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STRUCTURAL CONTINUITY OF FRP SYSTEMS IN WOOD CARPENTRY

Giovanni Cenci[1]

ABSTRACT: The FRP systems focused in this study are the natural involvement of the next century realizations, which are briefly remembered here. Giovanni Cenci (born in Rome on 02.01.1940, with a school leaving certificate of land surveyor in 1960) in 1980 made ready a handbook for practical use: G. Cenci, Strutture in legno [1]. In 1992 he designs and calculates the cover of Casalecchio di Reno Sports Palace for Holzbau S.p.A. company of Bressanone (Bz).

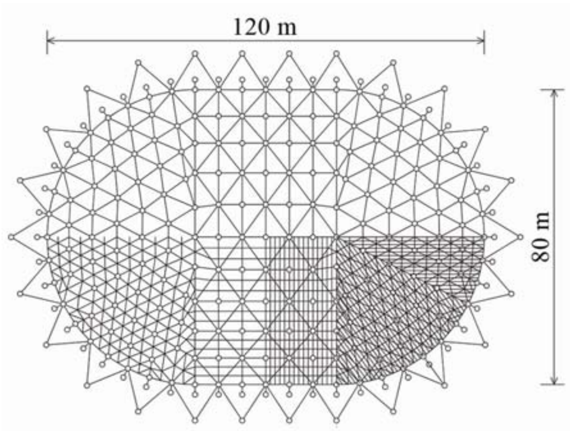

Figure 1: *Plan of Casalecchio di Reno Sports Palace 8.226 m² (1992-1993)*

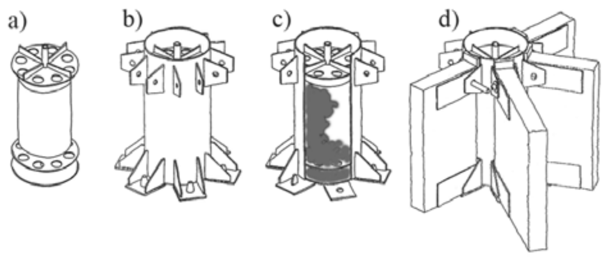

Figure 2: *The cylinder for joining the main glulam beams of Casalecchio di Reno Sports Palace. The connections of the joints are constituted by a double cylinder in steel with intervened concrete: a) inside cylinder; b) outside cylinder; c) simultaneous view of two cylinders; d) criterion of connection*

In 1994 starts to experiment gluing steel striated plate joints into laminated timber beams with epoxy adhesives in two applications in Milan and Perugia. Many realizations of glued joints with steel plate inserts or with steel bars have been carried out since. In that period resistance verification was evaluated only by means of a static inspection of the entire structure.

In 1996, at the University of Trento, joints made of "half wood" with steel bars were attempted, contextually within the construction of 500 m² grills in order to build the *Aquilone di Chicco [Chicco's Kite]* (*European Glulam Awards*, *1999*). Many on-site glued applications followed and in 1998 *reinforced wood* with steel bars was realised. The *Lignomec '99* exposition in Bolzano is an important occasion to exhibit applications with the new joints. The publication [2] that contains papers of *Lignomec '99* conference dedicates a lots of space (40 pages) to realizations construction made by news systems.

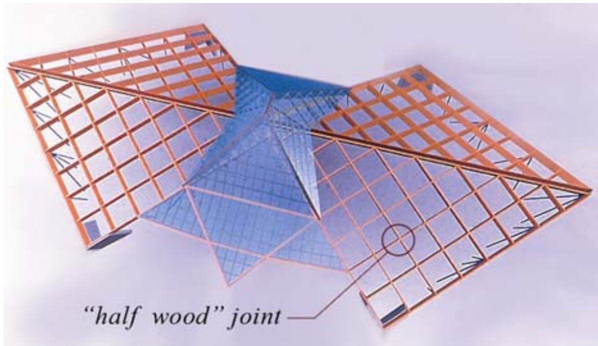

Figure 3: *Rendering of Chicco's Kite in Grandate, wanted by Pietro Catelli, founder of the Artsana S.p.A. (1996)*

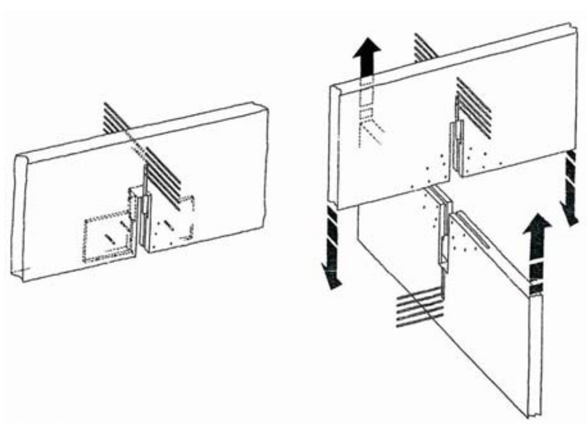

Figure 4: *"Half wood" CNP joint with B.8 steel bars and Xepox 35 adhesive for consolidate the main beams of the grillwork cover of Chicco's Kite*

These glued joints with steel inserts wrapped by epoxy adhesive are called *CNP* systems, acronym from the surnames of Mr. Cenci, Mr. Noseda and Mr. Piazza, whom respectively give contributions to think the system and to define the models, to define the verifications and make laboratory experiments. From the beginning Cenci Legno provides to the diffusion of the methods of calculation and to give information regarding the apllications methods and on site works.
The result is that many little companies manage in autonomy so much pleasant and high load-bearing timber constructions, because they are able to give the continuity to shorts elements, which are easy to transport and to become like au unique piece when necessary.

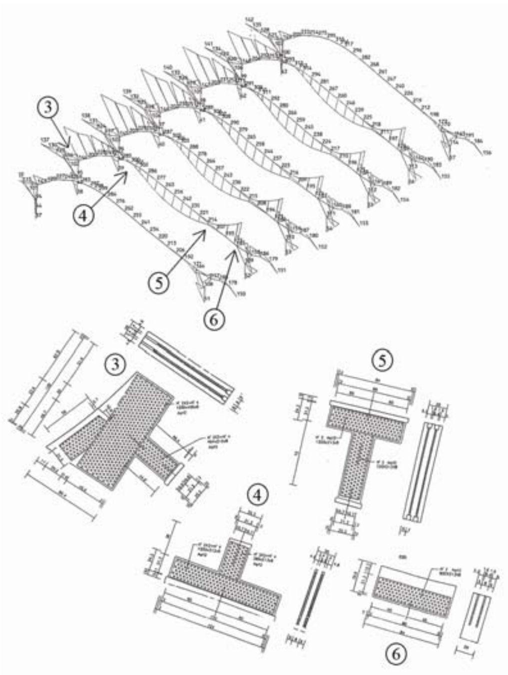

Figure 5: *CNP joints with hidden perforated sheet inserts and Xepox 26 adhesive for the gym on the island of Mazzorbo – city of Venezia (1996)*

In 2007 Cenci and the Cenci Legno firm begin to dedicate themselves to joints made with Fiber Reinforced Polymer (FRP) for different rehabilitations (trusses at Signa) and several restorations, such as the cantilever roof of the *Pontificio Oratorio di San Paolo Fuori le Mura* in Rome with the new support corbels in laminated wood attached with CFRP realized on site.
The first realizations stimulates the thought about major economic convenience and most easy applications of the FRP joints instead of steel ones.

Towards the end of 2008 Cenci Legno proposes new connection joints, hidden inside wood beams, in GFRP, made with glass plain *Polyevery* woven roving and *Xepox* polymer matrix, reinforced with unidirectional carbon fibre, which are very useful, as in the case of beams connection with concave profile. The new FRP joints, called *Giunti Italia [Italy Joints]*, may be flat (linear) or multidirectional.
In 2009 the Department of Structural Engineering of Politecnico di Milano starts a series of tests of *Giunti Italia*, comparing them with other glued types .
The purpose of this paper is to give further details on the design of CNP joints and present a plausible model for the computation of FRP *Giunto Italia* connections, easily adoptable by timber engineers.

