HIGH PERFORMING JOINTING TECHNIQUE USING GLUED-IN RODS

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ABSTRACT: The paper demonstrates the great possibilities in using glued-in rods for connections, where high performance in strength and stiffness are required. Through an optimized design of the GSA®-rods and the combination with a special created strong epoxy glue, a ductile behaviour is ensured. The design of performing joints is also a result of the correct placement of the rods: in accordance to the main lines of forces acting in the joint and considering the peculiar properties of the timber parts to be connected.

KEYWORDS: Glued-in rods, ductile behaviour, group effect, effect of humidity and temperature.

1 INTRODUCTION

Limiting factor in a timber structure is usually the low performance of the joints or connections. The most promising way would be to link wood fibre to wood fibre; nearest to that is the connection by finger-jointing. Here the highest performance was obtained in the past.

Joints using glued-in bars have also shown high performance. This is the result of large research done in the last 20 years. Numerous applications have meanwhile showed the adequacy of such jointing technique.

Both jointing techniques are based on the strength of the glue. Strong glues on epoxy basis are now available, but high performance is only achieved by an adequate design of the joints (which takes in consideration the peculiar characteristic of the timber), the use of a reliable technology and of qualified procedures. High production quality can only be achieved in factory.

Larger structures must be transported in sections. Therefore a jointing technique is required which uses the higher performance of factory gluing and the simple and reliable mechanical joint by use e.g. of steel pins or bolts at the erection place.

Such a high performing jointing technique was created, by the combination of glued-in bars and pinned steel connections. The target: high performance of the joint (in strength, stiffness and ductility) is achieved; the erection in place is easy and reliable: sections are only pinned together (steel to steel connection).

2 PRINCIPLE OF THE GSA® JOINTING TECHNIQUE

The principle of the GSA® technology is shown in Figure 1. The joint itself is classical steel-to-steel connection, which design follows well known requirements. To these steel parts are screwed or welded special formed steel rods, which are than inserted and glued to the timber parts to be jointed.

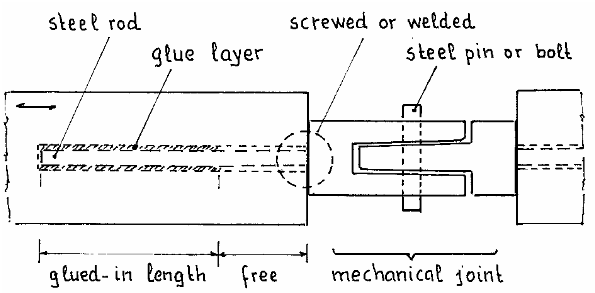

Figure 1: *View – Principle of GSA®-joint*

The joint is only very efficient, if the resulting forces are transmitted in the direction of the rods. Forces with varying direction should therefore be transmitted by two inclined rods (see Figure 2).

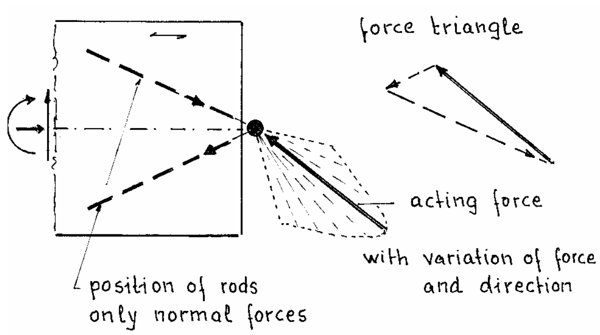

Figure 2: *Equilibrium and parallelogram of forces*

The problem of the connection is therefore reduced to:
- the equilibrium of forces, with forces mainly acting in direction of the rod;
- the interplay of forces at the rod (mainly consideration of the pull-out strength);

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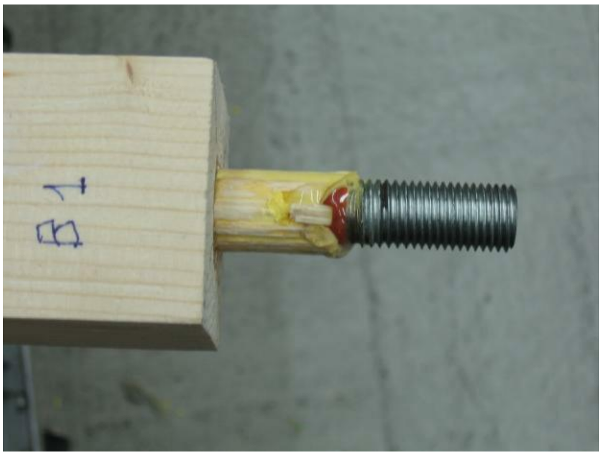
- the behaviour of the timber at the area of the connection (often determinant since the peculiar properties of the timber are not adapted).
The last two points will now be considered in more detail.

