# The Ligno-Force® Tube Connection

## 1. Introduction

In this chapter the attention is focussed on a new type of timber connection. It was developed in the late-80's – early-90's at Delft University of Technology in The Netherlands, as a reaction to the severe limitation of the traditional connections. As the element is a steel tube fastener, it is occasionally referred to as the tube connection. Another aspect is the use of densified plywood as a means to reinforce the timber in the connection area. All specific elements of the connection and its behaviour will be highlighted in the next chapters. Design information as well as examples of a few timber structures will be given later. A comparison will be between the application of the traditional dowel type fasteners and the potential benefits will be demonstrated. The reliability of the connection is such that application in statically indeterminate structures is possible leading to considerable material savings.

## 2 Dowel Type Fasteners

In Civil Engineering there are three key properties which are of great importance for optimal structural performance. The most important of these are specified as strength, stiffness and ductility. Ideally the connection should be as strong as the timber elements. How strong, stiff and ductile are our connections actually? Although very strong, glued connections, such as finger connections, always fail in a brittle manner. Mechanically connected connections usually can be regarded as ductile, although the amount of ductility may be uncertain due to unreliable occurrence of cracks. Compared to the members, the capacity of dowel type connections never exceeds 40% and 60% of the timber bending and tension capacity, respectively. There are methods to increase the strength by reducing the spacing, but this causes an increased danger of brittle splitting and plug shear failure.

In the past many investigations focussed only on the strength while stiffness was considered a minor importance. The reasons for this are a large scatter of the test results, the large number of parameters involved and the inability to control their behaviour sufficiently. However, a reliable stiffness is important for serviceability calculations, and may even govern the beam dimensions. Currently, code guidelines are still very rough. As many countries are presently changing from permissible stress to the ultimate limit state design, ductility gets more attention. Particularly in statically indeterminate structures, reliable stiffness and ductility play an essential role in structural performance. It allows utilising the structural capacity of the timber more efficiently. Therefore, it is essential to continue the search for high capacity timber connections that are more able to satisfy all requirements of optimal design.

## 2.1 The Main Problems of many types of connections

### 2.1.1 Splitting Cracks

As timber is a highly orthotropic material and dowel-type fasteners impose highly concentrated forces, it is not surprising that splitting cracks occur; thus calling for prevention.

In connections with dowel type fasteners yielding should preferably appear in the steel fasteners (plastic hinges), and the timber should be able to develop its full embedment resistance before cracks appear. Therefore, timber design codes contain spacing requirements, which are meant to delay the cracks and guarantee some ductility.

A golden rule for new connections is to leave the wood fibre unaffected as much as possible. The more high strength wood fibres left intact, the better. For this reason many small fasteners are often more effective than a few large ones. Good examples of this are truss plates (punched metal plates) and Glulam rivets.

### 2.1.2. Hole Clearance

The method of manufacturing dowel-type connections is usually associated with low and unreliable stiffness. Although the holes to accommodate fasteners should be tight fitting to obtain a direct load take up, the tolerances of both dowel and hole diameters makes tight-fitting fasteners virtually impossible. When the bolt or dowel fits too tightly, or the spacing of holes is slightly unequal, splitting will already happen at in the assembly stage. Therefore, precise drilling equipment is required. To overcome this problem, there are efforts to drill over-sized holes and use injection resin, as done for steel structures. Because quality control is difficult, this method is not yet appropriate for timber practice. Therefore, it is inevitable that the current method of connection assembly is used for traditional dowel-type fasteners. Again, easy fit is practical but catastrophic for stiffness, which makes most dowel type fastener connections unreliable, particularly in moment transmitting connections.

## 3 How to solve the problems

The first problem is to prevent the occurrence of cracks. To facilitate this, the most convenient solution is to protect the timber by gluing some kind of reinforcement onto the surface – a well-known technique already known to the Egyptians. At the interface of the connected section, where the highest loads need to be transferred, reinforcement is glued to all timber members separately. In the past, steel plates and glassfibre were examined, however, without much success. The effect of glassfibre strengthening (50 to 200 gr/m$^2$) was insufficient, although it considerably improved the ductility. Steel plates, though very effective, were regarded as unsuitable for practical application due to many problems such as the necessary gluing precautions that had to be taken. Finally, we focussed on an old and forgotten material, densified veneer wood (dvw).

The second problem, that of hole clearance (the void that remains between the bolt and the hole), was easily solved with the use of tubes which were inserted in oversized holes. This eased the assembly of the connection members after which the diameter of the tube was expanded to obtain a perfect fit. Thus, by slightly extending the expansion, the material becomes even prestressed, Figure 1.

