Mixed systems in reinforcement of old structures

Mixed Systems in Reinforcement of Old Structures

Systèmes mixtes pour le renforcement de structures anciennes

Verbundbauweise zur Verstärkung von Altbauten

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SUMMARY
The results of a research program oriented towards finding some static restoration techniques for old woden horizontal structures are reported here. The proposed reinforcement technique consists of building a "composite timber-timber structure", i.e. basically, in causing a static interaction between some "wooden slabs" (made of wooden boards) and the existing timber beams. The static interaction among the different components of the structures takes place thanks to special connectors, i.e. steel pins glued into the wood by means of epoxy resin.

RÉSUMÉ
On rapporte ici les premiers résultats d'un programme de recherche pour la détermination de techniques de renforcement de structures horizontales en bois de vieux bâtiments. Cette technique vise à réaliser une structure mixte bois-bois et consiste à faire collaborer statiquement une nouvelle dalle en bois (composée de planches en bois) avec les poutres en bois existantes. L'interaction statique des diverses parties composant la structure se fait au moyen de dispositifs spéciaux (connecteurs en acier) généralement collés au moyen de résine époxyde.

ZUSAMMENFASSUNG
Umrissen werden die ersten Ergebnisse eines Forschungsprogramms, dessen Ziel es ist, Techniken zur statischen Wiederherstellung horizontaler Holzstrukturen bei Altbauten zu entwickeln. Diese Techniken fördern den Einsatz einer gemischten Holzstruktur und dienen dem statischen Zusammenwirken einer neuartigen, aus Holzbrettern bestehenden Holzstruktur mit den vorhandenen Holzträgern. Das statische Zusammenwirken der verschiedenen Strukturteile wird durch besondere Verbindungsglieder ermöglicht, die in der Regel mittels Epoxydharz aufgeklebt werden.

1. PRELIMINARY REMARKS

Among the various techniques for the static reinforcement, the execution of ***composed structures*** is proposed as an effective restoration to make up for various origin static deficiencies (such as material decay or poor resistance and stiffness of elements) or to adapt the existing structural characteristics to new functional needs. Among the bent composed structures, the "deformable connection composed beam" typology has a remarkable importance.

This is a model structure composed of a series of in-plane beams with parallel axes (arranged in the same plane), joined with connectors which are presumed to have a general k stiffness as regards relative $\Delta\xi$ displacements of the points connected in the direction parallel to the axes, and presumed to be indeformable as regards relative displacements orthogonal to the former. The classical composite two-layer beam structures may be recognized as conforming to this structural model.

In correspondance with the extreme values of the k parameter variability field, it is possible to recognize straight away the well known "limit cases" of composed beam behaviour; " beams in parallel" (that is having the same curvature in correspondance with axis points initially having the same abscissa) for k null values, composed beams "keeping their plane global cross section" for k high values ($k \twoheadrightarrow \infty$).

To the last limit case normally refer the structural mathematical models in the analysis of the usual steel-concrete composite beams. The results obtained sufficiently adhere to the real behaviour of the com-posite beam.

2. CHOICE OF A COMPOSITE REINFORCEMENT STRUCTURE

To design correctly a composite structure subjected to a bending moment it is above all necessary to choice carefully the composite structure to adopt. It will be absolutely necessary to examine accurately the existing "wooden" material, to define first of all its "average" resistance and stiffness characteristics. It will be then necessary to have a perfect knowledge of the connection system behaviour, not only in the elastic field, but also in next-to-collapse fields or as a consequence of time-depending phenomena. The behaviour "elementary laws" for the connections mentioned in Paragraph 3 can be obtained through some Push-out tests (Fig.1).

It is also evident that a correct restoration technique will obtain the desired result if the existing wooden elements maintain their own essential static function. Composite structures permitting a combination of the (existing) wooden element with other materials are thus particularly interesting for us.

Wood-wood composite structures were currently employed in old buildings to make, for example, very long beams having a large transversal section (Fig. 2). It is nevertheless to be remarked that the "connections" used had a poor static efficiency (i.e. a poor stiffness), since they were obtained through a pretensioning orthogonal to the main wood fibres. It is known that such pretensioning loses its efficacy very soon.

The connection efficiency problem will be solved by adopting steel connectors glued in holes made in the wood. The mainly function of these connectors is to resist against shear forces. In Fig. 3 are shown some examples of modern composite wooden beams. In diagrams A and B (push-out tests) are indicated the behavioural differences between a "shear" connection carried out with non-glued connectors (A) and a glued connection (B). The advantages obtained thanks to the glue are evident.