3 PERFORMANCE OF GLUED-IN RODS

3.1 PULL-OUT STRENGTH OF INDIVIDUAL ROD

The actual used special GSA® epoxy glues show at room temperature a shearing strength of more than 30 N/mm². This is a few times stronger than the normally used softwoods and still much stronger than hardwoods. An adequate gluing leads normally to failures in the timber; therefore the shearing strength of the timber will be determinant.



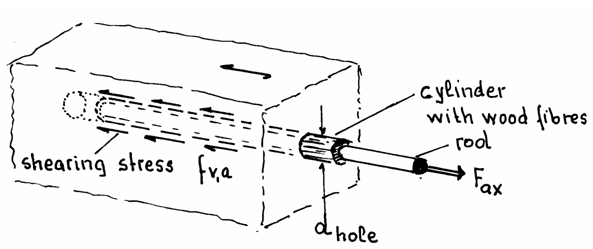


Figure 3: *Shearing of a wood cylinder (pull-out)*

Through adequate design of the rod and using a sinking length (without load transfer) other failure modes like splitting of the timber are generally avoided (see Figure 3).

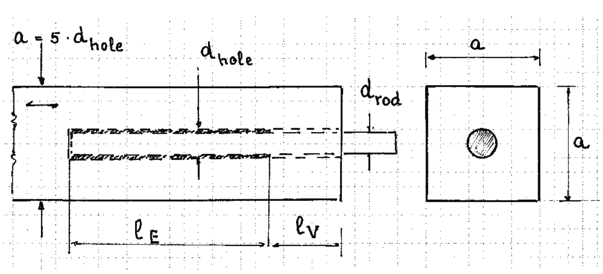


Figure 4: *Basic geometry of test specimens*

In such a case the pull-out strength can easily be described as function of the glued area A_{shear} and the shearing capacity of the timber species (for background see [1]):

$$F_{ax} = a \cdot A_{shear}{}^{\alpha} \qquad (1)$$

where A_{shear} = glued area: a function of hole diameter and glued-in length ℓ_E, α = exponent: which considers direction of force to the grain and a = factor, depending on timber species and only valid for a specific geometry of the test specimen e.g. as given in Figure 4.
For spruce and direction of force parallel to the grain the characteristic pull-out strength (short time test under normal conditions) may be written to:

$$F_{ax,k} = 40 \cdot A_{shear}{}^{0,8} \qquad (2)$$

where $F_{ax,k}$ in Newton and A_{shear} in mm².
Higher values are achieved for other directions than parallel to the grain; for practical use this may be disregarded. Remember: a similar approach – based on data available at that time - was given in ENV 1995-2: 1997:

$$F_{ax,k} = 1{,}2 \cdot 10^{-3} \cdot \pi \cdot d_{equ}{}^{0,8} \cdot \ell_a \cdot \rho_k{}^{1,5} \qquad (3)$$

Assuming a rod slenderness of ≤ 15 (normal practical range) and a characteristic density of 420 kg/m³, the equation (3) results for rods of diameter 16 to 20 mm to quite the same expression.
The value given was the same for all load-to-grain directions; in the Final draft of EN 1995-1 the drafting group proposed to differentiate: this would lead to a reduction of 2/3 for load direction to the grain. The reduction leads to conservative values, but was justified by the use of non-optimized glued-in rods.

3.2 EFFECT OF SIZE

The effect of size or the influence of fastener spacings on joint performance was discussed in [2]. It is shown that spacing greater than $5{\cdot}d$ have no influence on the pull-out strength. The use of smaller spacings leads to a reduction (on the individual rod), but nevertheless to an increase of the performance of the connection.
A conservative approach leads to the following reduction factor (based on the pull-out strength with the reference value for $a = 5\ d$):

$$k_{red} = (a / 5d)^{0,35} \qquad (4)$$

3.3 GROUP OF RODS

Glued-in rods are not only very strong but also very stiff. The deformation at failure state (for the case of pull-out failure) is less than 0.5 mm (at least for a load direction parallel to the grain). Uneven distribution of forces in a group can therefore not be absorbed. Only by creating the possibility to have larger plastic deformations in the rod, before the start of a brittle pull-out failure of any individual rod, leads to a ductile behaviour of the group of rods.
This is a main point of the GSA®-technology. The joint behave ductile, by the plastic deformation of the steel rods. Therefore any reduction due to group effect can be disregarded.

