Glued-in bolts

STEP lecture C14
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Objective

To describe the behaviour, design and manufacture of glued-in bolts primarily in glued laminated timber.

Prerequisites

A4 Wood as building material
A8 Glued laminated timber - Production and strength classes
A12 Adhesives
C2 Tension perpendicular to the grain in joints
C7 Bolted and dowelled joints II

Summary

An introduction to the major fields of application is presented together with the manufacturing procedure for glued-in bolts. The behaviour is described with emphasis on factors influencing the short-term strength of axially loaded bolts. The effect of changing moisture content in the wood is also mentioned. Finally the design of axially and laterally loaded bolts is shown.

Introduction

Glued-in bolted connections have been used in the Scandinavian countries and in Germany for more than 20 years. The major area of application has been in glulam structures. Figures 1 and 2 shows some examples. The bolts are used to prevent cracks in the apex zone of curved beams and in end notched beams or to transfer forces into a structure or part of a structure as in a column-foundation joint and in a frame corner. The bolts can be loaded either axially or laterally or by a combination of both.

Advantages obtained by using glued-in bolts include:

- High local force transfer.
- Very stiff connection when loaded in the axial direction.
- Good fire properties. The surrounding wood protects the steel.

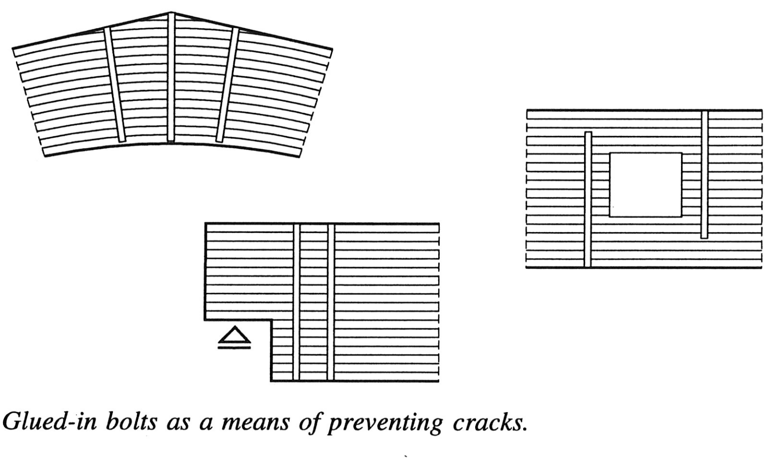


Figure 1 Glued-in bolts as a means of preventing cracks.

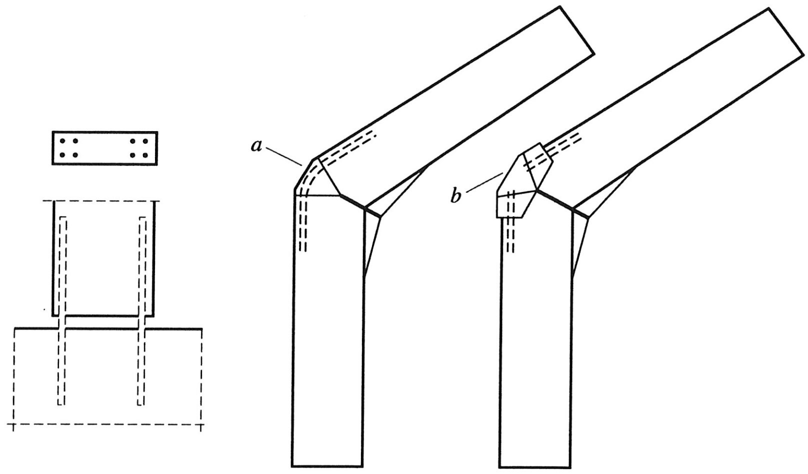


Figure 2 *Glued-in bolts in moment stiff column-foundation joint and moment stiff frame corner. (a) Space filled with mortar. (b) Steel fitting.*

