$

and

- $\varnothing$ = the capacity factor of the timber member
- k_1 = duration of load factor for members
- k_4, k_6 = modification factors given in section 2 of NZS AS 1720.1
- A_{ef} = A maximum area of 36 D^2 per rod or bar shall be taken into consideration. For a group of rods or bars, the overlapping effect of adjacent rods or bars shall be taken into consideration (refer to Figure C3).
- f'_t = the characteristic value in tension parallel to grain of the timber member

If glued-in rods or bars are used in perpendicular to grain joints, the tension perpendicular to grain stresses shall be verified with the provisions in section 4A.7.3.3 Table 4.34 of NZS AS 1720.1. Alternatively, the formulation provided in section C5.1 of the *NZ Wood Guide - Reinforcement of Timber members* (NZ Wood, 2020) shall be used. The effective depth d_e is the projection of the embedment length l_{ef} sin a, where a is the angle between the bar or rod and the wood fibres.

C1.2.1

For joints with axially loaded glued-in rods or bars, it is recommended that the embedment length l_{ef} and distances a_2 and $a_{4,c}$ are chosen so that the steel tensile strength as per Equation (5) is less than the pull-out strength of the bar or rod as per Equation (6) or the tensile strength of the timber as per Equation (10). This recommendation is even more important in cases where the rods are not uniformly stressed (i.e. when several rows of rods are used to resist a moment couple, with the outermost bar carrying higher loads due to the higher lever arm), in this way a redistribution of forces through the plasticization of the highest loaded rods can be achieved. Overstrength demand of the steel rod or bar might need to be taken into consideration, depending on the desired hierarchy of strength and Potential Ductile Element considerations.

The bond line strength f_a is limited by the strength of the bond line between the adhesive and the steel rod or bar, the strength of the adhesive, the strength of the bond line between the adhesive and the timber and the strength of the timber at the hole. There is no clear separation of the failure mechanisms and the best prediction is based on equation (8) and shown in Figure C2. Because of the complexity of the adhesion failure modes, it is always recommended to design glued-in rods and bars that develop the full steel tensile capacity.

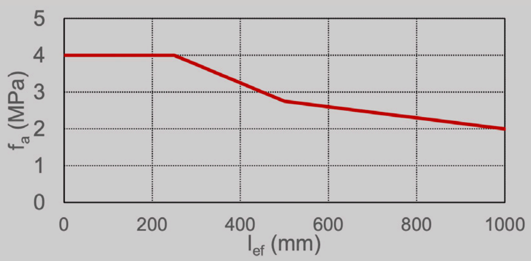


Figure C2: Bond line strength f_a between the glued-in rod or bar and the timber in function of the embedment length l_{ef}

The minimum embedment lengths as per Equation (7) are required to avoid brittle failure modes of the glued-in rods or bars.

The limitation of the tension area for a single rod or bar is limited to a square of area *36 D^2* to account for the limited load distribution in the timber member. If the rods or bars are placed at less than *6D*, the overlapping area should be ignored as shown in Figure C3. By taking only the tensile strength of the cross section of the timber member under consideration, the shear strength along the failure plane is conservatively ignored.

Note that the sum of both the tensile and shear strength contributions leads to unconservative values, as the failures modes have different stiffnesses.

It is always recommended to stagger the rod or bar embedment lengths in order to reduce stress concentrations and reduce the potential for splitting.

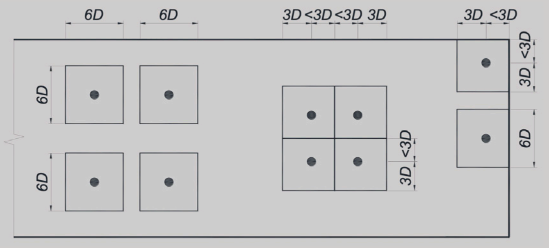


Figure C3: Tension areas (hatched) for individual and group of glued-in rods or bars in direct tension

Glued-in rods or bars under axial compression loads should also be verified for buckling. Refer to section C7.2 of the *NZ Wood Guide - Reinforcement of Timber members* (NZ Wood, 2020) for more information on buckling capacities of steel members embedded in timber.

