

Structural Restoration of Historical Constructions Built with Gypsum Pillars and Floors for New Standards of Living

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Abstract: Tía Cayetana's inn is an old road motel erected at the end of the 19th Century at Torrebaja (Spain). This inn was built using local vernacular construction techniques, i.e., with a structure made of gypsum pillars, and floors built with beams and gypsum vaulting. The facades and interior walls were built in a combination of stone masonry for the basement and either rammed earth walls or thin stone slabs wall for the upper parts. The local city hall bought the building and entrusted the rehabilitation of the building to the authors of this paper for its future use as a four-star hotel, i.e., the same use for the building more than one hundred years after its original completion. The authors of this paper made an exhaustive study of the fabrics of this building, its construction, material pathologies... and, taking into account these data, elaborated the restoration project for the building that previewed the use of the same original structure made of gypsum to be reinforced with compatible techniques. This article introduces the analysis of the local constructive technique based on the general use of gypsum for the vertical and horizontal structure, the bonding of fabrics and the external and internal coatings, and their structural performance. It also describes the reasoning that took the authors to respect the existing structure in its original condition and the reinforcements made mainly at the foundations and at the floors to assume the new weight of a four-star hotel.

Keywords: Gypsum pillar, reinforcement, wooden floor, jack vaulting, vernacular, foundation

Introduction

As usual in vernacular architecture, this traditional architecture of the region was strictly born from functional aspects such as the availability of materials in the surroundings, the cost of manufacturing and building with them, the satisfaction of the personal needs of its inhabitants and the answer to the requirements of climate and geographical milieu. The traditional architecture of the area has been under examination since 1996 in fifteen international workshops with the participation of students and lecturers from some twenty universities from all over the world, where composition, morphology, construction, costs, etc. have been studied. Although there are slight variations, the configuration of the houses has certain building features common to the whole area. The load-bearing structure is not based, as one might think at first glance, on masonry walls. On the contrary, this architecture presents very peculiar endogenous features and consists of a general use of gypsum for the supporting structure, floors, facades and partition walls (Vegas et al. 2001). Its structure is formed by pillars made of poured gypsum, wooden beams and joists, and gypsum jack vaulting between joists (Fig. 3a). The roof is built with wooden rafters, either reed or strips of wood, and curved tiles. The basement is built with solid stone masonry fabrics bonded with mud mortar in order to avoid the ascending humidity and to resist to shoves of persons, animals and carriages. But the facades and interior partition walls are usually built with thin stone slabs vertically set bonded with gypsum mortar. Some of these walls are rendered with gypsum and some of them show the stone slabs in their apparently unbalanced state.

The Old inn of Tía Cayetana: Previous State

In spite of its dimensions, the old inn at Torrebaja, already abandoned in 1950s, is built with the described traditional constructive techniques (Mileto et al. 2007). The ground floor is surrounded by masonry walls bonded with mud in order to avoid ground humidity, that show a good state of

conservation. Nevertheless the rain has washed some of the mud mortar away. The upper floors' façades are built mainly with stone slabs vertically set bonded and slightly coated with gypsum, and there is also a small part built with rammed earth (Fig. 1a). They are in good condition although show lack of maintenance and need of small repairs. Wooden beams and joists that form the floors were affected in some degree by rot because of water infiltration. Being built with gypsum, floors' jack vaulting was also weakened by water. Indeed, the roof, built with pine wood beams and purlins, reed and curved tiles bonded with mud and straw, showed a bad state of conservation, with plenty of leaks.



Figure 1: a. Façade previous to restoration. b. Ground layout with existing and added pillars

The Restoration Project: a Four-Star Hotel

The restoration of the old inn to become a four-star hotel aims to be an intervention where a satisfactory compromise between the new function of the building and the material conservation of its vernacular construction and its traces of history (Doglioni 2008). Our main goal, as architects that developed the project and presently supervise the building works, was to find solutions to harmonize the functional, accessibility, structural, decorum, comfort, etc. needs and the preservation of its traditional character expressed through its material, historical, constructive, functional characteristics. Therefore, the project aimed to maintain the existing fabrics and structure, repairing where necessary after the tradition with compatible materials. Wooden beams and joists have been repaired in situ if possible, except when the element was so affected by rot that made it necessary to substitute it. The traditional gypsum coating in the façade has been just cleaned and repaired with similar mortars. The original thin façades' skin has been maintained, adding enough thermic isolation and a brick wall behind connected with the stone slabs historical wall in order to give more stability to the whole. The traditional constructive system in the roof has also been preserved, but supplemented with a 4 cm layer of local gypsum after Moslem's constructive tradition in Spain reinforced with glass fibre, an extra waterproof layer as well as thermic isolation in order to reach the necessary comfort level.