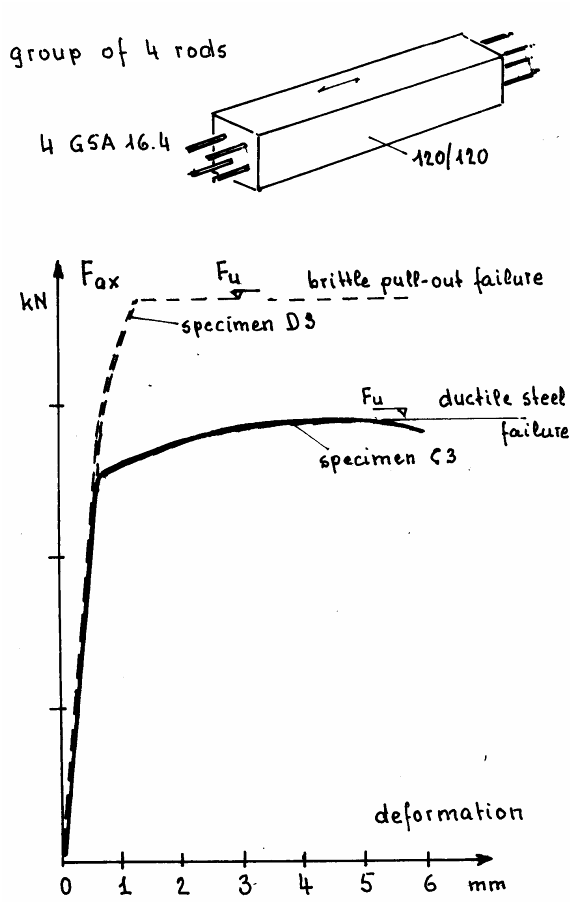


Figure 5: *Ductile behaviour of a GSA®-joint*

The only difference between specimens C3 and D3 in Figure 6 was the steel quality. Inadequate – in this case stronger - steel quality led to a brittle pull-out failure. Such a connection presents therefore very low robustness.

3.4 EFFECT OF MOISTURE CONTENT AND TEMPERATURE

The short term tests– which are generally the basis for the design values of most connection types – are conducted at room temperature and a moisture content of about 12% (normal climate: 20°C and 65% relative humidity). For practical use higher moisture contents and higher temperature have to be considered.
Higher moisture content affects only the timber properties (for changes after gluing); a higher temperature range will affect the properties for both, the timber and mainly the epoxy.
The effect of moisture on the shearing strength of the timber (main characteristic property for glued-in rods) is well known. Any increase of moisture by 1% leads to a reduction on the shearing strength of about 2.5 %. For use in service class 2, with often encountered moisture contents of 16 to 20%, and assuming a mean value of 18%, the decrease of strength is about 15%. It is astonishing – and inadmissible – that such an effect is disregarded in the Eurocode.
We propose – and it had been foreseen in ENV 1995-2:1997 – that for service class 2 the values of k_{mod} according to EN 1995-1-1 should be reduced by 20%. This is also the case for the GSA®-technology.
The effect of temperature is therefore to be considered:
- on the shearing strength of timber
- and on the shearing strength of the epoxy.

Schematically the two effects are described in Figure 6.

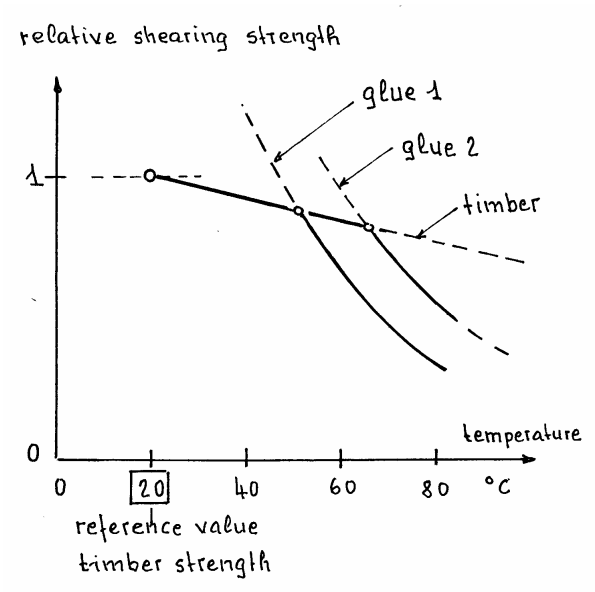


Figure 6: *Shearing strength of timber and epoxy in function of temperature for short term loading (relative to timber and to room temperature)*