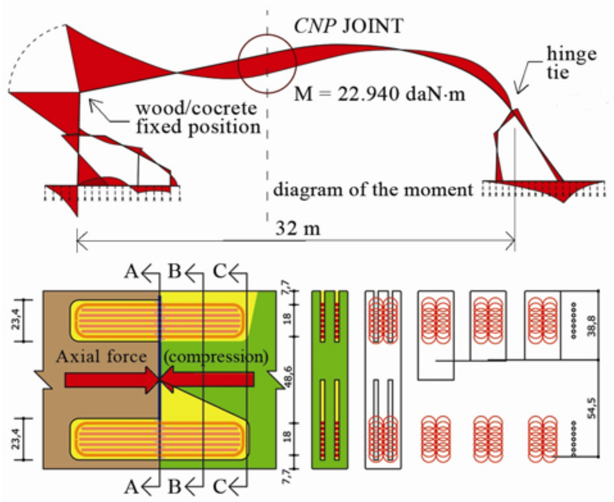

Figure 6: *The hidden bipolar joint with B450C steel bars for the sports centre in Gorla Maggiore (2000)*

Figure 7: *Lifting of a 1,000 m^2 spatial reticular cantilever roof in Bregnano, built on ground in a unique piece, with beams connected by CNP joints (2002)*

KEYWORDS: Cenci Legno, CNP, Giunto Italia, Polyevery, Xepox, CFRP, GFRP, CGFRP

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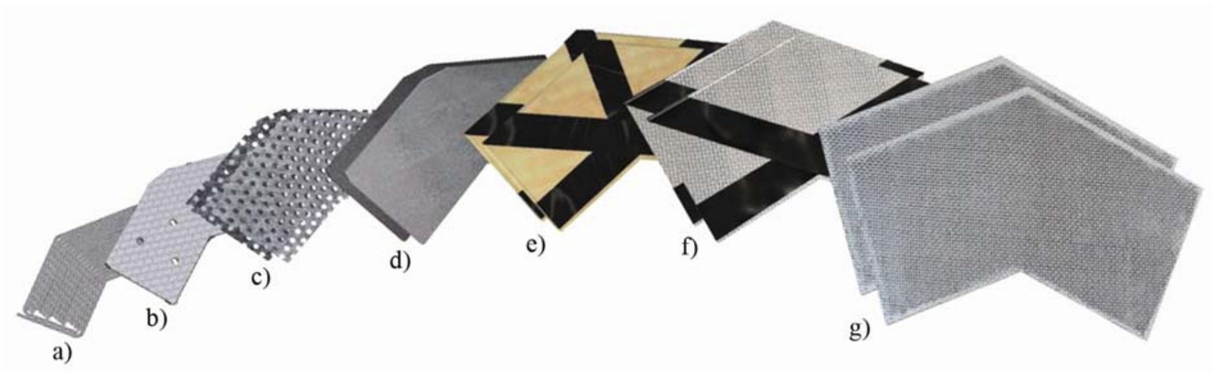

Figure 8: *The state of the art for hidden inserts for glued joints up to the end of 2008: a) CNP type with B450C bars; b) double striated sheet type; c) CNP with perforated sheet (quincunx); d) in bamboo with faces covered by an E-glass fabric glued with Xepox14 and reinforced with unidirectional carbon yarn tapes; f) in laminate with Xepox14 polymer matrix and intercrossed layers of E-glass Polyevery G800 woven rovings; reinforcements of the stressed area with carbon tapes; g) in laminate formed by the superimposition of layers of Polyevery G800 (E-glass) and Polyevery C400 (HTS carbon with 12k, 800 tex yarns) balanced woven rovings and Xepox14 matrix.*

1 INTRODUCTION TO DESIGN AND VERIFICATION MODEL

What could be a better introductory thought to the most recent structural applications than that of professors Guagenti, Buccino, Garavaglia, and Novati? I quote: "*We shall briefly say here that, albeit with their differences, philosophical positions agree in granting degrees of usefulness, and not truthfulness, to scientific theories, particularly when expressed in mathematical terms. This is reflected by the fact that nowadays it almost more customary to speak of models rather than theories. The same phenomenon may be usefully formalized in various models, depending on the aspects that one wishes to highlight*" [3].

2 THE *CNP*® JOINT, PRECURSOR OF *GIUNTO ITALIA*®

Giunto Italia represents a turning point in sand-blasted and protected sheet metal *CNP* joints. Undoubtedly, it further improves the entrepreneurship of wood carpentries and stimulates the design quality of their engineers.

The procedure for joints calculation and control remains virtually unchanged: a) control of the timber's usable sections; b) control of joint solidity, in the connected elements head to head position; c) establishing the size of the glued insert's arms; d) assessment of the interfaced surfaces torsion resistance. All four conditions shall be analyzed in depth in the *Giunto Italia* explanation.
For the time being it is proposed what regards the head to head position of *CNP* joint, with the aim to underline the general aspects that cannot be left out of consideration.

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2.1 CROSS REFERENCE TO THE RIGID CONNECTION MECHANISM BETWEEN ELEMENTS, OBTAINED WITH *CNP* JOINTS

With *CNP* joints, the fixed joint between two or more wooden beams, in the "head-to-head" contact position, is achieved by the resistance of the glued inserts and the participation of wood. For practical reasons, we shall refer to sheet metal *CNP* joints in general. The allocation of the respective share of participation of the two elements is defined by the homogenization ratio:

$$m = E_{Fe} / E_L \quad (1)$$

where:

m homogenization coefficient;

E_{Fe} modulus of elasticity for steel;

E_L modulus of elasticity for wood.

Figure 9: *Example of a CNP joint with sheet inserts. The surfaces cannot be as smooth as they were originally, however they are revived with SA3 grade sandblasting and immediately protected with Xepox14 adhesive, applied by painting brush or roll.*

As a way to further guarantee the functionality of the contact system, a slight depression is applied to the wood heads, as in figures 10 and 11. The space is occupied by a Xepox adhesive "buffer", better if reinforced by B450C steel bars or composite strips. Adhesive perculates from above, fills all voids, including very small ones, and penetrates in the lumen entrances.

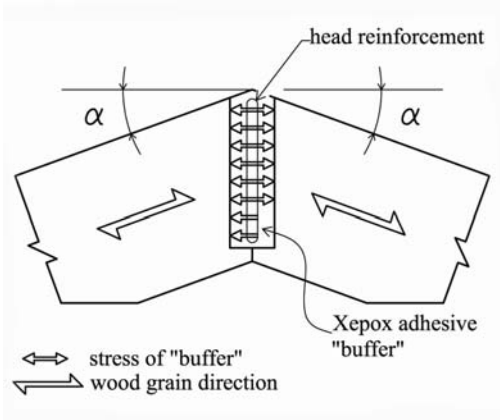


Figure 10: *Schematization of the strength-wood's grain α angle*

When joining beams forming an angle between them (figure 10), the compressive stress of wood is conditioned by Hankinson's equation:

$$\sigma_{c,\alpha,d} \leq \frac{f_{c,0,d}}{\frac{f_{c,0,d}}{f_{c,90,d}} sen^2\alpha + cos^2\alpha} \quad (2)$$

where:

$\sigma_{c,\alpha,d}$ design compressive stress at angle α to the grain ;

$f_{c,0,d}$ design compressive strenght along the grain;

$f_{c,90,d}$ design compressive strenght perpendicular to grain;

α angle between the force and the directions of grain which considers presence of adhesive like a "buffer" between beam's heads;

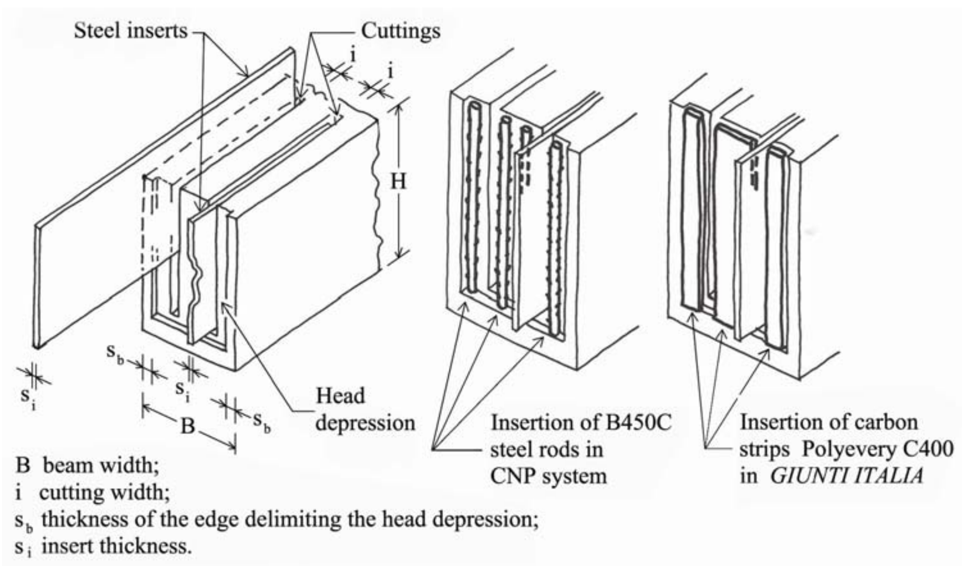
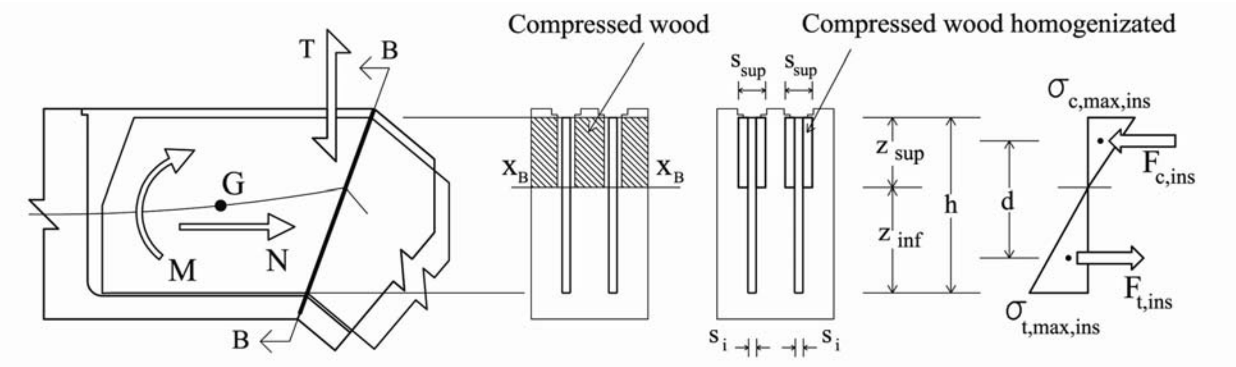


Figure 11: *Usable width and thickness of the head depression of elements that need to be joined*



z_{sup} distance from the neutral axis of the compressed upper edge;
z_{inf} distance from the neutral axis of the stretched lower edge;
h insert height.