Structural Intervention

Criteria. The preservation of the building structure was also considered essential reconciling it with the new needs derived from the new use as four-star hotel. Nevertheless, being an isostatic structure built mainly with wood and gypsum, i.e., materials with a difficult mechanical characterization with structural joints of scarce rigidity, a common structural design in order to estimate its strength was not justified. Therefore, following the same constructive and structural philosophy of the building, we thought that both the structural design to estimate its stability and strength and the project possible reinforcement had to be based on the same concepts (Vegas and Mileto 2007), but adapted to nowadays legal standards. Even so, it was difficult to establish criteria for the verification of elements like gypsum pillars with no previous experience or legal background (Bianco and Guerrisi 2005), although their good shape and condition after 100 years guaranteed its behaviour. The following pages show the hypothesis used for pillars, foundations, floors and their fire behaviour.

Pillars. An estimate of the existing self-weights and proved overloads and project loads based upon experience and nowadays standards respectively has been used.

Table 1: Existing self-weights and proved overloads vs project self-weights and overloads [kN/m²]

PREVIOUS TO RESTORATION		AFTER THE RESTORATION AS A HOTEL	
Existing floors' self-weight	1.50	Reinforced floors' self-weight	3.50
Previous proved overload on floors (storage)	2.00	Average approximate overload	2.50
Existing roof's self-weight	1.50	Restored roof's self-weight	2.00
Previous proved overload on roof (snowfall)	0.50	Considered overload after standards	0.50

Therefore, it may be considered that the self-weight has increased 2.00 KN/m², and the overload 0.50 KN/m². Three new pillars n. 17, n. 18, n. 19) have been inserted in the restoration project in order to reduce the excessive span of 8 m of some of the existing beams and, simultaneously, to reduce the load surface area of the adjacent pillars (Fig. 1b).

Pillars that reduce or match with their existing loads. The insertion of new pillars has reduced the load area in some existing pillars. This has helped to reduce or match with their existing loads, being therefore unnecessary to reinforce them in this case. Let us see some examples:

Table 2: Pillars that reduce or match with their existing loads after the restoration

Pillar	Former load area [m ²]	Supported load per floor [kN/m ²]	New load area [m ²]	Supported load per floor [kN/m ²]
n. 3	11.65	40.77	3.50	21.00
n. 4	19.31	67.59	11.86	71.16
n. 6	14.45	50.57	3.52	21.12
n. 7	18.29	64.02	6.80	46.24

Assimilation of the strength after other pillars' performance. Taking as a reference the compression stress that has been supporting the material of the former pillar n.4, it may be justified the admission of the new loads that other pillars will be supporting after the restoration:

Table 3: Assimilation of the strength after other pillar's performance

Pillar	Situation	Load area (m ²)	Total load (kN)	Dimension (m)	Area (m ²)	Max. stress (N/mm ²)
n. 4	Former use	19.31	173.78	0.4x0.4	0.16	1.08
n. 2	New use	8.89	124.46	0.4x0.4	0.16	0.78
n. 9	New use	18.82	263.48	0.5x0.5	0.25	1.09
n. 12	New use	12.11	169.54	0.4x0.4	0.16	1.05

Pillars that increase their section. Besides, some of the peripheral pillars, either with smaller load areas like n. 7 or the same load area like n. 5, whose strength could be already justified with the previous two explanations, have been anyway reinforced increasing their section with anchored brick masonry as shown in the drawing (Fig. 2a) in order to give better support for their respective beams, reducing simultaneously the stress on them.

Foundations. The foundations of these vernacular buildings are often very scarce and it is necessary to check their conservation state and dimensions through prospection. In this case, although we could have followed the same criteria adopted for the pillars, existing foundations have been systematically enlarged in order to reduce in any case the pressure on the ground, especially in the nobler area with bigger loads. The existing foundation that matched with the area of the pillar has

been surrounded by a rectangular ring of reinforced concreted 40 cm wide, connecting the former and the new foundation through corrugated iron bars 16 cm diameter in each of the four faces (Fig. 2b).

