



**Task 9**  
**REAL LIFE CASE STUDY TRIALS**  
**Sub-task 9.2:**  
**INSTALLATION AND MONITORING**

Contribution from Legnodoc srl:  
**PALAZZO NOBILI IN LUCCA**

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**Abstract**

*A spruce floor beam, without significant decay, needed strengthening and increase of stiffness in order to be verified according to the current values for actions. The repair technology was chosen for both aesthetic reasons, on-site accessibility requirements (impossible to work from top) and cost analysis. The intervention was completely carried out from below the beam, with the use of a 2-component epoxy-based adhesives and CFRP plates.*

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## 1 General description

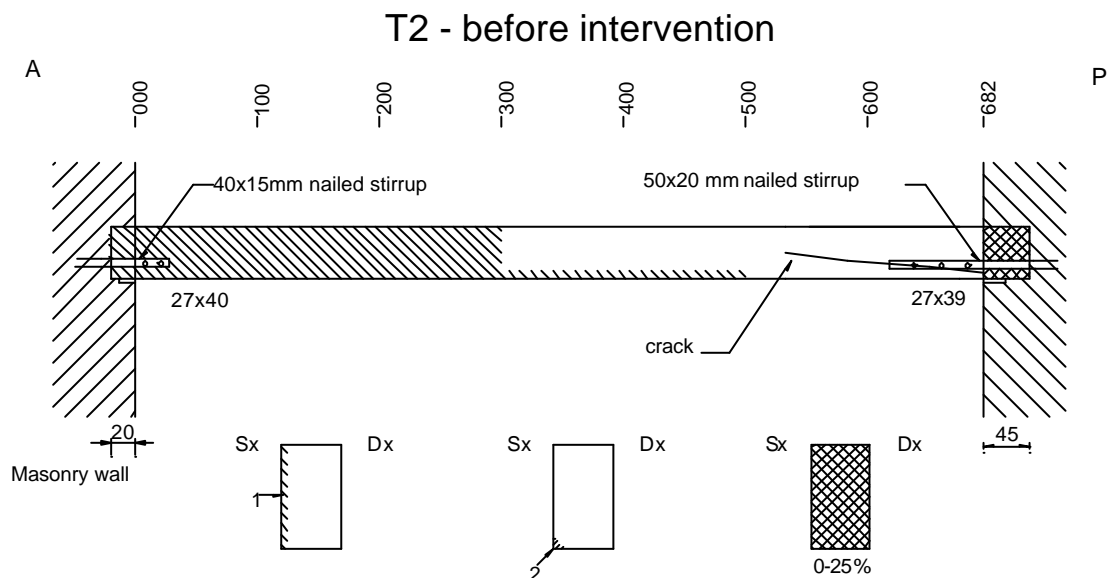
The beam is located within an historic palace, formerly the offices of the Bank of Italy in Lucca, now being converted to flats from a private investor.

The scope of the intervention was the need to eliminate the false ceilings and the steel I-beams installed in the 1960es, in order to restore the appearance of the decorated wood ceilings (now under a white paint), according to the requirements from the “Soprintendenza” (authority on Cultural Heritage).

## 2 Diagnostic survey

The diagnosis, made according to the methods previously reported (now UNI 11119 standard), provided evidence of little fungal decay on one beam end, low insect decay on one side and a shrinkage crack showing some slope of grain.

The grading of the beam and the further static verifications showed that it was impossible to meet strength and stiffness requirements with the currently adopted actions.