***Figure 12:** CNP joint. Sections end stress graphs in (B-B) head-to-head position*

The participation of materials (figure 12) is defined in the idealized substitutive section by making use of the following equations:

$$B_{id} = B - \sum(s_b + s_i) \quad (3)$$

$$p_1 = (B_{id} / m) / [(B_{id} / m) + \sum s_i] \quad (4)$$

$$p_2 = \sum s_i / [(B_{id} / m) + \sum s_i] \quad (5)$$

where:

B_{id} ideal beam width;
p_1 participation of wood to compression;
p_2 participation of insert to compression.

The neutral axis position in the substitutive section is defined by the following equilibrium equation:

$$\begin{cases} z_{sup} + z_{inf} = h \\ z_{inf} = \dfrac{(B_{id} / m) \cdot z_{sup} \cdot (h - z_{sup} / 2) + \sum s_i \cdot h^2 / 2}{(B_{id} / m) \cdot z_{sup} + \sum s_i \cdot h} \end{cases} \quad (6)$$

From the first equation

$$z_{inf} = h - z_{sup} \quad (7)$$

is obtained, which must then be applied to the second equation (6). Consequently the quadratic equation is obtained:

$$(-B_{id} / m) \cdot z_{sup}^2 - 2 \cdot \sum s_i \cdot h \cdot z_{sup} + \sum s_i \cdot h^2 = 0 \quad (8)$$

The Δ discriminant of equation (8) is

$$\Delta = 4 \cdot \sum s_i \cdot h^2 [\sum s_i + (B_{id} / m)] \text{ ; with } \Delta > 0 \text{ ;}$$

The z_{sup} value is the real solution by radical of equation (8):

$$z_{sup} = h \cdot \left[\sum s_i - \sqrt{\sum s_i^2 + [(B_{id} / m) \cdot \sum s_i]} \right] / (-B_{id} / m) \quad (9)$$

By applying the formula (9) in (7) the neutral axis position is defined.
On account of the well known equation

$$\sigma_M = M / W_X \quad (10)$$

where:

σ_M design compressive or tensile stress;
M maximum actual bending moment;
W_x section modulus about axis x; $W_X = J_X / z$.

Solicitations in section B-B are given by the following:

$$\sigma_{c,max,L} = M \cdot p_1 / W_{sup} \quad (11)$$

$$\sigma_{c,max,ins} = M \cdot p_2 / W_{sup} \quad (12)$$

$$\sigma_{t,max,ins} = M / W_{inf} \quad (13)$$

ove:

$\sigma_{c,max,L}$ maximum compressive stress in wood;
$\sigma_{c,max,ins}$ maximum compressive stress in insert;
$\sigma_{t,max,ins}$ maximun tensile stress in insert;
W_{sup}, W_{inf} sections modulus about compressed area and tensile area, computed by the following relations:
$W_{sup} = J_X / z_{sup}$; $W_{inf} = J_X / z_{inf}$.

Continuity between the beams is ensured when:

$$\sigma_{c,max,L} \le \sigma_{c,\alpha,d}$$

$$\sigma_{c,max,ins} \le f_{y,d}$$

$$\sigma_{t,max,ins} \le f_{y,d}$$

Shear verification is carried out on the cross section area of the inserts only. In the interest of safety, the strength of the Xepox adhesive which has saturated the reduction of surface ahead the beams (head depression) and penetrated the lumen entrances is not taken into consideration.

$$\tau_{max \perp} = \frac{T \cdot 1{,}5}{A_{Fe}} \quad (14)$$

where:

$\tau_{max \perp}$ maximum shear stress;
T shear force;
A_{Fe} cross-sectional area for steel insert.
The result must be:

$$\tau_{max \perp} \le f_{y,d} / \sqrt{3}$$

where:

$f_{y,d}$ design steel strength to be calculated referring to [5].

For the Giunto Italia too there are considered wide safety factors and the verifications are set up on the materials

$f_{y,d}$ design steel strength, to be calculated as follows [4]:

$$f_{y,d} = \left(f_{y,k} / \gamma_{Mo} \right) \quad (14)$$

where:

$f_{y,k}$ characteristic steel shear strength value;

γ_{Mo} partial factor for steel properties.

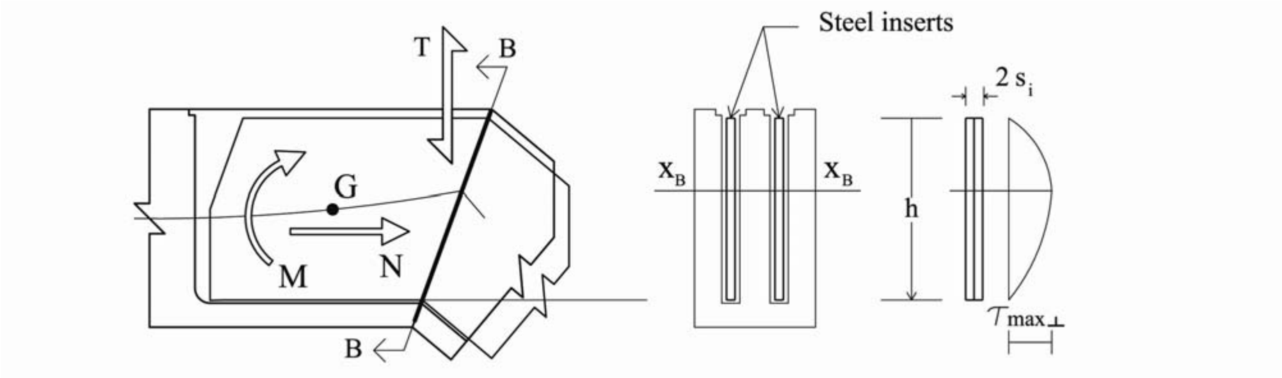


Figure 13: *Graphic of the shear for the insert: resistance to shear force is entrusted to the inserts only*

3 GIUNTO ITALIA® INTRODUCTORY CONCEPT

In short one can say that structural glued laminated timber (glulam) is the indissoluble aggregation of wood panels, freed from their defects. The union of laminations is obtained by gluing together the end edges and the superimposed surfaces. The head joints of the laminations in a layer must be at a distance from those of the adjacent strata. This techniques allows to completely recover servic fibrous functionality in each composed element.

Figure 14: *Example of a Giunto Italia with FRP inserts.*

The *Giunto Italia* is an element of construction, and a system, too, which makes use of FRP (Fiber Reinforced Polymer) laminates in order to form artificial fibre inserts. The main reason for this is to obtain a more natural structural continuity between the timber members that meet in a shared junction position.

The *Giunti Italia* laminates are manufactured with E-glass or carbon yarn Polyevery® balanced woven rovings. The woven rovings are assembled by placing them on top of each other alternating their orientation: 0°,90°; ±45°, 0°,90°, etc. (figure 15). Application of the Xepox 14 polymer epoxy matrix takes place at the same time the woven rovings are laid on each other. The Polyevery laminate is a balanced composite similar to isotropic material. During the manufacture of a *Giunto Italia*, unidirectional carbon tapes are inserted between the woven rovings. The purpose of the tapes is to reinforce the positions of the joint that are more under stress.

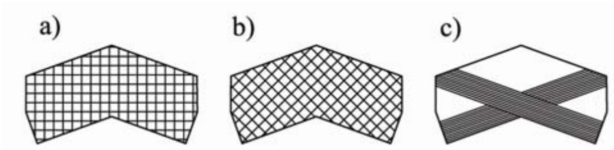


Figure 15: *a) 0,90° yarns orientation of woven roving;*
b) ±45° yarns orientation of woven roving;
c) unidirectional carbon yarns tapes.

Observations on tests and wood carpentery constructions accomplished confirm the belief that the materials which constitute an **appropriately sized** *Giunto Italia* jointly participate in all directions while perfectly adhering to the wood. This enables to maintain plain level of sections, and avoids significant deformation of interface surfaces until failure for rupture due to timber collapse, therefore well over two times the ultimate strength offered by timber calculated estimated at the ULS (Ultimate Limit State).

For these reasons *Giunto Italia* can be designed with the strength criteria of materials within its own elastic range. Its high safety coefficient ensures reliability.

The use of E-glass yarn or HTS carbon 12k yarn Polyevery woven rovings enables the formation of:

- *Giunti Italia GFRP* (Glass Fiber Reinforced Polymer);

- *Giunti Italia CFRP* (Carbon Fiber Reinforced Polymer);
- *Giunti Italia CGFRP* (Carbon-Glass Fiber Reinforced Polymer).

