Rigidity versus Ductility as an Exception in Timber Structures Planning in a Moderately Seismic Area

(The Rigid Timber Trusses Designed to Strengthen the Vasari´s Timber Ceiling in Palazzo Vecchio, Florence)

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INTRODUCTION

The timber roof and false ceiling built in 1563 by Giorgio Vasari, Architect and Painter, the Father of the artistic Historiography, on the Salone dei Cinquecento in Palazzo Vecchio, Florence, and the huge timber work built in the XIX c. to strengthen the ceiling, have enormous interest for the history of the architecture and especially for the history of the timber carpentry in Italy.
Recently the authors (Tampone, Derinaldis, 2005, cit.) assigned, on the base of a specific detailed survey and the discovery of unpublished documents, the paternity of the strengthening work to the Architect Domenico Giraldi, Officer of the Municipality of Florence who is owner of the Monumental Building, assessing definitely the dating of this intervention to 1854.
The Vasari´s work consists of a system of classic trusses - two rafters, kingpost with two struts, chord of two jointed pieces - of extraordinary span (almost 25 m), a great bay (4 m average), meant to support the covering and sustain as well the heavy false ceiling which is hung to the chords of the trusses, according to the system in use at the time; the trusses are equipped with excellent iron fittings and the nodes and the central connection of the chord are stiffened with iron ties in the shape of stirrups completed with gibs and cotters.
The sizing of the members and the geometry of the units are absolutely suitable, how the mathematical checks and the lack of significant failures confirm.
The ceiling is composed by longitudinal joists resting on the chords of the trusses to which is suspended a faint, thin horizontal frame of joists and planks; the latter are placed in the vertical and horizontal plane, boxed and arranged in a way to resemble, from the intrados, a set of principal and secondary beams with the lacunars of a real ceiling.
The ceiling is the week part of the vasarian structural system because its structure is not rigid enough and the bay of the supports too large.
Very soon the ceiling was affected by sagging also caused by creep effects.
The urban territory of Florence is characterized by moderate seismic activity. In these areas timber as a building material is very much appropriate, in comparison with masonry, due to its characteristics of light weight, flexural strength, deformability, ductility of the joints.
There is a first question to be put, whether the complex and audacious structural system designed by Vasari is compliant with a seism-resistant structural conception.
Except for a few personal observations made by Leonardo da Vinci, at the time no explicit principles for the construction in seism prone areas were established; it is known that one of the first Authors of Architecture concerned with the problem, two centuries later, was Francesco Milizia; clear knowledge of the building problem in a seismic area are to be found only after the disastrous earthquakes which hit Lisbon and later the Southern Italy during the second half of the same century.

Before this time the only possible reference were the practice, the intuition, the rules of the craft. The stability of the complex vasarian system, especially the system of trusses, to horizontal forces acting along the longitudinal direction of the Hall is ensured by a few factors:

- the good quality of the material. The grading of the wood (*Abies alba*) in order to supply an excellent stock has been very strict: all the members are made of material of straight grain, with only very few knots etc. besides working and placing were very accurate (these conditions are confirmed by the specification annexed in the contract of 1563 with the craftsmen)
- the wise design of the configuration, especially the connections of the single units in a series of units, obtained by means of firm and well connected subsidiary members running in the longitudinal direction, i.e. the ridge purlin and the side purlins, the joists and the boarding. It is to be stretched out that the subsidiary beams and the boarding play an important role in stiffening the whole system and preventing deformations in the longitudinal direction
- the wise design of the joints (except a few nodes) which ensure tight connections of all the parts thus making effective the structural conception
- the massive peripheral walls at both ends of the hall. In fact the system does not show any stability problem.

Figure 1: General view of the "soffitta" (the garret) of the Salone dei Cinquecento

THE STRENGTHENING WORK OF THE XIX CENTURY

The Giraldi´s truss system was installed, at the end of a series of unsuccessful attempts, to stabilize the ceiling and counteract its sagging, which started not long after the completion of the work. It is composed by a series of trusses of very original design being very low-sloped, shaped like lens-beams, with all the members connected at both ends and the connections secured with iron belts.