Materials and manufacture

It is difficult to achieve sufficient adhesion between a smooth steel surface and glue. Therefore threaded bolts are preferred in order to obtain a mechanical bond between the bolt and the glue. Bolts with a diameter of between 12 and 24 *mm* are common. The bolts are glued-in either by injection of the glue as is shown in Figure 3 or by screwing in the bolt. In the first case the holes are normally 1 *mm* larger than the diameter of the threaded part of the bolt to give sufficient clearance for the injection of glue. In the other case the hole is smaller than the bolt diameter, normally by an amount equal to the depth of the thread. Glue is poured into the hole and the bolt is screwed in. To allow for distribution of the glue the bolt has to have a channel cut along its length. The glue can also be applied along the depth of the hole and the length of the bolt with a brush and then it is not always necessary to use grooved bolts.

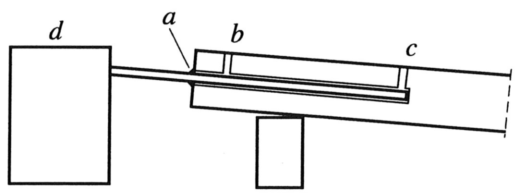


Figure 3 *Injection of glued bolt connection. (a) sealing, (b) glue out, (c) glue in, (d) block to prevent the bolt from being forced out by the glue.*

Different types of adhesives, such as phenol-resorcinol, two-component polyurethane and two-component epoxy, are being used. The choice of adhesive has to be related to the production method and how the bolts are loaded. With the injection method, where the hole is larger than the bolt diameter, the withdrawal strength of the bolt to a very large extent depends on the strength and durability of the glue line. In bolts that are screwed in, the forces between wood and bolt are transferred mechanically to a great extent in areas where glue is missing or if the properties of the glue are insufficient.

The phenol-resorcinol adhesives have a long history of use in structural applications, for instance in glulam. Riberholt (1988), however, suggests that phenol-resorcinol should not be used in connection with the injection method and oversized holes, due to the strength reducing effect of the initial hardening shrinkage of the glue. Two-component polyurethane adhesive is sensitive to elevated temperature (Aicher 1992) and should therefore be used with caution especially in bolts under high permanent loads if the injection method is used.

In laterally loaded bolts the choice of adhesive is less important as the forces are mainly transferred via compression in the glue line.

Strength of axially loaded bolts

Factors influencing the short term strength

Gerold (1992) has analysed a large number of test results and his conclusions can be summarised as follows:

- The strength of bolts loaded in tension and compression is the same.
- Strain measurements along glued-in bolts confirm that the shear stress distribution corresponds with that obtained with the Volkersen (1953) theory (see Table 1). The axial strength is influenced by the difference in stiffness between steel and wood, the glued length of the bolt and the stiffness of the bond between bolt and wood.
- The axial bolt strength also to some extent depends on the wood density.
- In general the axial strength is somewhat higher for bolts glued-in perpendicular to the grain direction than parallel to the grain direction.

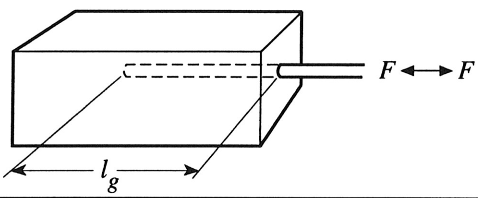
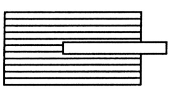
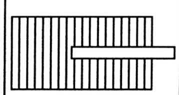
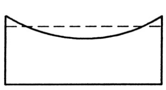
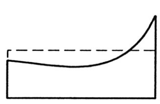
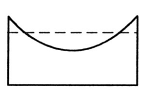
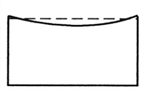
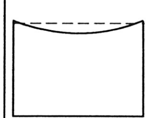
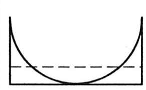
			F force l_g glued length of the bolt d bolt diameter		
Components with equal stiffness EA	Components with different stiffness	Components with equal stiffness			
		Bond with high stiffness	Bond with low stiffness	Short glued length	Long glued length
					