4 POLYEVERY® WOVEN ROVINGS

Impregnated balanced woven rovings use the same quantity of yarns with identical section in both warp and weft main directions (figure 16). They are obtained from weaving 2400 tex E-glass yarns, or 800 tex HTS carbon yarns. The manufacturing cycle ends with the impregnation of the textile with a *Xepox Finish* preparation, which penetrates between the filaments.

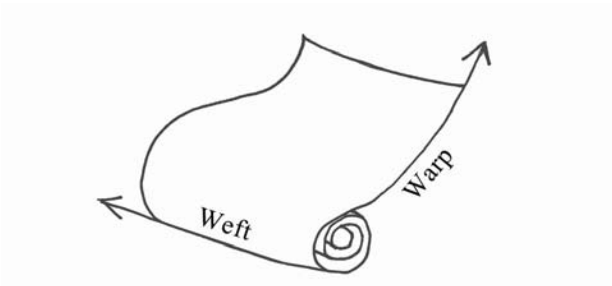


Figure 16: *Warp (longitudinal yarns) and weft (transverse yarns) directions*

4.1 POLYEVERY G800 E-GLASS WOVEN ROVINGS

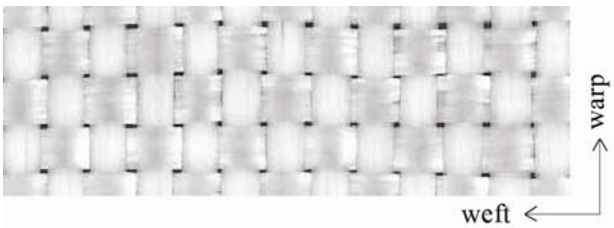


Figure 17: *Polyevery G800 E-glass balanced woven roving*

Polyevery G800 E-glass woven rovings are manufactured in 2.50 metres wide cloths. Normally they are marketed with a width of 1.25 metres. Their dry weight is approximately 800 g/m^2 and they have 1.7 yarns/cm in the warp direction and 1.6 yarns/cm in the weft direction. The considered average is 1.65 2400 tex yarns per centimeter in each direction. The woven roving's thickness is 0.8 mm.

4.2 POLYEVERY C400 12k HTS CARBON WOVEN ROVINGS

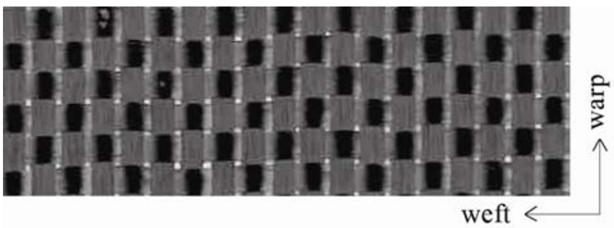


Figure 18: *Polyevery C400 12k yarn, 800 tex, in HTS carbon*

Polyevery C400 12k HTS carbon woven rovings are manufactured in 1.00 metres wide cloths, their dry weight is approximately 400 g/m^2 and they have 2.5 yarns 800 tex per centimeter in both directions (warp and weft). The woven roving's thickness is 0.8 mm.

4.3 12k HTS CARBON REINFORCING TAPES

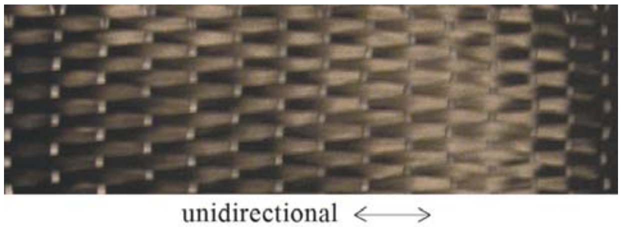


Figure 19: *12k HTS carbon tape*

Reinforcing tapes are formed by unidirectional 800 tex HTS carbon yarns, with 520 12k yarns per transverse metre. Nominal weight is 416 g/m^2. Tapes are available in any desired width, the most common being 10 cm.

5 DESIGN VALUES OF THE COMPOSITE

The CNR-DT 200/2004 [5] Italian instructions describe how to determine the design values of the mechanical characteristics of FRP reinforcements in case of wet lay-up systems. These indications are referred to static consolidation interventions, which we also adopt for the *Giunti Italia* meant to achieve beams static continuity.

The following equations are applied respectively to the SLS (Serviceability Limit States) and ULS (Ultimate Limit State):

$$A_f \cdot E_f = \alpha_{fE} \cdot A_{fib} \cdot E_{fib} \quad (15)$$

$$A_f \cdot f_f = \alpha_{ff} \cdot A_{fib} \cdot f_{fib} \quad (16)$$

In order, the symbols represent:

A_f the area of the FRP composite;

E_f Young's modulus of elasticity for the FRP composite;

f_f tensile strength of the FRP composite;

A_{fib} cross sectional area of the fibres;

E_{fib} Young's modulus of elasticity for fiber only;

f_{fib} tensile strength of the fibres;

α_{fE} safety factor for stiffness;

α_{ff} safety factor for strength.

Favourable to safety, the area of the composite is assimilated to that of the "dry" [6] fabric only. Moreover, the α_{fE} and α_{ff} reduction factors proposed by the leading manufacturers are applied.

Table 1: *safety factors proposed by manufacturers*

α_{fE} (SLS) safety factor for stiffness	0,90
α_{ff} (ULS) safety factor for strength	0,70

Therefore:

$$E_f = \alpha_{fE} \cdot E_{fib}; \quad E_f = 0,9 \cdot E_{fib} \tag{17}$$

$$f_f = \alpha_{ff} \cdot f_{fib}; \quad f_f = 0,70 \cdot f_{fib} \tag{18}$$

In practice, for ULS verifications, the design resistance of FRP materials is defined by applying a $K_{globale}$ factor, which is the product of the values identifying safety. The $K_{globale}$ factor includes the α_{ff} reduction factor (table 1), the η_a conversion factor (table 2) and the γ_m and γ_{Rd} (table 4 and 5) partial coefficients. Such identifying values are those indicated in DT 200/2004 and shown in the following tables. The η_l conversion factor is relevant to SLS verifications.

$$K_{SLU,globale} = \frac{\alpha_{ff} \cdot \eta_a}{\gamma_m \cdot \gamma_{Rd}} \tag{19}$$

Table 2: *Environmental conversion factors due to various exposure conditions and FRP systems*

Exposure condition	Type of fibre/resin	η_a
Internal	Glass/ Epoxy	0.75
	Aramid/Epoxy	0.85
	Carbon / Epoxy	0.95
External	Glass / Epoxy	0.65
	Aramid/Epoxy	0.75
	Carbon / Epoxy	0.85
Aggressive environment	Glass / Epoxy	0.50
	Aramid/Epoxy	0.70
	Carbon / Epoxy	0.85

Table 3: *Conversion factors for long term effects for several FRP system (SLS)*

Loading mode	Type of fibre/resin	η_l
Continuous (creep and relaxation)	Glass / Epoxy	0.30
	Aramid/Epoxy	0.50
	Carbon / Epoxy	0.80
Cyclic (fatigue)	all	0.50

Table 4: *Partial factors for materials and products*

Failure mode	Partial factor	Application	
		Type A	Type B
FRP rupture	γ_f	1.10	1.25
FRP debonding	$\gamma_{f,d}$	1.20	1.50

Table 5: *Partial factors for resistance*

Resistance model	γ_{Rd}
Bending/Combined bending and axial load	1.00
Shear/Torsion	1.20
Confinement	1.10

The general evaluation criteria for laminates constituted by Polyevery woven rovings and carbon tapes are described here below.

5.1 POLYEVERY G800 (E GLASS) LAMINATE

Here is an example for ULS evaluation of a *Giunto Italia* in Polyevery G800 woven rovings (thickness, s = 0,8 mm), prepared on the spot (type B) to be applied internally. It must satisfy the design resistance to failure risk for rupture and request for shear resistance.

Table 6: *Identifying safety values of Polyevery G800 woven roving*

$p_G = 38\%$	$p_m = 62\%$	$p_{fib\,G} = 19\%$
$f_{fib\,G} = 3.500\ MPa$		$E_{fib\,G} = 74.000\ MPa$
$\alpha_{ff} = 0,70$		$\eta_a = 0,75$
$\gamma_m = \gamma_f = 1,25$		$\gamma_{Rd} = 1,20$

where:

p_G comprehensive percentage of warp and weft;

p_m percentage of Xepox polymer matrix;

$p_{fib\,G}$ percentage of the fibre considered;

$f_{fib\,G}$ tensile strength of the E-glass fibre;

$E_{fib\,G}$ Young's modulus of elasticity of the glass yarn.

By applying the formula (19)

$$K_{SLU(G800)} = \frac{0,7 \cdot 0,75}{1,25 \cdot 1,20} = 0,35$$

and being:

$$f_{G800,d} = K_{SLU(G800)} \cdot \left(s \cdot p_{fibG}\right) \cdot f_{fibG} \tag{20}$$

for each Polyevery G800 woven roving applied, the result for each transverse centimetre is:

$$f_{G800,d} = 0,35 \cdot (0,8 \cdot 0,19) \cdot 3.500 =$$
$$= 186,2\ N/mm = 1,8\ kN/cm$$

where:

$f_{G800,d}$ design unitary strength assigned to a Polyevery G800 woven roving, further to it being part of the laminate considered to be isotropic.