Being interposed to the Vasari´s units and resting on the same longitudinal walls, they have the same span and bay.
They are meant to co-operate in the support of the ceiling, dividing the bay in half. Wisely the drastic Giraldi´s system did not modify the Vasari´s system.
According to the conception, they behave in a very rigid way. The intervention, based on stiffness, was successful; no significant failures of the system are recorded since the construction.

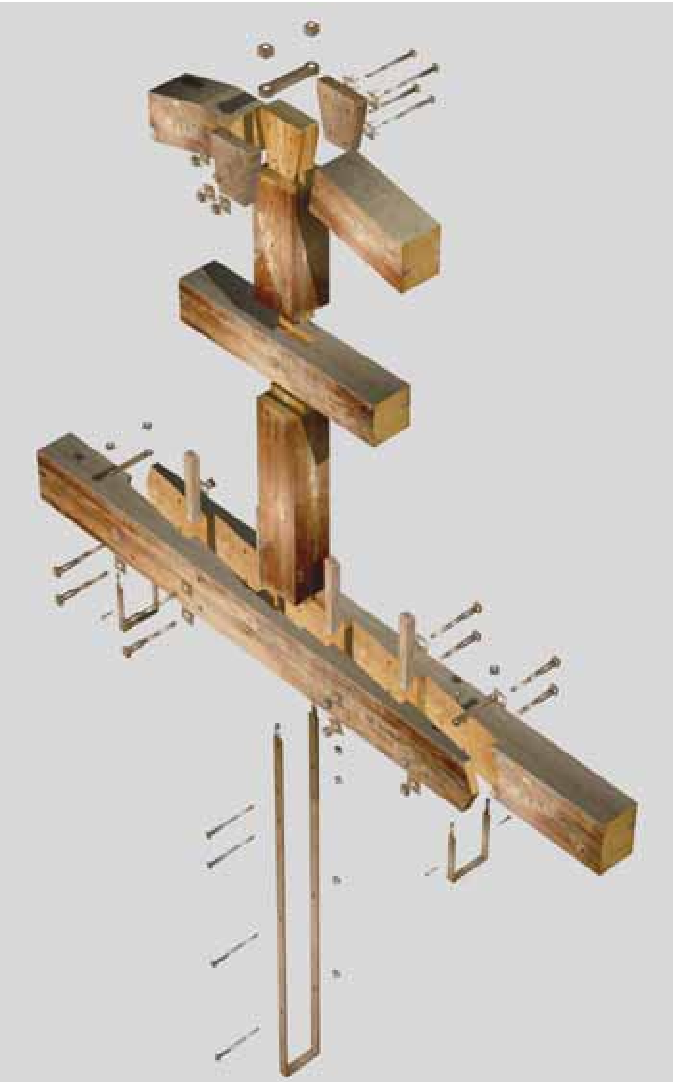

Figure 2: Exploded axonometric view of the node: king post-rafter-chord of the Giraldi´s truss

Figure 3: Exploded axonometric view of the nod of the same truss. Two "voussoirs" of hard wood (oak) have been inserted between the concurring members to convey the stresses

CHECK

The second question is whether the rigid Giraldi´s structural addition is suitable in a seismic prone area.
In practice we know that it was suitable for the purpose and well designed also against earthquakes; no signs of dynamic failure, in fact, are detectable on the system.