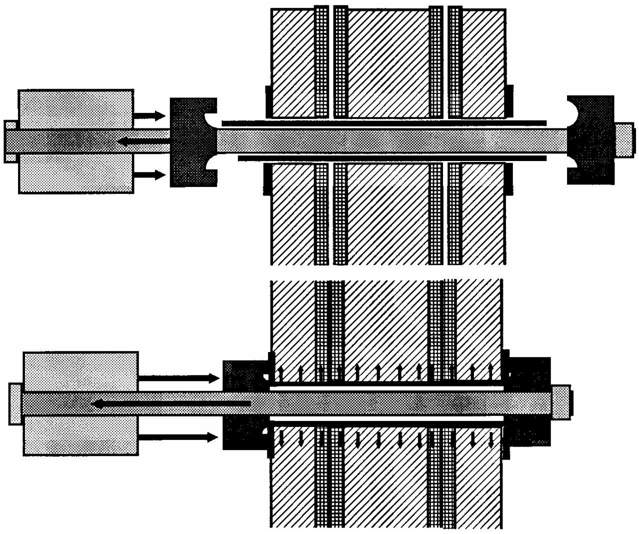

Figure 1: The expansion of the tube

After some tentative tests we became convinced of the potential of this connection and initiated a comprehensive study. More details on the properties of the dvw and the method of prestressing the connection will be presented in the following sections.

## 3.1 Densified Veneer Wood

This special plywood material has many advantages and is still commercial produced in many countries. Its trade name varies from “Lignostone” in Europe, to “Compreg” in the United States and United Kingdom. As it is wood based, densified veneer wood is easy to glue using well-known structural adhesives. Only the pointed end of the drill needs to be modified to drill effectively in this highly dense material. No ordinary spiral drill should be used as for steel but a typical wood pointed drill with a center point and precutting edges. Therefore, commercially available spiral drills we cut to suite our purpose. Dvw has a remarkably high embedment strength and stiffness modulus, and in certain circumstances, good ductile properties. We will elaborate on this further more in the following.

Densification of solid wood i.e. compression in the grain direction, was first patented by Robert Stockhart (Leipzig, 1886). In 1922, the Austrian brothers, Pfleumer, found a more effective method of densification, accidentally placing a piece of wood in an autoclave filled with rubber. Due to the high pressure (300 atm) and temperature, the wood was changed to dark dense mass. This densification method gradually improved by trial-and-error, until a more practical commercial method was developed. Rapidly, many densification methods were invented and patented, although few still exist. The method generally used applies compression perpendicular to the grain, combined with high temperatures.

The densification occurs when wood is placed between heated plates and compressed perpendicular to the grain. The combination of heat and compression causes the lignin, an important cell wall constituent, and cellulose and hemi-cellulose, to begin to soften at temperatures in the range of 165°C to 175°C {330 –350$^0$F}. Eventually, through various links of building blocks for macromolecules, the molecular viscous flow facilitates the cell to drift and move within the conglomerate of cells, to all open space veins. New molecular bounds are created and a rapid drop of temperature while still maintaining the elevated pressure, will result in solidification of the material. The wood grain as such is hardly damaged, while the material becomes increasingly homogeneous. Wood that is to be compressed consists of either solid wood, solid laminated wood, or stacks of veneers. Dvw thicknesses of 6 mm to 120 mm {0.24" to 4.7"}are available. It is possible to impregnate the material prior to compression with the assistance of chemicals. This can improve or influence certain properties such as durability and dimension stability. Although many wood species are fit to densify, beech is the species commonly used in Europe for reasons explained later.

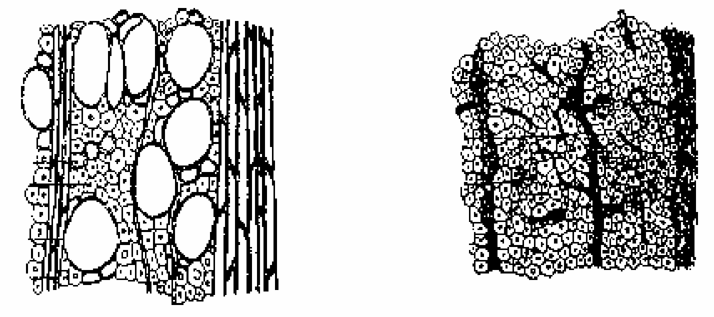

Figure 2: Poplar before and after densification

The densification is not completely irreversible but recovery strongly depends on the moisture content of the wood before compression, as well as the use conditions. This shape memory effect depends on the density and type of the densified product, as it takes longer for the moisture to penetrate a more dense material. Swelling leads to a severe decrease of the mechanical properties. For standard indoor climates the dvw of our research can be used. In climates where the relative humidity is for months higher than 90%, the performance of the normal dvw will decrease. In that case resin impregnated dvw can be used as it is impenetrable for moisture. The dryer the climate conditions the better. The most important source of information about the performance of dvw is the German 1951-1954 Edition of "Technology des Holzes" by Kollmann.