The timber strength may be described by the following expression (valid for spruce):

$$f_{v,a,T} = f_{v,a,20°} [1 - 0.0038 (T - 20°)] \qquad (5)$$

where $f_{v,a,T}$ is the strength at a given temperature related to the shearing strength at room temperature $f_{v,a,20°}$.
The above expression is based on data published by Sano [3] and Hilty [4].
The epoxy glues present a larger variability of properties, depending on the hardener used and on the temperature history (at setting) and possible tempering. In any case the influence of temperature on the shearing strength is much greater and specially when considering load duration.
The intersection of timber and glue line is shown in Figure 6 as a point. In reality there is an intersection zone, considering the variability of the material properties.
Most room setting epoxies are used up to a temperature of 50°C. This may be enough for usual structural applications; but often the requirement is fixed to 60°C. In such cases strength of epoxies may fallen below the strength of the timber and therefore be determinant (see in Figure 6, glue 1).
When using better performing epoxies (at temperatures of 60°C or more) still a reduction has to be considered, since the shearing strength of the timber has decreased (e.g. for T = 60°C about 15%). This affects not only the strength of glued-in rods, but all connection types which relay on the shear capacity of the timber, and that are quite all!

3.5 QUALITY ASSURANCE

High performance can only be achieved if any of the influencing parameters are near to the optimum. This requires a reliable control of the design and of the production process. This is the main reason for a factory made connection, where the production is made under better controlled climatic conditions.
Similar as for other gluing processes, at the beginning and at the end of the fabrication period, control samples are produced and latter on tested on strength.

4 APPLICATIONS

4.1 SUPPORTS AND HINGED JOINTS

In traditional timber structures supports and hinged joints are often used. In general it is assumed that the timber will adapt locally to the small movements at the supports. The result is the appearance of crush zones and of larger deformations. Both should be avoided.
It is therefore good practice to require:
- That the deformation of a structure due to loading, moisture changes, variation of temperature and deformability of the connections should be limited, appropriate to the type of construction
- Timber zones under compression perpendicular to the grain should – in case of high compression or larger variations of moisture content – be avoided.
- A simple and efficient way is to use glued-in bars for the load introduction: besides the elimination of movements due to moisture changes (resulting forces must be considered), they create a better flux of forces in the timber element.

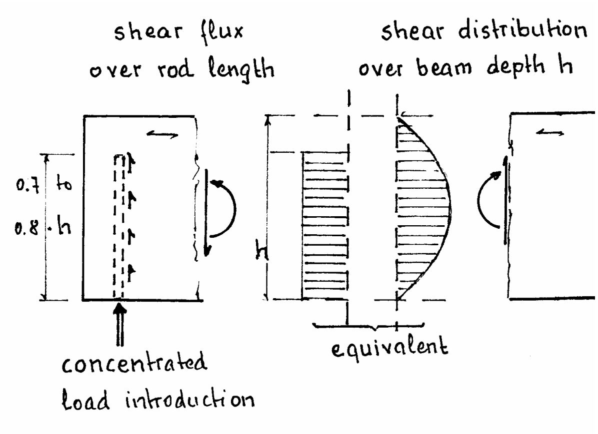


Figure 7: *Glued-in rods for load introduction (beam support)*

Through the application of glued-in rods the support is reduced (point or concentrated load) and the deformations are substantial smaller. The rod direction corresponds to the direction of the support force.
The distribution of forces can in such a case be admitted as uniform over the length of the rod. Those forces are in equilibrium with the shear force (assumed to be distributed parabolic over the depth of the girder). The length of the rod should be chosen about 0.7 to 0.8 of the girder depth, to obtain a favourable field of forces; in case of tension load introduction use as possible rods over the full depth.