For the same design, the SLS verification imply the application of the following formula:

$$E_{fG} = \alpha_{fE} \cdot E_{fibG} \cdot p_{fibG} \tag{21}$$

$$E_{fG} = 0,9 \cdot 74.000 \cdot 0,19 = 12.600\ MPa$$

5.2 POLYEVERY C400 (12k, 800 tex HTS CARBON YARNS) LAMINATE

Here is an example for ULS evaluation of a *Giunto Italia* in Polyevery C400 woven rovings (thickness, s = 0,8 mm) with the same design conditions required at number 6.1 above.

Table 7: *Identifying safety values of Polyevery C400 woven roving*

p_C = 28%	p_m = 72%	$p_{fib\,C}$ = 14%
$f_{fib\,C}$ = 4.300 MPa		$E_{fib\,C}$ = 240.000 MPa
α_{ff} = 0,70		η_a = 0,95
$\gamma_m = \gamma_f$ = 1,25		γ_{Rd} = 1,20

where:

p_C comprehensive percentage of warp and weft;

p_m percentage of Xepox polymer matrix;

$p_{fib\,C}$ percentage of the fibre considered;

$f_{fib\,C}$ tensile strength of the carbon yarn;

$E_{fib\,C}$ Young's modulus of elasticity of the carbon yarn.

By applying the formula (19)

$$K_{SLU(C400)} = \frac{0,7 \cdot 0,95}{1,25 \cdot 1,20} = 0,44$$

and being:

$$f_{C400,d} = K_{SLU(C400)} \cdot \left(s \cdot p_{fibC}\right) \cdot f_{fibC} \qquad (22)$$

for each Polyevery C400 woven roving applied, the result for each transverse centimetre is:

$$f_{C400,d} = 0,44 \cdot (0,8 \cdot 0,14) \cdot 4.300 = $$
$$= 213,2\ N/mm = 2,1\ kN/cm$$

where:

$f_{C400,d}$ design unitary strength assigned to a Polyevery C400 woven roving, further to it being part of the laminate considered to be isotropic.

For the same design, the SLS verification imply the application of the following formula:

$$E_{fC} = \alpha_{fE} \cdot E_{fibC} \cdot p_{fibC} \qquad (23)$$

$$E_{fC} = 0,9 \cdot 240.000 \cdot 0,14 = 30.200\,MPa$$

5.3 12k, 800 tex, 5.2 YARN/cm HTS CARBON TAPES

Here is an example of how to consider a 10 cm wide carbon reinforcing tape, inserted between the woven rovings, in the design of a *Giunto Italia* in ULS evaluation. The general condition is the same of the two examples detailed above.

Table 8: *Characteristics of the HTS carbon tape (10 cm)*

n_{fil} = 12k	Ø = 7 μm	D_{lin} = 800 tex
D_{fil} = 1,77 g/cm^3	n_{yarn} = 52	A_{nastro} = 240 mm^2

Table 9: *Identifying safety values of the HTS carbon tape*

f_{fibHTS} = 4.300 MPa	E_{fibHTS} = 240.000 MPa
α_{ff} = 0,70	η_a = 0,95
$\gamma_m = \gamma_f$ = 1,25	γ_{Rd} = 1,20

where:

12k is equivalent to 12,000 filaments for each yarn;

800 tex is equivalent to 800 grams per kilometre;

n_{fil} filament number;

D_{fil} filament density;

Ø filament diameter;

D_{lin} 12k yarn linear density;

n_{yarn} number of yarns per transverse 10 centimetre;

A_{nastro} area of the yarns in one tape;

f_{fibHTS} tensile strength of the carbon yarn;

E_{fibHTS} Young's modulus of elasticity of the carbon yarn.

Determination of the tape yarns area is:

$$A_{nastro} = n_{yarn} \cdot n_{fil.} \cdot \left[(0,5 \cdot Ø)^2 \cdot \pi\right] \qquad (24)$$

The 10 cm wide carbon tape area is:

$$A_{nastro} = 52 \cdot 12.000 \cdot \left[(0,5 \cdot 7\mu m)^2 \cdot \pi\right] = 24 mm^2$$

By applying the formula (19)

$$K_{SLU(HTS)} = \frac{0,7 \cdot 0,95}{1,25 \cdot 1,20} = 0,44$$

and being:

$$f_{HTS,d} = K_{SLU(HTS)} \cdot A_{nastro} \cdot f_{fibHTS} \qquad (25)$$

For each centimetre of the tape's width (no. 5.2 12k yarns per centimetre), the result is:

$$f_{HTS,d} = 0,44 \cdot 2,4 \cdot 4.300 = $$
$$= 4.541\ N/mm = 4,5\ kN/cm$$

where $f_{HTS,d}$ is the design unitary strength assigned to the carbon tape inserted between the woven rovings, in the only compatible direction.

For the same design, SLS verification assumes that the volume of the matrix is equivalent to volume of the fibre. As an exemplification, the following formula is applied:

$$E_{fHTS} = 0,5 \cdot \alpha_{fE} \cdot E_{fibHTS} \qquad (26)$$

$$E_{fHTS} = 0,5 \cdot 0,9 \cdot 240.000 = 108.000\,MPa$$

Application of carbon reinforcing tapes is influenced by the shape of the joint (figure 20). The evaluation criteria is always favourable to safety.

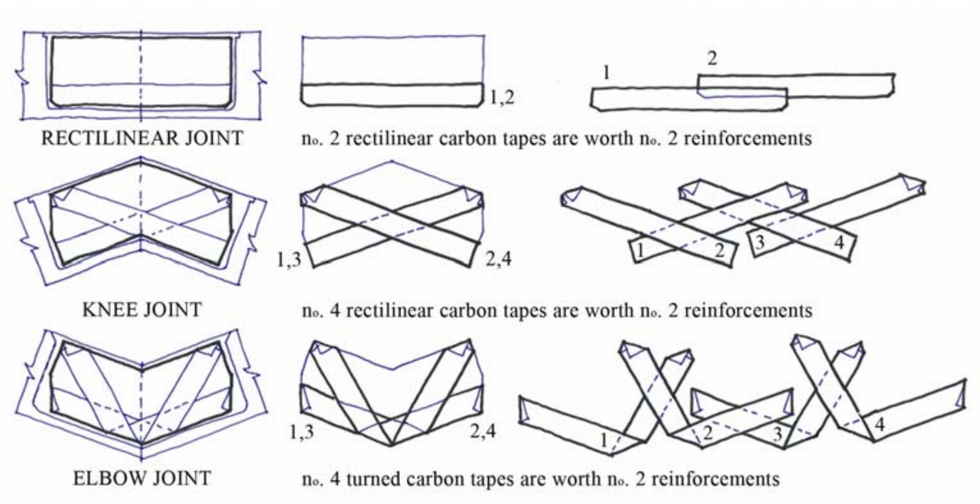


Figure 20: *Examples of 12k HTS carbon tapes applications*

6 GIUNTO ITALIA®: VERIFICATION EXAMPLE

Similarly to *CNP* joints with sand-blasted sheets, *Giunti Italia* may be constituted by one or more inserts, and, with reference to figure 21, they are applicable to rectilinear beams (a), elbow beams (b), knee beams (c) and also to three-way (d) or multi-way (e) spatial systems.

The beam in figure 22 is composed from two timber members rigidly connected together for becoming an unique piece. The external load activate actions inside the beam solicited to bending and to shear.

The constitutive system of connection is formed by along fibers cuttings ahead beams, inserts and adhesive which is interposed between surfaces. The insert's function is to give back continuous the resistance between the parts of beams previously were separated. The continuity of strength is achieved with indissoluble connection of the insert's arms in timber members. Effectiveness resistance of the connection have to be contextual and mutual. Spreaded gluing of insert's surfaces in cuttings beam provides required resistance.

The glued particles resist in proportion to the their distance multiplied by itself two times from the intersection of the principal axis of its whole interfaced surface. Consequently the check to bending and shear should be extended also to the torsion resistance of glued surfaces.