To prevent premature splitting of the timber member at the glued-in rods or bars loaded in direct tension, reinforcing in the form of fully threaded screws or secondary glued-in rods or bars perpendicular to the main rods or bars is recommended. It is recommended that the reinforcing has an effective steel area of 1/25 of the steel area of the main rods or bars. Refer to the *NZ Wood Guide - Reinforcement of Timber members* (NZ Wood, 2020) for more information.

All nuts in a group of axially loaded threaded rods should be tightened uniformly so that the tensile forces are distributed evenly to all rods. To avoid overtightening of the rods and to limit the tensile force into the rods during tightening a torque-wrench should be used.

1.2.2 Spacing, edge and end distances for Type 2 joints (axial)

For glued-in rods or bars installed perpendicular to the wood fibres and loaded in direct tension the minimum distances shown in Figure 2 apply.

For glued-in rods or bars installed parallel to the wood fibres and loaded in direct tension the minimum distances shown in Figure 3 apply.

1.3 Joints with glued-in rods or bars loaded in shear and in direct tension

For glued-in rods or bars in joints loaded both in shear and direct tension, the following shall be satisfied

$$\left(\frac{V^*}{V_{d,j}}\right)^2 + \left(\frac{N^*}{N_{d,j}}\right)^2 \leq 1 \qquad (11)$$

where

V^* = the design action effect of the joint in shear

$V_{d,j}$ = design capacity for the type 1 joint with glued-in rods or bars resisting lateral loads

N^* = the design action effect of the joint in direct tension

$N_{d,j}$ = design capacity for the type 2 joint with glued-in rods or bars loaded in direct tension

C1.3

Depending on the failure mode in shear as per Table 4.31 of NZS AS 1720.1, the bond line strength between the rod or bar might become compromised, resulting in lower axial capacities. Engineering judgement should be applied in order to assure that the rods or bars provide enough capacity under combined loading.

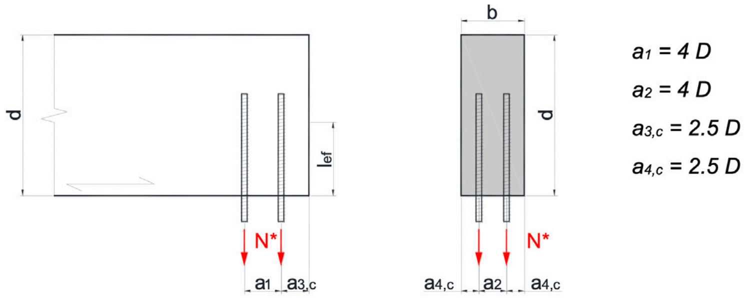


Figure 2: Distances for glued-in rods or bars installed perpendicular to the wood fibres and loaded in direct tension

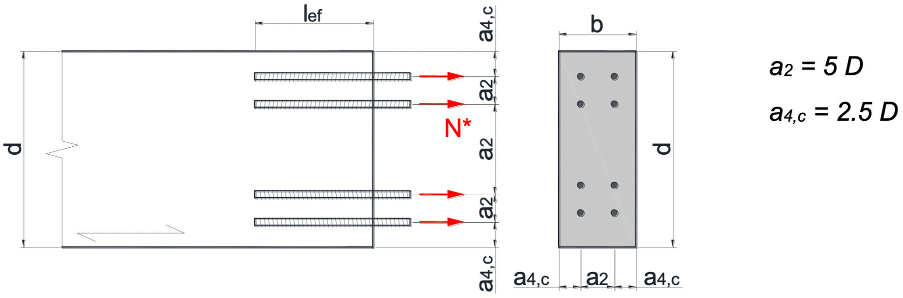


Figure 3: Distances for glued-in rods or bars installed parallel to the wood fibres and loaded in direct tension

REFERENCES

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