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Seismic strengthening and seismic improvement of timber structures

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HIGHLIGHTS

- Seismic strengthening plans should consider the levels of structure, element, joint.
- The structural scheme must be verified to balance horizontal forces.
- Slab reinforcing options yield various stiffness levels apt to fit different needs.
- In earthquake conditions, joints disassembly and brittle failure must be prevented.
- Inappropriate positioning of reinforcement even in small amount may cause brittleness.

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ABSTRACT

In European seismic areas timber structures are found as building frames, in combination with masonry infills, in bridges, but most frequently in roof structures and floor slabs of traditional buildings. Seismic strengthening of existing structures should provide a well-defined and simple path to seismic forces, maintain timber members elastic, and develop as much as possible the post-elastic behaviour of joints. Provisions must be adopted to avoid sudden loss of capacity and brittle failure, and to foster ductility. Different criteria for seismic strengthening of floor slabs and of carpentry joints are presented.

1. Introduction

The development or the updating of seismic zonation in a country may require reconsideration of existing structures that were built for lower levels of seismic action, or even without seismic provisions, in order to comply with current safety requirements. In Italy, for instance, the building code [1] requires that buildings undergoing major renovation or a change of use be checked also for earthquake loading. Reference is made to the seismic action to be applied in the design of new buildings. This rule aims at the progressive upgrading of the significant fraction of the building stock that was originally built without adequate consideration of seismicity. In the specific case of timber structures, plain timber sections and carpentry joints, which were the basis of traditional construction, may not satisfy the new requirements; seismic strengthening may become necessary in order to continue their use.

In Europe, the regions affected by the highest seismicity are in the south, where buildings erected completely in timber are not frequent. Yet, in traditional construction, including common buildings as well as historical architecture and monuments, timber has been used extensively to build structures for supporting floors and roofs. This chapter will focus particularly on such structures and their components.

Timber has been used since antiquity in the Mediterranean region to improve the seismic response of masonry, as witnessed by findings at archaeological sites, e.g. [2]. Different arrangements of the two materials have been developed in time, corresponding to different views of the way collaboration should be accomplished. They range, geographically and formally, from the infilled timber frames of the Pombaline architecture in Portugal, e.g. [3], through the timber framing of southern Italian "case baraccate", [4], to the timber frame-and-wall system found in Greece in the

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island of Leukada where a secondary frame parallels the stone masonry walls [5], again to Greece [6] and to the many solutions offered by Turkey, e.g. [7]. The close interaction between timber and masonry that is inherent in all these systems leads to their classification as composite structures rather than timber structures. Their seismic capacity may be deemed insufficient, in spite of the original intention of the builders to withstand strong earthquakes or because of reduced capacity due to damage and decay. Provisions for improving them require considering features specific to each type, e.g. [8].

Traditional full-timber buildings in many different forms and structural types are found most frequently in Turkey, both for residential use [9] and for significant religious sites [10]. Some are outstanding for their constructive boldness and beauty, like for instance the Prinkipo palace [11] at the Princess island in the Marmara sea, as shown in Fig. 1. The 6-storey high building is completely built in wood, in its main structural parts as well as in its secondary walls and partitions, and in its decorations, presenting an encyclopaedic collection of techniques and elements constructed in timber. Unfortunately, the cultural value of the Prinkipo palace and of some of these buildings was not recognized early enough and they are highly damaged. The main issue is their survival rather than their seismic resistance, which could be, in any case, attained with the criteria for interventions described here.

Bridges, which are also traditional timber structures, are present in a small number in European seismic areas and are generally considered as heritage structures. Although they may require special attention and treatment, the considerations developed in the following may be extended to their case.

Common criteria for strengthening interventions usually derive from constructional tradition. Yet, originally, strengthening methods did not address the problem of seismic response but would, rather, concern malfunctions for common vertical loads or deterioration. Their effectiveness toward seismic actions needs to be confirmed.

New intervention technologies, often based on the application of advanced materials, like polymers reinforced with fibres of different kind, have been proposed also for timber structures. Some of their mechanical characteristics and easy implementation make them particularly appealing for strengthening existing structures. The interventions, again, must comply with criteria and requirements suitable for seismic conditions. It must be noted that in general interventions for rehabilitation or structural upgrading may be similar in the seismic and non-seismic case. In the former case, however, interventions must also adhere to principles stemming from the basic philosophy of seismic design, discussed in the following.

Often, existing timber structures belong to buildings listed as part of the cultural heritage of a country: as such, they are subjected to conservation requisites. All structural upgrading operations need to comply with criteria for restoration of heritage as well as safety. In this perspective, according to a categorization commonly used in earthquake engineering, the interventions to reduce seismic vulnerability may be distinguished between,

- *seismic strengthening*, which technically corresponds to putting the structure in the condition to withstand a design earthquake of exceptional level like a newly designed one (sometimes the term *upgrading* is also used), and
- *seismic improvement*, which is a milder, less invasive, and more local intervention intended to eliminate possible criticalities without implementing a general upgrading of the structural capacity to the same level as in new designs.

The approach of seismic improvement has been deemed suitable for operations on cultural heritage also by national authorities in the field [12]. Nowadays, many recent studies and observations are pointing out that less invasive interventions may yield better results even in proper seismic strengthening. In the following, the term "strengthening" will be mainly used in the more general and generic sense of structural upgrading, yet the distinction of strengthening versus improvement in the sense described above will be recalled when necessary.

In the following, general criteria are first presented; timber structures are then examined as a system and in their components, indicating which situations may be critical in seismic conditions and what interventions may be most profitably performed.

2. Strengthening criteria

The properties of wood as a construction material may influence the seismic response of the structure positively, because the low density generates fairly small inertia forces, and negatively because of brittleness, which is particularly significant perpendicular to the fibre direction. When designing new structures, the material behaviour can be exploited optimizing the favourable contributions and providing for the drawbacks by choosing suitable structural types and details. For new timber structures, design codes and norms indicate the approach to be followed in order to obtain a suitable seismic behaviour. Basically, the current philosophy for seismic design entails exploiting post-elastic resources to an extent reasonable for the structure, depending on material, type, and construction details. For timber structures, given the very limited ductility offered by the material, wood components are

Fig. 1. The Prinkipo palace (left, the façade; right, interior view).