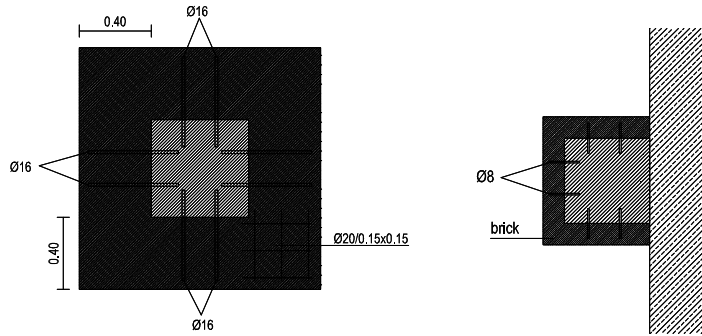


Figure 2: Enlargement of structural elements. a) Section of peripheral pillars. b) Foundations

The surface area of the historical foundations was $0.40 \times 0.40 = 0.16 \text{ m}^2$. The new surface area of the reinforced foundations is $1.20 \times 1.20 = 1.44 \text{ m}^2$. Therefore, the contact surface with the ground has been increased up to 9 times, so that the pressure on the ground has become 9 times smaller.

Floors. Given the existence of big areas of unevenness in the original floors, its reinforcement has been designed supplementing each historical joist with levelling wooden pegs and another upper joist well screwed together, as if it were a wooden Vierendel beam of changing section (Fig. 4b). A whole carpet made by two $2,3 + 2,3 \text{ cm}$ phenolic plywood boards have been screwed together, that serve as an added reinforcement for the joists, compression and distribution layer and flexible brace-diaphragm to hold together the whole of the façades and internal pillars thanks to its peripheral connection through L-profiles. The resulting section of each joist is highly increased. The space between the historical gypsum floor (Fig. 3a) and the new reinforcement boards have been employed to pass all the wiring, plumbing, etc, and it has finally been filled with small cork pieces, that do not increase the load and help improving the acoustical isolation (Fig. 5b). Thus, all the historical floors may be seen from the lower side, contributing to maintain the vernacular character of its internal spaces. For the structural calculations, a first estimation of the historical state of loads and the structural answer of the historical floors previous to restoration has been made for an average max. span of 5 m. The mechanical properties of the joists' section (Alonso & Martínez 2008) previous and after the floor reinforcement are different, increasing the inertia almost ten times over the original (Fig. 3b). The calculation of stresses and the checking of the ultimate limit state of the existing joists' sections (Timoshenko 1970), for an average max. span of 5 m, may be seen in following table:

Floor's self-weight	$1,50 \text{ kN/m}^2$	$M = \frac{qL^2}{8} \times 0.6$	$\frac{3.50 \times 5^2}{8} \times 0.6 = 6.56 \text{ m} \cdot \text{kN}$
Proved overload	$2,00 \text{ kN/m}^2$	$\sigma_{m,d} = \frac{M}{W} \times \gamma_f$	$\frac{6.56 \times 10^3}{740} \times 1.44 = 12.77 \frac{\text{N}}{\text{mm}^2}$
Security coefficient	$\frac{1.50 \times 1.35 + 2.00 \times 1.5}{3.5} = 1.4$		

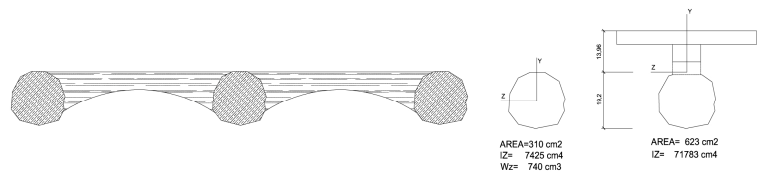


Figure 3: a. Typical jack vaulting of the floors. b. Joist's inertia previous and after the reinforcement

The stress on the joists for the floor's self-weight previous to the reinforcement will be:

Self-weight

$$1,50 \times 0,6 = 0,90 \text{ kN/m}$$

$$M = \frac{qL^2}{8}$$

$$\frac{0,90 \times 25}{8} = 2,81 \text{ mkN}$$

$$\sigma_m = \frac{M}{W}$$

$$\frac{2,81 \times 10^3}{740} = 3,80 \frac{\text{N}}{\text{mm}^2}$$

The calculation of the reinforcement section with phenolic boards has been done for the whole load less the self-weight of the original floor. The new overload due to the new use is 2.50 kN/m².

Phenolic board's weight

$$0,50 \text{ kN/m}^2$$

Pavement and partition

walls weight

$$1,50 \text{ kN/m}^2$$

Use overload

$$2,50 \text{ kN/m}^2$$

Each joist = q x 0,6 m

$$4,5 \times 0,6 = 2,7 \text{ kN/m}$$

$$M = \frac{qL^2}{8}$$

$$\frac{2,7 \times 25}{8} = 8,45 \text{ mkN}$$

Upper compression stress

$$\sigma_{mc} = \frac{M}{I} y_s$$

$$\frac{8,45 \times 10^3}{71783} \times 13,96 = 1,64 \text{ N/mm}^2$$

Lower tension stress

$$\sigma_{mt} = \frac{M}{I} y_i$$

$$\frac{8,45 \times 10^3}{71783} \times 19,20 = 2,26 \text{ N/mm}^2$$

The final estate of the joists in the reinforced floor and its maximal stress is as follows (Fig. 4a):

$$\sigma_{m,d} = (3,80 + 2,26) \times 1,44 = 6,06 \times 1,44 = 8,73 \text{ N/mm}^2$$