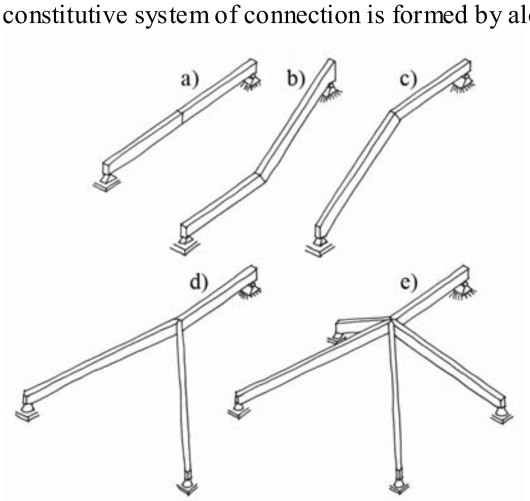


Figure 21: *Rigid joints beams types*

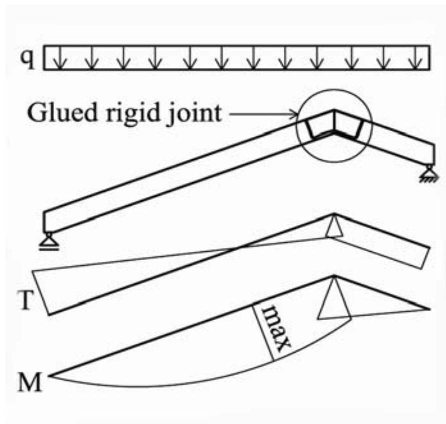


Figure 22: *Static and generic graphics of forces (T, M) in a knee beam*

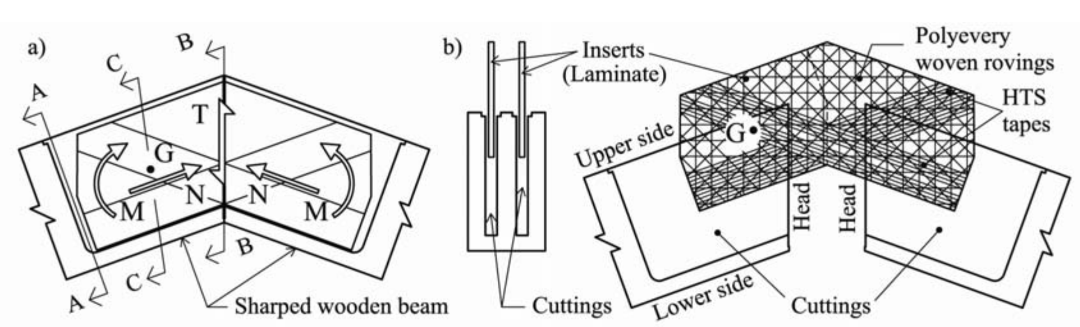


Figure 23: *a) A-A, B-B, C-C check positions; b) parts constituting a Giunto Italia in a knee beam*

The following example describes a knee beam with a double insert joint.
Referring to figure 23 the essential verifications needed to ensure the safety of the connection :

pos. A-A beam's cross section net of cuttings;
pos. B-B cross section in correspondence of the elements "head to head" contacts;
pos. C-C interfacing of the insert's arms.

6.1 BEAM'S CROSS SECTION (*A-A*) NET OF CUTTINGS

Referring to figure 24, the useable beam cross section net of the cuttings, immediately before the participation of inserts, is considered.
The classic verifications apply:

$$\pm F_{c,t} = M / d \; ; \quad \sigma_{c,t} = M / W_x \qquad (27\text{ a,b})$$

$$\sigma_{c,t} = 2 \cdot F_{c,t} / \left(B_{utile} \cdot 0{,}5H\right) \qquad (28)$$

where:
$F_{c,t}$ compression or tensile force;
M maximum bending moment;
d equilibrium distance of internal stresses;
H beam height;
B_{utile} useable width;

W_x modulus of resistance;
$\sigma_{c,t}$ design compressive stress or tensil stress;

$$B_{utile} = B - \sum i \qquad (29)$$

$$W_x = \left(B_{utile} \cdot H^2\right) / 6 \qquad (30)$$

where:
i cutting width.

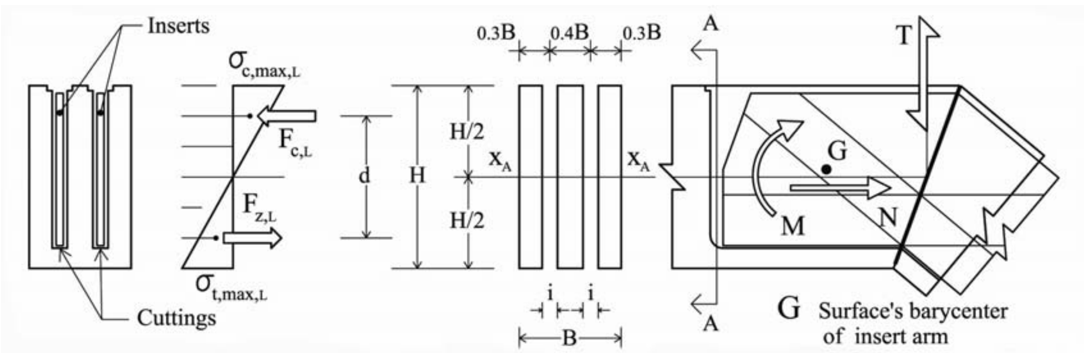


***Figure 24:** Section and schematization of stresses in the beam in the A-A position*

In case of a contextual *N* force (figure 25):

$$\sigma_{c,eff} = \frac{N_c \cdot \omega}{A_{utile}} \pm \frac{M}{W_x} \cdot \frac{f_{c,0,d}}{f_{m,d}} < f_{c,0,d} \qquad (31)$$

$$\sigma_{t,eff} = \frac{N_t}{A_{utile}} \pm \frac{M}{W_x} \cdot \frac{f_{t,0,d}}{f_{m,d}} < f_{t,0,d} \qquad (32)$$

where:
$\sigma_{c,eff}$ effective compressive stress;
$\sigma_{t,eff}$ effective tensile stress;
$N_{c,t}$ axial force;
ω amplifying factor for load;
A_{utile} useable section area;
M maximum bending moment;
W_x section modulus about axis *x*;
$f_{c,0\,d}$ design compressive strenght along the grain;
$f_{t,0\,d}$ design tensile strenght parallel to the grain;
$f_{m,d}$ design bending strength;

$$A_{utile} = B_{utile} \cdot H \qquad (33)$$

In the cross section net of cuttings the result must be:

$$\sigma_{c,max,L} \leq \sigma_{c,\alpha,L}$$

$$\sigma_{t,max,L} \leq f_{t,0,d}$$

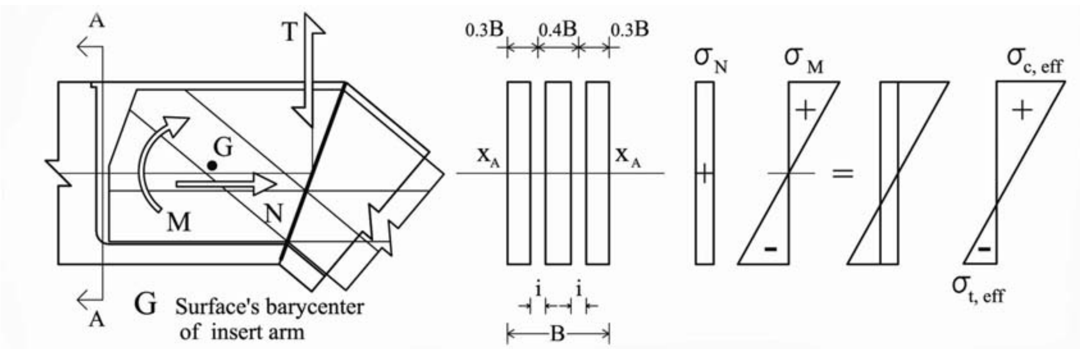


***Figure 25:** Graphic and diagram of combined beam compression and bending stresses A-A position*

6.2 HEAD JOINT OF THE CONNECTED ELEMENTS (*B-B*)

The "head to head" fixed joint between timber elements is achieved by the resistance offered by the insert. The timber-timber contact in compressed area participates in the strength.

Unitary strength properties defined for fibre materials indicated in paragraph 4 are used. In case of beams having different orientations, timber contribution is reduced by the angle between the force and the grain (figure 10), applying the well-known Hankinson's equation (2).

Participation of materials is correlated to their strength until they remain in balance, that is to say until the system collapses. *Giunto Italia* must always be designed for a strength not below that offered by the useable section of timber. The adhesive interposed between the insert and the timber is considered equivalent to timber.

For the compressed area, similarly to the *CNP* joint, making reference to figure 26, the beam width is defined by formula (3), where thickness of insert is:

$$s_i = n_{stuoie} \cdot 0{,}8mm \qquad (34)$$

The idealized design strength is:

$$\Sigma f_{c,sup} = \left(B_{id} \cdot \sigma_{c,\alpha,d}\right) + \left(n_{stuoie} \cdot f_{G800,d}\right) \qquad (35)$$

Participations of wood and inserts are given by the following equations:

$$p_1 = \left(B_{id} \cdot \sigma_{c,\alpha,d}\right) / \Sigma f_{c,sup} \qquad (36)$$

$$p_2 = \left(n_{stuoie} \cdot f_{G800,d}\right) / \Sigma f_{c,sup} \qquad (37)$$

where:

B_{id} ideal beam width;

s_b thickness of the edge delimitate the head depression;

s_i thickness of insert;

$\Sigma f_{c,sup}$ idealized design strength of the compressed area substitutive of materials (beam, insert);

p_1 participation of timber to compressive strength;

p_2 participation of the insert to compressive strength;

$\sigma_{c,\alpha,d}$ design compressive strength of wood;

$f_{G800,d}$ design unitary strength assigned to Polyevery G800 woven roving

$f_{G800,d}$ = 1.8 kN/cm;

n_{stuoie} number of woven rovings;

In the stressed area, design strength for Polyevery G800 woven rovings and the 10 cm wide carbon reinforcing tapes (800 tex yarns; no. 5.2 yarns per centimetre) is:

$$\Sigma f_{t,inf} = \left(n_{stuoie} \cdot f_{G800,d}\right) + \left(n_{nastri} \cdot f_{HTS,d}\right) \qquad (38)$$

Partecipatios are:

$$p_3 = \left(n_{stuoie} \cdot f_{G800,d}\right) / \Sigma f_{t,inf} \qquad (39)$$

$$p_4 = \left(n_{nastri} \cdot f_{HTS,d}\right) / \Sigma f_{t,inf} \qquad (40)$$

where:

$\Sigma f_{t,inf}$ idealized design strength of the stressed area;

p_3 tensile participation of woven rovings;

p_4 tensile participation of tapes;

n_{nastri} number of tapes between the woven rovings;

$f_{HTS,d}$ design unitary strength assigned to the carbon tape.

