Structural diagnosis on ancient timber structures: the example of the Diplomatic Room at the Royal Palace in Naples

Nicola Macchioni[1], Mauro Bernabei[1], Michele Brunetti[1], Claudio Pollini[1], Donato Calicchio[2], Alan Crivellaro[3]

EXTENDED ABSTRACT

The Sala Diplomatica, anti-chamber of the Throne room, is one of the most relevant rooms in the Royal Palace, due to its dimensions and decorations; its location is in the centre of the historic building facade, facing Piazza del Plebiscito, which is considered the main square of Naples.
Few years ago the vault of the room was inspected due to the presence of several deformations on its surface.
Deformations and cracks were ascribed to the overload generated by late above constructed apartments (XIX century) which did modify the original structural scheme, causing deflection in the timber structure supporting the vault.
Paper will describe all the steps of the performed diagnosis, and the information that the diagnosis gave to the design of the intervention.
The timber structure is a slab made of 17 horizontal composed beams (each beam is made of two pieces) of sweet chestnut (Castanea sativa Mill.) wood, 14,5 m long; only one big beam is made of European fir (Abies alba Mill.). The chestnut timber is roundwood only slightly squared by axes (only the fir beam is completely squared), and simply leaning on the walls. The two portions of each beam are coupled, approximately for 5 m of length, on the middle part by big hand made nails. Each beam has underneath a system of supporting inclined rafters that collaborates in load-bearing approximately at 1/3 of length and transferring the load to the side bearing walls and to a thin horizontal element which lies underneath (and parallel to) the central portion of each beam. A 6 meters tall wooden truss, discovered during the demolition of the apartments, is located at mid span of the slab, perpendicular to the beams axes. Such system was deeming to support the charge of the beams at mid span, getting the entire construction exceptionally complex.
The aim of the diagnostic intervention was the evaluation of mechanical properties of each member of the timber structure in order give to structural engineer the basic information to design the restoration. The on-site diagnosis was made during 2004 winter, following the Italian standard "UNI 11119:2004 Cultural Heritage – Wooden artefacts – On site inspections for the diagnosis of timber members", in order to evaluate for each timber member the original characteristics and the modification occurred during the service of the structure, taking into account the decay from the structural and biotic point of view, and to produce the structural visual grading. In order to improve the knowledge on the timber characteristics and to know the history of the structure, on many elements it was performed the dendrochronological dating. For dendrochronological analysis the samples were taken from beams in the slab and from the large central truss. Pressler's corer was used to obtain a sample in a non-destructive (at least from the structural point of view) way, since this tool can perform core boring with a diameter of only 0,5 cm. In two cases, an electric drill was also used.

1 Nicola Macchioni, Mauro Bernabei, Michele Brunetti, Claudio Pollini, CNR – IVALSA, Italy, macchioni@ivalsa.cnr.it, bernabe@ivalsa.cnr.it, brunetti@ivalsa.cnr.it, pollini@ivalsa.cnr.it
2 Donato Calicchio, Architect, Department of Cultural Field, Naples, Italy.
3 Alan Crivellaro, University of Padova, alan.crivellaro@unipd.it

The visual analysis of the anomalies highly affecting the mechanical performances of the elements shows that the ancient carpenters made a good choice of the material to be used: the presence of knots is rather low and, mostly, their average dimensions are rather low. Chestnut wood faced the carpenters with several problems to be solved. Firstly the stems were typically small, with an important taper and not perfectly straight, and that's why they couldn't cover the whole span and had to make the coupling of two members. But that was the material available and the structure was not made to be visible.

From the biotic attack point of view we have recorded the presence of ancient attacks, no more active, by insects from the Anobium genus and by termites. In both cases they destroyed only the sapwood of chestnut elements (less than one centimeter on the external surface), which in most cases was already removed by the squaring of timber. Insect attacks, even if visible, didn't cause any reduction of mechanical performances to the timber elements.

In the timber structure of the Sala Diplomatica we have discovered an important ancient fungal attack on many timber elements caused by rain infiltration close to the northern wall. The heads of tie beam and of the northern rafter of the central truss were completely destroyed, causing the inefficiency of that frame as supporter of the mid span of the horizontal beams. Less serious attacks, but still working, were discovered in the portions of the beams that were directly underneath the kitchens and the bathrooms of the apartments.

The grading was made not only on each member, because each horizontal beam was considered as a single structural component, but divided in three different sectors, according to the imposed stresses and according to what is reported by the standard UNI 11119 that suggests to divide the structural elements into critical zones. So we graded the two sectors from each wall up to the rafters, separately from the mid-span central portion, between the two rafters.

We considered that the designer, who conceived the structure, took into account the weakness of the mid-span portion, where the sections were smaller, the defectiveness of timber is higher and where the coupling was ensured only by some nails. So he decided to support that weakness by way of a perpendicular truss many time sewed, with iron ties, by its tie-beam to the beams underneath. Due to that from the original 87 elements, the grading was done on 124 portions of elements. Only 9 (7,3%) elements were considered no more suitable for structural uses.

The overall structure suffers for a very high deformation at mid-span of the beams which is due both to the overloading gave by the apartments and by the lack of support from the central truss.

From one point of view we could say that the structure, conceived only to support the vault in lathwork, was largely overstated, but for sure was not conceived to support two modern apartments with mezzanine.

Moreover the fungal attack made the supporting role of the central big truss not only ineffective, but also an overload supported by the horizontal beam system. Looking at the fungal attack we can also say that it was antecedent the construction of the apartments.

For dendrochronological dating the job was rather difficult due to the very limited number of rings in the material, the species (chestnut) being poorly suited to this type of study, and the lack of an extended master chronology for central Italy and for the species being considered. Nevertheless, 11 out of the 12 chronologies involved beams made of chestnut; the chronology for the large beam made of European fir was constructed using the average of three samples. The chestnut beams were obtained from trees of about the same age, with the possible exception of the trunk used to build a small reinforcement beam, whose chronology extends over only 12 years. Thus, the material probably came from a coppice with a rotation of around 12 years and was taken from 2-3 rotations, corresponding to 24-36 years. Absolute dating of the structure (chestnut + fir) to 1708 is statistically significant when correlated with the chronology of beech in central Italy and of European fir in the Monti della Laga area, in Southern Italy.

The dating results are also well synchronised with the recorded painting of the vault frescoes, done during 1738 by F. De Mura.

The described diagnosis allows specifically designing the restoration interventions. From one side it will be necessary to refit the few members no more suitable for structural uses: the broken beam and beams heavily attacked by fungi in order to make it possible to refer to the original characteristics of the structural material. Then the less effective connections must be strengthened.

Another side is the restoration of the truss and its connection to the slab; the high deformation recorded on the horizontal beams will make this effort difficult.

The restoration design will also include a maintenance program through visual inspections at least twice a year and through tests of the efficaciousness of the interventions, to be repeated during the service life.