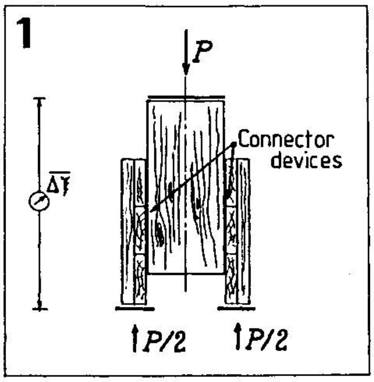
3. CHARACTERISTICS OF THE PROPOSED COMPOSITE STRUCTURE

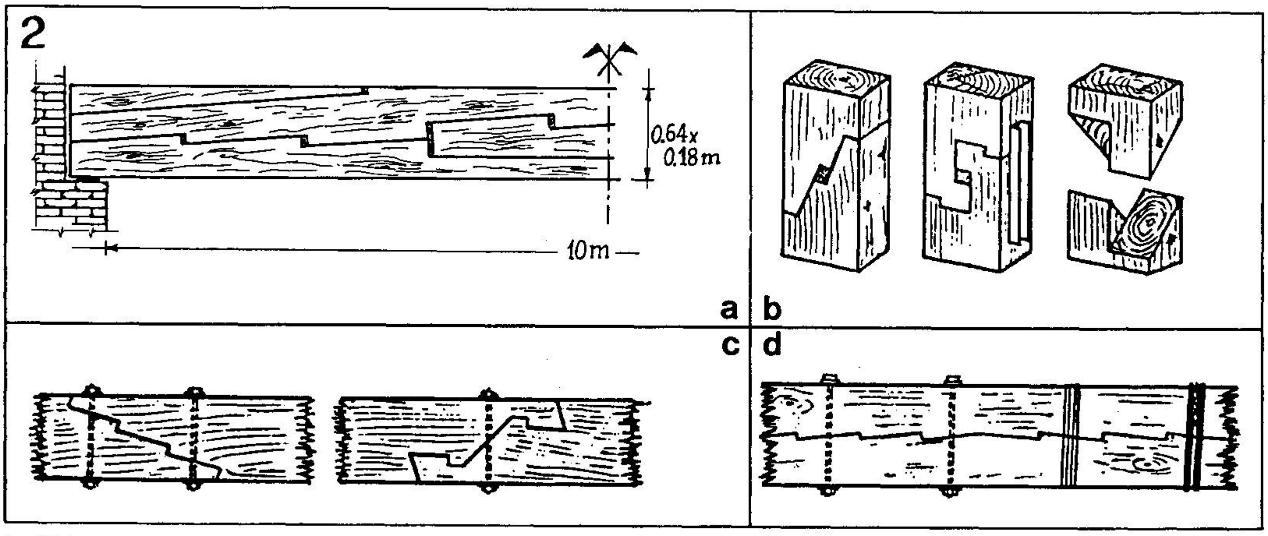
The connection system explained below can be easily used for wood-wood composite