**Summary of the diagnostic survey.**

### 3 Design of the intervention

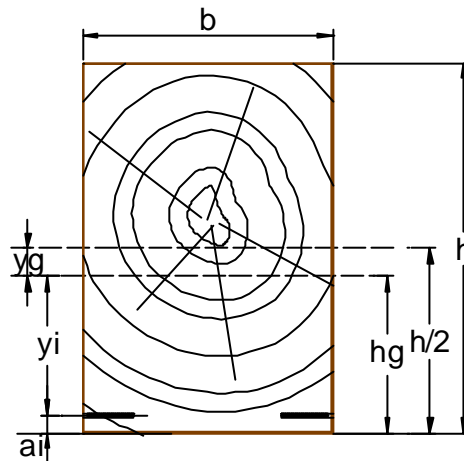
The design method for the wood-frp-adhesive composite section is based on the theory of uncracked concrete beam. With the assumption of the perfect adhesion between wood and carbon plates, we obtain a composite timber beam that can be calculated – in a simplified way- like an uncracked concrete beam, with a different ratio between the moduli of elasticity of the materials involved (steel-to-timber instead of steel-to-concrete)

The following assumptions are made:

- ◆ elastic behaviour of the materials involved; i.e., stresses and strains are proportional;
- ◆ perfect bond between carbon plates and wood.

The computation is lead with the calculation of “equivalent” geometrical parameters of the composite section: equivalent area  $A_{eq}$ , position of the neutral axis  $h_g$ , moment of inertia  $J_{eq}$ , top and bottom section modulus  $W_{eq,inf}$  and  $W_{eq,sup}$ .

After the determination of the actions in the beam (bending moment and shear force), it is possible to calculate the timber stresses at extreme top and bottom fibers and the carbon fibre stresses in tension, with the following formulas



$$n' = \frac{E_{FRP}}{E_W} \quad \text{ratio between the moduli of elasticity of the materials}$$

$$A_{eq} = b \cdot h + n' \cdot (t_p \cdot h_p) \cdot n \quad \text{equivalent area of the composite section}$$

$n$  number of carbon plates

$t_p$  thickness of the carbon plate

$h_p$  width of the carbon plate

$$h_g = \frac{\left[ \frac{bh^2}{2} + n' \cdot A_p \cdot (n_i \cdot a_i) \right]}{A_{eq}} \quad \text{position of the centroid of the composite section from the bottom}$$

$$y_g = \frac{h}{2} - h_g \text{ (see fig.)}$$

$$y_i = h_g - a_i \text{ (see fig.)}$$

Equivalent moment of inertia:

$$J_{eq} = \frac{bh^2}{12} + b \cdot h \cdot y_g^2 + n' \cdot [n_i \cdot A_p \cdot y_i^2]$$

Top and bottom section modulus:

$$W_{eq,inf} = \frac{J_{eq}}{h_g} \text{ and } W_{eq,sup} = \frac{J_{eq}}{h - h_g}$$

Stresses:

Timber:

$$s_{f,inf} = \frac{M}{W_{eq,inf}}$$

$$s_{f,sup} = \frac{M}{W_{eq,sup}}$$

$$t = 1,5 \frac{T}{b \cdot h}$$

Carbon plate:

$$s_{FRP,inf} = \frac{M}{J_{eq}} \cdot y_i$$

## ⇒ MATERIALS

### ✓ Existing timber beam

Wood species	CLASS	Compressive strength // to the grain	Bending strength // to the grain	Tensile strength // to the grain	Shear strength // to the grain	Bending MOE // to the grain
Fir (Abies alba Mill.)	S3	7	7,5	6	0,7	11 000

Rif. Table 3 – Formal Report 2.1- Strength classes for timber in service. Permissible stresses ( $N/mm^2$ ) traditionally used in Italy for the design of restoration works. To obtain the characteristic values, we apply an increasing factor of 1,5.

### ✓ CARBON FIBRE PLATES

CARBON FIBRE PLATES	
Thickness	1,4 mm
Width	50 mm
Modulus of Elasticity	170 GPa
Tension strength	> 3.100 MPa
Inter Lamina Shear strength	77 Mpa
Density	1,61 $kg/m^3$

✓ **Epoxy adhesives**

Type:

- 2-component epoxy, thixotropic

⇒ **BEAM GEOMETRY**

<i>Geometry</i>	
Beam span	$l = 6820 \text{ mm}$
Beam support length	$a = 200 \text{ mm}$
Beam width	$b = 270 \text{ mm}$
Beam depth	$h = 400 \text{ mm}$
Centre distance between beams	$i = 2900 \text{ mm}$