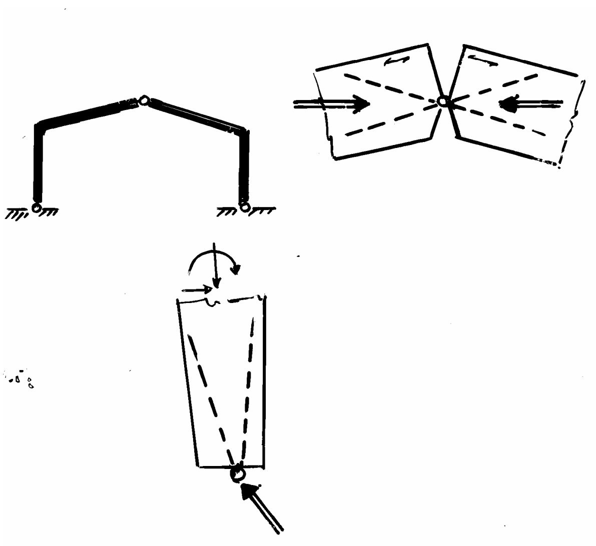


Figure 8: *Hinged arches or frames*

Hinged joints are typical for three-hinged frames and arches (see Figure 8). The resulting force acts concentrated on a point; the variation of the line of action is normally small, as are also the rotations. By using two inclined rods intersecting at the centre of the articulation, best configuration is achieved.

Figure 9: *Pivot hinge in GSA®-technology*

Figure 10: *Typical hinge with steel shoe*

Usually large steel shoes (see Figure 10) are applied; further it is assumed that the load is uniformly distributed. This is not the case if stiffness criteria are considered. In the case of the pivot hinge (see Figure 9) lifting forces can easily be taken.

4.2 BEAM JOINTS

Beam bending joints are seldom used. Reasons for that are the limited performance of such joints and the commonly brittle failure mode. Using GSA®-technology it is now possible to obtain high performance (in strength and stiffness) and a ductile behaviour.

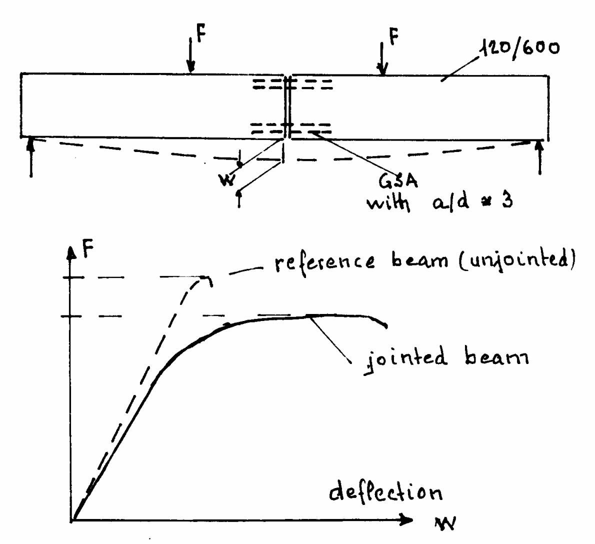


Figure 11: *Ductile joint of high performance*

Near the jointing area the timber is locally higher stressed than in the rest of the beam. Since this would be determinant for the joint efficiency, you may use in these areas higher strength timber (softwood lamellas of a superior strength class or even lamellas or inserts of hardwood).

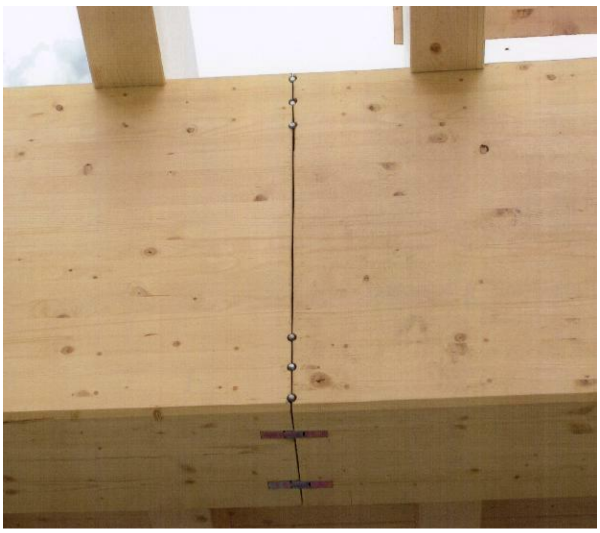


Figure 12: *Typical beam joint in GSA®-technology*

4.3 BEAM POST CONNECTIONS

Typical beam post connections are presented in Figure 13. The load-carrying capacity is given in (a) by the width *b* of the column (equal to the contact length); this value can be increased by the introduction of a hardwood piece.