Table 1: Properties of cross-wise layered dvw

| mechanical property density 1300 kg/m$^3$ | mean value [MPa] |
|---|---|
| in plane tension | 90 |
| in plane compression | 70 |
| in plane shear | 15 |
| modulus of elasticity (young's) | 16000 |

### 3.1.1 Properties of DVW

We now concentrate on the type of dvw used for this research, cross-wise layered beech dvw and its application as timber reinforcing.

In Table 1 a overview is given of some mechanical properties of cross-wise layered dvw obtained from research performed in the thirties at standard indoor conditions ($20^0$C and 60% m.c. - dvw moisture content 7%).

An important material parameter for the application in connections is the embedment strength. In the 1920s, Fahlbusch reported some test results, which indicated values of about 160 to 120 MPa. Ehlbeck and Werner (1992), and Rodd (1993) carried out a more comprehensive investigation. Veneers of beech, poplar and maritime pine as well as some eucalyptus veneer sheets were used to produce the dvw specimens, shown in Figure 3. The test can be performed in tension and compression, which only affects the bearing or foundation modulus. It appeared that the embedment strength was strongly correlated with density and wood species dependent. Clearly, as shown in Figure 5, the Beech veneers produced the highest values. As shown, some specimens had a density of about 1400 kg/m$^3$, which is near the density of the cell wall material of wood (1500 kg/m$^3$). The minimum dvw density for the application as a reinforcement material in connections can be set to 1300 kg/m$^3$ which corresponds to a mean embedment strength of 140 MPa for beech dvw. This is about 7 times higher than for softwood like European Spruce (380 kg/m$^3$).

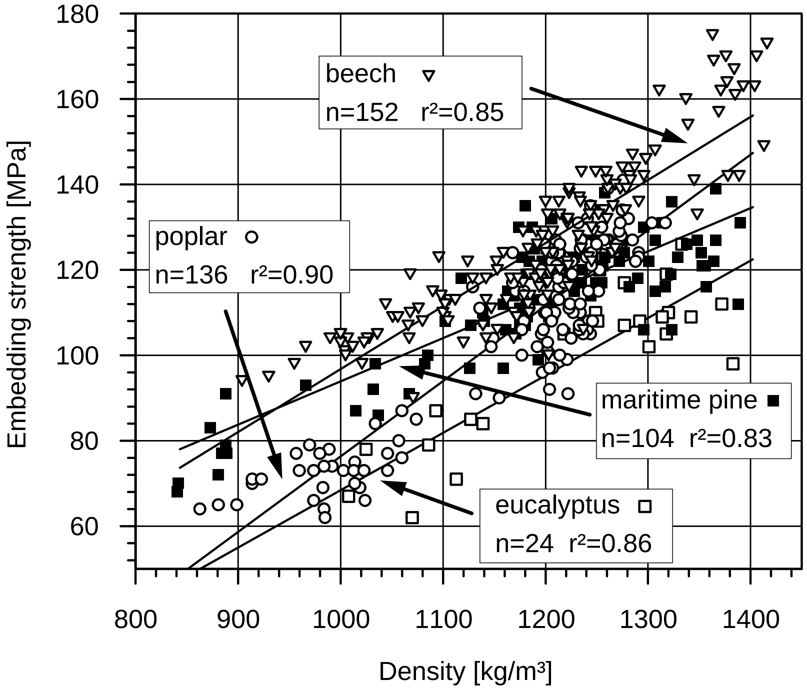

Figure 3: Embedment versus density and wood species

The embedment tests were performed using various end distances of 2, 3.5 and 5 times the dowel diameter. It was found that in order to prevent any premature splitting, the minimum loaded end distance should be greater than or equal to 3.5 times the tube diameter for a minimum dvw thickness of 12 mm and 18 mm and for the 17 mm and 35 tubes, respectively.

## 3.2 The Tube Fastener

This next and most crucial step was to develop a new connection method. As mentioned above, instead of a solid dowel, a tube was chosen to fit into oversized holes before expanding the diameter. The cheapest proved to be the best - low grade, mild steel, galvanised gas pipe Fe360 (ISO 65/DIN 2440, specified minimum yield stress Fu = 360 MPa).