Table 1 *Bond stress distribution in the joint assuming linear elastic behaviour of all materials according to the Volkersen (1953) theory (Gerold 1992). The dashed line represents the average shear stress ($F / (l_g d\pi)$).*

According to Riberholt (1988) the axial strength can be estimated with the following equations which are based on regression analysis of test results from bolts with diameters of 12 and 20 *mm* and with a ratio of glued-in length to diameter of 15:

$$F_{ax,est} = 0{,}784\,\rho d\sqrt{l_g} \tag{1}$$

for two-component polyurethane and other ductile glues, and

$$F_{ax,est} = 0{,}627\,\rho d\sqrt{l_g} \tag{2}$$

for two-component epoxy, phenol-resorcinol and other brittle glues where $F_{ax,est}$ is obtained in *N* and the symbols are defined as follows:

d	is the bolt diameter in *mm*.
l_g	is the glued-in length of the bolt in *mm*.
ρ	is the density of the surrounding wood in kg/m^3.

Equations (1) and (2) are valid for $l_g \geq 200$ *mm*. For lower values the equations tend to overestimate the axial bolt strength.

Effect of changing moisture content
Gerold (1992) indicates that shrinkage and swelling due to changing moisture content may cause considerable shear stresses in the bond between bolt and wood. Glued-in bolts should therefore be used with caution in service class 3 applications.

Laterally loaded bolts

The load-carrying capacity of laterally loaded bolts mainly depends on the embedding strength. By gluing in the bolts an almost infinite coefficient of friction is obtained between the steel and the wood surfaces. For bolts perpendicular to the grain direction Rodd et al. (1989) shows that this leads to a considerable increase of both the embedding strength and the stiffness (see Table 2).

Bolt diameter in *mm*	Load parallel to the grain direction		Load perpendicular to the grain direction	
	Strength increase factors	Stiffness increase factors	Strength increase factors	Stiffness increase factors
12	1,31	4,98	1,52	8,37
16	1,28	9,44	1,62	9,44
20	1,25	10,1	1,64	7,19
25	1,29	11,9	1,96	6,20

Table 2 Strength and stiffness increase factors (glued-in bolt/plain bolt) for laterally loaded bolts glued-in perpendicular to the member in spruce timber (Rodd et al., 1989).

Design of glued-in bolts

Axially loaded bolts
The following design rules are suggested by Riberholt (1988). The characteristic axial capacity in tension and compression is given by:

$$R_{ax,k} = f_{ws}\rho_k d\sqrt{l_g} \qquad for\ l_g \geq 200\,mm \qquad (4)$$

$$R_{ax,k} = f_{wl}\rho_k d\, l_g \qquad for\ l_g < 200\,mm \qquad (5)$$

where $R_{ax,k}$ is in N and where

f_{ws} is a strength parameter for Equation (4) in $N/mm^{1,5}$. For brittle glues, such as phenol-resorcinol and epoxy the value is 0,520 and for non-brittle glues, such as two-component polyurethane the value is 0,650.

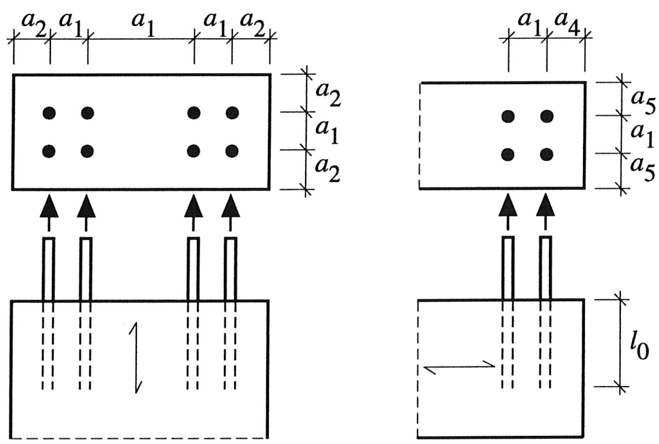
f_{wl} is a strength parameter for Equation (5) in *N/mm*. For brittle glues, such as phenol-resorcinol and epoxy the value is 0,037 and for non-brittle glues, such as 2-component polyurethane the value is 0,046.