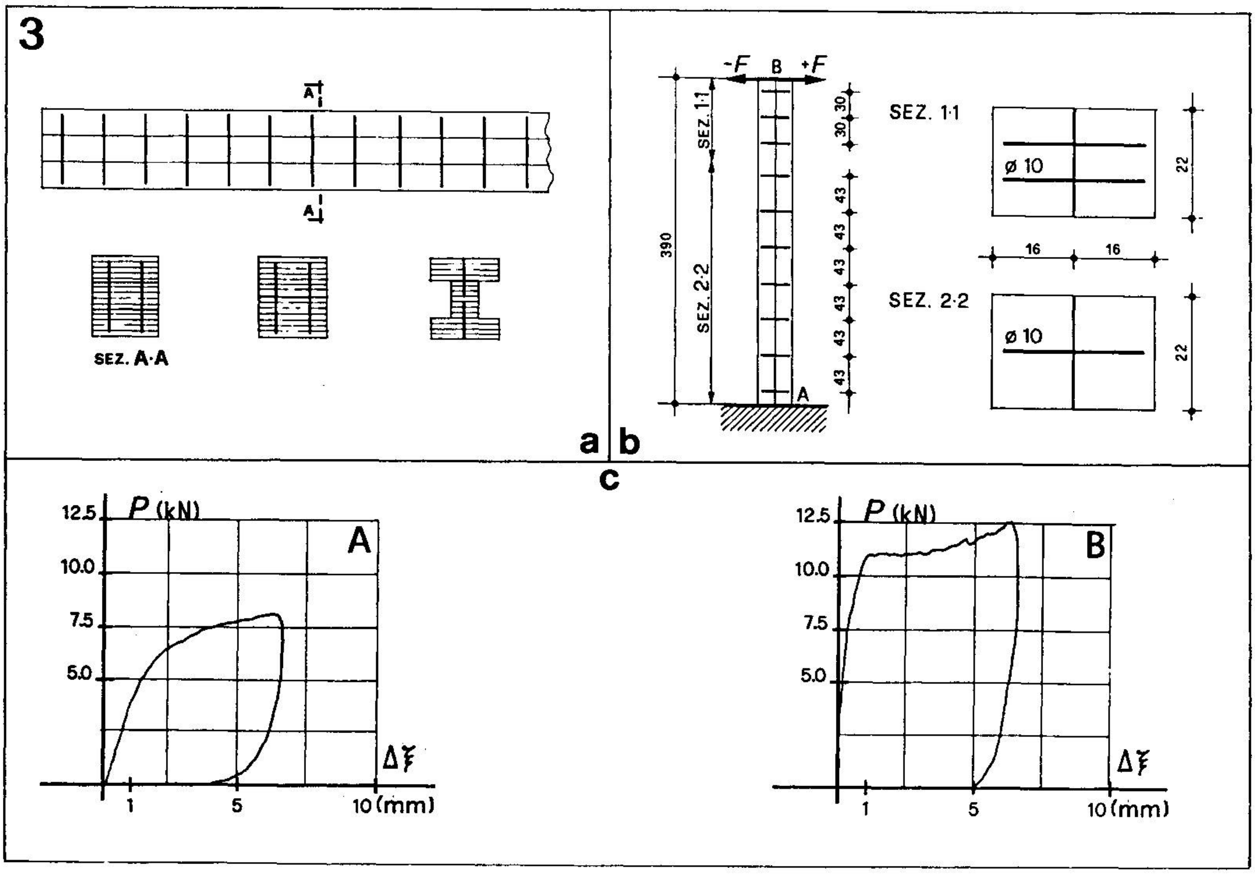
Fig.1 - Push-out test for the proposed connection system.

Fig.2 - Old composed wood structures.

Fig.3 - Drawings of modern composed wood beams.







structures. Such system uses the existing wooden beams making a wooden slab (made up of a double frame nailed boarding) cooperate with them by means of connectors glued in some holes made in both the beam and the boarding (Fig.4). These connectors are entirely threaded steel bars, the nut of which is screwed on a washer placed on the upper side of the boarding. The longitudinal distance between the connectors and their diameter shall evidently be choosen depending on the load (shear force) to be transmitted between the two elements of the composite structure and on the "efficiency degree" (i.e. stiffness in the elastic field) requested to the connection.

The diameter of the hole made in the wood to permit the insertion of the connector is slightly larger (3÷5 mm) than the connector's rated diameter. It should be kept in mind that the larger the hole the higher the glue consumption and the greater the connection deformability. On the contrary, when the hole's diameter is nearly the same as the connector's diameter, the glue might not wet completely the connector.

This glue, mainly constituted by epoxy resin, has been created thanks to a wide research program, and is a structural synthetic adhesive, to be employed at room temperature. It is a two-components adhesive, containing some inorganic inert matters, but no solvents, diluents, or softeners. After curing, this glue turns into a solid matter having the following characteristics: a high adhesive capacity, a very low shrinkage, a very low creeping, a very good behaviour towards static and dynamic stress, along with a very high resistance to chemical agents (see [1]).

The upper slab can be either composed of wooden boards or multilayer panels. In the following paragraph we are going to show the static characteristics of either systems.

4. LABORATORY TESTS

A wide program of push-out physical tests is being carried out in the Laboratory of Istituto di Scienza e Tecnica delle Costruzioni (University of Padua, Italy). These samples represent homogeneously the full range of parameters which can be adopted in the connection system, as follows:

- steel bar diameter: ϕ = 10,12,14,16 mm;
- boarding thickness: s = 45,60,75,95 mm;
- type of slab: boards, plywood, multilayer panels, and several types of wood.

Some push-out tests on the first group of 96 samples are now being carried out.

This research program has the end to supply a synthetical definition of the following mechanical parameters, which characterize the connection system: ***initial stiffness***, ***limit load*** (as a load beyond which we have value $\Delta\xi$ displacements over 1 mm), ***ultimate load*** and ***displacement*** (collapse situation).

As an example we show two typical push-out behavioural diagrams (the loads shown in the diagrams refer to one steel connector). The proposed connection system show the following characteristics: a very good behaviour in the elastic field, very high ductility values and a remarkably high reserve factor. Figure 5a shows the behaviour of the connection made up of wooden boards, while Figure 5b shows the one made up of multi-layer panels.