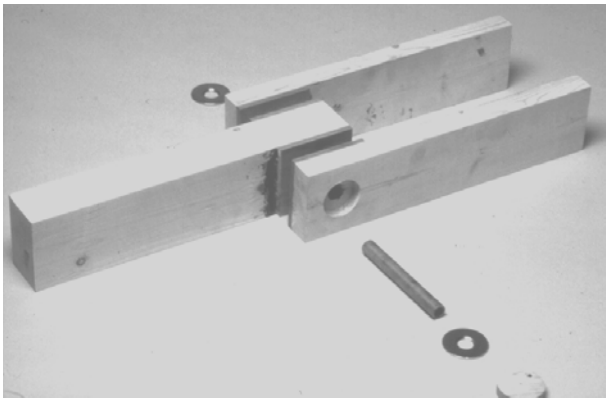

Figure 4: Elements of tube connection

Most tests were performed using 17 mm and 33 mm outer diameter tubes. It should be noted that after expansion they actually become about 18 mm and 35 mm in outer diameter. Bigger tubes require more powerful and heavier equipment, particular the hydraulic jack, see Figure 1, no longer to carry by one person. Figure 4 also shows the elements of the connection. The tube, which is about 10% longer than the thickness of the timber assembly, is pushed into pre-drilled holes. We effectively managed to produce connections with a total thickness up to 500 mm using 35 mm outer diameter tubes. Then, a rod with special end pieces is inserted in the tube, and using only a lightweight hydraulic jack, the end pieces compress the tube ends, Figures 5. This results in both forming a flared collar at each end of the tube and forcing the tube to expand in diameter, while the central rod prevents any inward deformation. Evidently, the clearance has vanished completely and immediate load take up is assured. The flared tube ends fit into washers, Figure 6, to provide the anchorage for the tube which activates the full embedment capacity of the dvw and the timber. There is only one aspect that needs to be taken care of, that being the overlength of the tube. If it is too long, we tried 20% overlength, the expansion will be too much for the surrounding material and the whole connection will blow up. Insufficient expansion, such as 5% overlength, will leave some hole clearance and, therefore, result in a reduction in stiffness. 10% proved to be best.

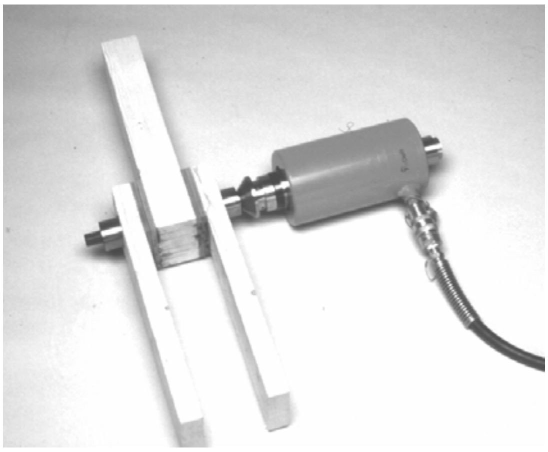

Figure 5 : Expansion of the tube

It is evident that a reliable stop criterion is required. The force required to expand the tube is considerable, 100 kN to 200 kN for the 17 mm and 33 mm tubes, respectively. The oil pressure of the hydraulic jack will increase only slightly when the washers are squeezed into the timber surface, thereby, proving to be unsatisfactory by providing a reliable stop. At the final stage of tube diameter expansion the largest tube expansion appears directly behind the washer, Figure 6. This heavily deformed part of the tube severely crushes the timber. This crushing of fibres generates a sound that triggers the bell to stop the prestress procedure. It will be clear that deaf employees should not be allowed to work with this apparatus. Another advantage using standard tubes is the option to increase the wall thickness of the tube fastener by expanding a smaller size tube inside a bigger one, so-called double tubes.

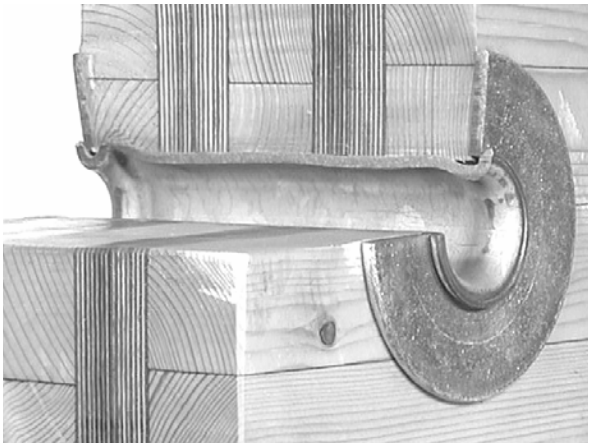

Figure 6: Tube fastener with washer

# 4 Experimental Result

Having explained the essential elements of the connection, the next step is to highlight the performance of the connection. It is well known that the behaviour of dowel type fasteners, specially the stiffness is dependent on the load to grain direction. This makes it hard to predict the moment rotation behaviour of a moment transmitting connection where the direction of the forces with respect to the grain direction varies per fastener. As the dvw is glued to the timber members this effect might be much less. It would at least ease the stiffness calculation in design considerably. Therefore, the main goal of the ramp tests was to determine the load-to-grain dependency of the strength and stiffness of the connection. For all specimens the wood species used was European Spruce with a mean density of about 380 kg/m$^3$. Other questions needed an answer as well such as the validity of the minimum edge and end distances obtained with the embedment tests, and the consistency of the load-slip behaviour of the connections in the various type of tests. In addition also embedment creep tests were performed.