As this is a model that be used without excessive difficulties, a number of simplifications have been introduced, all in the safety advantage. Operating in the field of materials strengths, and to avoid misunderstandings, we introduce the D-D discriminant axis between the stressed and the compressed areas, which has the same function of the X-X neutral axis in *CNP* systems (timber steel), however, in *Giunti Italia*, with the method based on strengths. The end results remain within values that are absolutely compatible with the most sophisticated verification systems.

The position of the discriminant axis is defined by the following equilibrium equation:

$$\begin{cases} z_{sup} + z_{inf} = h \\ z_{sup} \cdot \Sigma f_{c,sup} = \left(z_{inf} \cdot \Sigma f_{t,inf}\right) - \left(z_{inf} - 10\right) \cdot f_{HTS,d} \end{cases} \qquad (41)$$

From the first equation

$$z_{sup} = h - z_{inf}$$

is obtained, which must be then applied to the second equation (41).

Consequently:

$$z_{inf} = \frac{10 \cdot f_{HTS,d} - \Sigma f_{c,sup} \cdot h}{\left(f_{HTS,d} - \Sigma f_{t,inf} - \Sigma f_{c,sup}\right)} \qquad (42)$$

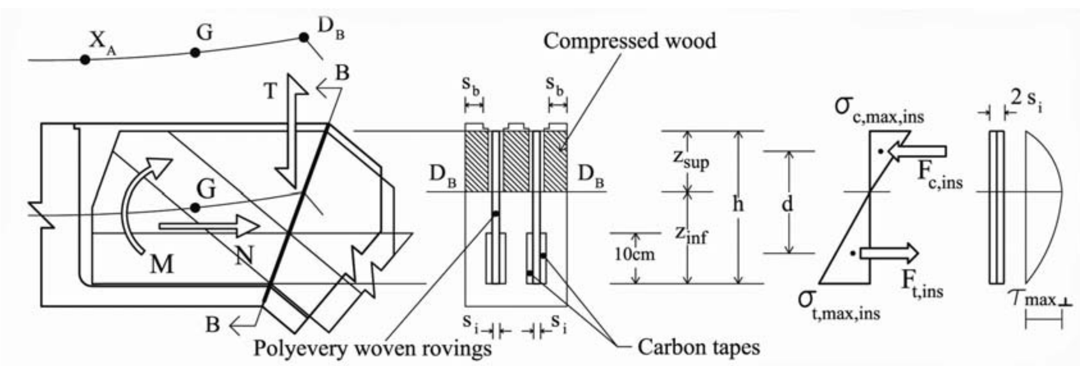


Figure 26: *Sections and stress graph in the B-B position*

On account of the well known equation:

$$\pm F_{c,t} = M / d \qquad (43)$$

where:

$F_{c,t}$ compressive or tensile strength;

M maximum effective bending moment;

d equilibrium distance of internal stresses,

tension in compressed timber shall be:

$$\sigma_{c,L_{eff}} = \left(2 \cdot F_c \cdot p_1\right) / \left(z_{sup} \cdot B_{id}\right) \qquad (44)$$

where:

$\sigma_{c,L_{eff}}$ effective compressive stress relevant to wood.

The resistances for the layers of the fibrous materials used can be defined, too, evaluating them in proportion to their respective potential:

$$f_{c,G800_{eff}} = \left(2 \cdot F_{c,ins} \cdot p_2\right) / \left(z_{sup} \cdot n_{stuoie}\right) \qquad (45)$$

$$f_{t,G800_{eff}} = \left(2 \cdot F_{t,ins} \cdot p_3\right) / \left(z_{inf} \cdot n_{stuoie}\right) \qquad (46)$$

$$f_{t,HTS_{eff}} = \left(2 \cdot F_{t,ins} \cdot p_4\right) / \left(z_{inf} \cdot n_{nastri}\right) \qquad (47)$$

where:

$f_{c,G800_{eff}}$ compressive strenght relevant to the woven roving;

$f_{t,G800_{eff}}$ tensile strength relevant to the woven roving;

$f_{t,HTS_{eff}}$ tensile strength relevant to the tape;

n_{stuoie} number of Polyevery woven rovings;

n_{nastri} number of HTS carbon tapes.

Continuity between the beams is ensured when:

$$\sigma_{c,L_{eff}} \leq \sigma_{c,\alpha,d}$$

$$f_{c,G800_{eff}} \leq f_{G800,d}$$

$$f_{t,G800_{eff}} \leq f_{G800,d}$$

$$f_{t,HTS_{eff}} \leq f_{HTS,d}$$

where:

$\sigma_{c,\alpha,d}$ design compressive stress at angle α to the grain;

$f_{G800,d}$ design unitary strength assigned to a Polyevery G800 woven roving

$f_{G800,d}$ = 1.8 kN/cm;

$f_{HTS,d}$ design unitary strength assigned to HTS carbon tape;

$f_{HTS,d}$ = 4.5 kN/cm.

In the event of geometric or load asymmetry, the joint is subject to transverse shear. Even should this not be the case, in the interest of safety it is reasonable to take into account a plausible shear force. The insert section and the resin that has been let in between the opposite head faces and is penetrated in lumen entrances (figure 27), work against the shear force. However, favourable to safety, only the insert cross section area is considered:

$$A_{ins} = \sum s_i \cdot h \qquad (48)$$

where:

A_{ins} area of the FRP insert.

As the Polyevery woven rovings composite has been considered similar to an isotropic material, the application of the following formula is recommended:

$$\tau_{G800_{eff}} = \frac{T \cdot 1,5}{A_{ins}} \qquad (49)$$

where:

$\tau_{G800_{eff}}$ design shear stress in the insert;

T shear force.

The design shear strength is given by the equation:

$$f_{v,G800,d} = \left(\frac{n_{stuoie} \cdot f_{G800,d}}{\sqrt{3}}\right) \qquad (50)$$

where:

$f_{v,G800,d}$ design shear strength in the insert.

The result must therefore be:

$$\tau_{G800_{eff}} \leq f_{v,G800,d}$$

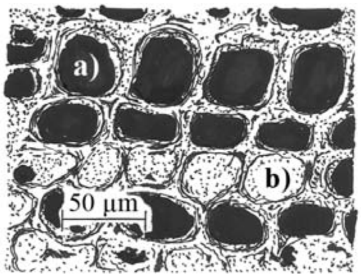


Figure 27: *Tensile test of the adhesive that penetrates in the lumen entrance [7]: a) the adhesive is pulled out from tracheids; b) the adhesive is fixed to tracheids.*

6.3 SIZING OF THE ARMS SURFACE AREA

To achieve full continuity between the elements to be connected it is preferable that *Giunti Italia* are made with two laminates in each join.

The availability of a double insert reduces transverse stresses in timber. It further offers higher resistance in the transverse direction. The dimension of timber cuttings is dependent on processing techniques and on the portion of material that one wishes to keep intact, for instance keeping timber thickness unchanged for fire protection. It is preferable to use the maximum height allowed, which then influences the other dimensions of the insert: length, surface interfaced to timber and, consequently, interface polar inertia ($J_p = J_x + J_y$).

The model used considers that interfacing of the inserts glued to the surfaces of the timber cutting determines the mutual exchange of stresses caused by the bending moment. The length of the joint is defined by the shear force in the interfaces. The assumption is that the maximum adherence stresses coincide with the maximum stresses caused by the moment and that they manifest themselves in correspondence of the insert edges farthest away from the conventional neutral axis (D-D discriminant axis) coincident to G (figure 28).

Shear resistance by the insert and the epoxy adhesive are both very much higher than timber's. Consequently the l_{min} insert arm length is given by the equation:

$$l_{min} = \frac{2 \cdot F_{t_{ins}}}{n.\ interfacce\ \cdot 0{,}5h \cdot f_{v,d}} \qquad (51)$$

where:

$f_{v,d}$ design wood shear strength (adherence or interfacing).

It is recommended to perform the verification (51) also with z_{inf} that replaces *0,5h*.

6.4 CALCULATION OF RESISTANCE TO TORSION

Giunto Italia (similarly to the *CNP* joint), draws further reliability from the resistence to torsion of the interfaced surfaces. As they are made of balanced woven rovings with multi-directional fibres, Polyevery laminations have a good grip on the wood's grains. Further, the effect expands in depth in wood. Verification of resistance to torsion guarantees the safety of joint.