Figure 6 shows the cutting up of one sample after the push-out test. It can be clearly seen the good behaviour of the glue also for what regards the good distribution of the stresses against the hole walls.

5. THE STATIC BEHAVIOUR OF THE WOOD-WOOD COMPOSITE STRUCTURE

In order to verify the real advantages offered by the proposed system as far as resistance and stiffness are concerned, we are carrying out some numerical tests on the

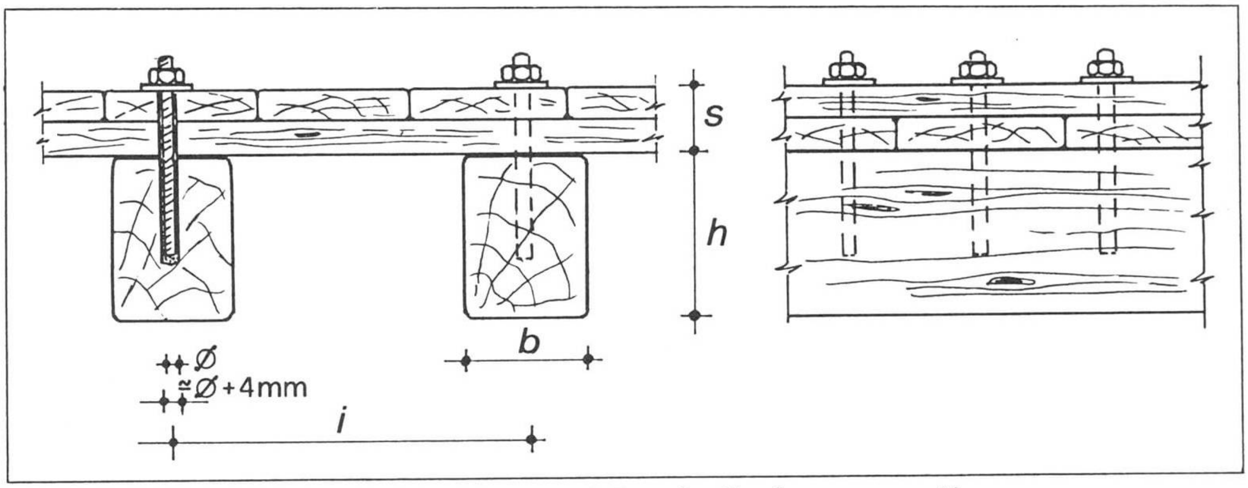


Fig.4 - Transversal and longitudinal cross sections.

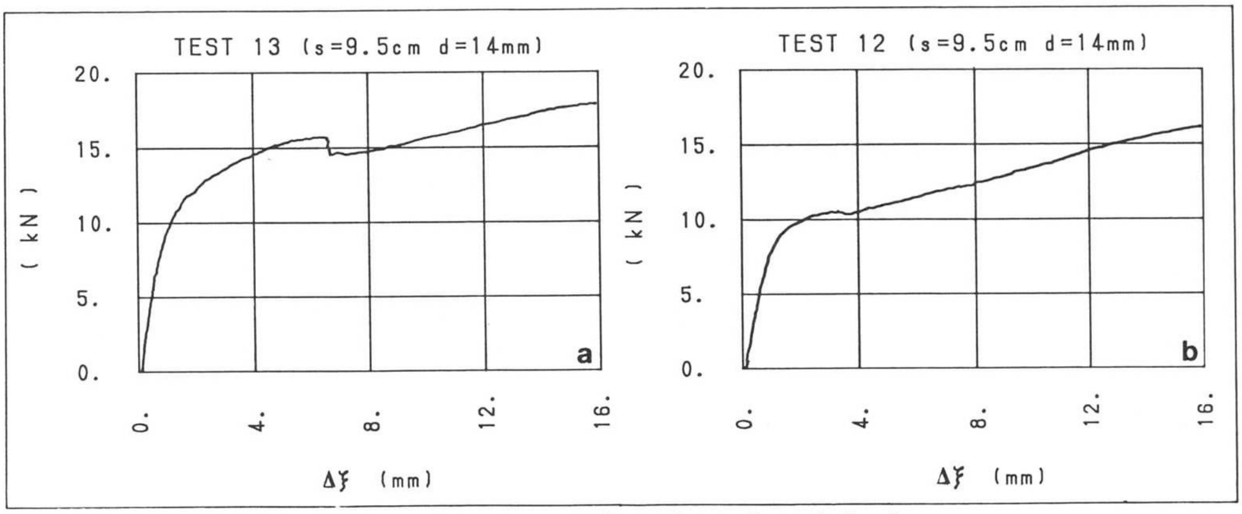


Fig.5 - Some results of push-out test.