The connection was tested extensively. Not only ramp tests were performed but also cyclic tests on the parallel tensile connections and full sized portal frames with 18 mm and 35 mm tubes. This provided valuable information regarding the energy dissipation capacity and ductility of the connection.

## 4.1 Ramp Tests

Not only was the dvw thickness varied but also the tube diameter as mentioned above. The load to timber grain angle in every type of connection is different. In the parallel tensile tests, the load direction coincides with the timber grain. In general the scatter in the behaviour proved to be very small as for instance shown in the load slip curves of Figure 7 for 16 experiments.

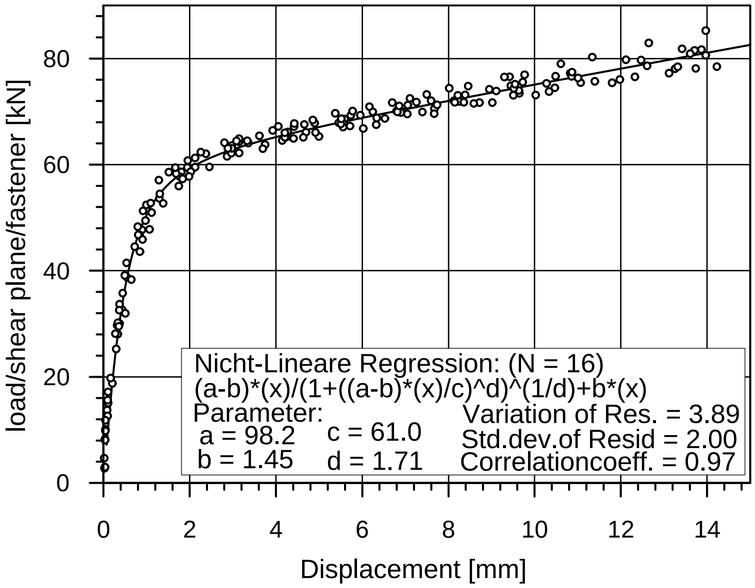

Figure 7: Load slip curve of connections (n=16) with 35 mm tubes

In order to detect any influence of the load to grain direction all test results were transformed to simple load-slip curves. Transforming moment rotation data to load-slip of the individual fastener, it was assumed that the rotation centre stayed in the geometrical centre of the fastener pattern. This was allowed since the measuring equipment detected only small translations (less than 0.2 mm until the end of the tests). Evaluation of the curves was performed by means of a non-linear regression model. In timber research there is the model of Foschi (1974) while in steel research Jaspart (1991) model is well known. Both of these models are used for the characterisation of the connection behaviour. Foschi's model has three parameters, and Jaspart's model has four parameters. Therefore, it is obviously better equipped to follow the non-linearity of the load slip behaviour.

Foschi's model:

$$F = \left(c + b - \left(\delta - \delta_o\right)\right)\left(1 - \exp(-a * \left(\delta - \delta_o\right)/c\right)$$

Jaspart's model:

$$F = \frac{(a-b)\delta}{\left\{1 + \left[\frac{(a-b)\delta}{c}\right]^d\right\}^{1/d}} + b\delta$$

in which:

$F$ is the load per shear plane per fastener
$a$ is the initial stiffness
$b$ is the post-yield stiffness
$c$ is the load at which the deformation behaviour changes from elastic to semi-plastic
$d$ is a curve parameter
$\delta$ is the slip or displacement, and
$\delta_o$ is the offset from the origin for zero load.

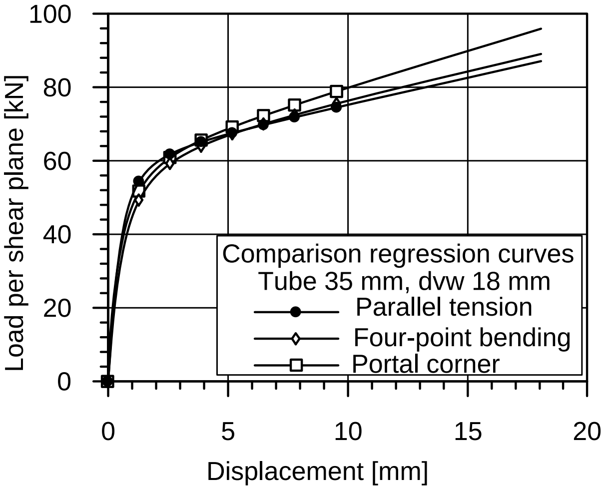

Figure 8: Summary of tests with Jaspart's model

It appeared that Foschi's model was unable to represent the load-slip curve with sufficient accuracy, therefore, Jaspart's model was adopted and applied throughout. In Figure 7 an example is given of this curve fit model for one test series. According to the test standard most tests were terminated at a slip of 15 mm. Surprisingly, the ductility is large, and above all immediate load take up is apparent. Although the tested differences in dvw thickness appeared not to be of great importance, it is important for minimum edge and end distance. The resistance of thicker material against edge cracks or end distance splits is of course higher than for thin dvw material.