ρ_k is the characteristic density in kg/m^3.

$$d = \max \begin{cases} \text{hole diameter} \\ \text{bolt diameter} \end{cases} \text{ in } mm$$

l_g is the glued in length in *mm*.

Equations (4) and (5) are valid provided that the minimum distances are according to Figure 4.



Minimum distance	
a_1	2d
a_2	1,5d
a_4	2d
a_5	2,5d

Figure 4 Minimum distances for axially loaded bolts.

In addition to this the following points should be considered:

- For bolts parallel to the grain direction it should be shown that the total force in a group of bolts is less than the tensile strength of the effective area behind the bolts.
- Due to stability failure in a compressed bolt the axial stress in it should not exceed 400 N/mm^2.

- Experience from tested bolts shows that the withdrawal failure mode is rather brittle when the glued-in length is short. If the force distribution over a group of bolts is statically indeterminate, the glued-in length should be at least d^2, d in *mm*.

Laterally loaded bolts

Glued-in bolts perpendicular to the grain:

EC5: Part 1-1: 6.5.1

The design load-carrying capacity of bolts glued in perpendicular to the fibre direction may be calculated according to EC5. The effect of the glue may be considered by increasing the embedding strength by a factor 1,2.

Glued-in bolts parallel to the grain:
Riberholt (1988) suggests the following design rules:

The characteristic load-carrying capacity for a bolt carrying a force acting a distance *e* from the wood surface is

$$R_k = \left(\sqrt{e^2 + \frac{2\,M_{y,k}}{d f_h}} - e \right) d f_h \qquad (6)$$

where

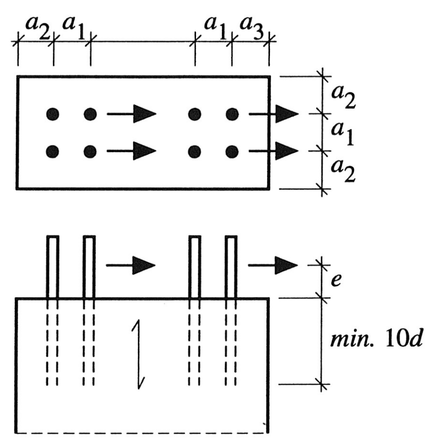
$M_{y,k}$ is the characteristic yield moment of the bolt in *Nmm*.

$$d = \max \begin{cases} \text{hole diameter} \\ \text{bolt diameter} \end{cases} \quad \text{in } mm$$

f_h is the embedding strength parameter in N/mm^2.

$$f_h = (0{,}0023 + 0{,}75 d^{-1,5})\rho_k \qquad (7)$$

Minimum distances should be according to Figure 5.



Minimum distance	
a_1	2d
a_2	2d
a_3	4d

Figure 5 Minimum distances for laterally loaded bolts.

Splitting can occur, see STEP lecture C2. Riberholt (1988) shows how the load-carrying capacity can be improved by bonding plywood sleeves to the end grain.

Protection against corrosion

For bolts loaded axially it is essential that corrosion is prevented. Riberholt (1988) points to the risk of the bond between steel and wood being destroyed by expansion of rust. Glued-in bolts therefore have to be protected against corrosion, for example with zinc coating. Riberholt (1986) found that some adhesives, for example epoxy, also give a good protection against corrosion.

Concluding summary

- The connections are produced either by injecting the glue in an over-sized hole or by screwing in the bolt.

- Adhesives with sufficient strength and durability properties should be used.

- The axial strength is influenced by the difference in stiffness between the wood and the bolt, the glued-in length, the stiffness and strength of the bond between bolt and wood and the density.

- Changing moisture content may cause considerable shear stresses in the bond, especially for bolts placed perpendicular to the grain direction.

- For laterally loaded bolts the glue causes an increase in the embedding strength of at least 20%.

- Glued bolts normally have to be protected against corrosion by zinc coating.

References

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