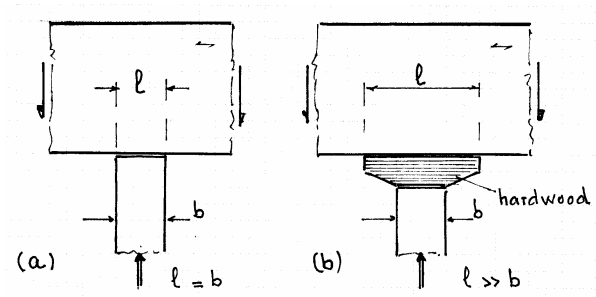


Figure 13: *Typical connections*

Alternative solutions are shown in Figure 14. In (a) the hardwood is directly inserted into the beam (hardwood pieces finger-jointed to softwood laminations): in (b) the load is introduced through glued-in rods into the beam (higher loads admissible) using an additional steel contact plate.

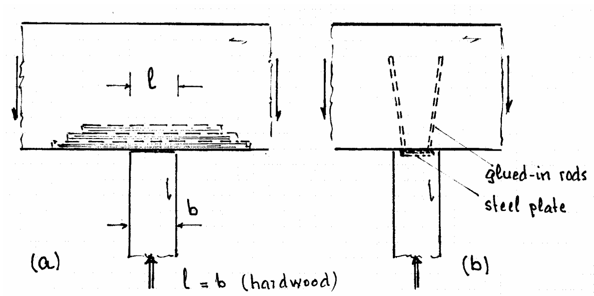


Figure 14: *Alternative solutions*

One problem is often ignored: the lack of continuity (in bending stiffness) of the column into the girder.

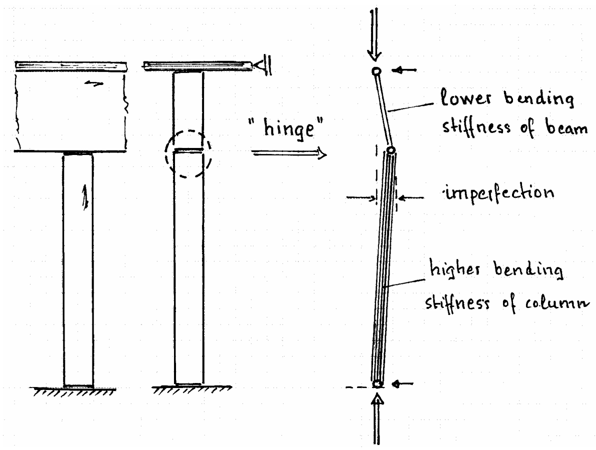


Figure 15: *System instability*

At the connection zone is a clear need for continuity of the column into the beam (which is here part of the column). This can be achieved by a bending stiff connected column to the beam, as shown in Figure 16.

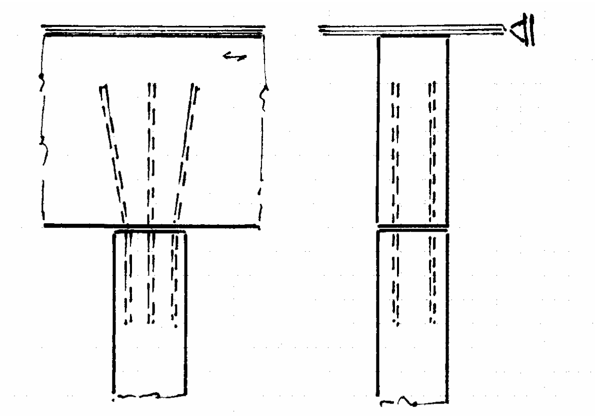


Figure 16: *Solution with GSA®-technology*

In case of multi-storey structure decision has to be taken, which element, column or beam, has to be interrupted; normally the columns are going through. Using the GSA®-technology it was more efficient and economic to interrupt the column.

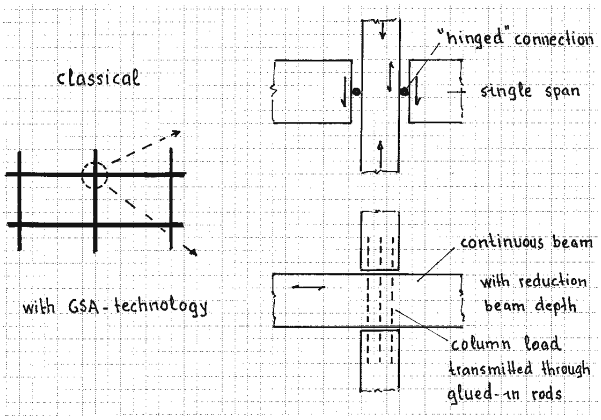


Figure 17: *Connections in multi-story structures*

The transfer of forces through the beam by compression perpendicular to the grain was avoided through the application of glued-in bars, connected on both sides, bending stiff to the columns.