The torque resistance mechanism in the insert's layer is easily perceptible by referring to the bolted plates subject to bending model. The model is substantially similar to that used for calculate torsional resistance in the layer's steel insert (connection's layers) of bolted sheets connection (figure 29,a).

In the reference model the most solicited bolts are those farthest away from the barycentre G_{Fe} of the system. In *Giunto Italia* arms the most shear solicited interfaced particles are those farthest away from the barycentre G of the glued surfaces (figure 29,b). In the example, for practical reasons, the interfaced perimeter has been reduced, taking away a small portion in the compressed area in the interest of safety.
It may be that the joint is not subject, too, to axial force, or shear force, or both. In that case, making reference to figure 29,b, the following formula, written hereunder in its maximum extension, shall be applied:

$$\tau_{max} = \frac{M_{torcente} \cdot a}{n.\ facce\ \cdot J_p} + \frac{R}{n.\ facce\ \cdot A} \qquad (52)$$

The origin of the formula (52) lies in the following:

$$M_{torcente} = (M_{flettente} + M_{trasporto}) \qquad (53)$$

$$M_{trasporto} = T \cdot e \qquad (54)$$

$$J_p = J_x + J_y \qquad (55)$$

$$R = \sqrt{N^2 + T^2} \qquad (56)$$

where:

$M_{torcente}$ torsion moment;
$M_{flettente}$ bending moment;
$M_{trasporto}$ transport moment;

e eccentricity, i.e. the distance between the *B-B* position where the shear (*T*) is applied and the barycentre *G*;

a distance of the interfaced point farthest away from the barycentre *G*;

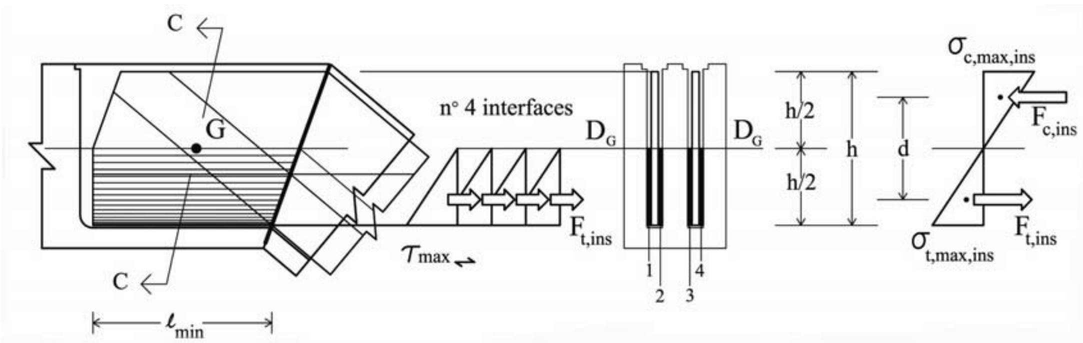


Figure 28: *Section and graphic of stresses on interfaced surfaces*

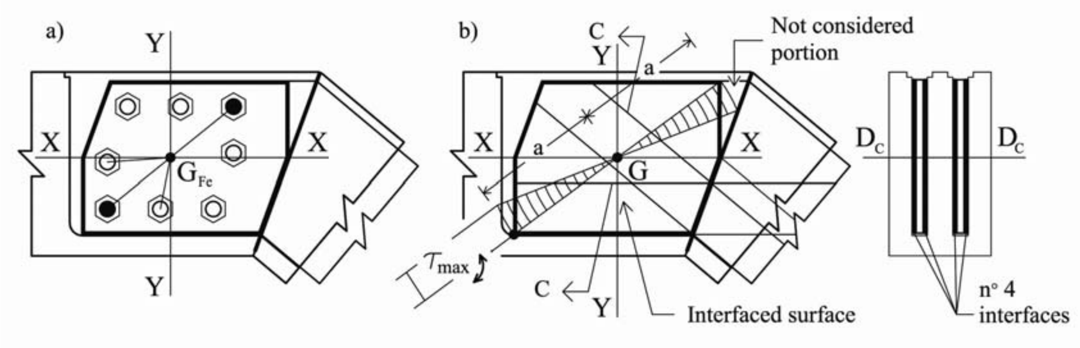


Figure 29: *Joint's models: a) model with bolted sheets connection subject to bending in own layers; b) model with glued inserts which interfaces are subject to bending.*

J_p moment of polar inertia in the insert's layer;
J_x moment of inertia to the x-x axis;
J_y moment of inertia to the y-y axis;
R resulting from N and T forces;
A interfaced surface;
N axial force;
T shear force.

In the absence of shear and axial force, the formula is expressed as follows:

$$\tau_{max}\,\Sigma = \frac{M_{torcente} \cdot a}{n.\ \ facce\ \ \cdot J_p} \qquad (57)$$

Verification is satisfied when:

$$\tau_{max}\,\Sigma \leq f_{v,d}$$

The static functionality of the joint is confirmed by the four verifications described. Let us make the following reflection: the adopted model is the linear stress model, which is undoubtedly valid within the scope of routine loads. The linear stress model is adopted in the interest of safety also for ULS loads. As we get nearer, and even exceed the ULSs, the assumption is that a gradual transformation takes place until it conforms to the parable-rectangle model, notwithstanding the flatness of sections.

7 CONCLUSIONS

Compared to previous systems, the introduction of glass and carbon woven rovings offers new possibilities to continuity joints of timber beams. The works carried out suggest a simple and reliable application model. The objective is to achieve the restoration of structural continuity in joints, making use of multidirectional artificial fibres: carbon tape reinforced woven rovings. All of which is fully compatible with the natural grain structure of timber and surely with the requirement of earthquake protection of buildings.

Figure 30: *Example of Giunto Italia® with double GFRP inserts*

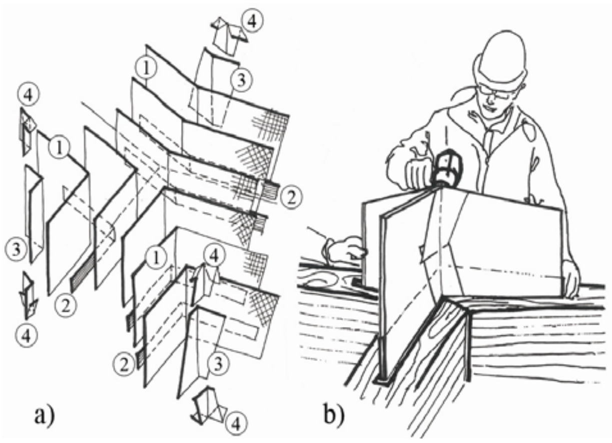


Figure 31: *a) composition of three-ways Giunto Italia: 1) glass or carbon woven rovings; 2) carbon tapes reinfocements; 3) Polyevery C400 carbon reinforcement of angle positions;4) "fasteners" (ligaments) in Polyevery C400 woven roving; b) the insert are formed by wood carpentries under their engineers design end check. The insert are carried leveled plain. The insert's arms are open and angulated when applied on spot. The joint is completed with the Xepox 40 adhesive percolation after the position of the insert in beams cuttings.*

Figure 32: *Placement of Giunto Italia® with double GFRP inserts reinforced by carbon tapes*

ACKNOWLEDGEMENT

To the memory of Pietro Catelli, founder of the Artsana S.p.A. (Chicco) company;

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To the dozens of clients who have encouraged our initiative and supported our endeavours.
To the hundreds of firms, their technicians and staff, that with their intelligence, vitality and loyalty have allowed the positive outcome of so many testing efforts, both at the design and at the construction stage;
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REFERENCES

[1] G. Cenci: Strutture in legno – calcolo e costruzione con riferimento alla DIN 1052, Edizioni Meta, Milano, 1980.
[2] E. Rachello, O. Delmarco, M. Piazza: Tecnologie avanzate nell'impiego strutturale del legno, CNR-I.T.L. Istituto per la Tecnologia del Legno, San Michele all'Adige, 1999.
[3] E. Guagenti, F. Buccino, E. Garavaglia, G. Novati: Fondamenti di meccanica strutturale, McGraw-Hill, Milano, 2005.
[4] NTC 2008 - Norme Tecniche per le Costruzioni, D.M. 14 gennaio 2008 (G.U. 04/02/2008 n. 29 - Suppl. Ord. n. 30) and Technical References advisable to the chapter 12).
[5] CNR-DT 200/2004 – Istruzioni per la Progettazione, l'Esecuzione ed il Controllo di Interventi di Consolidamento Statico mediante l'utilizzo di Compositi Fibrorinforzati – Materiali, strutture di c.a. e di c.a.p., strutture murarie, Roma, 13 luglio 2004.
[6] L. Ascione, A. Giordano: Riabilitazione strutturale con materiali compositi fibririnforzati - Interventi su edifici di conglomerato cementizio armato, Polipress, Milano, 2009.
[7] J. Follrich, A. Teischinger, W. Gindl, U. Müller: Adhesive bond strength of end grain joints in softwood with varying density. Holzforschung, Vol. 62, pages 237-242. Walter de Gruyter, Berlin-New York, 2008.

Figure 33: *TechnoDomus exhibition, RiminiFiera, March 2009. Hypothesis of a space membrane in glulam and Polyevery G800 woven rovings; for the multidirectional connections a multi-way Giunto Italia® in GFRP has been designed*