⇒ **LOADS**

<i>Loads</i>	
Permanent actions	$G_k = 1,50 \text{ kN/m}^2$
Variable actions	$Q_k = 2,00 \text{ kN/m}^2$
Partial safety factor for permanent actions	$g_G = 1,35$
Partial safety factor for variable actions	$g_Q = 1,5$

## ⇒ COMPUTATION

### ✓ ULTIMATE LIMIT STATE

LINEAR LOAD ACTING ON T2:

The total linear design load acting on the beam T2 is, considered to be the width of the floor area supported by the beam (the so-called "influence area") is 2,90m:

$$q_d = (G_k \cdot i + g_k + r \cdot b \cdot h) + Q_k \cdot i =$$

$$= 1,35 \times (1,50 \times 2,90 + 6 \times 0,27 \times 0,40) + 1,5 \times 2 \times 2,90 = 6,75 + 8,70 = 15,45 \text{ kN/m}$$

DETERMINATION OF THE INTERNAL ACTIONS:

Bending moment acting at midspan:

$$M = \frac{q_d l^2}{8} = \frac{15,45 \times 6,82^2}{8} = 89,81 \text{ kNm}$$

Support reaction

$$T = \frac{q_d l}{2} = \frac{15,45 \times 6,82}{2} = 52,685 \text{ kN}$$

$n'$	=	22.73	
$n$	=	4	
$t_p$	=	1,4mm	
$h_p$	=	50 mm	
$A_p$	=	70 mm <sup>2</sup>	
$a_i$	=	20 mm	
$A_{eq}$	=	1143.64	cm <sup>2</sup>
$h_g$	=	19.00	cm
$y_g$	=	1.00	cm
$y_i$	=	16,998	cm
$J_{eq}$	=	163470.9	cm <sup>4</sup>

$$W_{eq,inf} = 8604 \text{ cm}^3$$

$$W_{eq,sup} = 7784 \text{ cm}^3$$

**Stresses:**

Timber:

Bending:

$$s_{f,inf} = \frac{M}{W_{eq,inf}} = 10,44 \text{ N/mm}^2 < 1,5 \times 7,5 = 11,25 \text{ N/mm}^2$$

$$s_{f,sup} = \frac{M}{W_{eq,sup}} = 11,54 \text{ N/mm}^2 > 1,5 \times 7,5 = 11,25 \text{ N/mm}^2, \text{ accepted anyway}$$

Shear:

$$t = 1,5 \frac{T}{b \cdot h} = 0,75 \text{ N/mm}^2 < 1,5 \times 0,7 = 1,05 \text{ N/mm}^2$$

Carbon plate:

$$s_{FRP,inf} = \frac{M}{J_{eq}} \cdot y_i = 9,34 \text{ N/mm}^2$$

✓ **SERVICEABILITY LIMIT STATE – DEFLECTIONS**

⇒ **The creep phenomenon**

Creep deformation is strongly influenced by the *load duration*: it increases as the load duration increases. To be on the safe side, the creep coefficients are weighted according to the loads, considering that an amount of the medium term loads (33%) is always present on the structures and therefore can be regarded as 'permanent'.

Timber creep coefficient:

$$k_{def, \text{ permanent load}} = 0,6$$

$$k_{def, \text{ medium term load}} = 0,25$$

$$f_{w,calc} = \frac{(1 + k_{def,perm}) \times (q_p + 0,33q_v) + (1 + k_{def,acc}) \times 0,67 \times q_v}{q_p + q_v}$$

$$f_{w,calc} = \frac{(1,6) \times (q_p + 0,33q_v) + (1,25) \times 0,67 \times q_v}{q_p + q_v} = 1,47$$

Limiting values of deflections are:

◆ Initial stage: deflection due to variable loads  $u_{2,inst} < \frac{l}{300}$

◆ Final stage:  $u_{fin} (= u_{1,fin} + u_{2,fin}) < \frac{l}{200}$

Where

$u_1$  is the deflection due to permanent loads

$u_2$  is the deflection due to variable loads

Initial stage:

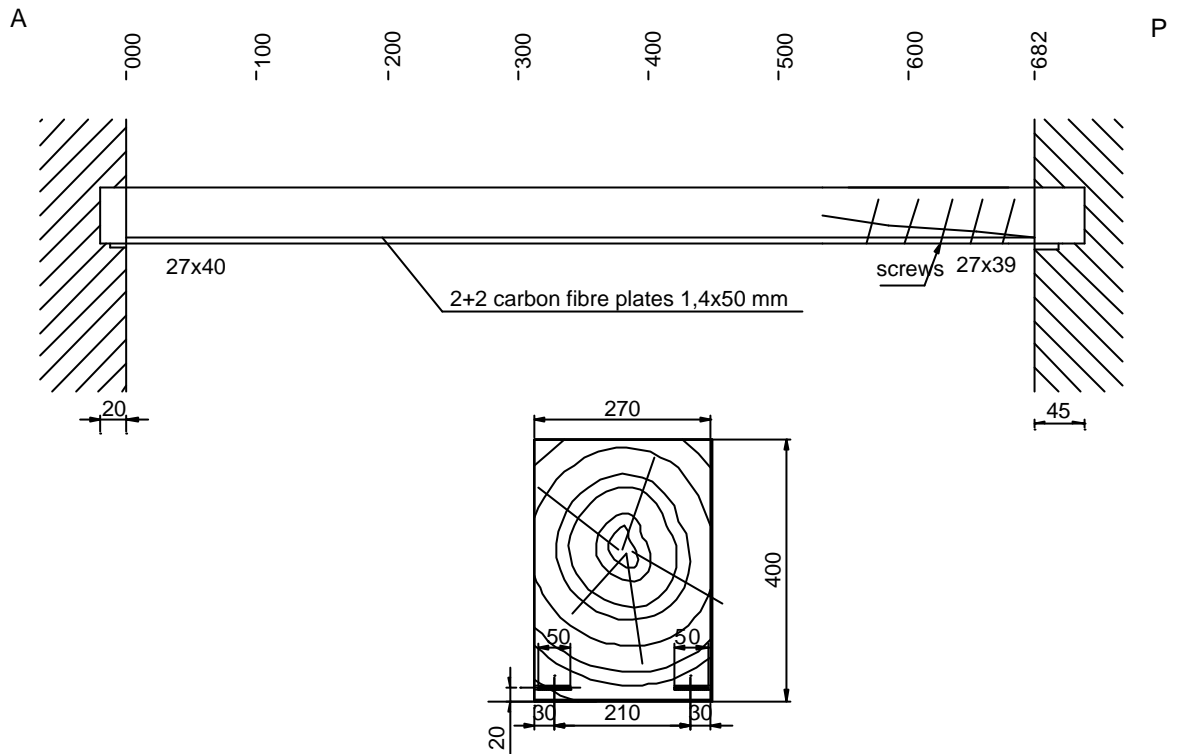
$$u_{1,inst} = \frac{5}{384} \frac{q_p l^4}{EJ_{eq}} = 7,83 \text{ mm}$$

$$u_{2,inst} = \frac{5}{384} \frac{q_v l^4}{EJ_{eq}} = 9,09 \text{ mm} < l/300 = 22,73 \text{ mm}$$

Final stage:

$$u_{fin} = 1,47 \times \frac{5}{384} \frac{q_d l^4}{EJ_{eq}} = 25 \text{ mm} < l/200 = 34,1 \text{ mm}$$

## T2 - after the intervention



## 4 Site work

The overall duration of the repair work was almost 10 days, as follows

Day	Operation
1	beginning of the installation of the working platform
2	end of the installation of the working platform and start of removal of the false ceiling
3	End of removal of false ceiling
4	Cutting and insertion of CFRP on one side (1/2 day)
5	Cutting and insertion of CFRP on the other side (1/2 day)
10	End of curing period, start of restorer's work (cleaning, decoration)

A preliminary preparation of the site work was necessary, consisting of placing a working platform 1,8 m beneath the beam. Propping of the beam was not needed because of the presence of the steel I-beams which were later on to be removed.