Figure 18: *Example Morenia*

4.4 FRAME CORNER – CORNER JOINT

All larger frames are cut – by reasons of transportation - into elements, most like Figure 19 into beams and columns, which seems logical at first regard. The moment acting at the corner can be – without difficulties - transmitted with glued-in rods but results in high shear stresses in the corner zone of the beam.

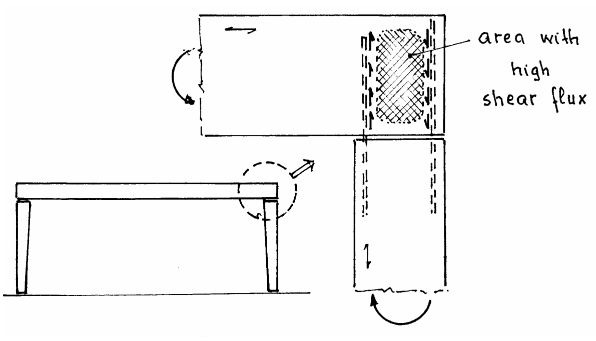


Figure 19: *Shear flux at the frame corner*

Timber and most wood products – with exception of plywood – present a low relationship shear to bending strength. Therefore the performance is low and the solution not indicated.

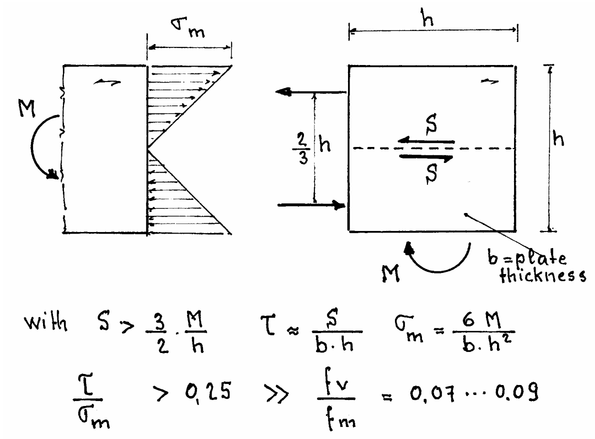


Figure 20: *Relationship shear to bending stress*

The assumption is simple but crude; the value of S is – due to the triangular stress distribution – greater. Therefore the relationship τ/σ_m will be greater than 0.25.

The performance related to bending is therefore low. This has been compensated in the past by increasing the size of the corner; since the effect is a function of h^2 it seemed the most interesting way.

A better solution is to place the joint at the intersection of both elements, as seen in Figure 21.

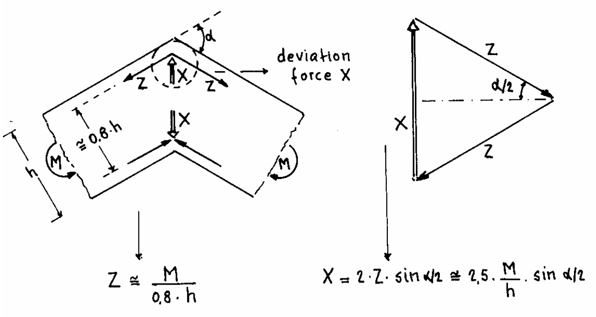


Figure 21: *Corner joint – equilibrium condition*

The basic idea is simple. First the equilibrium conditions are to be fulfilled. Since the deviation forces can not been taken by the timber itself, a connecting element is needed.

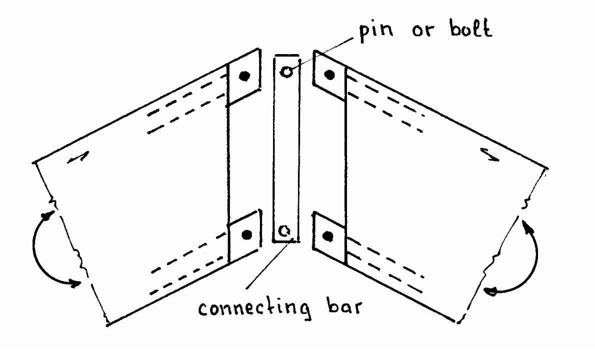


Figure 22: Principle – exploded view

The principle shown in Figure 22 follows the main principle of the GSA®-technology as presented in Figure 1.
For reasons of transportation, the connecting element is subdivided in two parts, each part being integrated into the timber member to be jointed.

5 IMPORTANCE OF HARDWOODS

As explained in section 3, determinant for the pull-out capacity of glued-in rods is the shearing strength of the timber material. Using instead of the usual softwoods, a stronger material like hardwoods, e.g. beech or ash, with more than 50% higher shearing strength, a higher pull-out capacity can be achieved with the same rod size.
This is an advantage for structures completely made of hardwoods (actually seldom) but also very interesting as local reinforcement in the zone of jointing.