To give a theoretical answer to this question the type truss designed by Giraldi has been checked by means of a numerical analysis using the calculation code Straus 7. Numerical FEM models have been generated: "beam" elements have been associated to the members and "truss" to the iron fittings.
The external supports on the walls have been supposed as a hinge (one end) and a movable hinge. For the internal connections various hypothesis have been made, varying them from hinge to fixed joint. The unit has been subjected to the static loads first, later to a combinations of static plus dynamic loads, simulating an acceleration in the longitudinal direction, typical of a medium-high earthquake (7th degree of the Mercalli scale roughly approximately corresponding to Magnitude 6.1 of the Richter scale).
The results are that the kind of internal connections has almost no influence and that the increments of the internal stresses due to dynamic loads added to the static ones are negligible.
Anyhow a propensity to rotation around the horizontal axis passing trough the supports has been detected.(see table 1)

Table 1: State of stress and displacements

Structure under the action of self weight and accidental loads		Structure under the action of self weight, accidental loads and medium-high earthquake		
Beam stress N/cm^2	Beam displacement max (y) cm	Beam stress N/cm^2	Beam displacement max (y) cm	Beam displacement max (z) cm
1865.1 (metallic element)	-5.35	1865.4 (metallic element)	-5.35	1.15
-1158.2 (wooden joist)		-1187.1 (wooden joist)		

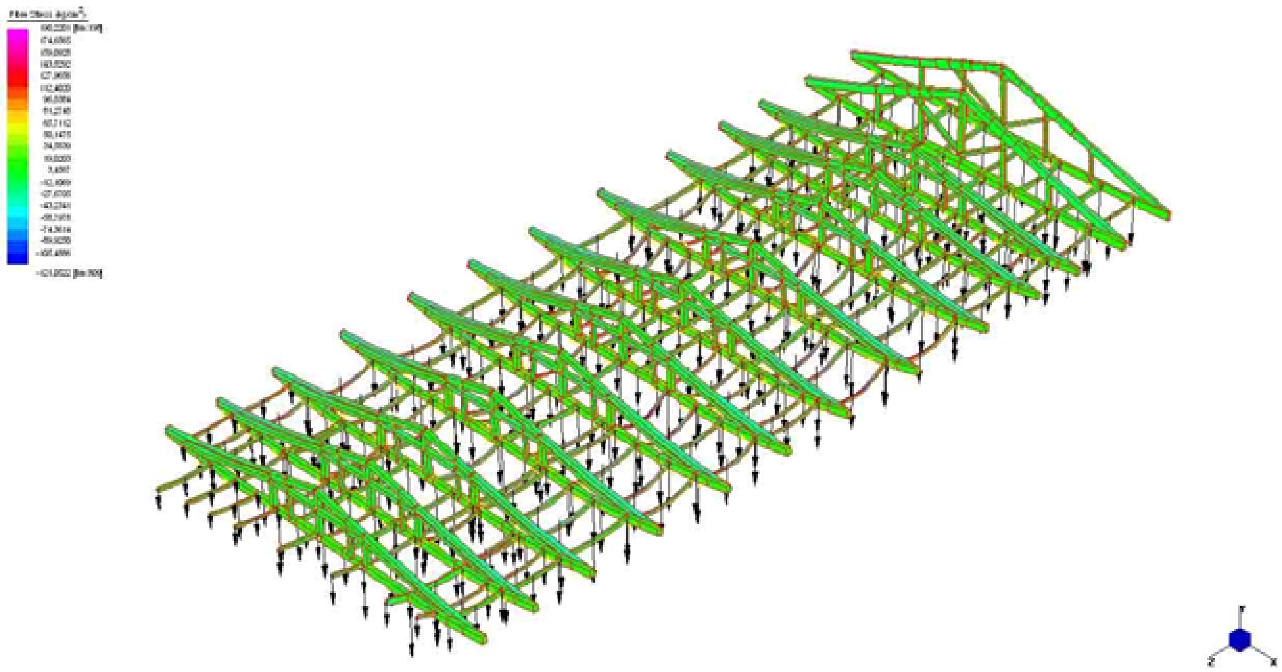

Figure 4: Stresses and displacements of the Giraldi´s structural system

CONCLUSIONS

The Giraldi´s truss is very stiff; the stiffness depends on the geometry more than the kind of internal connections. The truss is extremely efficient because of its stiffness which was in the present case a far more important requisite than ductility.
The propensity to rotation is caused by the lack of bracing between the trusses.

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