Next step was the cutting of the slots with a circular saw, which proved to be quite difficult because of the thickness required (6 mm) which was higher than the sawblade thickness (3,5 mm). The solution was to cut in 3 steps, as shown in the figure below: the first cut (white) had a depth of only 3 cm instead of 6, the second cut (yellow) had the full depth and therefore the sawblade found some lateral support on the inner 3 cm, the final cut (red) was needed to eliminate a smaller portion of wood and did not apply much lateral pressure on the sawblade, whose stiffness was therefore sufficient to avoid deviations and excessive friction on the wood.



The slots were cleaned and all sawdust was removed by vacuum, and all components were checked for cleanliness and dryness before the adhesive operation commenced.

Next step was the application of the tixotropic adhesive between the two CFRP laminates and within the slot (all with a spatula) and the insertion of the two laminates within the slot.

In order to push the CFRP laminates 10 mm down the slot, plywood blocks were machined with a "T" cross section of the desired shape, which was then tightened with wood screws.

A minimum cure time was allowed (5 days) before letting the restorers start cleaning the surfaces. The steel I-beams were removed later by the building contractor.



Cutting slots: an upper side guidance (A) and a lower anti-tilting support (B), made with 25 mm plywood, are fixed on the beam.



Left: peeling and applying the adhesive on the CFRP plates.  
Right: pushing the CFRP plates with a plywood block machined with a "T" section.

## 5 Costings

The actual costs were as follows:

Item	Unit	Quantity	Price/unit (€)	Total cost (€)
CFRP plates	m	25	25	625
Epoxy adhesive	kg	20	9	180
Cost of labour	h	32	30	960
				<b>1.765</b>

### Reference documents for Italy

#### LOADS

- ◆ DM 16/1/96 Norme tecniche relative ai “Criteri generali per la verifica di sicurezza delle costruzioni e dei carichi e sovraccarichi”.
- ◆ CM 4/7/96 Istruzioni per l'applicazione dei “Criteri generali per la verifica di sicurezza delle costruzioni e dei carichi e sovraccarichi.” di cui al DM 16/1/96.

#### STRUCTURES (in seismic zones)

- ◆ Legge 02/02/74 n. 64: Provvedimenti per le costruzioni con particolari prescrizioni per le zone sismiche.
- ◆ DM 16/1/96 n. 11951: Norme Tecniche per le costruzioni in zone sismiche.
- ◆ CM 10/4/97 n. 65/AA.GG.: Istruzioni per l'applicazione delle “Norme tecniche per le costruzioni in zone sismiche.” di cui al DM 16/1/96.

#### STEEL

- ◆ CNR-UNI 10011 Giugno 1988– Costruzioni in acciaio – Istruzioni per il calcolo, l'esecuzione, il collaudo e la manutenzione.
- ◆ DM 09/01/1996 – Norme Tecniche per il calcolo, l'esecuzione ed il collaudo delle strutture in cemento armato, normale e precompresso e per le strutture metalliche.

#### MASONRY

- ◆ DM 02/07/1981 – Normativa per le riparazioni ed il rafforzamento degli edifici danneggiati da sisma nelle regioni Basilicata, Campania e Puglia.
- ◆ CM 30/07/1981 n. 21745 – Istruzioni relative alla normativa tecnica per la riparazione ed il rafforzamento degli edifici in muratura danneggiati dal sisma.
- ◆ DM 20/11/87 Norme tecniche per la progettazione, esecuzione e collaudo degli edifici in muratura e per il loro consolidamento.

#### TIMBER

- ◆ UNI ENV 1995-1-1: Eurocode 5 – Design of timber structures : General rules and rules for buildings (Feb. 1995) ;
- ◆ UNI ENV 1995-2: Eurocode 5 – Design of timber structures : Bridges (september 1999) ;
- ◆ EN 338: “Structural timber – strength classes”.
- ◆ EN 1194: “Timber structures – Glued laminated timber – Strength classes and determination of characteristic values”.