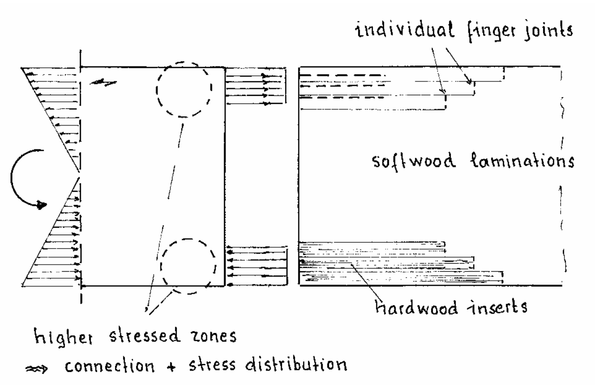


Figure 23: Local reinforcement using hardwood insert

By such a local reinforcing as shown in Figure 23 the full capacity of the member without joints may be used or by other terms, efficiency of 100% - with a simultaneous ductile behaviour – can be achieved.
The correct placement of the hardwood parts (to be jointed before into the lamination) requires experienced personal and a perfect organization.

In the case of e.g. two-hinged frames or rigid frames the greatest bending moment mostly occurs in the corner, exactly where a joint has to be provided.

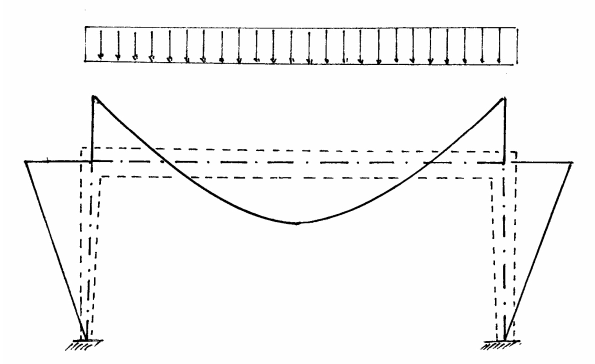


Figure 24: Two-hinge frame with typical moment diagram

The joint efficiency dictates directly the dimensions of the whole frame. Therefore it is extremely important to achieve here a high efficiency, possible through local reinforcement with hardwood, ash in the case shown in Figure 24.

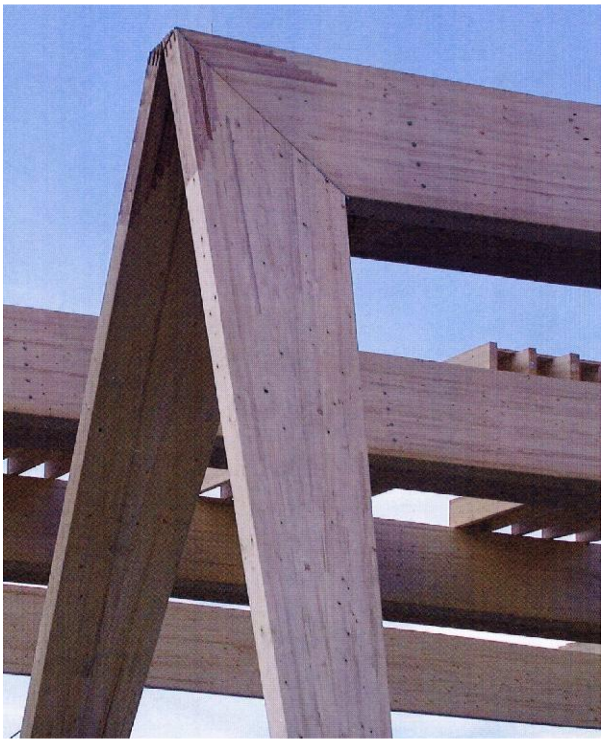


Figure 24: Framed structure – Detail: corner in GSA®-technology with inserts of ash

For such frame corners design rules were established. The strength model has been verified by large number of tests with realistic configurations and sizes (beam depth up to 800 mm). They showed that the models were correct and reliable.
In Figure 25 a test configuration corresponding to the structure presented in Figure 24 can be seen; the scale was about 1:2.

Figure 25: *Test at the "neue Holzbau AG"*

6 CONCLUSIONS

A new and high performing jointing technique based on glued-in rods is now available. Large numbers of applications have proved the efficiency, which can be increased by the combination with hardwoods.

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