Having fitted Jaspart's model to the test results of the parallel tensile connection and four-point bending specimens, they now could be projected together in one graph. For the connections with 35 mm diameter tubes these load-slip curves are presented in Figure 8. An tentative conclusion was that the load to grain angle did not have a significant effect on the load-slip curve. This would indicates an isotropic behaviour.

To check the consistency of this result portal corner connections were tested, Figure 9. At the connection not only a bending moment need to be transmitted but also shear forces. A special measuring tool was developed and placed accurately in the centre of the connectioned area. Comparing the rotation as well as the translation caused by bending moments and shear respectively with the previous simple tests confirmed the tentative conclusion. Meaning that the connection behaviour is consistent isotropic and reliable in stiffness.

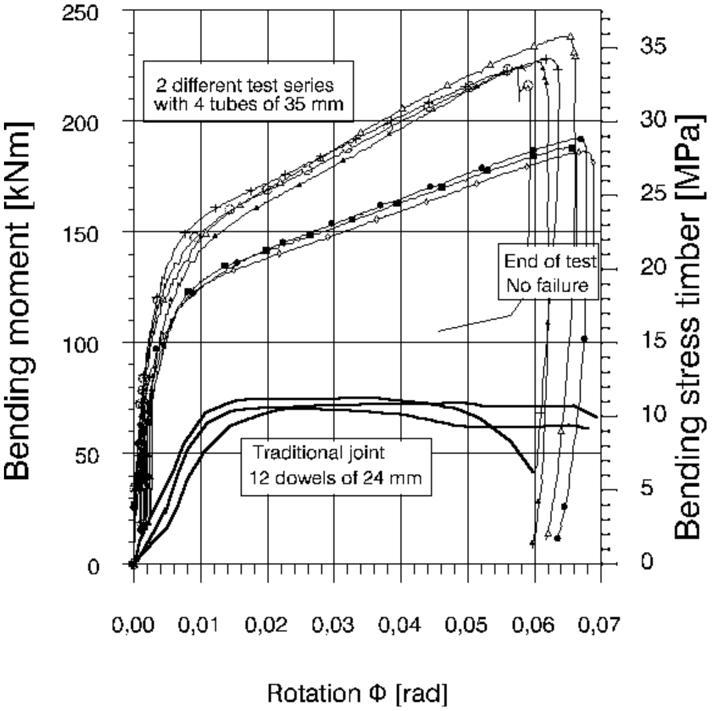

Figure 10: Moment rotation curves of moment transmitting connections

We now turn to the moment rotation results of those moment connections which are presented in Figure 10. This graph shows the results of three test series. The top two results originate from two test sets with 35 mm diameter tubes and dvw reinforcement while the bottom series represent the behaviour of the same connection with the conventional drift-pins or dowels, 12 dowels of 24 mm diameter arranged in a circle pattern. The tests with the dvw reinforced connections terminated when the stroke length of the hydraulic equipment was reached so actually no failure occurred. On the right side axis the timber bending stresses are indicated. As expected, the low strength of the traditional connections is reflected in the low bending stresses. The new connection is able to force bending stresses near to the bending strength of the Glulam which is unique for timber connections. Figure 11 shows the deformation capacity of the 18 mm diameter tube.

Figure 11: cut open view of the tube connection

## Cyclic Tests and Seismic Behaviour

In seismic design it is generally accepted that, under a severe earthquake, a structure may suffer a certain level of damage providing that no collapse occurs. This implies that a structure is able to undergo plastic deformations without significant loss of strength, that is, that a suitable level of ductility is available. This ability of a structure to behave in an inelastic mode and to dissipate energy under alternating load cycles is a fundamental aspect to consider. As structural timber behave brittle in bending and tension, energy dissipative mechanisms should generally be developed in the connections. Mechanical connections represent the only source of ductility that may be mobilised during an earthquake. To find out the suitability of the tube connection for seismic design cyclic tests where performed.