Fig.6 - One sample after the push-out test.

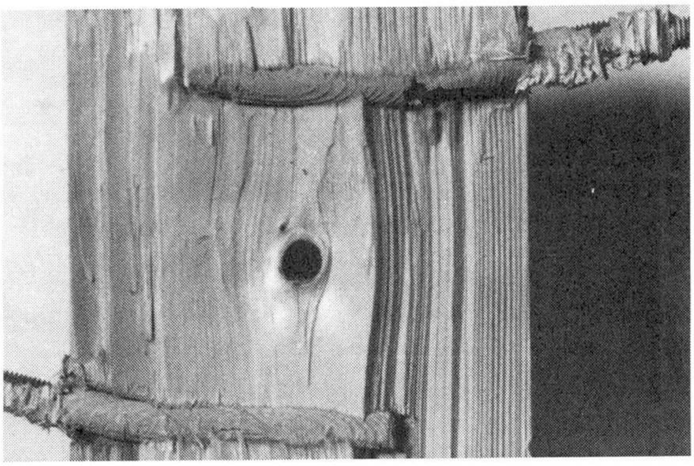
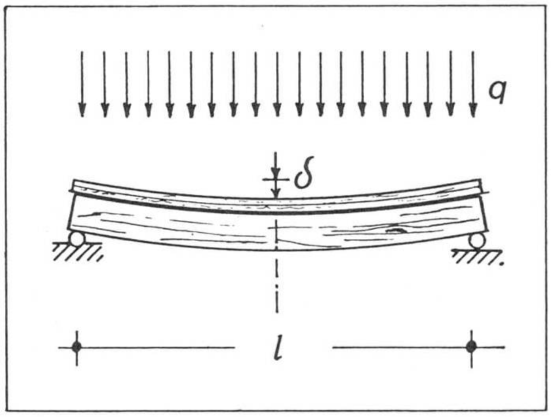


Fig.7 - Typical floor longitudinal section, having composite structure.



floor shown in Fig.7. We are using the already set up F.E. program used before for the analysis of some composite structures (made up of "beams"), keeping in mind the non-linearity of the connection behaviour and of the materials making up the beams (see [2] and [4]). This research also aims at supplying some simple laws for a correct and quick design and verification of the proposed structure.

Due to the lack of room, we will only put in evidence, in Table I, the behaviour of the composite structure of Fig.7 under working load. In the same Table are reported the results for k = 0, $k = \infty$ and actual stiffness k^*. The last is the result of a choice of connectors carried out following a criterion of limitation of the maximum displacements Δf for the same. This choice has been carried out for a load (beyond its dead load) equal to 5.0 kN/m^2. The distance between the connectors and their diameter are shown in the same Table. All the values indicated in the Table are expressed as a ratio between these values and the analogue values (indicated by the "0" subscript) which could be found for the existing wooden beam. σ corresponds to the wooden beams maximum positive stress (for geometrical references refer to Fig.4 where i = 60 cm).

It soon appears clear the remarkable increase of the resistance of the composite structure compared to those of the existing element (increase=1.8÷2.5 times), and its stiffness (increase=2.5÷3 times).

6. CONCLUSIONS

The composed structure here described is proposed as a reinforcement system and a means of effective restoration of the existing structures' essential static functions.

The success of this intervention is strictly related to a necessary and complete study of the existing structural materials and elements, and to a perfect knowledge of the static behaviour of the connection. The reinforcement operation is aimed, in this case, at assuring an effective transmission of mutual forces among several components: the static efficiency of the connection is thus responsible for the correct behaviour of the structure according to a "composite structure" functioning scheme.

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b h s	Connectors	l	σ/σ_0			δ/δ_0		
[cm]		[m]	k=0	$k=\infty$	k^*	k=0	$k=\infty$	k^*
11 13 4.5	1Ø14/12	4.0	0.82	0.39	0.43	0.82	0.21	0.35
10 16 4.5	1Ø14/12.5	4.5	0.88	0.43	0.55	0.88	0.24	0.38
13 19 6.0	1Ø14/14	5.0	0.87	0.42	0.57	0.87	0.24	0.41
16 21 6.0	1Ø14/12	6.0	0.92	0.46	0.59	0.92	0.27	0.42
19 24 9.5	1Ø14/13	7.0	0.84	0.40	0.52	0.84	0.23	0.33

TABLE I