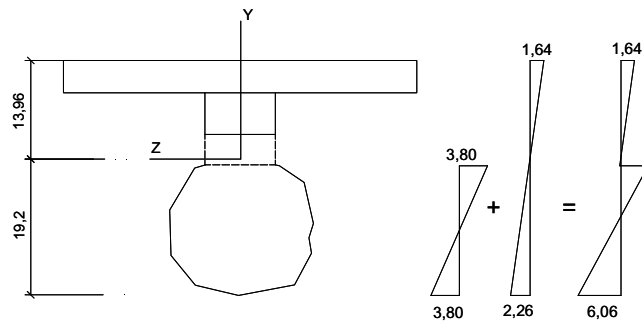


Figure 4: a) Reinforced joist's stress under service, b) Reinforcement of the floors under construction

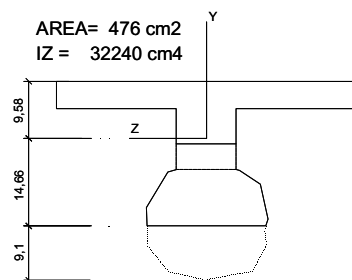


Figure 5: a) Joist's carbonization previewed depth, b) Reinforcement of the floors coming to an end

Thus, the calculation stress has been reduced a 70% [8.73 N/mm² in front of 12.77 N/mm²] in the final situation compared with the original floor.

Stability against fire. Given a required fire resistance of 120 min, the carbonization depth (UNE ENV 1995-1-2. Eurocódigo 5) in this case would be: $K_0=1$ and $\beta_n=0,7$ mm/min. The effective definitive depth = $0,7 \times 120 + 7\text{mm} = 42 + 7 = 91$ mm. With this condition the resistant section of the reinforced joists has the following parameters (Fig. 5a):

With this values, the comprobation of the resistance against fire results in an acceptable behaviour against fire with a generous security gap (stress after the loss of material by fire 5.11 N/mm²)

	Span 5 m
Total load, new situation	1,50+2,00+2,50 kN/m ²
Each joist = q x 0,5 m	6,00 x 0,6 = 3,60 kN/m
$M = \frac{qL^2}{8}$	$\frac{3.60 \times 25}{8} = 11.25\text{mkN}$
Upper compression stress	
$\sigma_{mc} = \frac{M}{I} y_s$	$\frac{11.25 \times 10^3}{32240} \times 9.58 = 3.34\text{N/mm}^2$
Lower tension stress	
$\sigma_{mt} = \frac{M}{I} y_t$	$\frac{11.25 \times 10^3}{32240} \times 14.66 = 5.11\text{N/mm}^2$

Conclusions

During the refurbishment of a building with the same use as it once had, as this old inn becomes a four star hotel, where the pressure of the official hotel regulations for such a high standard hotel is very strong, several agreements have been searched between the conservation of the existing traditional building and its finishings and the bringing up to date of the building function, from an old muleteer inn to a luxurious hotel. Even having this strong pressure on the building program and installations, the presently being finished refurbishment is showing that it is effectively possible to conserve the traditional structures and architecture of the region, not only in the case of the houses, but also in the case of public buildings with a lot more complex infrastructure and requirements.

References

- [1] Alonso, A (2001). Estatical, Universidad Politécnica de Valencia, Valencia
- [2] Bianco, A, and Guerrisi, G (2005). La arquitectura tradicional a examen. Loggia, 17, 106-113
- [3] Doglioni, F (2008). Nel restauro. Progetti per l'architettura del passato. Italia: IUAV/Marsilio
- [4] Mileto, C, Vegas, F, Cruzans, P (2007). Rehabilitación de antiguas posadas vernáculas para el nuevo turismo interior. CISAV'05, Spain: Ministerio de Cultura, 374-381
- [5] Timoshenko, S P (1970). Resistencia de Materiales. Spain: Espasa Calpe
- [6] Vegas, F, and Mileto, C (2007). Renovar conservando. Spain: Mancomunidad Rincón de Ademuz
- [7] Vegas, F, Mileto, C, and Zuccolotto, M (2001). Memoria construida. Spain: ADIRA
- [8] UNE ENV 1995-1-2. Eurocódigo 5: Proyecto de estructuras de madera