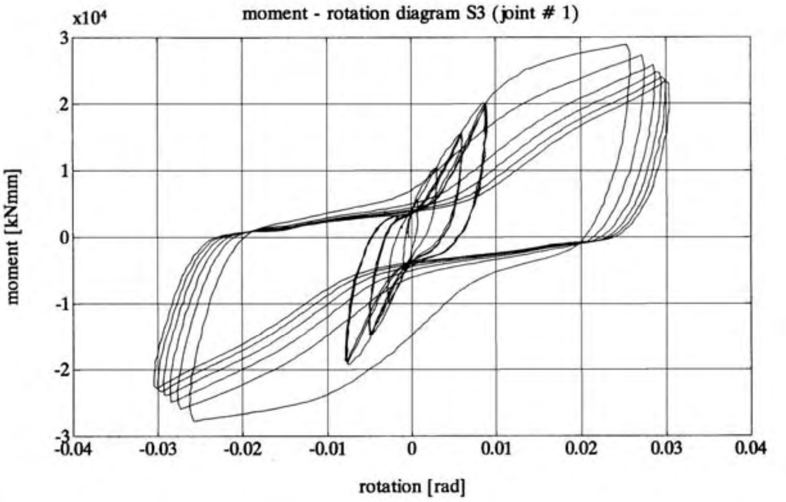

Figure 12: Cyclic tests on portal frames with 18 mm tubes

There are a number of basic parameters, which reveal the suitability of a connection to resist cyclic loads. One is the ductility, the impairment of strength and the energy. The ductility, as defined, is the ability of the connection to undergo large plastic slip without a substantial reduction of strength. It is measured by the ratio between the ultimate slip and the first yield slip. The impairment of strength is measured as the reduction in the resistance for a given slip from the first to the third cycle of the same amplitude, in percentage of the resistance developed in the first cycle. The dissipation of energy is a non-dimensional parameter expressing the hysteresis damping properties of the connection. The connection shall be verified to have appropriate low-cycle fatigue properties under large amplitudes of loads to ensure the intended ductility. An European requirement is that the connection shall be able to deform plastically for at least three fully reversed load cycles at a ductility ratio of 4 (i.e. four times their yield slip) without an impairment of the resistance larger than 20%.

The moment rotation curve of a cyclic test on a portal frame with the four 18 mm diameter tubes at the corners of the fastener area (like in Figure 10) is presented in Figure 12. The evaluation of the test results revealed the enormous energy absorption of this connection and the excellent ductility while the impairment of strength satisfies the standards requirement, Table 2.

Table 2: Results of Tests on Portal Frames.

| Tube size (mm) {inch} | Mean max. moment (kNm) | Failure mode | Mean ductility ratio* | Mean impairment strength (%) |
|---|---|---|---|---|
| 18 | 37.2 | Timber | 6 | 6 |
| 35 | 204 | --- | 11 | 3.5 |

## Main conclusions

Regarding the densified veneer wood (dvw):

- Dvw is stronger than any other type of plywood. The material properties lie between tropical hardwood and mild steel except for the modulus of elasticity which is similar to hardwoods.
- The embedment strength is correlated with the wood species and density and independent of load to grain angle.
- The use of beech veneers for the production of dvw gave the highest embedment results. For a given density of 1300 kg/m$^3$ the characteristic (the 5% lower fractile) is 120 MPa independent of the dowel diameter
- The foundation modulus is almost independent with density and load angle to the grain.

Regarding the dvw reinforced connections with the expanded tube fasteners.

Using 18 mm and 35 mm diameter tubes with a dvw thickness of 12 mm and 18 mm and a minimum density of 1300 kg/m$^3$, respectively the following can be stated;

- The tube connection can be considered as a high capacity connection with respect to strength, stiffness and ductility. The connection can be designed as strong as the timber.
- The connection behaves isotropic, i.e. there is no load to grain effect for strength and stiffness.
- The connection behaves reliable with respect to strength, stiffness and ductility.
- The minimum end and edge distance is 3.5 times the tube diameter. It will be obvious that smaller distances can be allowed when the dvw thickness is increased. However, at this stage no research is under taken to investigate this in detail.
- The tube connection has a high energy dissipation capacity and therefore is worth to be considered in seismic active area's.

## Advantages for Practice

The advantages in practice are considerable:

- The oversized holes makes the assembly of large parts on site much easier.
- The number of holes required is much less than with traditional dowels.
- No new techniques are involved nor special skills.
- The drilling precision is less and can be done on site if necessary. The only requirement in the alignment of the holes is to get the tube through.
- The adhesives used to glue dvw to timber are the familiar structural types well known in glue laminated industry.
    - 4 maal sterker en zeven maal stijver dan traditionele stift- of boutverbindingen
    - 75% reductie van de verbindingsmiddelen
    - 30% Hout besparing door slankere kontruktiemethode mogelijk + effiecienter ontwerp
    - Bewezen 25% kosten reductie t.o.v. volle wand liggers bij grotere overspanningen
    - Lignostone® DVW is in staat hoge stuikspanningen te weerstaan
    - Lignostone DVW is in staat om plastisch te kunnen vervormen
    - Gatspeling wordt opgelost door buis te expanderen
    - Aarbevingsbestendig
    - Universele techniek
    - Mobiel inzetbaar, dus besparing op transport kosten

## Design Information

For the benefit of the engineer some structural design data is presented in Table 3.

More general design formulae are given below. The formulae have been verified for a minimum dvw density greater than density 1300 kg/m$^3$ glued to structural timbers like Spruce or Maritime Pine, having densities of up to 650 kg/m$^3$.
The first formula represents the limitation of the steel tube when deforming to such an extend that a combined shear tension mode occurs. The second expression represents the limitation due to embedment failure.

Table 3. Design values of the tube connection.

| Expanded diameter d [mm] | Wall thickness [mm] | Minimum dvw thickness [mm) | Charact. Strength* [kN] | Stiffness** [kN/mm] |
|---|---|---|---|---|
| 18 | 2.35 | 12 | 35 | 30 |
| 22 | 2.65 | 14 | 55 | 53 |
| 28 | 2.65 | 16 | 70 | 58 |
| 35 | 3.25 | 18 | 95 | 65 |

* per shear plane per tube for ultimate limit state design
**per shear plane per tube for serviceability design
***1 kip = 1000 lbs
The minimum edge/end distance is 3.5d

$$F_{\max} = \min \begin{bmatrix} A_{st} \ f_t \\ \\ \left(t_1 \ f_{emb,timber} + t_2 \ f_{emb,dvw}\right) d_{nom} \end{bmatrix}$$

where:

| | |
|---|---|
| $F_{max}$ | is the strength per fastener per shear plane |
| $A_{st}$ | is the cross-section of the tube |
| $f_t$ | is the tension strength of the steel tube material |
| $t_1$ and $t_2$ | are the timber and dvw thickness |
| $f_{emb,timber}$ | is the embedment strength of the timber |
| $f_{emb,DVW}$ | is the embedment strength of the dvw |
| $d_{nom}$ | is the tube diameter |

In cases where the timber member thickness $t_1 > 2\ t_2$ the value of $t_1$ substituted should not exceed 2 $t_2$.
Another limitation not given in the above expressions is the capacity of the glueline to transfer the dvw shear stresses to the timber. When we distinguish between applications in moment transmitting connections where bending moments are dominant and in truss elements where bending moments are negligible the glueline capacity can be derived as follows. It is assumed that the dvw sheets are square and the sides are glued parallel and perpendicular to the timber grain direction.

For normal forces as in truss connections we can take the glued area multiplied by the shear timber strength ($f_v$) times 0.75. This factor accounts for the stress concentrations.

For moment connections it is assumed that only the areas where the deformation of the dvw sheet more or less corresponds to the timber grain direction contribute to the moment capacity. In Figure 13, the shear stresses at that glueline are roughly indicated. Reason for the assumption just mentioned is that the shear modulus along the grain is much higher than perpendicular to the grain. Therefore, only the indicated top and bottom triangle of the shear area effectively contribute. This assumption results:

$$M_{glueline} = bh^2 f_v/8$$

where:

b dimension of the dvw in grain direction
h dimension perpendicular to the grain of dvw
$f_v$ is the shear strength of the timber.

For the benefit of those who want to know the entire load-slip curve of connections with 18 and 35 mm combined with 12 mm and 18 mm dvw, respectively, Table 4 shows the relevant parameters of Jaspart's model.

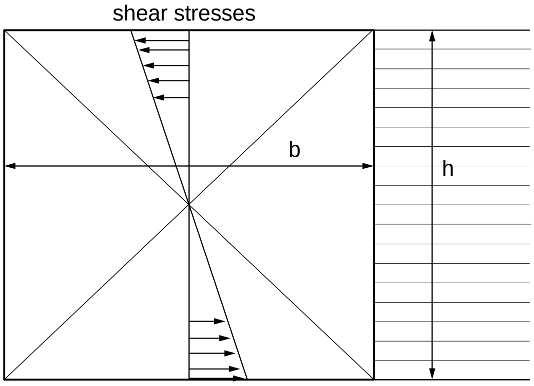

Figure 13: shear stress distribution in dvw moment connection

Table 4: Parameters of Jaspart's model

| tube diameter | parameters of Jasparts model | | | |
|---|---|---|---|---|
| parameters | a | b | c | d |
| [mm] | [kN/mm] | [kN/mm] | [kN] | - |
| 18 | 37.6 | 0.88 | 26.7 | 1.61 |
| 35 | 95.0 | 1.68 | 61.4 | 1.52 |

## CONCLUDING

In order to overcome the main deficiencies of connections with drift pins (dowel-type fasteners) such as premature timber splitting hole clearance two new elements were introduced. The first is densified veneer wood (dvw), a very high quality plywood, that is glued to the timber where high concentrated forces caused by the fasteners are expected. The second, the use of cheap mild steel gas tube, which fit into oversized holes and is expanded after assembly of the connection to get a perfect tight fit. As was demonstrated by tests the connection appeared to be very reliable in terms of strength and stiffness with good ductility properties. It can be classified as a high strength and stiffness capacity connection. Besides applied in trusses the tube connection is very suitable for use in portal frames for moment transmitting purposes. Is can be shown that considerable technical and economical advantages are realised with timber savings up to 30% in statically indeterminate structures.